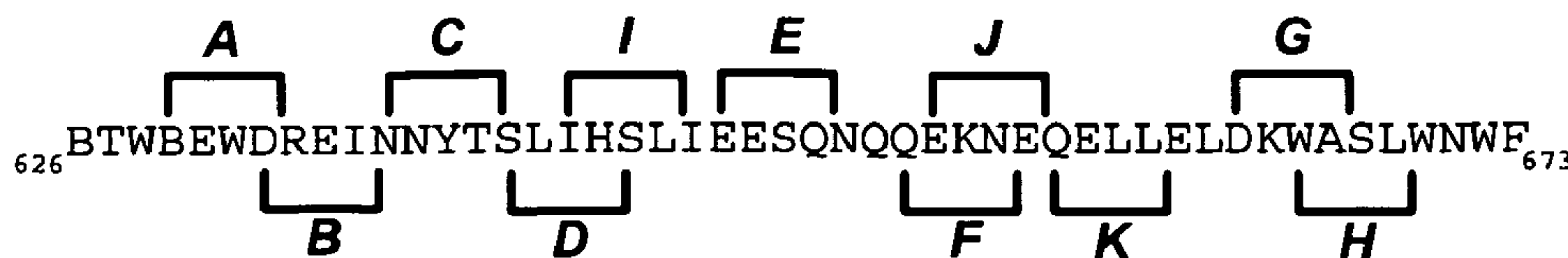




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(54) **Titre : COMPOSITIONS ET METHODES DE TRAITEMENT DES INFECTIONS VIRALES**
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BTWBEWDREINNYTSLIHSLIEESQNQQEKNEQELLE
 BTWBEWDREINNYTSLIHSLIEESQNQXKKNXQELLE
 BTWXEWDXEINNYTSLIHSLIEESQNQQEKNEQELLE
 BTWBEWDREINNYTSLIHSLIXESQXQQEKNEQELLE

gp41₍₆₂₆₋₆₆₂₎
 SAH-gp41₍₆₂₆₋₆₆₂₎(F)
 SAH-gp41₍₆₂₆₋₆₆₂₎(A)
 SAH-gp41₍₆₂₆₋₆₆₂₎(E)

YTSLIHSLIEESQNQQEKNEQELLELDKWASLWNWF
 YTXLIHXLIIEESQNQQEKNEQELLELDKWASLWNWF
 YTSLIHSLIEESQNQXKKNXQELLELDKWASLWNWF
 YTSLIHSLIEESQNQQEKNEQELLELXKWAXLWNWF
 YTSLIHSLIEESQNQQEKNEQELLELDKXASLXNWF
 YTSLXHSLXEESQNQQEKNEQELLELDKWASLWNWF
 YTSLIHSLIXESQXQQEKNEQELLELDKWASLWNWF
 YTSLIHSLIEESQNQXKKNEXELLELDKWASLWNWF
 YTSLIHSLIEESQNQQEKNEXELLXLDKWASLWNWF

gp41₍₆₃₈₋₆₇₃₎
 SAH-gp41₍₆₃₈₋₆₇₃₎(D)
 SAH-gp41₍₆₃₈₋₆₇₃₎(F)
 SAH-gp41₍₆₃₈₋₆₇₃₎(G)
 SAH-gp41₍₆₃₈₋₆₇₃₎(H)
 SAH-gp41₍₆₃₈₋₆₇₃₎(I)
 SAH-gp41₍₆₃₈₋₆₇₃₎(E)
 SAH-gp41₍₆₃₈₋₆₇₃₎(J)
 SAH-gp41₍₆₃₈₋₆₇₃₎(K)

(57) **Abrégé/Abstract:**

The invention provides compositions, kits and methods utilizing polypeptides having a viral alpha-helix heptad repeat domain in a stabilized α -helical structure (herein also referred to as SAH). The compositions are useful for treating and/or preventing viral infections. The invention is based, at least in part, on the result provided herein demonstrating that viral hydrocarbon stapled alpha helical peptides display excellent proteolytic, acid, and thermal stability, restore the native alpha-helical structure of the peptide, are highly effective in interfering with the viral fusogenic process, and possess superior pharmacokinetic properties compared to the corresponding unmodified peptides.

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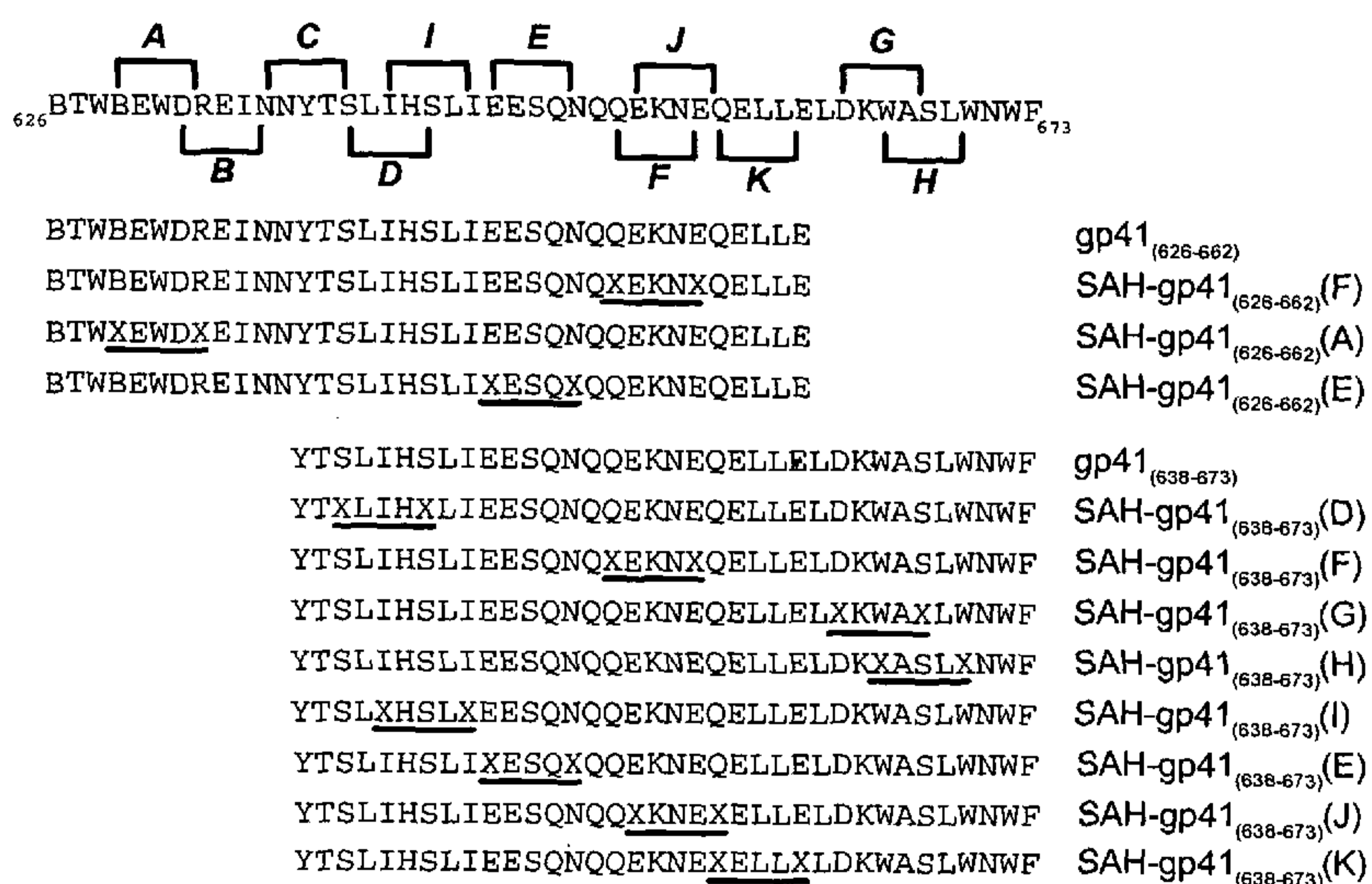
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FIGURE 11



(57) Abstract: The invention provides compositions, kits and methods utilizing polypeptides having a viral alpha-helix heptad repeat domain in a stabilized α -helical structure (herein also referred to as SAH). The compositions are useful for treating and/or preventing viral infections. The invention is based, at least in part, on the result provided herein demonstrating that viral hydrocarbon stapled alpha helical peptides display excellent proteolytic, acid, and thermal stability, restore the native alpha-helical structure of the peptide, are highly effective in interfering with the viral fusogenic process, and possess superior pharmacokinetic properties compared to the corresponding unmodified peptides.

WO 2009/108261 A3

COMPOSITIONS AND METHODS FOR THE TREATMENT OF VIRAL INFECTIONS

5

BACKGROUND

The molecular process of viral fusion, in which viral coat proteins recognize and bind to surface receptors of the host cell, is a critical target in the prevention and treatment of viral infections. Upon recognition of the viral glycoprotein by host cellular receptors, viral fusion proteins undergo conformational changes that are essential to viral fusion and infection. A series of hydrophobic amino acids, located at the N- and C-termini organize to form a complex that pierces the host cell membrane. Adjacent viral glycoproteins containing two amphipathic heptad repeat domains fold back on each other to form a trimer of hairpins, consisting of a bundle of six α -helices. This six-helix bundle motif is highly conserved among many viral families, including Filovirus (ebola), (Malashkevich, V.N., *et al.*, *PNAS*, 1999. 96(6): p. 2662-2667; Weissenhorn, W., *et al.*, *Molecular Cell*, 1998. 2(5): p. 605-616), Orthomyxovirus (influenza) (Wilson, I.A., J.J. Skehel, and D.C. Wiley, *Nature*, 1981. 289(5796): p. 366-37; Bullough, P.A., *et al.*, *Nature*, 1994. 371(6492): p. 37-43), Coronavirus (SARS) (Xu, Y.H., *et al.* *Journal of Biological Chemistry*, 2004. 279(47): p. 49414-49419), Paramyxovirus (HRSV) (Zhao, X., *et al.*, *PNAS*, 2000. 97(26): p. 14172-14177) and Retrovirus (HIV) (Chan, D.C., *et al.*, *Cell*, 1997. 89(2): p. 263-27; Weissenhorn, W., *et al.*, *Nature*, 1997. 387(6631): p. 426-430).

HIV envelope proteins gp120 and gp41 non-covalently associate with each other to form a trimer of dimers. On the host cell, gp120 specifically interacts with CD4, CXCR4, and CCR5, which are the glycoproteins involved in host-cell recognition. gp41, the viral membrane spanning glycoprotein, is responsible for fusing the viral and cellular membranes, resulting in viral particle uptake by the host cell. Once gp120 binds to CD4, gp41 undergoes a conformational change, transforming from its native state into a fusogenic six-helix bundle. The regions of

30

gp41 involved in this change are 43 (C43) residues of the C-terminal heptad repeat (CHR or HR-2), near the transmembrane domain, and 51 (N51) residues of the N-terminal heptad repeat (NHR or HR-1), found just proximal to the fusion peptide domain. Peptides N51 and C43 orient to form helical antiparallel heterodimers, which
5 associate to form a higher order trimeric complex that is thermo- and proteolytically stable.

Peptides which interfere with this viral fusogenic process can be used for the prevention and treatment of viral infections. For example, peptides corresponding to residues 553-590 of the gp41 N-terminal heptad repeat domain (HR-1) and residues
10 630-659 and 648-673 of the C-terminal heptad repeat domain (HR-2) of HIV have been shown to inhibit the replication of a variety of HIV strains. Studies have determined that these peptides inhibit cell-cell fusion by interacting with the HIV envelope glycoproteins.

T20 or enfuvirtide, is the first fusion inhibitor peptide developed based on the
15 CHR region of gp41 for the treatment of HIV. Enfuvirtide is active at nanomolar concentrations against many strains and subtypes of HIV, including the common lab strains and primary isolates of HIV-1 and HIV-2 (Wild, C.T., *et al.*, *PNAS*, 1994. 91(21): p. 9770-9774).

However, enfuvirtide has remained a tertiary treatment option due to a variety
20 of factors which include cost, no oral bioavailability (subcutaneous injections limit accessibility and compliance) and poor *in vivo* stability (Kilby, J.M., *et al.*, *Nuclie Aids Research and Human Retroviruses*, 2002. 18(10): p. 685-693), and loss of bioactive secondary structure. Thus, although peptide-based inhibition of viral fusion processes is mechanistically feasible and clinically effective, the biophysical and
25 biochemical properties of amphipathic fusion peptides present numerous challenges which hinder their use.

SUMMARY OF THE INVENTION

The present invention is directed to compositions, kits and methods utilizing polypeptides with stabilized α -helical structures (herein also referred to as SAH).
30 The compositions are useful for treating and/or preventing viral infections. The invention is based, at least in part, on the result provided herein demonstrating that

viral hydrocarbon stapled alpha helical peptides display excellent proteolytic, acid, and thermal stability, restore the native alpha-helical structure of the peptide, are highly effective in interfering with the viral fusogenic process, and possess superior pharmacokinetic properties compared to the corresponding unmodified peptides.

5 In a first aspect, the invention is directed to a modified polypeptide having a stabilized viral alpha helix heptad repeat domain. Preferably the alpha helix heptad repeat domain is stabilized with at least one hydrocarbon staple, but could include two, three or more hydrocarbon staples. Suitable hydrocarbon staples (e.g., tethers) are described herein. Suitable viral alpha helix heptad repeat domains are derived
10 from any virus with an alpha helix domain or analog thereof that is directly or indirectly involved in cell attachment and/or fusion. Suitable stabilized alpha helical heptad repeat domains can be derived from numerous viruses, including respiratory syncytial virus, parainfluenza virus, influenza virus, coronavirus, ebolavirus and HIV. The modified polypeptides of the invention can include a stabilized HIV gp41 heptad
15 repeat domain (e.g., heptad repeat domain 1 or 2, or portions thereof).

Any of the modified polypeptides of the invention can be included in compositions and kits.

In another aspect, the invention is directed to a method for inhibiting the transmission of HIV to a cell. In the method, the HIV virus is contacted with an
20 effective dose of a modified polypeptide so that the HIV virus is inhibited from infecting the cell. Preferably, the modified polypeptide has an HIV gp41 heptad repeat domain (e.g., heptad repeat domain 1 or 2, or portions thereof) that is stabilized with a hydrocarbon staple.

The invention may also include a method for treating or delaying the onset of
25 AIDS in an HIV infected individual. A pharmaceutical composition having a modified polypeptide with a stabilized HIV gp41 heptad repeat domain (e.g., heptad repeat domain 1 or 2, or portions thereof) is administered to an individual infected with HIV, thus treating or delaying the onset of AIDS. Preferably the HIV gp41 heptad repeat domain is stabilized with a hydrocarbon staple.

30 In still another aspect, the invention is directed to a method for increasing the number of CD4+ cells in an individual infected with HIV. The method involves

administering to the individual infected with HIV an effective dose of a pharmaceutical composition having a modified polypeptide with a stabilized HIV gp41 heptad repeat domain (*e.g.*, heptad repeat domain 1 or 2, or portions thereof). The administration of the composition results in an increase in the number of CD4+ cells in the individual. Preferably the HIV gp41 heptad repeat domain is stabilized with a hydrocarbon staple.

In yet another aspect, the invention is directed to a method for inhibiting syncytia formation between an HIV infected cell and an uninfected cell. The method involves contacting the infected cell with an effective dose of a modified polypeptide having a stabilized HIV gp41 heptad repeat domain (*e.g.*, heptad repeat domain 1 or 2, or portions thereof), thereby inhibiting syncytia formation between the cells. Preferably the HIV gp41 heptad repeat domain is stabilized with a hydrocarbon staple.

In still another aspect, the invention is directed to a method for inactivating HIV. The method involves contacting the virus with an effective dose of a modified polypeptide having a stabilized HIV gp41 heptad repeat domain (*e.g.*, heptad repeat domain 1 or 2, or portions thereof) so that the HIV is rendered inactive (*e.g.*, non-infectious). Preferably the HIV gp41 heptad repeat domain is stabilized with a hydrocarbon staple.

In still another aspect, the invention is directed to a method for preventing an HIV infection in an individual. The method involves administering to an individual an effective dose of a pharmaceutical composition having modified polypeptide with a stabilized HIV gp41 heptad repeat domain (*e.g.*, heptad repeat domain 1 or 2, or portions thereof). Administration of the stabilized HIV gp41 heptad repeat domain interferes with the ability of the HIV to infect the individual. Preferably the HIV gp41 heptad repeat domain is stabilized with a hydrocarbon staple.

The modified polypeptides can be used to inhibit the transmission of RSV to a cell. The virus is contacted with an effective dose of a modified polypeptide having a stabilized RSV viral alpha helix heptad repeat domain analog thereby inhibiting transmission of the virus to a cell. Preferably the heptad repeat domain analog is stabilized with the hydrocarbon staple.

The modified polypeptides can also be used to inhibit the transmission of a parainfluenza virus to a cell. The virus is contacted with an effective dose of a modified polypeptide having a stabilized parinfluenza viral alpha helix heptad repeat domain analog, thereby inhibiting transmission of the virus to a cell. Preferably the heptad repeat domain analog is stabilized with the hydrocarbon staple.

In another aspect, the modified polypeptides can also be used to inhibit the transmission of an influenza virus to a cell. The virus is contacted with an effective dose of a modified polypeptide having a stabilized influenza viral alpha helix heptad repeat domain analog, thereby inhibiting transmission of the virus to a cell. Preferably the heptad repeat domain analog is stabilized with the hydrocarbon staple.

In still another aspect, the invention is directed to a method for inhibiting the transmission of a coronavirus to a cell. The method includes contacting the coronavirus with an effective dose of a modified polypeptide having a stabilized coronavirus alpha helix heptad repeat domain analog, thereby inhibiting transmission of the virus to a cell. Preferably the heptad repeat domain analog is stabilized with the hydrocarbon staple.

In yet still another aspect, the invention is directed to a method for inhibiting the transmission of an ebolavirus to a cell. The method includes contacting the ebolavirus with an effective dose of a modified polypeptide having a stabilized ebolavirus alpha helix heptad repeat domain analog, thereby inhibiting transmission of the virus to the cell. Preferably the heptad repeat domain analog is stabilized with a hydrocarbon staple.

In an aspect of the invention, the invention provides modified peptides of the inventions as a pharmaceutical composition. In some embodiments, the pharmaceutical composition is for enteral administration, preferably oral administration.

In yet another aspect, the alpha helix heptad repeat domains and analogs thereof are used to generate an antibody response to the polypeptides by administering the polypeptides to a subject. Furthermore, the antibodies generated directly or indirectly (e.g., humanized antibodies) by the administration of the polypeptides may then be used to prevent or treat a viral infection (e.g., HIV, RSV, parainfluenza,

influenza, coronavirus, ebolavirus).

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates the domains of the gp41 glycoprotein.

5 Figures 2A and B illustrate amino acid sequence for A)HX-strain of gp160 and B) YU2-strain of gp160, with HR-1 domain bolded and underlined and HR-2 domain bolded and italicized.

Figure 3 illustrates the amino acid sequences for HIV-1 gp41 HR-1 and HR-2 domains and homologous regions in other viruses.

10 Figure 4A illustrates the HIV six-helix bundle and key interhelix interactions of the helices N36 and C34. One of the N36 and two C34 helices are faded for clarity. The helical wheel further illustrates key contacts among the helices based upon the a, b, c, d, e, f, g, nomenclature.

Figure 4B illustrates the fusogenic bundle formed by HR-analog domains from 15 RSV, influenza, SARS and Ebola. The six-helix fusogenic bundle is highly conserved across many species.

Figure 5A provides examples of amino acid sequence templates from within the HIV-1 HR-2 domain polypeptides with sequential N-terminal truncations.

20 Figure 5B provides examples of amino acid sequence templates from within the HIV-1 HR-2 domain polypeptides with sequential C-terminal truncations.

Figure 6 provides examples of sequence templates from within the HIV-1 HR2 domain depicting staggered N- and C-terminal truncations.

Figure 7 illustrates a synthetic design of a truncated SAH-gp41 compound, SAH-gp41₍₆₂₆₋₆₄₅₎(A). X= S5 amino acid, B=norleucine

25 Figure 8 provides examples of sequence templates from within the HR2 domains of SIV and the HX and YU2 strains of HIV-1 depicting the generation of chimeras.

Figure 9 illustrates the heptad repeat domain motif as applied to HIV gp41 (626-663) and associated preferred amino acid residues. Examples of sequence

template from within the HIV-1 HR2 domain depicting the specific amino acid residues necessary to preserve the HR1 interaction are provided. Thus, the positions indicated with a dash may be amenable to substitution/mutation without disruption of activity.

5 Figures 10A-D illustrate the possible combinations of helix-stabilizing crosslinks formed at positions A) *i*, and *i*+4 across one turn in the helix using two S5 amino acids; B) *i*, and *i* +7, across two turns of the helix using one S8 and one R5 amino acid or one R8 and one S5 amino acid; C) a double crosslink employing two *i*, *i*+4, two *i*, *i*+7, or one *i*, *i*+4 and one *i*, *i*+7 crosslink; and D) a triple crosslink
10 employing any combination of *i*, *i*+4, *i*, *i*+7, or other crosslinks (e.g. *i*, *i*+3).

 Figure 11 illustrates SAH-gp41 singly stapled peptides. (e.g., N-term: Ac, FITC-βAla, Biotin-βAla; C-term: CONH₂, COOH). X= S5 amino acid, B=norleucine

 Figure 12 Sequences of doubly and triply stapled SAH gp41 peptides. (e.g., N-
15 term: Ac, FITC-βAla, Biotin-βAla; C-term: CONH₂, COOH). X= S5 amino acid, B=norleucine

 Figure 13 illustrates unstapled, singly stapled and doubly stapled gp41 HR-2 peptides and illustrates a strategy for locating the staples in the helix. Staples are positioned so as to preserve and/or optimize inter-helix interaction surfaces. X= S5
20 amino acid, B=norleucine

 Figures 14A-F illustrate that singly and doubly stapled SAH-gp41 compounds exhibit greater helical stability as compared to the unmodified gp41 peptides at pH 7 and pH2. Percent helicity for each compound is indicated in parenthesis; A) SAH-gp41₍₆₂₆₋₆₆₂₎ singly- and doubly-stapled peptides at pH 7, B) SAH-gp41₍₆₃₈₋₆₇₃₎ singly-stapled peptides at pH 7, C) SAH-gp41₍₆₃₈₋₆₇₃₎ doubly-stapled peptides at pH 7, D) SAH-gp41₍₆₂₆₋₆₆₂₎ singly- and doubly-stapled peptides at pH 2, E) SAH-gp41₍₆₃₈₋₆₇₃₎ singly- and doubly-stapled peptides at pH 2, F) Table comparing calculated percent helicities of SAH-gp41 compounds at pH 7 and pH 2.

 Figures 15A-C illustrate that singly and doubly stapled SAH-gp-41
30 compounds exhibit greater thermal stability compared to the unmodified gp41 peptides at pH 7 A)select singly- and doubly-stapled SAH-gp41₍₆₂₆₋₆₆₂₎ compounds;

B) singly-stapled SAH-gp41₍₆₃₈₋₆₇₃₎ compounds; and C) doubly-stapled SAH-gp41₍₆₃₈₋₆₇₃₎.

Figures 16A-F illustrate that SAH-gp41 compounds exhibit greater protease resistance to chymotrypsin at pH 7 and pepsin at pH 2 compared to the unmodified gp41 peptides; A) SAH-gp41₍₆₂₆₋₆₆₂₎, chymotrypsin pH 7, B) SAH-gp41₍₆₃₈₋₆₇₃₎ chymotrypsin pH 7, C) Table of half-lives of SAH-gp41 compounds in the presence of chymotrypsin, pH 7, D) SAH-gp41₍₆₂₆₋₆₆₂₎, pepsin pH 2, E) SAH-gp41₍₆₃₈₋₆₇₃₎ pepsin, pH 2, F) Table of half-lives of SAH-gp41 compounds in the presence of pepsin, pH 2

Figure 17 shows a fluorescence polarization binding analysis of HIV fusion inhibitor peptides to the gp41 five-helix bundle illustrating enhanced binding of SAH-gp41 to the five-helix bundle compared to the unmodified peptides.

Figure 18 shows improved inhibition of syncytia formation by a truncated SAH-gp41 compound (A) compared to enfuvirtide (T20: gp41₍₆₃₈₋₆₇₃₎), highlighting the potential to retain, and even enhance, anti viral activity with shorter, stapled peptides.

Figure 19 demonstrates the anti-viral activity of select SAH-gp41 compounds against HIV strains HXBc2, ADA, and HXBc2P 3.2, and YU2. AMLV serves as a negative control.

Figures 20A-B demonstrate that A) SAH-gp41 compounds overcome HIV-1 HR1 resistance mutations that block the binding of unmodified gp41-based fusion peptides. Tabulated values indicate fraction of HR2 peptide input bound to the indicated FITC-HR1 peptide; and B) Select SAH-gp41 compounds are notably superior to the corresponding unmodified peptides in blocking the infectivity of a resistant HIV-1 strain, YU2.

Figure 21 shows that a doubly-stapled gp41 peptide has markedly enhanced pharmacologic properties *in vivo* (stability and bioavailability) compared to the corresponding unmodified peptide.

DETAILED DESCRIPTION

The present invention is directed to compositions, kits and methods utilizing polypeptides with stabilized alpha helical structures. The compositions are useful for

treating and/or preventing viral infections. The invention is based, at least in part, on the results provided herein demonstrating that viral hydrocarbon stapled alpha helical peptides have excellent structural, proteolytic, acid, and thermal stability, are highly effective in interfering with virus/cell fusion, and have superior pharmacologic properties *in vivo* compared to their unmodified counterparts.

The alpha helix heptad repeat domain is stabilized with at least one hydrocarbon staple, but could include two, three or more hydrocarbon staples. The inclusion of multiple hydrocarbon staples is particularly suited for alpha helical peptides that are 20 or more amino acids in length. In fact the inclusion of two more hydrocarbon staples, as shown herein, provides for exceptional structural, acid and thermal stability of the modified polypeptides, yielding bioactive peptides with strikingly enhanced pharmacologic properties *in vivo*.

Definitions

As used herein, the term “hydrocarbon stapling”, refers to a process for stably cross-linking a polypeptide having at least two modified amino acids that helps to conformationally bestow the native secondary structure of that polypeptide. Hydrocarbon stapling allows a polypeptide, predisposed to have an alpha-helical secondary structure, to maintain its native alpha-helical conformation. This secondary structure increases resistance of the polypeptide to proteolytic cleavage and heat, and also may increase hydrophobicity. Accordingly, the hydrocarbon stapled (cross-linked) polypeptides described herein have improved biological activity relative to a corresponding non-hydrocarbon stapled (uncrosslinked) polypeptide. For example the cross-linked polypeptide can include an alpha-helical domain of an HIV polypeptide (*e.g.*, HR-1/HR-2 domain), which can interfere with HIV attachment, fusion with, and infection of a cell. In some instances, the cross-linked polypeptide can be used to inhibit virus entry into a cell. The cross-linked polypeptides described herein can be used therapeutically, *e.g.*, to treat HIV infection and/or AIDS.

The hydrocarbon stapled polypeptides include one or more tethers (linkages) between two non-natural amino acids, which tether significantly enhances the alpha helical secondary structure of the polypeptide. Generally, the tether extends across the length of one or two helical turns (*i.e.*, about 3.4 or about 7 amino acids). Accordingly, amino acids positioned at i and $i+3$; i and $i+4$; or i and $i+7$ are ideal

candidates for chemical modification and cross-linking. Thus, for example, where a peptide has the sequence . . . X1, X2, X3, X4, X5, X6, X7, X8, X9 . . . , cross-links between X1 and X4, or between X1 and X5, or between X1 and X8 are useful as are cross-links between X2 and X5, or between X2 and X6, or between X2 and X9, etc.

5 The use of multiple cross-links (*e.g.*, 2, 3, 4 or more) is also contemplated. The use of multiple cross-links is very effective at stabilizing and optimizing the peptide, especially with increasing peptide length, as is the case for some gp41 fusion peptides. Thus, the invention encompasses the incorporation of more than one crosslink within the polypeptide sequence to either further stabilize the sequence or
10 facilitate the structural stabilization, proteolytic resistance, acid stability, thermal stability, and biological activity enhancement of longer polypeptide stretches.

The term “stable” or “stabilized”, as used herein with reference to a polypeptide, refers to polypeptides which have been hydrocarbon-stapled to maintain their natural alpha-helical structure and/or improve protease resistance and/or improve
15 acid stability and/or improve thermal stability.

As used herein, “HIV” is meant to include HIV-1 and HIV-2 and SIV. “HIV-1” means the human immunodeficiency virus type-1. HIV-1 includes but is not limited to extracellular virus particles and the forms of HIV-1 associated with HIV-1 infected cells. “HIV-2” means the human immunodeficiency virus type-2. HIV-2
20 includes but is not limited to extracellular virus particles and the forms of HIV-2 associated with HIV-2 infected cells. The term “SIV” refers to simian immunodeficiency virus which is an HIV-like virus that infects monkeys, chimpanzees, and other nonhuman primates. SIV includes but is not limited to extracellular virus particles and the forms of SIV associated with SIV infected cells.

25 As used herein a “heptad repeat domain” and “HR domain” refers to a polypeptide that forms an alpha-helix when properly folded. The terms, “heptad repeat domain” and “HR domain” include “HR-like” and “HR-analog” polypeptides. Numerous viral proteins involved in cell attachment and fusion contain HR, HR-like and HR-analog domains including, HIV, parainfluenza, coronavirus, and others.
30 Generally, HR domains are derived from gp41 of HIV, while HR-analog domains are derived from the envelope glycoproteins of non-HIV viruses. Many HR and HR-analog domain polypeptides are known in the art and described herein. In one

embodiment, the HR domain has an amino acid sequence which is 40%, 50%, 60%, 70%, 80%, or more identical to FIG. 5, FIG. 6 or SEQ ID NO:1-14. It should be noted that HR and HR-like domains may have low homology but will share a common alpha helical structure, with more conservation on the interaction surfaces than non-interacting surfaces (see FIGs. 4 and 9).

In one embodiment, the HR modified polypeptide includes a heptad repeat domain having the formula: a b c d e f g, wherein a and d are hydrophobic amino acid residues and b, c, e, f and g are any amino acid. Preferably, the formula is repeated in tandem two or more times.

For example, in a further embodiment the heptad repeat domain of the modified polypeptide has the formula: W(a), b, c, W(d), e, f, g, I(a), b, c, Y(d), e, f, g, I(a), b, c, L(d), e, f, g, S(a), b, c, Q(d), e, f, g, N(a), b, c, E(d), e, f, g, L(a), or conservative amino acid substitutions thereof and wherein the b, c, e, f and g can be any amino acid.

In a further, embodiment the heptad repeat domain of the modified polypeptide has the formula: T(g), W(a), b, c, W(d), D(e), R(f), g, I(a), b, c, Y(d), e, f, g, I(a), b, c, L(d), I(e), f, g, a, Q(b), c, d, Q(e), E(f), K(g), a, E(b), c, d, L(e), f, E(g), L(a), or conservative amino acid substitutions thereof and wherein non-designated amino acids can be any amino acid.

The HR regions are known to comprise a plurality of 7 amino acid residue stretches or "heptads" (the 7 amino acids in each heptad designated "a" through "g"), wherein the amino acids in the "a" position and "d" position are generally hydrophobic. Generally the HR region will include one or more leucine zipper-like motifs (also referred to as "leucine zipper-like repeats") comprising an 8 amino acid sequence initiating with, and ending with, an isoleucine or leucine. Heptads and leucine zipper like-motifs contribute to formation of a coiled coil structure of gp41, and of a coiled coil structure of peptides derived from the HR regions. Generally, coiled coils are known to be comprised of two or more helices that wrap around each other in forming oligomers, with the hallmark of coiled coils being a heptad repeat of amino acids with a predominance of hydrophobic residues at the first ("a") and fourth ("d") positions, charged residues frequently at the fifth ("e") and seventh ("g") positions, and with the amino acids in the "a" position and "d" position being primary

determinants that influence the oligomeric state and strand orientation (see, e.g., Akey et al., 2001, *Biochemistry*, 40:6352-60).

The effect on stability and oligomerization state of a model coiled coil, by substituting various amino acids at various positions including the "a" and "d" positions, have been reported previously, wherein formation of a trimeric structure was particularly dependent on the substitution at the "d" position (see, e.g., Tripet et al., *J. Mol. Biol.* 300:377-402 (2000); Wagschal et al., *J. Mol. Biol.* 285:785-803 (2000); and Dwyer et al., *PNAS USA*. 104:12772-12777 (2007).

It will be apparent to one skilled in the art that any peptide derived from the native sequence of the HR1 domain or HR2 domain of HIV gp41 which has antiviral activity (as can be determined using methods standard in the art without undue experimentation), and which contains all or a fraction of the region can be used as a native sequence into which one or more amino acid substitutions, preferably conservative, in the domain may be introduced to produce a synthetic peptide provided with the present invention. For purposes of illustration, such HR2 peptides derived from the native sequence, and from which a synthetic peptide may be produced, may include, but are not limited to, those illustrated in FIGS 5 and 6.

It is apparent to those of ordinary skill in the art that some HR and HR-analog domain residues are less prone to substitution while others are more accepting of changes. For example, it is preferable not to mutate or to only conservatively mutate the amino acids at positions a and d of the heptad repeat (See FIG. 9). In one embodiment, the heptad repeat domain has the formula a, b, c, d, e, f, g, wherein a and d are hydrophobic amino acids. In a further embodiment, the heptad repeat domain has two or more repeats of the formula a, b, c, d, e, f, g. For example, in one embodiment the HR domain will have the amino acid sequences illustrated in FIG. 9 or conservative substitutions thereof. Thus, the HR and HR-like domains have significant variability in amino acid sequence but will maintain an alpha helical structure and antiviral activity.

In one embodiment, the modified polypeptide includes a heptad repeat domain having the formula: a b c d e f g, wherein a and d are hydrophobic amino acid residues and b, c, e, f and g are any amino acid. Preferably, the formula is repeated in tandem two or more times.

For example, in a further embodiment the heptad repeat domain of the modified polypeptide has the formula: W(a), b, c, W(d), e, f, g, I(a), b, c, Y(d), e, f, g, I(a), b, c, L(d), e, f, g, S(a), b, c, Q(d), e, f, g, N(a), b, c, E(d), e, f, g, L(a), or conservative amino acid substitutions thereof and wherein the b, c, e, f and g can be any amino acid.

In a further, embodiment the heptad repeat domain of the modified polypeptide has the formula: T(g),W(a), b, c, W(d),D(e),R(f), g,I(a), b, c, Y(d), e, f, g, I(a), b, c, L(d), I(e), f, g, a, Q(b), c, d, Q(e), E(f), K(g), a, E(b), c, d, L(e), f,E(g), L(a), or conservative amino acid substitutions thereof and wherein non-designated amino acids can be any amino acid.

The HR, HR-like and HR-analog domains are readily identifiable by those possessing ordinary skill in the art by sequence based homology, structural homology and/or functional homology. Such methods are well known in the art and include bioinformatics programs based on pairwise residue correlations, which have the ability to recognize coiled coils from protein sequences and model their structures (See Lupas, A., et al. Science 1991. 252(5009); p. 1162-1164). Additional methods for identifying HR, HR-like and HR-analog domains are described in U.S. Patent No. 6,824,783; U.S. Patent No. 7,273,614; U.S. Patent No. 5,464,933; and U.S. Patent No. 7,122,190.

In one embodiment, the modified polypeptide of the invention is 70% or more similar at the interacting face to the amino acid sequence of SEQ ID NO:1-14, FIG. 5 or FIG. 6. The "interacting face" of the alpha helix includes those amino acid residues which interact with other amino acid residues. For example, in the HIV gp41 HR-2 domain the interacting face includes the "a" and "d" position amino acids (See FIG. 4A and 9), while the interacting face of the HIV gp41 HR-1 domain includes amino acids at positions e, g that interact with HR-2 and a, d that engage in HR1-HR1 interactions (See FIG. 4A). Methods for identifying heptad repeats and the interacting face residues are well known in the art and described herein.

An "HR-1 domain of HIV" or "heptad repeat one domain of HIV" is an N-terminal portion of the gp41 protein of HIV (the transmembrane subunit of HIV envelope) that forms an alpha-helix when properly folded. The HR-1 domain of HIV

gp41 can include between 5 and 55 amino acid residues and is based on the sequence of the native HR-1 domain of HIV gp41, or a combination or chimera thereof. The HR-1 domain of HIV can include the N36 domain which encompasses amino acid residues 546-581 HIV-1 Env (See FIG. 2 and Bewley *et al.*, *J. Biol. Chem.*

5 277:14238-14245 (2002)). HR-1 domain polypeptides are known in the art and described herein. In one embodiment, the HR-1 domain has an amino acid sequence which is 30% or more identical to SEQ ID NO:2 or 14.

An "HR-2 domain of HIV" or a heptad repeat two domain of HIV is a C-terminal portion of the gp41 protein of HIV (the transmembrane subunit of HIV
10 envelope) that forms an alpha-helix when properly folded. The HR-2 domain of HIV can include the C34 domain which encompasses amino acid residues 628-661 of HIV-1 Env (See FIG. 2). HR-2 domain polypeptides are known in the art and described herein. In one embodiment, the HR-2 domain has an amino acid sequence which is 40% or more identical to SEQ ID NO:1 or 13.

15 As used herein, the term "chimera" or "chimeric", with reference to the polypeptides of the invention refers to a polypeptide having at least two different HR domains or having a single HR domain region that is combined in a manner not found in nature (FIG 8). For example, the chimera polypeptide may have a first portion of an HIV-1 gp41 HR-2 domain and a second portion from a SIV gp41 HR-2 domain.
20 These chimeric polypeptides are encoded by nucleotide sequences which can be fused or ligated together resulting in a coding sequence which does not occur naturally. The chimera includes any functional derivative, fragments, variants, analogues, or chemical derivatives which may be substantially similar to the wild-type HR polypeptides (HIV-1 gp41 HR-2) and which possess similar activity (*i.e.*, most
25 preferably, 90%, more preferably, 70%, preferably 40%, or at least 10% of the wild-type HR activity, e.g., inhibiting fusion, viral infectivity).

The terms "treat," and "treating," as used herein, shall mean decrease, suppress, attenuate, diminish, arrest, or stabilize the development or progression of a disease or decrease the occurrence of pathological cells (*e.g.*, infected cells) in an
30 animal who is infected with the viral disorder. The treatment may be complete, *e.g.*, the total absence of HIV in a subject. The treatment may also be partial, such that the occurrence of infected cells in a subject is less than that which would have occurred

without the present invention. Treatment results in the stabilization, reduction or elimination of the infected cells, an increase in the survival of the patient or decrease of at least one sign or symptoms of the disease.

The terms “prevent,” “preventing,” and “prevention,” as used herein, shall refer to a decrease in the occurrence of a disease, or decrease in the risk of acquiring a disease, or a decrease in the presentation of at least one sign or associated symptom of the disease in a subject. The prevention may be complete, *e.g.*, the total absence of disease or pathological cells in a subject. The prevention may also be partial, such that the occurrence of the disease or pathological cells in a subject is less than that which would have occurred without the present invention.

The term “inhibits” as used herein with reference to a viral infection refers to a decrease in viral transmission, decrease in virus binding to a cellular target or decrease in disease. For example, the polypeptides of the present invention are used to inhibit viral transmission, syncytia formation, and disease associated with the virus (*e.g.* AIDS). A compound of the invention can be screened by many assays, known in the art and described herein, to determine whether the compound inhibits the virus (*e.g.*, infectivity, transmission, etc.). For example, a compound of the invention can be assayed for its ability to inhibit viral infectivity by contacting a cell culture that is incubated with the virus with a test compound. The compound is found to inhibit viral infectivity when viral infectivity is 90%, 80%, 75%, 70%, 60%, 50%, 40%, 30%, 20%, 10%, 5% or less in the presence of the test compound as compared to a suitable control (population of cells not subjected to inhibitor).

The term “inhibit transmission”, as used herein, refers to the agent’s ability to inhibit viral infection of cells, via, for example, cell--cell fusion or free virus infection. Such infection may involve membrane fusion, as occurs in the case of enveloped viruses, or some other fusion event involving a viral structure and a cellular structure.

The term “inhibiting syncytia formation”, as used herein, refers to an agent’s ability to inhibit or reduce the level of membrane fusion events between two or more moieties relative to the level of membrane fusion which occurs between said moieties in the absence of the agent. The moieties may be, for example, cell membranes or viral structures, such as viral envelopes.

The terms “effective amount,” or “effective dose” refers to that amount of an agent to produce the intended pharmacological, therapeutic or preventive result. The pharmacologically effective amount results in the amelioration of one or more symptoms of a viral disorder, or prevents the advancement of a viral disease, or causes the regression of the disease or decreases viral transmission. For example, a therapeutically effective amount preferably refers to the amount of a therapeutic agent that decreases the rate of transmission, decreases HIV viral load, or decreases the number of infected cells, by at least 5%, preferably at least 10%, at least 15%, at least 20%, at least 25%, at least 30%, at least 35%, at least 40%, at least 45%, at least 50%, at least 55%, at least 60%, at least 65%, at least 70%, at least 75%, at least 80%, at least 85%, at least 90%, at least 95%, or more. A therapeutically effective amount, with reference to HIV, also refers to the amount of a therapeutic agent that increases CD4+ cell counts, increases time to progression to AIDS, or increases survival time by at least 5%, preferably at least 10%, at least 15%, at least 20%, at least 25%, at least 30%, at least 35%, at least 40%, at least 45%, at least 50%, at least 55%, at least 60%, at least 65%, at least 70%, at least 75%, at least 80%, at least 85%, at least 90%, at least 95%, or more.

The term “amino acid” refers to a molecule containing both an amino group and a carboxyl group. Suitable amino acids include, without limitation, both the D- and L-isomers of the 20 common naturally occurring amino acids found in peptides (*e.g.*, A, R, N, C, D, Q, E, G, H, I, L, K, M, F, P, S, T, W, Y, V (as known by the one letter abbreviations)) as well as the naturally occurring and non-naturally occurring amino acids prepared by organic synthesis or other metabolic routes.

A “non-essential” amino acid residue is a residue that can be altered from the wild-type sequence of a polypeptide (*e.g.*, an HR-1 or HR-2 domain) without abolishing or substantially altering its activity/secondary structure (alpha-helical structure). An “essential” amino acid residue is a residue that, when altered from the wild-type sequence of the polypeptide, results in abolishing or substantially abolishing the polypeptide activity and/or secondary structure. Substantially abolishing is understood as reducing the activity of the peptide to less than about 30%, less than about 20%, less than about 10%, less than about 5% of the wild-type peptide in an appropriate assay (*e.g.*, a syncytia formation assay, a viral fusion assay).

The essential and non-essential amino acid residues of the HR and HR-like domains can readily be determined by methods well known in the art and are described herein. In one embodiment, an essential amino acid residue is in the “a” or “d” position of a heptad repeat domain, while non-essential amino acids may occur in a “b”, “c”, “e”, “f” or “g” position (FIG. 9). The term “essential” amino acid residue as used herein, includes conservative substitutions of the essential amino acid. Generally, the “essential” amino acid residues are found at the interacting face of the alpha helix. For example, in the HIV gp41 HR-2 domain the interacting face includes the “a” and “d” position amino acids. (See FIG. 4A and 9). In another embodiment, a modified polypeptide comprises a gp41 HR-1 domain having a Leu-556, Leu-565, Val-570, Gly-572, and Arg-579 (Lu, M., et al., J. Vir, 2001. 75(22); p. 11146-11156).

A “conservative amino acid substitution” is one in which the amino acid residue is replaced with an amino acid residue having a similar side chain. For example, families of amino acid residues having similar side chains have been defined in the art. These families include amino acids with basic side chains (*e.g.*, lysine, arginine, histidine), acidic side chains (*e.g.*, aspartic acid, glutamic acid), uncharged polar side chains (*e.g.*, glycine, asparagine, glutamine, serine, threonine, tyrosine, cysteine), nonpolar side chains (*e.g.*, alanine, valine, leucine, isoleucine, proline, phenylalanine, methionine, tryptophan), beta-branched side chains (*e.g.*, threonine, valine, isoleucine) and aromatic side chains (*e.g.*, tyrosine, phenylalanine, tryptophan, histidine). Other conserved amino acid substitutions can also occur across amino acid side chain families, such as when substituting an asparagine for aspartic acid in order to modify the charge of a peptide. Thus, a predicted nonessential amino acid residue in a HR domain polypeptide, for example, is preferably replaced with another amino acid residue from the same side chain family or homologues across families (*e.g.* asparagine for aspartic acid, glutamine for glutamic acid).

As used herein, the terms “identity” or “percent identity”, refers to the subunit sequence similarity between two polymeric molecules, *e.g.*, two polynucleotides or two polypeptides. When a subunit position in both of the two molecules is occupied by the same monomeric subunit, *e.g.*, if a position in each of two peptides is occupied by serine, then they are identical at that position. The identity between two sequences is a direct function of the number of matching or identical positions, *e.g.*, if half (*e.g.*,

5 positions in a polymer 10 subunits in length), of the positions in two peptide or compound sequences are identical, then the two sequences are 50% identical; if 90% of the positions, *e.g.*, 9 of 10 are matched, the two sequences share 90% sequence identity. The identity between two sequences is a direct function of the number of matching or identical positions. Thus, if a portion of the reference sequence is deleted in a particular peptide, that deleted section is not counted for purposes of calculating sequence identity. Identity is often measured using sequence analysis software *e.g.*, BLASTN or BLASTP (available at the world wide web site (“www”) of the National Center for Biotechnology Information (“.ncbi”) of the National Institutes of Health (“.nih”) of the U.S. government (“.gov”), in the “Blast” directory (“/BLAST/”). The default parameters for comparing two sequences (*e.g.*, “Blast”-ing two sequences against each other), by BLASTN (for nucleotide sequences) are reward for match = 1, penalty for mismatch = -2, open gap = 5, extension gap = 2. When using BLASTP for protein sequences, the default parameters are reward for match = 0, penalty for mismatch = 0, open gap = 11, and extension gap = 1. Additional, computer programs for determining identity are known in the art.

“Similarity” or “percent similarity” in the context of two or more polypeptide sequences, refer to two or more sequences or subsequences that are the same or have a specified percentage of amino acid residues, or conservative substitutions thereof, that are the same when compared and aligned for maximum correspondence, as measured using one of the following sequence comparison algorithms, or by visual inspection. By way of example, a first polypeptide can be considered similar to an HIV-1 HR-1 domain when the amino acid sequence of the first polypeptide is at least 20%, 50%, 60%, 70%, 75%, 80%, 90%, or even 95% or more identical, or conservatively substituted, to a region of the HIV-1 HR-1 domain when compared to any sequence of an equal number of amino acids as the number contained in the first polypeptide as aligned by a computer similarity program known in the art and described herein. Preferably, the polypeptide region of the first protein and the second protein includes one or more conserved amino acid residues.

As used herein, an “antibody” includes any reactive fragment or fragments of antibodies such as Fab molecules, Fab proteins, single chain polypeptides, or the multi-functional antibodies having binding affinity for the antigen. The term includes

that the group may have from 2 to 10 (inclusive) carbon atoms in it. The term "lower alkenyl" refers to a C₂-C₈ alkenyl chain. In the absence of any numerical designation, "alkenyl" is a chain (straight or branched) having 2 to 20 (inclusive) carbon atoms in it.

5 The term "alkynyl" refers to a hydrocarbon chain that may be a straight chain or branched chain having one or more carbon-carbon triple bonds. The alkynyl moiety contains the indicated number of carbon atoms. For example, C₂-C₁₀ indicates that the group may have from 2 to 10 (inclusive) carbon atoms in it. The term "lower alkynyl" refers to a C₂-C₈ alkynyl chain. In the absence of any numerical designation,
10 "alkynyl" is a chain (straight or branched) having 2 to 20 (inclusive) carbon atoms in it.

 The term "aryl" refers to a 6-carbon monocyclic or 10-carbon bicyclic aromatic ring system wherein 0, 1, 2, 3, or 4 atoms of each ring may be substituted by a substituent. Examples of aryl groups include phenyl, naphthyl and the like. The term
15 "arylalkyl" or the term "aralkyl" refers to alkyl substituted with an aryl. The term "arylalkoxy" refers to an alkoxy substituted with aryl.

 The term "cycloalkyl" as employed herein includes saturated and partially unsaturated cyclic hydrocarbon groups having 3 to 12 carbons, preferably 3 to 8 carbons, and more preferably 3 to 6 carbons, wherein the cycloalkyl group
20 additionally may be optionally substituted. Preferred cycloalkyl groups include, without limitation, cyclopropyl, cyclobutyl, cyclopentyl, cyclopentenyl, cyclohexyl, cyclohexenyl, cycloheptyl, and cyclooctyl.

 The term "heteroaryl" refers to an aromatic 5-8 membered monocyclic, 8-12 membered bicyclic, or 11-14 membered tricyclic ring system having 1-3 heteroatoms
25 if monocyclic, 1-6 heteroatoms if bicyclic, or 1-9 heteroatoms if tricyclic, said heteroatoms selected from O, N, or S (e.g., carbon atoms and 1-3, 1-6, or 1-9 heteroatoms of N, O, or S if monocyclic, bicyclic, or tricyclic, respectively), wherein 0, 1, 2, 3, or 4 atoms of each ring may be substituted by a substituent. Examples of heteroaryl groups include pyridyl, furyl or furanyl, imidazolyl, benzimidazolyl,
30 pyrimidinyl, thiophenyl or thienyl, quinolinyl, indolyl, thiazolyl, and the like. The term "heteroarylalkyl" or the term "heteroaralkyl" refers to an alkyl substituted with a

heteroaryl. The term "heteroarylalkoxy" refers to an alkoxy substituted with heteroaryl.

The term "heterocyclyl" refers to a nonaromatic 5-8 membered monocyclic, 8-12 membered bicyclic, or 11-14 membered tricyclic ring system having 1-3
5 heteroatoms if monocyclic, 1-6 heteroatoms if bicyclic, or 1-9 heteroatoms if tricyclic, said heteroatoms selected from O, N, or S (e.g., carbon atoms and 1-3, 1-6, or 1-9 heteroatoms of N, O, or S if monocyclic, bicyclic, or tricyclic, respectively), wherein 0, 1, 2 or 3 atoms of each ring may be substituted by a substituent. Examples of heterocyclyl groups include piperazinyl, pyrrolidinyl, dioxanyl, morpholinyl,
10 tetrahydrofuranyl, and the like.

The term "substituents" refers to a group "substituted" on an alkyl, cycloalkyl, aryl, heterocyclyl, or heteroaryl group at any atom of that group. Suitable substituents include, without limitation, halo, hydroxy, mercapto, oxo, nitro, haloalkyl, alkyl, alkaryl, aryl, aralkyl, alkoxy, thioalkoxy, aryloxy, amino, alkoxy carbonyl, amido,
15 carboxy, alkanesulfonyl, alkylcarbonyl, and cyano groups.

Ranges provided herein are understood to be shorthand for all of the values within the range. For example, a range of 1 to 50 is understood to include any number, combination of numbers, or sub-range from the group consisting 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29,
20 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, or 50.

Unless specifically stated or obvious from context, as used herein, the term "or" is understood to be inclusive.

Unless specifically stated or obvious from context, as used herein, the terms "a", "an", and "the" are understood to be singular or plural.

25 Unless specifically stated or obvious from context, as used herein, the term "about" is understood as within a range of normal tolerance in the art, for example within 2 standard deviations of the mean. About can be understood as within 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, 1%, 0.5%, 0.1%, 0.05%, or 0.01% of the stated value.

The recitation of a listing of chemical groups in any definition of a variable herein includes definitions of that variable as any single group or combination of listed groups. The recitation of an embodiment for a variable or aspect herein includes that embodiment as any single embodiment or in combination with any other
5 embodiments or portions thereof.

Any compositions or methods provided herein can be combined with one or more of any of the other compositions and methods provided herein.

Polypeptides

Described herein are modified peptides which exhibit antiviral activity. It is
10 believed that the modified peptides exhibit antiviral activity via their ability to inhibit virus-cell fusion by interfering with viral coat proteins. The modified peptides of the invention may include a stabilized alpha helix heptad repeat domain derived from a virus. Preferably, the alpha helix heptad repeat domain is stabilized with hydrocarbon staples. Suitable viral alpha helix heptad repeat domains can be derived from any
15 virus with an alpha helical domain (*e.g.*, RSV, influenza, parainfluenza, coronavirus, ebolavirus, HIV) that is directly or indirectly involved in cell attachment or entry.

While not limited to any theory of operation, the following model is proposed to explain the potent anti-viral activity of the modified polypeptides described herein. When synthesized as stabilized peptides, the modified polypeptides of the invention
20 are potent inhibitors of viral infection and fusion, likely by virtue of their ability to form complexes with viral glycoproteins and interfere with the fusogenic process; *e.g.*, during the structural transition of the viral protein from the native structure to the fusogenic state. While not being bound by theory, it is believed the modified peptides gain access to their respective binding sites on the viral glycoprotein, and exert a
25 disruptive influence which inhibits fusion of the virus with the cell. The modified polypeptides are particularly useful as a result of their increased stability and efficacy.

In a first aspect, the invention is directed to a modified polypeptide having a stabilized viral alpha helix heptad repeat domain (*e.g.*, HR-1, HR-2, HR-like or HR-analogs) or active fragment thereof. The modified polypeptide may also comprise a
30 chimera of an HR domain. Suitable viral alpha helix heptad repeat domains can be derived from any virus with an alpha helix domain that is directly or indirectly

involved in cell attachment or entry.

In another aspect, the invention is directed to a modified polypeptide having a stabilized HIV gp41 heptad repeat domain (*e.g.*, heptad repeat domain 1 or 2 of HIV-1 or HIV-2). The amino acid sequences of heptad repeat-1 and heptad repeat-2
5 domains are well known in the art and include those represented by SEQ ID NO:2 and SEQ ID NO:1, respectively. In one embodiment, the heptad repeat domain 1 is 30% or more identical to an amino acid sequence of SEQ ID NO:2, SEQ ID NO:3 or SEQ ID NO:14 and forms an alpha helix. Alternatively, the heptad repeat one domain of
10 the modified polypeptide may differ by more than 30% as long as the residues of the interacting face are identical to those of SEQ ID NO:1 or 2 or are conservative substitutions thereof. Methods for identifying the interacting face residues of the heptad repeat are well known in the art and described herein.

In another embodiment, the heptad repeat domain 2 is 30% or more identical to an amino acid sequence of FIG 4, FIG. 6 or SEQ ID NO:1 and forms an alpha-helix.
15 Alternatively, the heptad repeat two domain of the modified polypeptide may differ by more than 30% as long as the residues of the interacting face are identical to those of SEQ ID NO:1 or 2 or have conservative substitutions thereof. Methods for identifying the interacting face residues of the heptad repeat are well known in the art and described herein.

20 In one embodiment, the modified polypeptide includes a heptad repeat domain having the formula: a b c d e f g, wherein a and d are hydrophobic amino acid residues and b, c, e, f and g are any amino acid. Preferably, the formula is repeated in tandem two or more times.

For example, in a further embodiment the heptad repeat domain of the
25 modified polypeptide has the formula: W(a), b, c, W(d), e, f, g, I(a), b, c, Y(d), e, f, g, I(a), b, c, L(d), e, f, g, S(a), b, c, Q(d), e, f, g, N(a), b, c, E(d), e, f, g, L(a), or conservative amino acid substitutions thereof and wherein the b, c, e, f and g can be any amino acid.

In a further, embodiment the heptad repeat domain of the modified
30 polypeptide has the formula: T(g),W(a), b, c, W(d),D(e),R(f), g,I(a), b, c, Y(d), e, f, g, I(a), b, c, L(d), I(e), f, g, a, Q(b), c, d, Q(e), E(f), K(g), a, E(b), c, d, L(e), f,E(g),

L(a), or conservative amino acid substitutions thereof and wherein non-designated amino acids can be any amino acid.

In another embodiment, the modified polypeptide of the invention is has the same amino acid residues, or conservative substitutions thereof, of the interacting face of the amino acid sequence of SEQ ID NO:1-14, FIG. 5 or FIG. 6. The “interacting face” of the alpha helix are those amino acid residues which interact with other amino acid residues in a coiled coil structure. For example, in the HIV gp41 HR-2 domain the interacting face includes the “a” and “d” position amino acids. (See FIG. 4A and 9), while the interacting face of the HIV gp41 HR-1 domain includes amino acids at positions e, g that interact with HR-2 and a, d that engage in HR1-HR1 interactions (See FIG. 4A). Methods for identifying heptad repeats and the interacting face residues are well known in the art and described herein.

Preferably the alpha helix heptad repeat domain is stabilized with a hydrocarbon staple (e.g., FIG. 10). Hydrocarbon staples suitable for use with any of the modified polypeptides are described herein and in U.S. Publication No. 2005/0250680. Hydrocarbon stapling allows a polypeptide, predisposed to have an alpha-helical secondary structure, to maintain its native alpha-helical conformation and increase its stability and efficacy. In one embodiment, the modified polypeptide has at least 10%, 20%, 30%, 35%, 40%, 45%, 50%, 60%, 70%, 80%, or 90% or more alpha helicity in an aqueous solution as determined by circular dichroism. Assays for determining circular dichroism are known in the art and described herein.

The hydrocarbon stapled polypeptides include a tether (linkage) between two amino acids, which tether significantly enhances the alpha helical secondary structure of the polypeptide. Generally, the tether extends across the length of one or two helical turns (i.e., about 3.4 or about 7 amino acids). Accordingly, amino acids positioned at i and $i+3$; i and $i+4$; or i and $i+7$ are ideal candidates for chemical modification and cross-linking. Thus, any of the amino acid residues of the modified polypeptides of the invention may be tethered (e.g., cross-linked) in conformity with the above. Suitable tethers are described herein and in U.S. Patent Publication No. 2005/0250680.

In a further embodiment, the hydrocarbon staple(s) is positioned so as to link a

first amino acid (i) and a second amino acid (i+3) which is 3 amino acids downstream of the first amino acid. In another embodiment, the hydrocarbon staple links a first amino acid (i) and a second amino acid (i+4) which is 4 amino acids downstream of the first amino acid. In yet another embodiment, the hydrocarbon staple links a first amino acid (i) and a second amino acid (i+7) which is 7 amino acids downstream of the first amino acid.

In yet a further embodiment, the modified polypeptides include a heptad repeat domain with the sequence:

BTWXEWDXEINNYTSLIHSL,
 10 BTWBEWDREINNYTSLIHSLIEESQNQQXKNEXELLE,
 BTWBXWDRXINNYTSL,
 BTWBEWDREINNYTSLIHSLIEXSQNXQEKNEQELLE,
 BTWBXWDRXINNYTSLIHSLIEESQNQQEKNEQELLE,
 BTWBXWDRXINNYTSLIHSLIEXSQNXQEKNEQELLE,
 15 BTWBEWDREINNYTSLIHSLIEESQNQQXKNEXELLE,
 BTWBXWDRXINNYTSLIHSLIEESQNQQXKNEXELLE,
 BTWBEWDXEINXYTSLIHSLIEESQNQQXKNEXELLE,
 BTWBEWDREINXYTSXIHSXIEESQNQQXKNEXELLE,
 BTWBEWDREINNYTSXIHSXIEESQNQQXKNEXELLE,
 20 BTWBXWDRXINNYTSXIHSXIEESQNQQXKNEXELLE,
 YTSXIHSXIEESQNQQEKNEQELLELDKWASLWNWF,
 YTSLIXSLIXESQNQQEKNEQELLELDKWASLWNWF,
 YTSLIHSLIEXSQNXQEKNEQELLELDKWASLWNWF,
 YTSLIHSLIEESQNQQXKNEXELLELDKWASLWNWF,
 25 YTSLIHSLIEESQNQQEXNEQXLELDKWASLWNWF,
 YTSLIHSLIEESQNQQEKNEQXLELDKWASLWNWF,
 YTSLIHSLIEESQNQQEKNEQELLELDXWASXWNWF,
 YTSLIHSLIEESQNQQEKNEQELLELDKWASLWXWF,
 YTSLIHSLIEXSQNXQEKNEQXLELDKWASLWNWF,
 30 YTSXIHSXIEESQNQQEKNEQELLELDKWASLWXWF,
 YTSLIHSLIEESQNQQXKNEXELLELDKWASLWXWF,
 YTSXIHSXIEESQNQQXKNEXELLELDKWASLWNWF,

YTSXIHSXIEESQNQQEKNEQELLELDXWASXWNWF,
 YTSLIHSLEIXSQNXQEKNEQELLELDXWASXWNWF,
 YTSXIHSXIEESQNQQXKNEXELLELDXWASXWNWF,
 BTWBXWDRXINNYTSLIHSLEIESQNQXEKKNXQELLE, or
 5 BTWBXWDRXINNYTSLIHSLEIESQNXQEKXEQELLE;

wherein X is any amino acid and further identifies the amino acid residues which are linked by a hydrocarbon staple, and B is methionine or norleucine. The modified polypeptides will generally have the structure of Formula (I), (II) or (III), as described herein.

10 The invention is also, *inter alia*, directed to modified polypeptides from other viruses with alpha helical domains that are either directly or indirectly involved in the attachment and/or fusion of a virus to a cell. For example, in one aspect the invention is directed to a modified polypeptide having a stabilized viral alpha helix (*e.g.*, heptad repeat domain) that is derived from respiratory syncytial virus. The alpha helix may
 15 include any alpha helical domain derived from RSV that is involved in viral infectivity. Suitable RSV alpha helix domains include those which are 30% or more identical to

YTSVITIELSNIKENKCNGTDAKVKLIKQELDKYKNAVTELQLLMQST (SEQ ID NO:4);

20 FYDPLVFPSDEFDASISQVNEKINQSLAFIRKSDELL (SEQ ID NO:5);

SGIAVSKVLHLEGEVKNKIKNALLSTNKAVVSLSNGVSVLTSKVLDLKSINNQLLPI- (SEQ ID NO: 11) or

PIINYDPLVFPSDEFDASISQVNEKINQSLAFIRRSDELLHNVNTGKSTTNIM (SEQ ID NO: 12); and form an alpha-helix.

25 Alternatively, the heptad repeat analog domain of the modified polypeptide may differ by more than 30% as long as the residues of the interacting face are identical to those of SEQ ID NOs: 4, 5, 11 and 12 or are conservative substitutions thereof. Methods for identifying the interacting face residues of the heptad repeat analogs are well known in the art and described herein.

30 In yet another aspect, the invention is directed to a modified polypeptide having a stabilized viral alpha helix heptad repeat domain that is derived from a

parainfluenza virus. Suitable parainfluenza virus heptad repeat domains include those which are 30% or more identical to

ALGVATSAQITAAVALVEAKQARSDIEKLKEAIR (SEQ ID NO:6) and form an alpha-helix. Alternatively, the heptad repeat domain of the modified parainfluenza polypeptide may differ by more than 30% as long as the residues of the interacting face are identical to those of SEQ ID NO: 6 or are conservative substitutions thereof. Methods for identifying the interacting face residues of the heptad repeat are well known in the art and described herein.

In another aspect, the invention is directed to a modified polypeptide having a stabilized viral alpha helix heptad repeat domain derived from a paramyxovirus, orthomyxovirus coronavirus, and a filovirus.

Coronavirus alpha helix heptad repeat domains are known in the art and include those which have an amino acid sequence which are 30% or more identical to NVLYENQKQIANQFNKAISQIQESLTTTSTALGKLQDVVNQNAQALNTLVKQLSSNFGAISSVLNDILSRLDKVEAE (SEQ ID NO:7) or TSPDVDFGDISGINASVVNIQKEIDRLNEVAKNLNESLIDLQELGKY (SEQ ID NO:8) and form an alpha-helix. Alternatively, the heptad repeat domain of the modified coronavirus polypeptide may differ by more than 30% as long as the residues of the interacting face are identical to those of SEQ ID NOs: 7 and 8 or are conservative substitutions thereof. Methods for identifying the interacting face residues of the heptad repeat are well known in the art and described herein.

Similarly, filovirus alpha helix heptad repeat domains are known in the art and include those that are 30% or more identical to DGLICGLRQLANETTQALQLFLRATTELRTFSILNRKAIDFLL (SEQ ID NO:9) or DWTKNITDKIDQIIHDFVDKTLPD (SEQ ID NO:10) and form an alpha-helix. Alternatively, the heptad repeat domain of the modified filovirus polypeptide may differ by more than 30% as long as the residues of the interacting face are identical to those of SEQ ID NO: 10 or are conservative substitutions thereof. Methods for identifying the interacting face residues of the heptad repeat are well known in the art and described herein.

Influenza heptad repeat domains are also known in the art. For example, a

heptad repeat domain in Influenza A Virus (strain A/Aichi/2/68) occurs at residues 379-436, 387-453, and 380-456. Similarly, residues 383-471 were shown by Carr and Kim to be an extended coiled coil when under acidic pH (Carr and Kim, 1993, Cell 73: 823-832).

5 The modified polypeptides of the invention will generally include the structure of Formula (I), (II) or (III) provided below.

Any of the modified polypeptides described herein can be present in a composition (*e.g.*, pharmaceutical composition) or kit. In some embodiments of the invention, the composition or kit comprises two or more modified polypeptides. For
10 example, the composition may include two or more modified polypeptides having a stabilized HIV gp41 heptad repeat domain.

For clarity of discussion, the invention will be further described primarily for HR-1 and HR-2 modified polypeptides of HIV. However, the principles may be analogously applied to other viruses, both enveloped and nonenveloped, and to other
15 non-viral organisms. As used herein the term "heptad repeat" includes HR-2 and HR-1 peptides.

HR-2 and HR-2- Peptides

The modified polypeptides of the invention include the HR-2 peptides (SEQ ID NO:1 and 13) which corresponds to amino acid residues 638 to 673 and 626 and
20 662 respectively of gp160 from the HIV-1 (SEQ ID NO:13), and has the 36 and 37 amino acid sequences, respectively, of (reading from amino to carboxy terminus): YTSLIHSLIEESQNQQEKNEQELLELDKWASLWNWF (SEQ ID NO:1) and MTWMEWDREINNYTSLIHSLIEESQNQQEKNEQELLE (SEQ ID NO:13).

Other useful HR-2 polypeptides for use with the current invention are
25 described in U.S. Patent No. 7,273,614.

In addition to the use of full-length HR-2 (SEQ ID NO:1 and 13) 36 and 37-
mers and the corresponding sequences and variants thereof found in the diversity of HIV-1 strains and mutants, the peptides of the invention may include truncations of
30 the HR-2 (SEQ ID NO: 1 and 13) peptide, gp41 polypeptide sequences that flank the HR-2 domain (*ie.* immediately upstream or downstream sequences), or chimeras

which exhibit antifusogenic activity and antiviral activity. Truncations of HR-2 (SEQ ID NO:1 and 13) peptides may comprise peptides of between 3 and 36 amino acid residues, as shown in FIGS. 5 and 6. Peptide sequences in this figure are listed from amino (left) to carboxy (right) terminus.

5 The modified peptides of the invention also include HR-2-like peptides. "HR-2-like" or "heptad repeat-like", as used herein, refers to full-length and truncated and chimeric HR-2 polypeptides which contain one or more amino acid substitutions, insertions and/or deletions as well as peptide sequences identified or recognized by homology searching. Representative HR-2 like polypeptides include those illustrated
10 in FIG. 5 or FIG. 6. The modified HR-2-like peptides of the invention may exhibit antifusogenic or antiviral activity. In one embodiment, the heptad repeat domain 2 is 30% or more identical to an amino acid sequence of FIG. 5, FIG. 6, SEQ ID NO:1 or SEQ ID NO:13 and form an alpha-helix. Alternatively, the heptad repeat domain 2 of the modified polypeptide may differ by more than 30% as long as the residues of the
15 interacting face are identical to those of FIG. 5, FIG. 6, SEQ ID NO:1 or SEQ ID NO:13 or are conservative substitutions thereof. Methods for identifying the interacting face residues of the heptad repeat are well known in the art and described herein.

HIV-1 and HIV-2 enveloped proteins are structurally distinct, but there exists
20 a striking amino acid conservation within the HR-2 regions of HIV-1 and HIV-2. The amino acid conservation is of a periodic nature, suggesting some conservation of structure and/or function. Therefore, one possible class of amino acid substitutions would include those amino acid changes which are predicted to stabilize the structure of the HR-2 peptides of the invention. Utilizing the HR-2 and HR-2 analog sequences
25 described herein, the skilled artisan can readily compile HR-2 consensus sequences and ascertain from these, conserved amino acid residues which would represent preferred amino acid substitutions.

The amino acid substitutions may be of a conserved or non-conserved nature. Conserved amino acid substitutions consist of replacing one or more amino acids of
30 the HR-2 (SEQ ID NO:1 or 13) peptide sequence with amino acids of similar charge, size, and/or hydrophobicity characteristics, such as, for example, a glutamic acid (E) to aspartic acid (D), aspartic acid (D) to asparagine (N), and glutamic acid (E) to

glutamine (Q) amino acid substitution. Non-conserved substitutions consist of replacing one or more amino acids of the HR-2 peptide sequence with amino acids possessing dissimilar charge, size, and/or hydrophobicity characteristics, such as, for example, a glutamic acid (E) to valine (V) substitution.

5 Amino acid insertions may consist of single amino acid residues or stretches of residues. The insertions may be made at the carboxy or amino terminal end of the full length or truncated HR-2 peptides, as well as at a position internal to the peptide. Such insertions will generally range from 2 to 15 amino acids in length. It is contemplated that insertions made at either the carboxy or amino terminus of the
10 peptide of interest may be of a broader size range, with about 2 to about 50 amino acids being preferred. One or more such insertions may be introduced into the full-length (SEQ ID NO:1 or 13) or truncated HR-2 polypeptides as long as such insertions result in modified peptides that exhibit antifusogenic or antiviral activity.

Preferred amino or carboxy terminal insertions are peptides ranging from
15 about 2 to about 50 amino acid residues in length, corresponding to gp41 protein regions either amino to or carboxy to the actual HR-2 gp41 amino acid sequence, respectively. Thus, a preferred amino terminal or carboxy terminal amino acid insertion would contain gp41 amino acid sequences found immediately amino to or carboxy to the HR-2 region of the gp41 protein.

20 Deletions of full-length (SEQ ID NO:1 or 13) or truncated HR-2 polypeptides are also within the scope of the invention. Such deletions consist of the removal of one or more amino acids from the HR-2 or HR-2-like peptide sequence, with the lower limit length of the resulting peptide sequence being 4 to 6 amino acids. Such deletions may involve a single contiguous or greater than one discrete portion of the
25 peptide sequences. One or more such deletions may be introduced into full-length (SEQ ID NO: 1 or 13) or truncated HR-2 polypeptides, as long as such deletions result in peptides which may still exhibit antifusogenic or antiviral activity.

HR-1 and HR-1- Peptides

Further, the modified peptides of the invention include peptides having amino
30 acid sequences corresponding to HR-1 analogs. HR-1 includes 38- and 51- amino acid peptides which exhibits potent antiviral activity, and corresponds to residues 553

to 590 and 542-592, respectively, of HIV-1 transmembrane (TM) gp41 protein, as shown below:

NNLLRAIEAQQHLLQLTVWGIKQLQARILAVEYLQDQ (SEQ ID NO:2) or
RQLLSGIVQQQ NNLLRAIEAQQHLLQLTVWGIKQLQARILAVEYLQDQQL
5 (SEQ ID NO:14.

In addition to the full-length HR-1 38-mer, the modified peptides of the invention include truncations of the HR-1 peptide which exhibit antifusogenic activity or antiviral activity. Truncations of HR-1 peptides can be made in a similar manner as those exemplified for the HR-2 peptides in FIG. 5 and FIG. 6.

10 The modified peptides of the invention also include HR-1-like peptides. "HR-1-like" or "heptad-repeat like", as used herein, refers to full-length and truncated HR-1 polypeptides which contain one or more amino acid substitutions, insertions and/or deletions and exhibiting antifusogenic or antiviral activity. In one embodiment, the heptad repeat domain 1 is 30% or more identical to an amino acid sequence of SEQ
15 ID NO:2, SEQ ID NO:3 or SEQ ID NO:14 and form an alpha-helix. Alternatively, the heptad repeat domain 1 of the modified polypeptide may differ by more than 30% as long as the residues of the interacting face are identical to those of SEQ ID NOs 2, 3 or 14 or are conservative substitutions thereof. Methods for identifying the interacting face residues of the heptad repeat are well known in the art and described
20 herein.

HIV-1 and HIV-2 enveloped proteins are structurally distinct, but there exists a striking amino acid conservation within the HR-1-corresponding regions of HIV-1 and HIV-2. The amino acid conservation is of a periodic nature, suggesting some conservation of structure and/or function. Therefore, one possible class of amino acid
25 substitutions would include those amino acid changes which are predicted to stabilize the structure of the HR-1 peptides of the invention. Utilizing the HR-1 and HR-1 analog sequences described herein, the skilled artisan can readily compile HR-1 consensus sequences and ascertain from these, conserved amino acid residues which would represent preferred amino acid substitutions.

30 The amino acid substitutions may be of a conserved or non-conserved nature. Conserved amino acid substitutions consist of replacing one or more amino acids of

the HR-1 peptide sequence with amino acids of similar charge, size, and/or hydrophobicity characteristics, such as, for example, a glutamic acid (E) to aspartic acid (D), aspartic acid (D) to asparagine (N), and glutamic acid (E) to glutamine (Q) amino acid substitution. Non-conserved substitutions consist of replacing one or more amino acids of the HR-1 peptide sequence with amino acids possessing dissimilar charge, size, and/or hydrophobicity characteristics, such as, for example, a glutamic acid (E) to valine (V) substitution.

Amino acid insertions may consist of single amino acid residues or stretches of residues. The insertions may be made at the carboxy or amino terminal end of the full-length or truncated HR-1 peptides, as well as at a position internal to the peptide. Such insertions will generally range from 2 to 15 amino acids in length. It is contemplated that insertions made at either the carboxy or amino terminus of the peptide of interest may be of a broader size range, with about 2 to about 50 amino acids being preferred. One or more such insertions may be introduced into full-length or truncated HR-1 polypeptides, as long as such insertions result in modified peptides which may still exhibit antifusogenic or antiviral activity.

Preferred amino or carboxy terminal insertions are peptides ranging from about 2 to about 50 amino acid residues in length, corresponding to gp41 protein regions either amino to or carboxy to the actual HR-1 gp41 amino acid sequence, respectively. Thus, a preferred amino terminal or carboxy terminal amino acid insertion would contain gp41 amino acid sequences found immediately amino to or carboxy to the HR-1 region of the gp41 protein.

Deletions of full-length or truncated HR-1 polypeptides are also within the scope of the invention. Such deletions consist of the removal of one or more amino acids from the HR-1 or HR-1-like peptide sequence, with the lower limit length of the resulting peptide sequence being 4 to 6 amino acids. Such deletions may involve a single contiguous or greater than one discrete portion of the peptide sequences. One or more such deletions may be introduced into full-length or truncated HR-1 polypeptides, as long as such deletions result in peptides which may still exhibit antifusogenic or antiviral activity.

HR-1 and HR-2 Analogs

Peptides corresponding to analogs of the full-length and truncated HR-1 and HR-2 polypeptides, described, above, may be found in other viruses. The term “HR-1 and HR-2 -analogs”, as used herein, refers to a peptide which is recognized or identified as having a heptad repeat-analog domain in a non-HIV virus. Methods for identifying heptad repeat-analog polypeptides are known in the art, for example, bioinformatics programs based on pairwise residue correlations,

which have the ability to recognize coiled coils from protein sequences and model their structures (See Lupas, A., et al. Science 1991. 252(5009); p. 1162-1164).

Further, such modified peptides exhibit antifusogenic or antiviral activity.

Such HR-2 and HR-1 analogs may, for example, correspond to peptide sequences present in transmembrane proteins of other enveloped viruses. Such peptides may exhibit antifusogenic activity or antiviral activity.

HR-2 analogs are peptides whose amino acid sequences are comprised of the amino acid sequences of peptide regions of, for example, other viruses that correspond to the gp41 peptide region from which HR-2 (SEQ ID NO: 1) was derived. Such viruses may include, but are not limited to, other HIV-1 isolates, HIV-2 isolates, SIV isolates, influenza, parainfluenza virus, coronavirus, RSV, etc.

HR-1 analogs are peptides whose amino acid sequences are comprised of the amino acid sequences of peptide regions of, for example, other viruses that correspond to the gp41 peptide region from which HR-1 (SEQ ID NO: 2) was derived. Such viruses may include, but are not limited to, other HIV-1 isolates HIV-2 isolates, SIV isolates, parainfluenza virus, coronavirus, RSV, etc.

HR-1 and HR-2 analogs or other heptad repeat polypeptides include peptides whose amino acid sequences are comprised of the amino acid sequences of peptide regions of, for example, other viruses that correspond to the gp41 peptide region from which HR-1 (SEQ ID NO: 2 or SEQ ID NO:3) and HR-2 (SEQ ID NO:1) were derived. These polypeptides include:

RSV heptad repeat domains which are 30% or more identical to (SEQ ID NO:4), (SEQ ID NO:5), (SEQ ID NO: 11), or (SEQ ID NO: 12) and form an alpha-helix.

Parainfluenza virus heptad repeat domains which are 30% or more identical to (SEQ ID NO:6) and form an alpha-helix.

Coronavirus alpha helix heptad repeat domains which are 30% or more identical to (SEQ ID NO:7) or (SEQ ID NO:8) and form an alpha-helix.

5 Filovirus alpha helix heptad repeat domains which are 30% or more identical to (SEQ ID NO:9) or (SEQ ID NO:10) and form an alpha-helix.

The modified polypeptides of the invention also contemplate the use of influenza virus heptad repeat domains.

10 Alternatively, the heptad repeat domains of the modified polypeptides may differ by more than 30% as long as the residues of the interacting face are identical to those of the interacting face of the reference sequence or are conservative substitutions thereof. Methods for identifying the interacting face residues of the heptad repeat are well known in the art and described herein.

15 Heptad repeats or heptad repeat –analogs are recognized or identified, for example, by utilizing computer-assisted search strategies known in the art. For example, bioinformatics programs based on pairwise residue correlations, which have the ability to recognize coiled coils from protein sequences and model their structures (See Lupas, A., et al. Science 1991. 252(5009); p. 1162–1164, and U.S. Patent 20 7,273,614). The search strategy can identify additional peptide regions which are predicted to have structural and/or amino acid sequence features similar to those of HR-1 and/or HR-2.

Stabilization of heptad repeat polypeptides

25 The modified polypeptides of the present invention have stabilized (*e.g.*, cross-linked) alpha helical domains. Preferable the polypeptides are hydrocarbon-stapled. Hydrocarbon stapling is described in U.S. Patent Publication No. 2005/0250680.

30 The peptide α -helix participates in critically important protein interactions by presenting specific amino acid residues in an ordered and precise arrangement over a relatively large contact surface area (Chittenden, T., *et al.*, *Embo Journal*, 1995. 14(22): p. 5589-5596; Kussie, P.H., *et al.* Science, 1996. 274(5289): p. 948-953;

Ellenberger, T.E., *et al.*, *Cell*, 1992. 71(7): p. 1223-1237). Alpha-helical domains are frequently stabilized by scaffold sequences in the remainder of the protein, which facilitate the preorganization of α -helical structure. When taken out of context, α -helical peptide motifs can unfold, leading to loss of biological activity. Critical challenges is developing α -helical peptides include maintaining their natural α -helical structure and preparing peptides that can resist proteolytic, acid and thermal degradation, and thereby remain intact *in vivo*.

Hydrocarbon stapling, refers to a process for stably cross-linking a polypeptide via at least two amino acids that helps to conformationally bestow the native secondary structure of that polypeptide. Hydrocarbon stapling allows a polypeptide, predisposed to have an alpha-helical secondary structure, to maintain its native alpha-helical conformation. This secondary structure increases resistance of the polypeptide to proteolytic cleavage and heat, and also may increase hydrophobicity. Accordingly, the hydrocarbon stapled (cross-linked) polypeptides described herein have improved biological activity relative to a corresponding non-hydrocarbon stapled (uncrosslinked) polypeptide. For example the cross-linked polypeptide can include an alpha-helical domain of an HIV polypeptide (*e.g.*, HR-1/HR-2 domain), which can interfere with HIV attachment, fusion with, and infection of a cell. In some instances, the cross-linked polypeptide can be used to inhibit virus entry into a cell. The cross-linked polypeptides described herein can be used therapeutically, *e.g.*, to treat HIV.

The hydrocarbon stapled polypeptides include a tether (linkage) between two amino acids, which tether significantly enhances the alpha helical secondary structure of the polypeptide. Generally, the tether extends across the length of one or two helical turns (*i.e.*, about 3.4 or about 7 amino acids). Accordingly, amino acids positioned at i and $i+3$; i and $i+4$; or i and $i+7$ are ideal candidates for chemical modification and cross-linking. Thus, for example, where a peptide has the sequence . . . X1, X2, X3, X4, X5, X6, X7, X8, X9 . . . , cross-links between X1 and X4, or between X1 and X5, or between X1 and X8 are useful as are cross-links between X2 and X5, or between X2 and X6, or between X2 and X9, etc. The use of multiple cross-links (*e.g.*, 2, 3, 4 or more) has also been achieved, compounding the benefits of individual stapled adducts (*e.g.* improved helicity and activity; improved helicity

each Xaa is independently an amino acid. The modified polypeptides may includes an amino acid sequence which forms an alpha-helix and is 30% or more identical to an amino acid sequence of SEQ ID NO:1-14, FIG 5, FIG. 6,

BTWXEWDXEINNYTSLIHSL,

5 BTWBEWDREINNYTSLIHSLIEESQNQQXKNEXELLE,

BTWBXWDRXINNYTSL,

BTWBEWDREINNYTSLIHSLIEXSQNXQEKNEQELLE,

BTWBXWDRXINNYTSLIHSLIEESQNQQEKNEQELLE,

BTWBXWDRXINNYTSLIHSLIEXSQNXQEKNEQELLE,

10 BTWBEWDREINNYTSLIHSLIEESQNQQXKNEXELLE,

BTWBXWDRXINNYTSLIHSLIEESQNQQXKNEXELLE,

BTWBEWDXEINXYTSLIHSLIEESQNQQXKNEXELLE,

BTWBEWDREINXYTSXIHSIEESQNQQXKNEXELLE,

BTWBEWDREINNYTSXIHSXIEESQNQQXKNEXELLE,

15 BTWBXWDRXINNYTSXIHSXIEESQNQQXKNEXELLE,

YTSXIHSXIEESQNQQEKNEQELLELDKWASLWNWF,

YTSLIXSLIXESQNQQEKNEQELLELDKWASLWNWF,

YTSLIHSLIEXSQNXQEKNEQELLELDKWASLWNWF,

YTSLIHSLIEESQNQQXKNEXELLELDKWASLWNWF,

20 YTSLIHSLIEESQNQQEXNEQXLELDKWASLWNWF,

YTSLIHSLIEESQNQQEKNEQXLELDKWASLWNWF,

YTSLIHSLIEESQNQQEKNEQELLELDXWASXWNWF,

YTSLIHSLIEESQNQQEKNEQELLELDKWASLWXWF,

YTSLIHSLIEXSQNXQEKNEQXLELDKWASLWNWF,

25 YTSXIHSXIEESQNQQEKNEQELLELDKWASLWXWF,

YTSLIHSLIEESQNQQXKNEXELLELDKWASLWXWF,

YTSXIHSXIEESQNQQXKNEXELLELDKWASLWNWF,

YTSXIHSXIEESQNQQEKNEQELLELDXWASXWNWF,

YTSLIHSLIEXSQNXQEKNEQELLELDXWASXWNWF,

30 YTSXIHSXIEESQNQQXKNEXELLELDXWASXWNWF,

BTWBXWDRXINNYTSLIHSLIEESQNQXEKXQELLE, or

BTWBXWDRXINNYTSLIHSLIEESQNQXEKXEQELLE;

wherein X is any amino acid and further identifies the amino acid residues which are

linked by a hydrocarbon staple, and B is methionine or norleucine.

The tether can include an alkyl, alkenyl, or alkynyl moiety (e.g., C₅, C₈ or C₁₁ alkyl or a C₅, C₈ or C₁₁ alkenyl, or C₅, C₈ or C₁₁ alkynyl). The tethered amino acid can be alpha disubstituted (e.g., C₁-C₃ or methyl).

5 In some instances, x is 2, 3, or 6.

In some instances, each y is independently an integer between 3 and 15.

In some instances each y is independently an integer between 1 and 15.

In some instances, R₁ and R₂ are each independently H or C₁-C₆ alkyl.

In some instances, R₁ and R₂ are each independently C₁-C₃ alkyl.

10 In some instances, at least one of R₁ and R₂ are methyl. For example R₁ and R₂ are both methyl.

In some instances R₃ is alkyl (e.g., C₈ alkyl) and x is 3.

In some instances, R₃ is C₁₁ alkyl and x is 6.

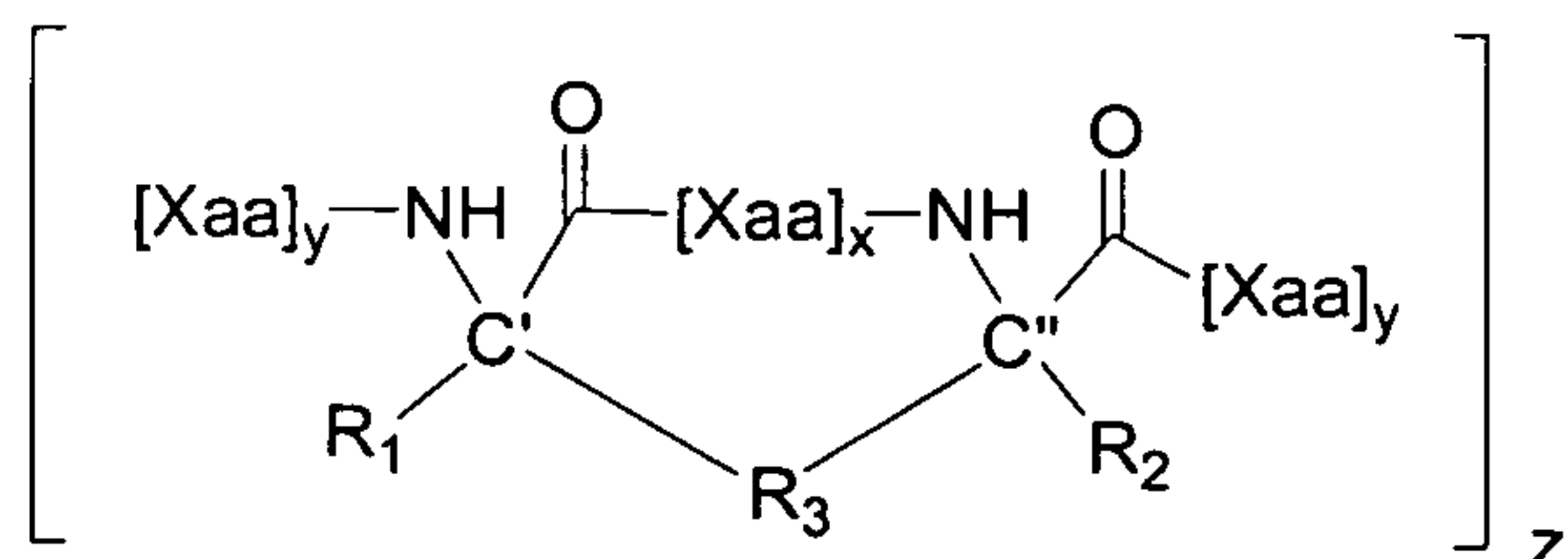
In some instances, R₃ is alkenyl (e.g., C₈ alkenyl) and x is 3.

15 In some instances x is 6 and R₃ is C₁₁ alkenyl.

In some instances, R₃ is a straight chain alkyl, alkenyl, or alkynyl.

In some instances R₃ is --CH₂--CH₂--CH₂--CH=CH--CH₂--CH₂--CH₂--.

In certain embodiments the two alpha, alpha disubstituted stereocenters are both in the R configuration or S configuration (e.g., i, i+4 cross-link), or one stereocenter is R and the other is S (e.g., i, i+7 cross-link). Thus, where formula I is depicted as



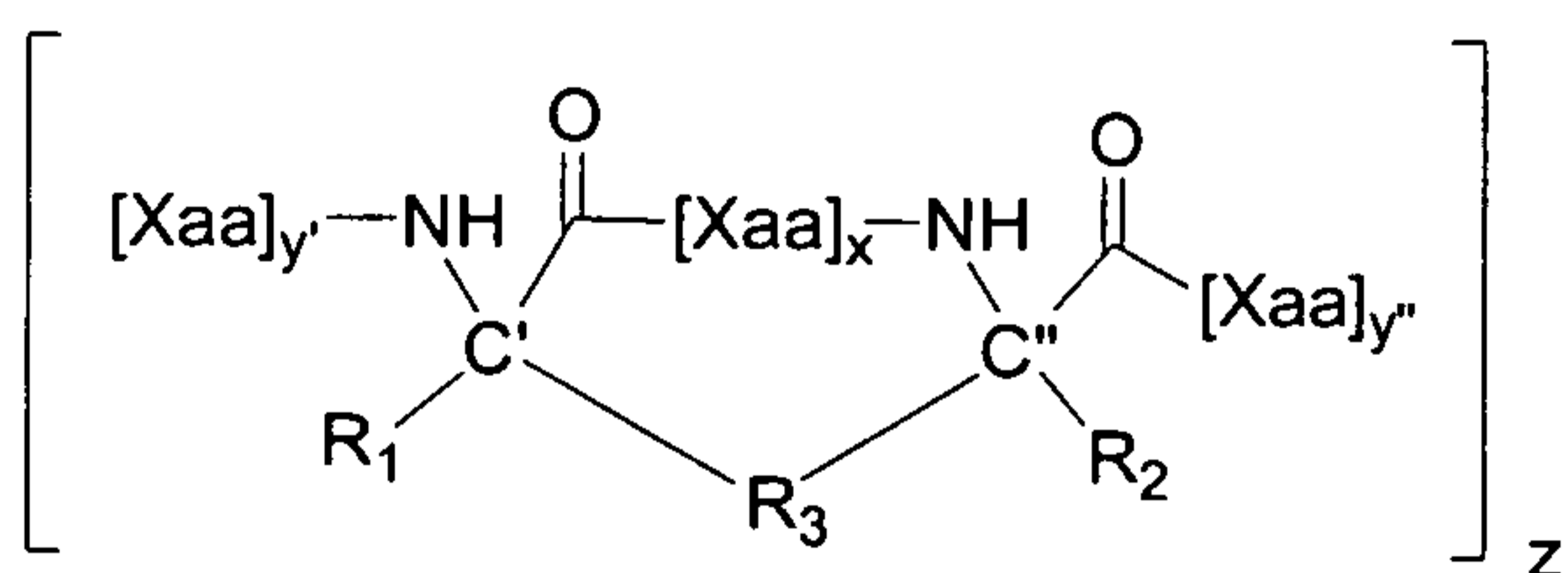
the C' and C'' disubstituted stereocenters can both be in the R configuration or they can both be in the S configuration, for example when X is 3. When x is 6, the C' disubstituted stereocenter is in the R configuration and the C'' disubstituted

stereocenter is in the S configuration. The R₃ double bond may be in the E or Z stereochemical configuration.

In some instances R₃ is [R₄--K--R₄]_n; and R₄ is a straight chain alkyl, alkenyl, or alkynyl.

5 In some embodiments the modified polypeptide comprises at least 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 45, 50, or more contiguous amino acids of a heptad repeat or heptad repeat like domain, e.g., a HIV-1 HR-1 or HR-2 domain. Each [Xaa]_y is a peptide that can independently comprise at least 5, 6, 7, 8, 9, 10, 11, 10 12, 13, 14, 15, 16, 17, 18, 19, 20, 25 or more contiguous amino acids of a heptad repeat or heptad repeat like domain, e.g., a HIV-1 HR-1 or HR-2 domain., e.g., a polypeptide depicted in any of FIGS. 5 and 6. [Xaa]_x is a peptide that can comprise 3 or 6 contiguous amino acids of acids of a heptad repeat or heptad repeat like domain, e.g., a HIV-1 HR-1 domain or HR-2, e.g., a polypeptide having the amino acid 15 sequence of SEQ ID NO:1-14 or FIGS 5 or 6.

The modified polypeptide can comprise 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 25, 30, 35, 40, 45, 50 contiguous amino acids of acids of a heptad repeat or heptad repeat like domain, e.g., a HIV-1 HR-1 domain or HR-2, e.g., a polypeptide having the amino acid sequence of SEQ ID NO:1-14 or FIGS 5 or 6, 20 wherein two amino acids that are separated by two, three, or six amino acids are replaced by amino acid substitutes that are linked via R₃. Thus, at least two amino acids can be replaced by tethered amino acids or tethered amino acid substitutes. Thus, where formula (I) is depicted as

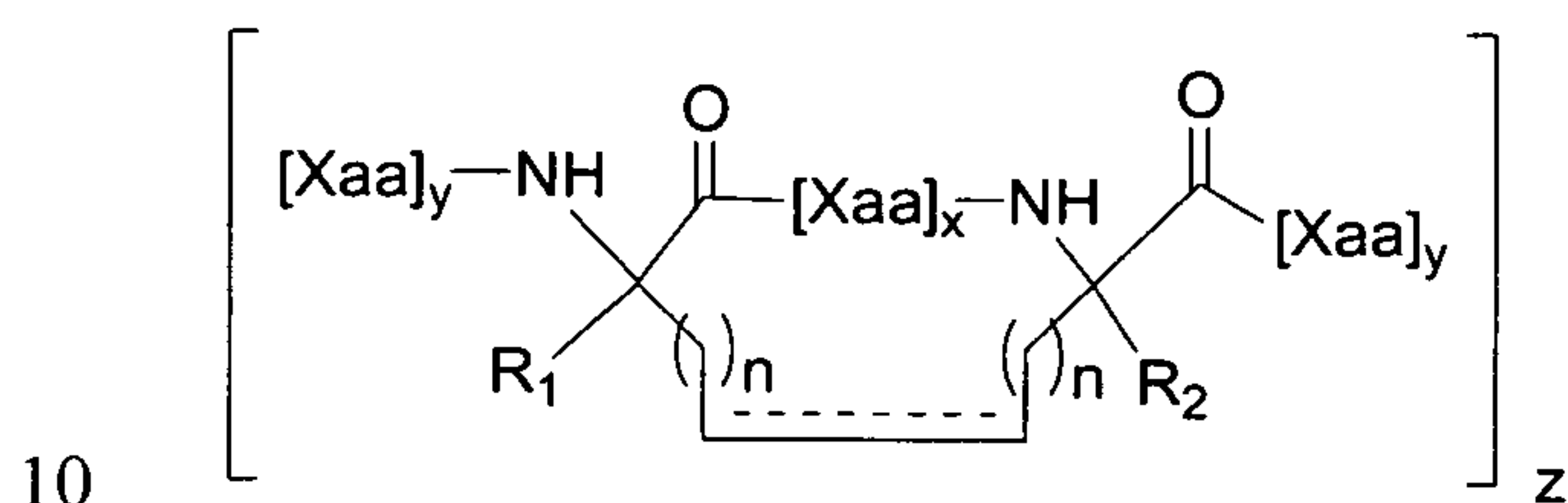


25 [Xaa]_y and [Xaa]_{y''} can each comprise contiguous polypeptide sequences from the same or different heptad repeat or heptad repeat like domains.

The invention features cross-linked polypeptides comprising 10 (11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 30, 35, 40, 45, 50 or more) contiguous

amino acids of a heptad repeat or heptad repeat like domain, e.g., a HIV-1 HR-1 domain or HR-2, e.g., a polypeptide having the amino acid sequence of SEQ ID NO:1-14 or FIGS 5 or 6, wherein the alpha carbons of two amino acids that are separated by two, three, or six amino acids are linked via R₃, one of the two alpha carbons is substituted by R₁ and the other is substituted by R₂ and each is linked via peptide bonds to additional amino acids.

In another embodiment, the modified polypeptides of the invention have the formula (II),



wherein

each R₁ and R₂ are independently H, alkyl, alkenyl, alkynyl, arylalkyl, cycloalkylalkyl; heteroarylalkyl; or heterocyclalkyl;

each n is independently an integer from 1-15;

15 x is 2, 3, or 6

each y is independently an integer from 0-100;

z is an integer from 1-10 (e.g., 1, 2, 3, 4, 5, 6, 7, 8, 9, 10);

each Xaa is independently an amino acid.

The modified polypeptide forms an alpha-helix and can have an amino acid sequence which is 30% or more identical to an amino acid sequence of SEQ ID NO:1-14, FIG 5, FIG. 6,

the modified polypeptides include a heptad repeat domain with the sequence:

BTWXEWDXEINNYTSLIHSL,

BTWBEWDREINNYTSLIHSLIEESQNQQXKNEXELLE,

25 BTWBXWDRXINNYTSL,

BTWBEWDREINNYTSLIHSLIEXSQNXQEKNEQELLE,

wherein;

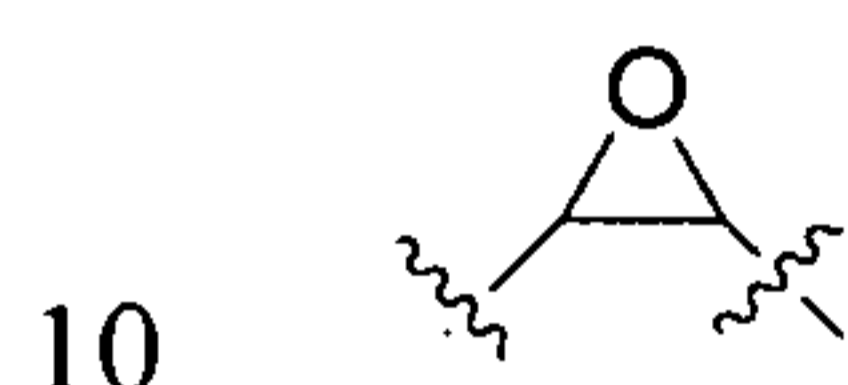
each R_1 and R_2 are independently H, alkyl, alkenyl, alkynyl, arylalkyl, cycloalkylalkyl, heteroarylalkyl, or heterocyclalkyl;

R_3 is alkyl, alkenyl, alkynyl; $[R_4--K--R_4]_n$ or a naturally occurring amino acid side chain; each of which is substituted with 0-6 R_5 ;

R_4 is alkyl, alkenyl, or alkynyl;

R_5 is halo, alkyl, OR_6 , $N(R_6)_2$, SR_6 , SOR_6 , SO_2R_6 , CO_2R_6 , R_6 , a fluorescent moiety, or a radioisotope;

K is O, S, SO, SO_2 , CO, CO_2 , $CONR_6$, or



R_6 is H, alkyl, or a therapeutic agent;

R_7 is alkyl, alkenyl, alkynyl; $[R_4--K--R_4]_n$ or an naturally occurring amino acid side chain; each of which is substituted with 0-6 R_5 ;

n is an integer from 1-4;

15 x is an integer from 2-10;

each y is independently an integer from 0-100;

z is an integer from 1-10 (e.g., 1, 2, 3, 4, 5, 6, 7, 8, 9, 10); and

each Xaa is independently an amino acid;

20 The polypeptide forms an alpha-helix and includes an amino acid sequence which is about 30% or more identical to an amino acid sequence of SEQ ID NO:1-14, FIG 5, FIG. 6 or

the modified polypeptides include a heptad repeat domain with the sequence:

BTWXEWDXEINNYTSLIHSL,

BTWBEWDREINNYTSLIHSLIEESQNQQXKNEXELLE,

25 BTWBXWDRXINNYTSL,

BTWBEWDREINNYTSLIHSLIEXSQNXQEKNEQELLE,

BTWBXWDRXINNYTSLIHSLIEESQNQQEKNEQELLE,

BTWBXWDRXINNYTSLIHSLEIEXSQNXQEKNEQELLE,
 BTWBEWDREINNYTSLIHSLEIESQNQQXKNEXELLE,
 BTWBXWDRXINNYTSLIHSLEIESQNQQXKNEXELLE,
 BTWBEWDXEINXYTSLIHSLEIESQNQQXKNEXELLE,
 5 BTWBEWDREINXYTSXIHSLEIESQNQQXKNEXELLE,
 BTWBEWDREINNYTSXIHSXIEESQNQQXKNEXELLE,
 BTWBXWDRXINNYTSXIHSXIEESQNQQXKNEXELLE,
 YTSXIHSXIEESQNQQEKNEQELLELDKWASLWNWF,
 YTSLIXSLIXESQNQQEKNEQELLELDKWASLWNWF,
 10 YTSLIHSLEIEXSQNXQEKNEQELLELDKWASLWNWF,
 YTSLIHSLEIESQNQQXKNEXELLELDKWASLWNWF,
 YTSLIHSLEIESQNQQEXNEQXLELDKWASLWNWF,
 YTSLIHSLEIESQNQQEKNEQXLELDKWASLWNWF,
 YTSLIHSLEIESQNQQEKNEQELLELDXWASXWNWF,
 15 YTSLIHSLEIESQNQQEKNEQELLELDKWASLWXWF,
 YTSLIHSLEIEXSQNXQEKNEQXLELDKWASLWNWF,
 YTSXIHSXIEESQNQQEKNEQELLELDKWASLWXWF,
 YTSLIHSLEIESQNQQXKNEXELLELDKWASLWXWF,
 YTSXIHSXIEESQNQQXKNEXELLELDKWASLWNWF,
 20 YTSXIHSXIEESQNQQEKNEQELLELDXWASXWNWF,
 YTSLIHSLEIEXSQNXQEKNEQELLELDXWASXWNWF,
 YTSXIHSXIEESQNQQXKNEXELLELDXWASXWNWF,
 BTWBXWDRXINNYTSLIHSLEIESQNQXEKNXQELLE, or
 BTWBXWDRXINNYTSLIHSLEIESQNQXEKXEQELLE;
 25 wherein X is any amino acid and further identifies the amino acid residues which are
 linked by a hydrocarbon staple, and B is methionine or norleucine.

While hydrocarbon tethers have been described, other tethers are also
 envisioned. For example, the tether can include one or more of an ether, thioether,
 ester, amine, or amide moiety. In some cases, a naturally occurring amino acid side
 30 chain can be incorporated into the tether. For example, a tether can be coupled with a
 functional group such as the hydroxyl in serine, the thiol in cysteine, the primary
 amine in lysine, the acid in aspartate or glutamate, or the amide in asparagine or
 glutamine. Accordingly, it is possible to create a tether using naturally occurring

amino acids rather than using a tether that is made by coupling two non-naturally occurring amino acids. It is also possible to use a single non-naturally occurring amino acid together with a naturally occurring amino acid.

It is further envisioned that the length of the tether can be varied. For instance, a shorter length of tether can be used where it is desirable to provide a relatively high degree of constraint on the secondary alpha-helical structure, whereas, in some instances, it is desirable to provide less constraint on the secondary alpha-helical structure, and thus a longer tether may be desired.

Additionally, while examples of tethers spanning from amino acids i to $i+3$, i to $i+4$; and i to $i+7$ have been described in order to provide a tether that is primarily on a single face of the alpha helix, the tethers can be synthesized to span any combinations of numbers of amino acids.

As can be appreciated by the skilled artisan, methods of synthesizing the compounds of the described herein will be evident to those of ordinary skill in the art. Additionally, the various synthetic steps may be performed in an alternate sequence or order to give the desired compounds. Synthetic chemistry transformations and protecting group methodologies (protection and deprotection) useful in synthesizing the compounds described herein are known in the art and include, for example, those such as described in R. Larock, *Comprehensive Organic Transformations*, VCH Publishers (1989); T. W. Greene and P. G. M. Wuts, *Protective Groups in Organic Synthesis*, 2d. Ed., John Wiley and Sons (1991); L. Fieser and M. Fieser, *Fieser and Fieser's Reagents for Organic Synthesis*, John Wiley and Sons (1994); and L. Paquette, ed., *Encyclopedia of Reagents for Organic Synthesis*, John Wiley and Sons (1995), and subsequent editions thereof.

25 Synthesis of peptides

The peptides of this invention can be made by chemical synthesis methods, which are well known to the ordinarily skilled artisan and described herein. See, for example, Fields *et al.*, Chapter 3 in *Synthetic Peptides: A User's Guide*, ed. Grant, W. H. Freeman & Co., New York, N.Y., 1992, p. 77. Hence, peptides can be synthesized using the automated Merrifield techniques of solid phase synthesis with the alpha-NH₂ protected by either t-Boc or F-moc chemistry using side chain protected amino

acids on, for example, an Applied Biosystems™ Peptide Synthesizer Model 430A or 431 or the AAPPTEC multichannel synthesizer APEX 396.

One manner of making of the peptides described herein is using solid phase peptide synthesis (SPPS). The C-terminal amino acid is attached to a cross-linked polystyrene resin via an acid labile bond with a linker molecule. This resin is insoluble in the solvents used for synthesis, making it relatively simple and fast to wash away excess reagents and by-products. The N-terminus is protected with the Fmoc group, which is stable in acid, but removable by base. Any side chain functional groups are protected with base stable, acid labile groups.

Longer peptides could be made by conjoining individual synthetic peptides using native chemical ligation. Alternatively, the longer synthetic peptides can be synthesized by well known recombinant DNA techniques. Such techniques are provided in well-known standard manuals with detailed protocols. To construct a gene encoding a peptide of this invention, the amino acid sequence is reverse translated to obtain a nucleic acid sequence encoding the amino acid sequence, preferably with codons that are optimum for the organism in which the gene is to be expressed. Next, a synthetic gene is made, typically by synthesizing oligonucleotides which encode the peptide and any regulatory elements, if necessary. The synthetic gene is inserted in a suitable cloning vector and transfected into a host cell. Furthermore, the host cell is engineered so as to be able to incorporate the non-natural amino acids for the hydrocarbon staple. The peptide is then expressed under suitable conditions appropriate for the selected expression system and host. See Liu et al. *Proc. Nat. Acad. Sci (USA)*, 94:10092-10097 (1997). The peptide is purified and characterized by standard methods.

The peptides can be made in a high-throughput, combinatorial fashion, e.g., using a high-throughput polychannel combinatorial synthesizer available from Advanced Chemtech.

Assaying anti-viral activity

Described herein, are methods for evaluating the ability of a compound, such as the peptides of the invention, to inhibit membrane fusion and/or exhibit anti-viral activity both *in vitro* and *in vivo*. Specifically, such assays are described below and in

Examples 4 and 5. Additional assays for evaluating anti-viral activity are well known to those with ordinary skill in the art.

The antiviral activity exhibited by the peptides of the invention may be measured, for example, by easily performed *in vitro* assays, such as those described
5 herein and known by those of ordinary skill in the art, which can test the peptides' ability to inhibit syncytia formation, or their ability to inhibit infection by cell-free virus (Madani, N., et al., *Journal of Virology*, 2007. 81(2): p. 532-538; Si, Z.H., M. Cayabyab, and J. Sodroski, *Journal of Virology*, 2001. 75(9): p. 4208-4218; Si, Z.H., et al., *PNAS USA*, 2004. 101(14): p. 5036-5041).

10 Using these assays, such parameters as the relative antiviral activity of the peptides exhibit against a given strain of virus and/or the strain specific inhibitory activity of the peptide can be determined.

Assays to test a peptide's antiviral capabilities are contemplated with the present invention. Taking HIV as an example, a reverse transcriptase (RT) assay may
15 be utilized to test the peptides' ability to inhibit infection of CD-4⁺ cells by cell-free HIV. Such an assay may comprise culturing an appropriate concentration (i.e., Tissue Culture Infectious Dose 50) of virus and CD-4+ cells in the presence of the peptide to be tested. Culture conditions well known to those in the art are used. A range of peptide concentrations may be used, in addition to a control culture wherein no
20 peptide has been added. After incubation for an appropriate period (e.g., 7 days) of culturing, a cell-free supernatant is prepared, using standard procedures, and tested for the present of RT activity as a measure of successful infection. The RT activity may be tested using standard techniques such as those described by, for example, Goff *et al.* (Goff, S. *et al.*, 1981, *J. Virol.* 38:239-248) and/or Willey *et al.* (Willey, R. *et al.*,
25 1988, *J. Virol.* 62:139-147).

Standard methods which are well-known to those of skill in the art may be utilized for assaying non-retroviral activity. See, for example, Pringle *et al.* (Pringle, C. R. *et al.*, 1985, *J. Medical Virology* 17:377-386) for a discussion of respiratory
30 syncytial virus and parainfluenza virus activity assay techniques. Further, see, for example, "Zinsser Microbiology", 1988, Joklik, W. K. *et al.*, eds., Appleton & Lange,

Norwalk, Conn., 19th ed., for a general review of such techniques.

It is known that HIV positive patients who respond to initial treatment with enfuvirtide, may ultimately develop a viral rebound that typically occurs within a maximum of 80 weeks. Resistance to enfuvirtide derives from mutations within the HR-1 region of gp41, although some genetic changes are found in the HR-2 domain (Xu, L., *et al.*, *Antimicrobial Agents and Chemotherapy*, 2005. 49(3): p. 1113-1119; Perez-Alvarez, L., *et al.*, *Journal of Medical Virology*, 2006. 78(2): p. 141-147). These mutations, such as I37V, V38A/E/M, Q39R, Q40H, N42T/Q/H, N43D/Q, are only found in enfuvirtide-experienced patients (Poveda, E., *et al.*, *Journal of Medical Virology*, 2004. 74(1): p. 21-28; Melby, T., *et al.*, *Aids Research and Human Retroviruses*, 2006. 22(5): p. 375-385; Sista, P.R., *et al.*, *Aids*, 2004. 18(13): p. 1787-1794; Wei, X.P., *et al.*, *Antimicrobial Agents and Chemotherapy*, 2002. 46(6): p. 1896-1905).

Modified polypeptides of the invention can be developed which are able to inhibit these enfuvirtide resistant HIV strains. One suitable method for assessing the ability of the modified polypeptides to treat these enfuvirtide resistant HIV strains is a five-helix bundle assay as described in Root, M.J., M.S. Kay, and P.S. Kim, *Science*, 2001. 291(5505): p. 884-888.

Briefly, the five-helix bundle assay would include polypeptides that incorporate resistance mutations. FITC-labeled SAH-gp41 compounds can then be screened against these mutant five-helix bundle proteins to determine if any native SAH-gp41 compounds retain activity despite HR domain mutations. The FITC labeled mutants SAH-gp41 (mSAH-gp41) compounds can be screened for binding affinity to mutant five-helix bundle proteins and for suppression of HIV infectivity using primary resistance strains.

In another aspect, the modified polypeptides of the invention can be used to monitor the evolution of resistance in HIV isolates. To explore the evolution of potential resistance to SAH-gp41 compounds, HIV strains can be incubated in the presence of increasing concentrations of lead SAH-gp41 compounds in a cell culture. Resistant strains can be genotyped to monitor the evolution of resistance. (See Dwyer *et al.* *Proc. Natl. Acad. Sci.*, 104:12772 (2007)). Because resistance to one modified

polypeptide of the invention may not affect susceptibility to other variants, (Ray, N., *et al.*, *Journal of Virology*, 2007. 81(7): p. 3240-3250) it is contemplated that treatment may include a combination of different SAH-gp41 polypeptides that are able to treat resistant strains of HIV.

5 *In vivo* assays may also be utilized to test, for example, the antiviral activity of the peptides of the invention. To test for anti-HIV activity, for example, the *in vivo* model described in Barnett *et al.* (Barnett, S. W. *et al.*, 1994, *Science* 266:642-646) may be used.

 Additionally, anti-RSV activity can be assayed *in vitro* using the RSV plaque
10 assay and *in vivo* via well known mouse models (Kong *et al.*, *Virology J.* 2(1):3
(2005). For example, RSV can be administered intranasally to mice of various inbred strains. Virus replicates in lungs of all strains, but the highest titers are obtained in P/N, C57L/N and DBA/2N mice. Infection of BALB/c mice produces an
asymptomatic bronchiolitis characterized by lymphocytic infiltrates and pulmonary
15 virus titers of 10^4 to 10^5 pfu/g of lung tissue (Taylor, G. *et al.*, 1984, *Infect. Immun.*
43:649-655). Cotton rat models of RSV are also well known. Virus replicates to high
titer in the nose and lungs of the cotton rat but produces few if any signs of
inflammation. Additional assays for evaluating the effectiveness of the modified viral
polypeptides are well known to those of ordinary skill in the art.

20 Pharmaceutical compositions and routes of administration

 As used herein, the compounds of this invention (*e.g.*, the modified polypeptides described herein), are defined to include pharmaceutically acceptable derivatives or prodrugs thereof. A “pharmaceutically acceptable derivative or prodrug” means any pharmaceutically acceptable salt, ester, salt of an ester, or other
25 derivative of a compound of this invention which, upon administration to a recipient, is capable of providing (directly or indirectly) a compound of this invention. Particularly favored derivatives and prodrugs are those that increase the bioavailability of the compounds of this invention when such compounds are administered to a mammal (*e.g.*, by allowing an orally administered compound to be
30 more readily absorbed into the blood) or which enhance delivery of the parent compound to a biological compartment (*e.g.*, the brain or lymphatic system) relative to the parent species. Preferred prodrugs include derivatives where a group which

enhances aqueous solubility or active transport through the gut membrane is appended to the structure of formulae described herein.

The compounds of this invention may be modified by appending appropriate functionalities to enhance selective biological properties. Such modifications are known in the art and include those which increase biological penetration into a given biological compartment (*e.g.*, blood, lymphatic system, central nervous system), increase oral availability, increase solubility to allow administration by injection, alter metabolism and alter rate of excretion. Pharmaceutically acceptable salts of the compounds of this invention include those derived from pharmaceutically acceptable inorganic and organic acids and bases. Examples of suitable acid salts include acetate, adipate, benzoate, benzenesulfonate, butyrate, citrate, digluconate, dodecylsulfate, formate, fumarate, glycolate, hemisulfate, heptanoate, hexanoate, hydrochloride, hydrobromide, hydroiodide, lactate, maleate, malonate, methanesulfonate, 2-naphthalenesulfonate, nicotinate, nitrate, palmoate, phosphate, picrate, pivalate, propionate, salicylate, succinate, sulfate, tartrate, tosylate and undecanoate. Salts derived from appropriate bases include alkali metal (*e.g.*, sodium), alkaline earth metal (*e.g.*, magnesium), ammonium and N-(alkyl)₄₊ salts. This invention also envisions the quaternization of any basic nitrogen-containing groups of the compounds disclosed herein. Water or oil-soluble or dispersible products may be obtained by such quaternization.

The compounds of the invention can, for example, be administered by injection, intravenously, intraarterially, subdermally, intraperitoneally, intramuscularly, or subcutaneously; or orally, buccally, nasally, transmucosally, intravaginally, cervically, topically, in an ophthalmic preparation, or by inhalation, with a dosage ranging from about 0.001 to about 100 mg/kg of body weight, or according to the requirements of the particular drug and more preferably from 0.5-10mg/kg of body weight. The methods herein contemplate administration of an effective amount of compound or compound composition to achieve the desired or stated effect. Typically, the pharmaceutical compositions of this invention will be administered from about 1 to about 6 times per day or alternatively, as a continuous infusion, or for example as an intravaginal foam or formulated for a cervical ring if used singly or in combination with a contraceptive. Such administration can be used

as a chronic or acute therapy. The amount of active ingredient that may be combined with the carrier materials to produce a single dosage form will vary depending upon the host treated and the particular mode of administration. A typical preparation will contain from about 1% to about 95% active compound (w/w). Alternatively, such
5 preparations contain from about 20% to about 80% active compound.

Lower or higher doses than those recited above may be required. Specific dosage and treatment regimens for any particular patient will depend upon a variety of factors, including the activity of the specific compound employed, the age, body weight, general health status, sex, diet, time of administration, rate of excretion, drug
10 combination, the severity and course of the disease, condition or symptoms, the patient's disposition to the disease, condition or symptoms, and the judgment of the treating physician.

Upon improvement of a patient's condition or prevention of infection, a maintenance dose of a compound, composition or combination of this invention may
15 be administered, if necessary. Subsequently, the dosage or frequency of administration, or both, may be reduced, as a function of the symptoms, to a level at which the improved condition is retained. Patients may, however, require intermittent treatment on a long-term basis upon any recurrence of disease symptoms (e.g. increase in HIV viral load).

20 Pharmaceutical compositions of this invention comprise a compounds of the invention or a pharmaceutically acceptable salt thereof; an additional agent including for example, morphine or codeine; and any pharmaceutically acceptable carrier, adjuvant or vehicle. Alternate compositions of this invention comprise a compound of the invention or a pharmaceutically acceptable salt thereof; and a pharmaceutically
25 acceptable carrier, adjuvant or vehicle. The compositions delineated herein include the compounds of the invention delineated herein, as well as additional therapeutic agents if present, in amounts effective for achieving a modulation of disease or disease symptoms, including HIV mediated disorders or symptoms thereof.

The term "pharmaceutically acceptable carrier or adjuvant" refers to a carrier
30 or adjuvant that may be administered to a patient, together with a compound of this invention, and which does not destroy the pharmacological activity thereof and is

nontoxic when administered in doses sufficient to deliver a therapeutic amount of the compound.

Pharmaceutically acceptable carriers, adjuvants and vehicles that may be used in the pharmaceutical compositions of this invention include, but are not limited to, ion exchangers, alumina, aluminum stearate, lecithin, self-emulsifying drug delivery systems (SEDDS) such as d- α -tocopherol polyethyleneglycol 1000 succinate, surfactants used in pharmaceutical dosage forms such as Tween® or other similar polymeric delivery matrices, serum proteins, such as human serum albumin, buffer substances such as phosphates, glycine, sorbic acid, potassium sorbate, partial glyceride mixtures of saturated vegetable fatty acids, water, salts or electrolytes, such as protamine sulfate, disodium hydrogen phosphate, potassium hydrogen phosphate, sodium chloride, zinc salts, colloidal silica, magnesium trisilicate, polyvinyl pyrrolidone, cellulose-based substances, polyethylene glycol, sodium carboxymethylcellulose, polyacrylates, waxes, polyethylene-polyoxypropylene-
10 block polymers, polyethylene glycol and wool fat. Cyclodextrins such as alpha-, beta-, and gamma-cyclodextrin, may also be advantageously used to enhance delivery of compounds of the formulae described herein.

The pharmaceutical compositions of this invention may be administered enterally for example by oral administration, parenterally, by inhalation spray,
20 topically, rectally, nasally, buccally, vaginally or via an implanted reservoir, preferably by oral or vaginal administration or administration by injection. The pharmaceutical compositions of this invention may contain any conventional non-toxic pharmaceutically-acceptable carriers, adjuvants or vehicles. In some cases, the pH of the formulation may be adjusted with pharmaceutically acceptable acids, bases,
25 or buffers to enhance the stability of the formulated compound or its delivery form. The term parenteral as used herein includes subcutaneous, intracutaneous, intravenous, intramuscular, intraarticular, intraarterial, intrasynovial, intrastemal, intrathecal, intralesional, and intracranial injection or infusion techniques.

Examples of dosage forms include, but are not limited to: tablets; caplets;
30 capsules, such as soft elastic gelatin capsules; cachets; troches; lozenges; dispersions; suppositories; ointments; cataplasms (poultices); pastes; powders; dressings; creams; plasters; solutions; patches; aerosols (e.g., nasal sprays or inhalers); gels; liquid

dosage forms suitable for oral or mucosal administration to a patient, including suspensions (e.g., aqueous or non-aqueous liquid suspensions, oil-in-water emulsions, or a water-in-oil liquid emulsions), solutions, and elixirs; liquid dosage forms suitable for parenteral administration to a patient; and sterile solids (e.g., crystalline or amorphous solids) that can be reconstituted to provide liquid dosage forms suitable for parenteral administration to a patient.

The pharmaceutical compositions may be in the form of a sterile injectable preparation, for example, as a sterile injectable aqueous or oleaginous suspension. This suspension may be formulated according to techniques known in the art using suitable dispersing or wetting agents (such as, for example, Tween® 80) and suspending agents. The sterile injectable preparation may also be a sterile injectable solution or suspension in a non-toxic parenterally acceptable diluent or solvent, for example, as a solution in 1,3-butanediol. Among the acceptable vehicles and solvents that may be employed are mannitol, water, Ringer's solution and isotonic sodium chloride solution. In addition, sterile, fixed oils are conventionally employed as a solvent or suspending medium. For this purpose, any bland fixed oil may be employed including synthetic mono- or diglycerides. Fatty acids, such as oleic acid and its glyceride derivatives are useful in the preparation of injectables, as are natural pharmaceutically-acceptable oils, such as olive oil or castor oil, especially in their polyoxyethylated versions. These oil solutions or suspensions may also contain a long-chain alcohol diluent or dispersant, or carboxymethyl cellulose or similar dispersing agents which are commonly used in the formulation of pharmaceutically acceptable dosage forms such as emulsions and or suspensions. Other commonly used surfactants such as Tweens or Spans and/or other similar emulsifying agents or bioavailability enhancers which are commonly used in the manufacture of pharmaceutically acceptable solid, liquid, or other dosage forms may also be used for the purposes of formulation.

The pharmaceutical compositions of this invention may be orally administered in any orally acceptable dosage form including, but not limited to, capsules, tablets, emulsions and aqueous suspensions, dispersions and solutions. In the case of tablets for oral use, carriers which are commonly used include lactose and corn starch. Lubricating agents, such as magnesium stearate, are also typically added. For oral administration in a capsule form, useful diluents include lactose and dried corn starch.

When aqueous suspensions and/or emulsions are administered orally, the active ingredient may be suspended or dissolved in an oily phase is combined with emulsifying and/or suspending agents. If desired, certain sweetening and/or flavoring and/or coloring agents may be added.

5 The pharmaceutical compositions of this invention may also be administered in the form of suppositories for rectal administration. These compositions can be prepared by mixing a compound of this invention with a suitable non-irritating excipient which is solid at room temperature but liquid at the rectal temperature and therefore will melt in the rectum to release the active components. Such materials
10 include, but are not limited to, cocoa butter, beeswax and polyethylene glycols.

 The pharmaceutical compositions of the invention may be administered topically or intravaginally. The pharmaceutical composition will be formulated with a suitable ointment containing the active components suspended or dissolved in a carrier. Carriers for topical administration of the compounds of this invention
15 include, but are not limited to, mineral oil, liquid petroleum, white petroleum, propylene glycol, polyoxyethylene polyoxypropylene compound, emulsifying wax and water. Alternatively, the pharmaceutical composition can be formulated with a suitable lotion or cream containing the active compound suspended or dissolved in a carrier. In still another embodiment, the pharmaceutical composition is formulated as
20 a vaginal ring. Suitable carriers include, but are not limited to, mineral oil, sorbitan monostearate, polysorbate 60, cetyl esters wax, cetearyl alcohol, 2-octyldodecanol, benzyl alcohol and water. The pharmaceutical compositions of this invention may also be topically applied to the lower intestinal tract by rectal suppository formulation or in a suitable enema formulation. Topically-transdermal patches and iontophoretic
25 administration are also included in this invention. In one embodiment, the compound of the invention is administered vaginally as a prophylactic treatment for a sexually transmitted disease, e.g., HIV.

 The pharmaceutical compositions of this invention may be administered by nasal aerosol or inhalation. Such compositions are prepared according to techniques
30 well-known in the art of pharmaceutical formulation and may be prepared as solutions in saline, employing benzyl alcohol or other suitable preservatives, absorption

promoters to enhance bioavailability, fluorocarbons, and/or other solubilizing or dispersing agents known in the art.

When the compositions of this invention comprise a combination of a compound of the formulae described herein and one or more additional therapeutic or prophylactic agents, both the compound and the additional agent should be present at dosage levels of between about 1 to 100%, and more preferably between about 5 to 95% of the dosage normally administered in a monotherapy regimen. The additional agents may be administered separately, as part of a multiple dose regimen, from the compounds of this invention. Alternatively, those agents may be part of a single dosage form, mixed together with the compounds of this invention in a single composition.

With respect to HIV, peptides of the invention may be used as therapeutics in the treatment of HIV infection and/or AIDS. In addition, the peptides may be used as prophylactic measures in previously uninfected individuals after acute exposure to an HIV virus (e.g. post-exposure prophylaxis). Examples of such prophylactic use of the peptides may include, but are not limited to, prevention of virus transmission from mother to infant and other settings where the likelihood of HIV transmission exists, such as, for example, sexual transmission or accidents in health care settings wherein workers are exposed to HIV-containing blood products.

Effective dosages of the peptides of the invention to be administered may be determined through procedures well known to those in the art which address such parameters as biological half-life, bioavailability, and toxicity.

A therapeutically effective dose refers to that amount of the compound sufficient to result in amelioration of symptoms or a prolongation of survival in a patient. Toxicity and therapeutic efficacy of such compounds can be determined by standard pharmaceutical procedures in cell cultures or experimental animals, e.g., for determining the LD₅₀ (the dose lethal to 50% of the population) and the ED₅₀ (the dose therapeutically effective in 50% of the population). The dose ratio between toxic and therapeutic effects is the therapeutic index and it can be expressed as the ratio LD₅₀/ED₅₀. Compounds which exhibit large therapeutic indices are preferred. The data obtained from these cell culture assays and animal studies can be used in formulating a range of dosage for use in humans. The dosage of such compounds lies

preferably within a range of circulating concentrations that include the ED50 with little or no toxicity. The dosage may vary within this range depending upon the dosage form employed and the route of administration utilized. For any compound used in the method of the invention, the therapeutically effective dose can be
5 estimated initially from cell culture assays. A dose may be formulated in animal models to achieve a circulating plasma concentration range that includes the IC₅₀ (*e.g.*, the concentration of the test compound which achieves a half-maximal inhibition of the fusogenic event, such as a half-maximal inhibition of viral infection relative to the amount of the event in the absence of the test compound) as determined in cell
10 culture. Such information can be used to more accurately determine useful doses in humans. Levels in plasma may be measured, for example, by high performance liquid chromatography (HPLC) or mass spectrometry (MS).

Prophylactic vaccine

The peptides of the invention may, further, serve the role of a prophylactic
15 vaccine, wherein the host raises antibodies against the peptides of the invention, which then serve to neutralize a virus (*e.g.*, HIV, RSV, influenza, parainfluenza, coronavirus, ebolavirus) by, for example, inhibiting further infection. Administration of the peptides of the invention as a prophylactic vaccine, therefore, would comprise administering to a host a concentration of peptides effective in raising an immune
20 response which is sufficient to neutralize the virus, by, for example, inhibiting virus ability to infect cells. The exact concentration will depend upon the specific peptide to be administered, but may be determined by using standard techniques for assaying the development of an immune response which are well known to those of ordinary skill in the art. The peptides to be used as vaccines are usually administered
25 intramuscularly.

The peptides may be formulated with a suitable adjuvant in order to enhance the immunological response. Such adjuvants may include, but are not limited to mineral gels such as aluminum hydroxide; surface active substances such as lysolecithin, pluronic polyols, polyanions; other peptides; oil emulsions; and
30 potentially useful human adjuvants such as BCG and *Corynebacterium parvum*. Many methods may be used to introduce the vaccine formulations described here. These

methods include but are not limited to oral, intradermal, intramuscular, intraperitoneal, intravenous, subcutaneous, and intranasal routes.

Alternatively, an effective concentration of polyclonal or monoclonal antibodies raised against the peptides of the invention may be administered to a host so that no uninfected cells become infected by the virus. The exact concentration of such antibodies will vary according to each specific antibody preparation, but may be determined using standard techniques well known to those of ordinary skill in the art. Administration of the antibodies may be accomplished using a variety of techniques, including, but not limited to those described in this section.

10 In one aspect, the invention is directed to a method of generating an antibody to a modified polypeptide. The method includes administering a modified polypeptide(s) of the invention to a subject so as to generate an antibody to the modified polypeptide.

15 In yet another aspect, the invention is directed to an antibody that specifically binds a modified polypeptide, wherein the modified polypeptide has an amino acid sequence of any of the sequences of FIGS 5, 6,

the modified polypeptides include a heptad repeat domain with the sequence:

BTWWEWDXEINNYTSLIHSL,
 BTWBEWDREINNYTSLIHSLIEESQNQQXKNEXELLE,
 20 BTWBXWDRXINNYTSL,
 BTWBEWDREINNYTSLIHSLIEXSQNXQEKNEQELLE,
 BTWBXWDRXINNYTSLIHSLIEESQNQQEKNEQELLE,
 BTWBXWDRXINNYTSLIHSLIEXSQNXQEKNEQELLE,
 BTWBEWDREINNYTSLIHSLIEESQNQQXKNEXELLE,
 25 BTWBXWDRXINNYTSLIHSLIEESQNQQXKNEXELLE,
 BTWBEWDXEINXYTSLIHSLIEESQNQQXKNEXELLE,
 BTWBEWDREINXYTSXIHSLIEESQNQQXKNEXELLE,
 BTWBEWDREINNYTSXIHSLIEESQNQQXKNEXELLE,
 BTWBXWDRXINNYTSXIHSLIEESQNQQXKNEXELLE,
 30 YTSXIHSLIEESQNQQEKNEQELLELDKWASLWNWF,
 YTSLIXSLIXESQNQQEKNEQELLELDKWASLWNWF,

YTSLIHSLIEXSQNXQEKNEQELLELDKWASLWNWF,
 YTSLIHSLIEESQNQQXKNEXELLELDKWASLWNWF,
 YTSLIHSLIEESQNQQEXNEQXLELDKWASLWNWF,
 YTSLIHSLIEESQNQQEKNEQXLELDKWASLWNWF,
 5 YTSLIHSLIEESQNQQEKNEQELLELDXWASXWNWF,
 YTSLIHSLIEESQNQQEKNEQELLELDKWXSXLWXWF,
 YTSLIHSLIEXSQNXQEKNEQXLELDKWASLWNWF,
 YTSXIHSXIEESQNQQEKNEQELLELDKWXSXLWXWF,
 YTSLIHSLIEESQNQQXKNEXELLELDKWXSXLWXWF,
 10 YTSXIHSXIEESQNQQXKNEXELLELDKWASLWNWF,
 YTSXIHSXIEESQNQQEKNEQELLELDXWASXWNWF,
 YTSLIHSLIEXSQNXQEKNEQELLELDXWASXWNWF,
 YTSXIHSXIEESQNQQXKNEXELLELDXWASXWNWF,
 BTWBXWDRXINNYTSLIHSLIEESQNQXEKNXQELLE, or
 15 BTWBXWDRXINNYTSLIHSLIEESQNXQEKXEQELLE;

wherein X is any amino acid and further identifies the amino acid residues which are linked by a hydrocarbon staple, and B is methionine or norleucine.

Uses of the modified polypeptides

The antifusogenic capability of the modified peptides of the invention may
 20 additionally be utilized to inhibit or treat/ameliorate symptoms caused by processes
 involving membrane fusion events. Such events may include, for example, virus
 transmission via cell-cell fusion and virus-cell fusion. The peptides of the invention
 may be used to inhibit free viral, such as retroviral, *e.g.*, HIV, transmission to
 uninfected cells wherein such viral infection involves membrane fusion events or
 25 involves fusion of a viral structure with a cell membrane.

In one aspect, the invention is directed to a method for inhibiting transmission
 of HIV to a cell. The method includes contacting the HIV virus with an effective
 dose of a modified polypeptide so that the HIV virus is inhibited from infecting the
 cell. Preferably, the modified polypeptide has a HIV gp41 heptad repeat domain (*e.g.*,
 30 heptad repeat domain 1 or 2, or combinations thereof) that is stabilized with a
 hydrocarbon staple. Suitable modified polypeptides include those directed to the
 heptad repeat domain 1, wherein the polypeptide is 30% or more identical to the

amino acid sequence of SEQ ID NO:2, SEQ ID NO:3 or SEQ ID NO:14 and forms an alpha-helix. Other suitable modified polypeptides include those directed to the heptad repeat domain 2, wherein the polypeptide is 30% or more identical to the amino acid sequence of FIG. 5, FIG. 6, SEQ ID NO:1 or 14 and forms an alpha-helix.

5 In yet another aspect, the invention is directed to a method for treating or delaying the onset of AIDS in an HIV infected individual. The method entails administering to an individual infected with HIV an effective dose of a pharmaceutical composition having a modified polypeptide with a stabilized HIV gp41 heptad repeat domain, thus treating or delaying the onset of AIDS. Preferably
10 the HIV gp41 heptad repeat domain is stabilized with a hydrocarbon staple(s). Suitable polypeptides include those directed to the heptad repeat domain 1, wherein the polypeptide is 30% or more identical to an amino acid sequence of SEQ ID NO:2, SEQ ID NO:3 or SEQ ID NO:14 and forms an alpha-helix. Other suitable polypeptides include those directed to the heptad repeat domain 2, wherein the
15 polypeptide is 30% or more identical to an amino acid sequence of FIG. 5, FIG. 6, SEQ ID NO:1 or 14 and forms an alpha-helix.

In still another aspect, the invention is directed to a method for increasing the number of CD4+ cells in an individual infected with HIV. The method involves administering to the individual infected with HIV an effective dose of a
20 pharmaceutical composition having a modified polypeptide with a stabilized HIV gp41 heptad repeat domain. The administration of the composition results in an increase in the number of CD4+ cells in the individual. Preferably the HIV gp41 heptad repeat domain is stabilized with a hydrocarbon staple(s). Suitable polypeptides include those directed to the heptad repeat domain 1, wherein the
25 polypeptide is 30% or more identical to an amino acid sequence of SEQ ID NO:2, SEQ ID NO:3 or SEQ ID NO:14 and forms an alpha-helix. Other suitable polypeptides include those directed to the heptad repeat domain 2, wherein the polypeptide is 30% or more identical to an amino acid sequence selected of FIG. 5, FIG. 6, or SEQ ID NO:1 and forms an alpha-helix.

30 In yet another aspect, the invention is directed to a method for inhibiting syncytia formation between an HIV infected cell and an uninfected cell. The method involves contacting the infected cell with an effective dose of a composition having a

modified polypeptide with a stabilized HIV gp41 heptad repeat domain, thereby inhibiting syncytia formation between the cells. Preferably the HIV gp41 heptad repeat domain is stabilized with a hydrocarbon staple. Suitable polypeptides include those that are 30% or more identical to an amino acid sequence of FIG. 5, FIG. 6,
5 SEQ ID NO:2, SEQ ID NO:3, SEQ ID NO:1, SEQ ID NO:13, or SEQ ID NO:14 and forms an alpha-helix.

In still another aspect, the invention is directed to a method for inactivating HIV. The method involves contacting the virus with an effective dose of a modified polypeptide having a stabilized HIV gp41 heptad repeat domain so that the HIV is
10 rendered inactive (*e.g.*, non-infectious). Preferably the HIV gp41 heptad repeat domain is stabilized with a hydrocarbon staple(s). Suitable polypeptides include those that are 30% or more identical to an amino acid sequence of FIG. 5, FIG. 6, SEQ ID NO:2, SEQ ID NO:3, SEQ ID NO:1, SEQ ID NO:13 or SEQ ID NO:14 and forms an alpha-helix.

15 In still another aspect, the invention is directed to a method for preventing an HIV infection in an individual. The method involves administering to an individual an effective dose of a pharmaceutical composition having modified polypeptide with a stabilized HIV gp41 heptad repeat domain, wherein the stabilized HIV gp41 heptad repeat domain interferes with the ability of the HIV to infect the individual. Suitable
20 polypeptides include those directed to the heptad repeat domain 1, wherein the polypeptide is 30% or more identical to an amino acid sequence of SEQ ID NO:2, SEQ ID NO:3 or SEQ ID NO:14 and forms an alpha-helix. Other suitable polypeptides include those directed to heptad repeat domain 2, wherein the polypeptide is 30% or more identical to an amino acid sequence of FIG. 5, FIG. 6,
25 SEQ ID NO:1 or 13 and forms an alpha-helix.

In another aspect, the invention is directed to a method for inhibiting the transmission of RSV to a cell. The method includes contacting the virus with an effective dose of a modified polypeptide having a stabilized RSV viral alpha helix heptad repeat-analog domain, thereby inhibiting transmission of the virus to a cell.
30 Preferably the heptad repeat domain is stabilized with a hydrocarbon staple(s). Suitable modified polypeptides include those which are 30% or more identical to SEQ ID NO:4, SEQ ID NO:5, SEQ ID NO:11 and SEQ ID NO:12 and forms an alpha-

helix.

In yet another aspect, the invention is directed to a method for inhibiting the transmission of influenza virus to a cell. The method includes contacting the virus with an effective dose of a modified polypeptide having a stabilized influenza viral
5 alpha helix heptad repeat-analog domain, thereby inhibiting transmission of the virus to a cell. Preferably the heptad repeat domain is stabilized with a hydrocarbon staple(s). Suitable polypeptides are known in the art.

In yet another aspect, the invention is directed to a method for inhibiting the transmission of a parainfluenza virus to a cell. The method includes contacting the
10 virus with an effective dose of a modified polypeptide having a stabilized parainfluenza viral alpha helix heptad repeat-analog domain, thereby inhibiting transmission of the virus to a cell. Preferably the heptad repeat domain is stabilized with a hydrocarbon staple(s). Suitable polypeptides include those which are 30% or more identical to (SEQ ID NO:6) and forms an alpha-helix.

In still another aspect, the invention is directed to a method for inhibiting the transmission of a coronavirus to a cell. The method includes contacting the coronavirus with an effective dose of a modified polypeptide having a stabilized coronavirus alpha helix heptad repeat-analog domain, thereby inhibiting transmission
15 of the virus to a cell. Preferably the heptad repeat domain is stabilized with a hydrocarbon staple(s). Suitable polypeptides include those which are 30% or more identical to (SEQ ID NO:7) or (SEQ ID NO:8) and forms an alpha-helix.
20

In yet still another aspect, the invention is directed to a method for inhibiting the transmission of an ebola virus to a cell. The method includes contacting the ebolavirus with an effective dose of a modified polypeptide having a stabilized
25 ebolavirus alpha helix heptad repeat-analog domain, thereby inhibiting transmission of the virus to a cell. Preferably the heptad repeat domain is stabilized with a hydrocarbon staple(s). Suitable polypeptides include those having an amino acid sequence which is 30% identical to (SEQ ID NO:9) or (SEQ ID NO:10) and forms an alpha-helix.

30 Preferably, any of the above modified polypeptides used in the methods of the invention have the structure of Formula (I), (II) or (III) as described herein.

Kits

The present invention also encompasses a finished packaged and labeled pharmaceutical product. This article of manufacture includes the appropriate unit dosage form in an appropriate vessel or container such as a glass vial or other container that is hermetically sealed. The pharmaceutical product may contain, for example, a compound of the invention in a unit dosage form in a first container, and in a second container, sterile water for injection. Alternatively, the unit dosage form may be a solid suitable for oral, transdermal, intranasal, intravaginal, cervical ring, or topical delivery.

In a specific embodiment, the unit dosage form is suitable for intravenous, intramuscular, intranasal, oral, intravaginal, cervical, topical or subcutaneous delivery. Thus, the invention encompasses solutions, solids, foams, gels, preferably sterile, suitable for each delivery route.

As with any pharmaceutical product, the packaging material and container are designed to protect the stability of the product during storage and shipment. Further, the products of the invention include instructions for use or other informational material that advise the physician, technician, or patient on how to appropriately prevent or treat the disease or disorder in question. In other words, the article of manufacture includes instruction means indicating or suggesting a dosing regimen including, but not limited to, actual doses, monitoring procedures (e.g. detection and quantitation of infection), and other monitoring information.

Specifically, the invention provides an article of manufacture comprising packaging material, such as a box, bottle, tube, vial, container, sprayer, insufflator, intravenous (i.v.) bag, envelope and the like; and at least one unit dosage form of a pharmaceutical agent contained within said packaging material, wherein said pharmaceutical agent comprises a compound of the invention, and wherein said packaging material includes instruction means which indicate that said compound can be used to prevent, manage, treat, and/or ameliorate one or more symptoms associated with a viral disease by administering specific doses and using specific dosing regimens as described herein.

The following examples are provided merely as illustrative of various aspects of the invention and shall not be construed to limit the invention in any way.

EXAMPLES

5 **Example 1. Synthesis of hydrocarbon stapled alpha helical polypeptides.**

A combined strategy of structural analysis and chemical synthesis is applied to construct the modified polypeptides. Asymmetric syntheses of α,α -disubstituted amino acids is first performed as previously reported (Schafmeister, C.E., J. Po, and G.L. Verdine, *Journal of the American Chemical Society*, 2000. 122(24): p. 5891-10 5892; Walensky, L.D., *et al.*, *Science*, 2004. 305(5689): p. 1466-1470). The modified polypeptide compounds are generated by replacing at least two naturally occurring amino acids with the α,α -disubstituted non-natural amino acids at discrete locations flanking either 2, 3 or 6 amino acids, namely the “*i, i+3*,” “*i, i+4*” or “*i, i+7*” positions, respectively.

15 Locations for the non-natural amino acids and subsequent hydrocarbon staple(s) are carefully chosen so as not to interfere with N36 interactions (Chan, D.C., *et al.*, *Cell*, 1997. 89(2): p. 263-273). Residues in positions *a* and *d* interact directly with N36, whereas, residues *e* and *g* may contact the N36 core as a result of the pitch of the six-helix bundle. Residues *b, f*, and *c* localize to the opposite face of the α -20 helix and are thus ideally located for placement of the hydrocarbon staple(s).

The modified polypeptides can be generated using solid phase Fmoc chemistry and ruthenium-catalyzed olefin metathesis, followed by peptide deprotection and cleavage, purification by reverse-phase high performance liquid chromatography, and chemical characterization using LC/MS mass spectrometry and amino acid analysis.

25 Alternatively an established fragment-based approach can be pursued ([Bray, B.L., *Nature Reviews Drug Discovery*, 2003. 2(7): p. 587-593; MYUNG-CHOL KANG, B.B., *et al.*, *Methods and compositions for peptide synthesis*, U.S.P.a.T. Office, Editor. January 18, 2000 USA). In this strategy, the peptide is divided into 3 fragments, such that an N-terminal, central, and C-terminal portion are synthesized30 independently. These polypeptide fragments should be generated using solid phase Fmoc chemistry and ruthenium-catalyzed olefin metathesis on super-acid cleavable

resins, which will yield fully protected peptides having an Fmoc at the N-terminus, and either a C-terminal amide (for the C-terminal fragment) or a free carboxylate (for the central and N-terminal fragments). These fully protected fragments are purified by reverse-phase high performance liquid chromatography, followed by sequential
5 deprotection, coupling, and purification, to yield the full length, fully protected polypeptides. Global deprotection, followed by reverse-phase high performance liquid chromatography will yield the final products, which can be characterized using LC/MS mass spectrometry and amino acid analysis.

**Example 2: Determining the secondary structure and proteolytic stability of the
10 modified polypeptides.**

The α -helicity of stapled modified polypeptides can be compared to their unmodified counterparts by circular dichroism. CD spectra can be obtained on a Jasco J-710 or Aviv™ spectropolarimeter at 20°C using the following standard measurement parameters: wavelength, 190-260 nm; step resolution, 0.5 nm; speed, 20
15 nm/sec; accumulations, 10; response, 1 sec; bandwidth, 1 nm; path length, 0.1 cm. The α -helical content of each peptide is calculated by dividing the mean residue ellipticity $[\Theta]_{222_{\text{obs}}}$ by the reported $[\Theta]_{222_{\text{obs}}}$ for a model helical peptide (Forood, B., E.J. Feliciano, and K.P. Nambiar, *PNAS*, 1993. 90(3): p. 838-842; J. Martin Scholtz, *Biopolymers*, 1991. 31(13): p. 1463-1470; Lawless, M.K., *et al.*, *Biochemistry*, 1996.
20 35(42): p. 13697-13708) or using, for example, the Aviv™ machine using CDNN software developed by Brohm in order to deduce five different secondary structure fractions (helix, parallel and antiparallel beta-sheet, beta-turn and random coil). *Protein Engineering*, 1992. 5(3); p. 191-195

To assess whether helix stabilization confers enhanced protease resistance and
25 serum stability, the modified polypeptides can be subjected to trypsin/chymotrypsin degradation assays and *in vitro* and *in vivo* serum stability assays, and compared to their unmodified counterparts as previously described (Walensky, L.D., *et al.*, *Science*, 2004. 305(5689): p. 1466-1470). Recovery of intact compound is determined, for example, by flash freezing the *in vitro* or serum specimens in liquid
30 nitrogen, lyophilization, and extraction in 50:50 acetonitrile/water containing 0.1% trifluoroacetic acid, followed by LC/MS based detection and quantitation.

Example 3: Optimization of the biophysical and biochemical properties of the modified polypeptides by evaluating diversified modified peptide libraries synthesized in high-throughput fashion.

High-throughput technologies can be used to optimize the modified polypeptides activities for cellular and *in vivo* studies. For example, an Apex 396™ multichannel synthesizer (AAPTEC; Louisville, Kentucky) can be used to produce polypeptide libraries for biological evaluation. The polypeptide compounds can be diversified by extension, truncation, or amino acid substitution across natural and select non-natural amino acids, and differential staple localization can be made to maximize their biophysical and biochemical properties. The libraries are generated using high-throughput solid phase Fmoc chemistry and ruthenium-catalyzed olefin metathesis and peptide deprotection and cleavage. Peptide purification is achieved by reverse phase C18 HPLC, and products characterized by LC/MS mass spectrometry and amino acid analysis.

Example 4: Evaluating the modified polypeptides ability to target and inhibit HIV fusion.

The binding activity and functional effects of the HIV modified polypeptides can be assessed in fluorescence polarization, syncytial fusion, and HIV infectivity assays. Equilibrium binding constants can be determined by fluorescence polarization assays (FPA) using fluorescein isothiocyanate (FITC)-labeled modified polypeptides and titrated recombinant five-helix bundle protein. FPA experiments can be performed using a BMG Labtech FLUOstar™ optima microplate reader, and dissociation constants determined by regression analysis using GraphPad software (Prism). The recombinant 5-helix bundle protein, first developed by Root *et al.*, contains five of the six helices that comprise the core of the gp41 trimer-of-hairpins, which are connected by short peptide linkers (Root, M.J., M.S. Kay, and P.S. Kim, *Science*, 2001. 291(5505): p. 884-888). Because the 5-helix bundle lacks the third C-peptide helix and under experimental conditions is soluble, stable, and helical, incorporation of the sixth C-peptide in the form of FITC-modified polypeptide would provide a direct measure of binding activity. In this manner, modified polypeptides, differing in peptide sequence, staple location, and staple number, can be screened for maximal *in vitro* binding activity. Binding activity can also be determined indirectly

by competition assays in which the 5-helix bundle is combined with a FITC-labeled unmodified HIV fusion inhibitor peptide and then unlabeled stapled gp41 peptides are added at increasing concentrations followed by measurement of fluorescence polarization and then calculation of K_i by nonlinear regression analysis, as indicated
5 above.

Alternatively, an alternative binding assay can be employed based upon the “gp41-5” construct of Frey *et al.* Gp41-5 binds with high affinity to added peptides that contain all or part of the missing CHR. For example, using gp41-5 and fluorescein-labeled C38 (residues 117-154), Frey *et al.* successfully generated an FPA
10 binding curve that revealed a K_d of 3.6 nM (Frey, G., *et al.*, *PNAS*, 2006. 103(38): p. 13938-13943).

Functional assays can also be used to evaluate the modified polypeptides activity. In culture, multinucleated giant cells or “syncytia” form as a result of direct cell-cell fusion between HIV-1-infected and uninfected CD4-positive cells. In the
15 syncytia formation assay, an indicator cell line expressing the CD4 receptor, and a fusogenic cell line that lacks the CD4 receptor but contains HIV-1 proteins on the surface, fuse to generate 70-100 multinucleated giant cells in culture within 48 h. Syncytia are then counted using an inverted microscope. The ability of stabilized alpha helix of gp41 (SAH-gp41) compounds to inhibit syncytia formation in a dose-
20 responsive fashion is used as a functional measure of fusion inhibition, for which IC_{50} s can be determined and compared with peptides T20 and T649 (Brenner, T.J., *et al.* *The Lancet*, 1991. 337(8748): p. 1001-1005; Madani, N., *et al.*, *Journal of Virology*, 2007. 81(2): p. 532-538).

Also the anti-viral properties of the modified polypeptides can be quantified
25 based upon their capacity to directly block HIV infection of CD4-positive and CCR5-expressing canine thymus cells. Recombinant HIV-1 viruses (eg. HXBc2, YU2, and additional strains available through the NIH AIDS Research and Reference Reagent Program) expressing firefly luciferase and containing the indicated envelope glycoproteins can be used to infect Cf2Th-CD4-CCR5/CXCR4 cells in the presence
30 of serially diluted HIV modified polypeptides. After 48 hours, the cells are lysed and luciferase activity is quantified (Si, Z.H., M. Cayabyab, and J. Sodroski, *Journal of Virology*, 2001. 75(9): p. 4208-4218 Si, Z.H., *et al.*, *PNAS*, 2004. 101(14): p. 5036-

5041). The identical experiment is performed with the amphotropic murine leukemia virus (AMLV), to monitor for any nonspecific effects of the modified polypeptides. Similar control assays may be performed with non-HIV modified polypeptides of the invention and are known in the art.

5 Example 5. Evaluate the ability of SAH-gp41 compounds to overcome resistance to enfuvirtide.

Heavily antiretroviral-treated HIV-positive patients who respond to initial treatment with enfuvirtide, may ultimately develop a viral rebound that typically occurs within a maximum of 80 weeks. Resistance to enfuvirtide derives from
10 mutations within the HR-1 region of gp41, although some genetic changes are found in the HR-2 domain (Xu, L., *et al.*, *Antimicrobial Agents and Chemotherapy*, 2005. 49(3): p. 1113-1119; Perez-Alvarez, L., *et al.*, *Journal of Medical Virology*, 2006. 78(2): p. 141-147). These mutations, such as I37V, V38A/E/M, Q39R, Q40H, N42T/Q/H, N43D/Q, are only found in enfuvirtide-experienced patients (Poveda, E.,
15 *et al.*, *Journal of Medical Virology*, 2004. 74(1): p. 21-28; Melby, T., *et al.*, *Aids Research and Human Retroviruses*, 2006. 22(5): p. 375-385; Sista, P.R., *et al.*, *Aids*, 2004. 18(13): p. 1787-1794; Wei, X.P., *et al.*, *Antimicrobial Agents and Chemotherapy*, 2002. 46(6): p. 1896-1905).

Structural analysis and molecular modeling can be used to evaluate the
20 impact of these mutations on the binding interface of the HR-1 domain with enfuvirtide. Five-helix bundle proteins incorporating resistance mutations can then be generated for binding analysis as described in Example 4. FITC-labeled SAH-gp41 compounds can then be screened against these mutant five-helix bundle proteins to determine if any native SAH-gp41 compounds retain activity despite HR domain
25 mutations. Alternatively, HR1 peptides that contain resistance mutations are synthesized and can be directly incubated with SAH-gp41 compounds, and then run on native gels to detect and quantitate the formation of heteroduplexes, which represent HR1-SAH-gp41 complex, detectable by fluorescence scanning of the gel (Fig. 20A). SAH-gp41 compounds should contain T649 sequences known to contact
30 two gp41 residues (Leu-568 and Trp-571) that are critical for fusion activity. By incorporating this sequence functionality, the SAH-gp41 compounds may overcome enfuvirtide-resistant virus and are less likely to elicit a resistant virus, in contrast to

analogs, like T20, that lack such residues at the N-terminal region of the HR-2 domain (Cao, J., *et al.*, *Journal of Virology*, 1993. 67(5): p. 2747-2755; Chan, D.C., C.T. *PNAS* 1998. 95(26): p. 15613-15617; Rimsky, L.T., D.C. Shugars, and T.J. Matthews, *J. Virol.*, 1998. 72(2): p. 986-993). Follow-up HIV infectivity studies would evaluate
5 the functional activity of such SAH-gp41 compounds against the corresponding primary resistant isolates.

To monitor for restoration of SAH-gp41 activity, FITC labeled mutants SAH-gp41 (mSAH-gp41) compounds can be screened for binding affinity to mutant five-helix bundle proteins and for suppression of HIV infectivity using primary resistance
10 strains.

To explore the evolution of potential resistance to SAH-gp41 compounds, HIV strains can be evolved in the presence of increasing concentrations of lead SAH-gp41 compounds. Resistant strains can be genotyped for comparative mutational analysis between these mutants and enfuvirtide-resistant mutants (Van Laethem, K.,
15 *et al.*, *Journal of Virological Methods*, 2005. 123(1): p. 25-34). Because resistance to one type of entry inhibitor may not affect susceptibility to other variants, (Ray, N., *et al.*, *Journal of Virology*, 2007. 81(7): p. 3240-3250) combined SAH-gp41 and mSAH-gp41 polypeptide compositions can be formulated.

Alternative, a phage display strategy can be employed. Lai *et al.* successfully
20 used phage display to restore heterodimerization of a coiled-coil pair of α -helices after destabilizing mutations were introduced (Lai, J.R., *et al.*, *Journal of the American Chemical Society*, 2004. 126(34); p. 10514-10515). Whereas complimentary electrostatic pairing preferences among helical residues that flank the core are readily apparent, less is known about the packing preferences of non-polar residues located at
25 core positions (Lumb, K.J. and P.S. Kim, *Science*, 1995. 268(5209): p. 436-439) Using phage display, one can screen all possible amino acid combinations at up to 7 variable locations of the HR-2 domain for binding affinity to a mutant HR-1 domain, using the corresponding five-helix bundle. In addition, phage display screening of fully randomized HR-2 domains against combinations of known mutations in HR-1
30 domains could be undertaken in order to determine the SAH-gp41 sequence capable of forming the most stable complex with the 5-helix bundle (Xu, L., *et al.*, *Antimicrobial Agents and Chemotherapy*, 2005. 49(3): p. 1113-1119; Perez-Alvarez,

L., *et al.*, *Journal of Medical Virology*, 2006. 78(2): p. 141-147). After three cycles of “panning”, phage DNA sequencing would reveal those peptide sequences having the highest binding affinities for the mutant 5-helix bundle. The corresponding SAH-gp41 derivatives would then be synthesized and evaluated in binding and activity studies as described above.

Example 6. Analyze the *in vivo* stability, pharmacokinetics, and biodistribution of SAH-gp41 compounds.

A rigorous assessment of the *in vivo* pharmacology of SAH-gp41 compounds can be used to determine and optimize the therapeutic potential of the modified polypeptides. For *in vivo* serum half-life studies, 5-50 mg/kg of FITC-labeled or unlabeled SAH-gp41 polypeptides can be injected or delivered orally into control mice and blood specimens withdrawn for example at 0, 0.25, 0.5, 1, 2, 4, 8, 12, and 24 hours post-injection to measure levels of intact compound by HPLC as previously described (Walensky, L.D., *et al.*, *Science*, 2004. 305(5689): p. 1466-1470]) or by reverse-phase LC/MS, followed by mathematical determination of pharmacokinetic parameters using formulas and software known in the art. LC/MS-based characterization of metabolites can also be performed. ¹¹¹In-DOTA-derivatized compounds can be synthesized and injected into control mice for measurement of tissue uptake, excretion, and biodistribution of the modified polypeptide compounds over time by radioisotope scintillation counting. SPECT/NMR imaging of control mice injected with ¹¹¹In-DOTA-derivatized modified compounds will provide high resolution images of biodistribution in real time as previously performed by the Walensky lab in collaboration with Ralph Weissleder, MD of Massachusetts General Hospital (Hird V, V.M., *et al.*, *Br J Cancer*, 1991. 64(5): p. 911-4). Chemical modifications, including lipidation, polysialylation, or antibody-conjugation, could be performed should optimization of pharmacokinetics and tissue targeting of modified compounds.

Example 7. Native gp41 C-terminal heptad peptides are predominantly random coils in solution.

gp41 HR-2-derived peptides based upon the sequences of T20 (residues 638-673) and a T649 variant, T649v (residues 626-662, rather than T649 is 628-663) were prepared and the circular dichroism (CD) spectra determined at physiologic pH. The

native peptides display only modest minima at 222 nm and 208 nm, suggesting predominantly random coil structure in solution. Indeed, the calculated α -helical content (Forood, B., E.J. Feliciano, and K.P. Nambiar, *PNAS*, 1993. 90(3): p. 838-84; J. Martin Scholtz, *Biopolymers*, 1991. 31(13): p. 1463-1470; Lawless, M.K., *et al.*, *Biochemistry*, 1996. 35(42): p. 13697-13708) was only ~25% for T20 and 14% for T649v. Thus, synthetic gp41-derived HR-2 peptides are predominantly disordered in solution, reflecting a significant loss of bioactive structure.

Example 8. Truncated C-terminal heptad peptides display enhanced α -helicity upon incorporation of an all-hydrocarbon staple.

10 In order to improve the biochemical properties of HIV gp41-HR-2 peptides the T649v peptide was truncated to yield a 20-mer consisting of residues 626-645 (FIG. 7). The truncated SAH-gp41 compound, SAH-gp41(626-645)(A), was successfully synthesized in high yield. Analysis of comparative CD spectra revealed marked enhancement of α -helical content for SAH-gp41(626-645)(A) compared to its
15 unstapled counterpart (48% vs. 20%). Evaluation of the compounds in an HIV syncytial formation assay revealed markedly enhanced inhibitory activity of SAH-gp41(626-645)(A) compared to its unstapled derivative. Thus, in spite of eliminating more than 40% of the residues of T649v, the hydrocarbon staple successfully transformed a 20-mer gp41 truncation with little α -helicity and only modest anti-
20 syncytial activity, into an α -helical compound with significant structural stabilization and potent anti-syncytial activity (IC₉₀, ~100 nM) (FIG. 18).

The activity of SAH-gp41(626-645)(A) peptide was compared to the clinically approved T20 peptide in an HIV infectivity assay using the HXBc2 strain. The SAH-gp41(626-645)(A) displayed significant anti-HXBc2 activity, particularly given the
25 markedly shortened construct.

Example 9. SAH-gp41 compounds demonstrate marked α -helical stabilization, proteolytic stability, thermal stability, 5-helix bundle binding affinity

To optimize the activity of tSAH-gp41 peptides, an alternative strategy based upon inserting one or more hydrocarbon staples into the full-length gp41-HR-2 constructs was pursued (Fig. 11, 12). Unmodified enfuvirtide and T649v were
30 predominantly unstructured in pH 7 aqueous solution at 21 °C, exhibiting less than

20% α -helicity (Fig 14A,B). All stapled derivatives displayed comparatively increased α -helical content, with up to 4.7-fold structural stabilization (Fig. 14A-C). The insertion of either one or two hydrocarbon staples consistently transformed the circular dichroism spectra from a random coil pattern with a predominant single
5 minimum at 204 nm to an α -helical contour with double minima at 208 and 222 nm. For select peptide templates, single C-terminal stapling conferred a greater degree of α -helical stabilization than single N-terminal stapling. Select doubly stapled SAH-gp41 compounds exhibited an intermediate enhancement in α -helical structure, balancing the effects of the N- and C-terminal singly stapled peptides. Enhancement
10 of peptide α -helicity was likewise observed at pH2, and in most cases, SAH-gp41 compounds were even more helical at pH2 than at pH7 (Fig. 14D-F).

To assess the resistance of SAH-gp41 peptides to thermal unfolding, we performed circular dichroism studies across a 1-91 °C temperature range. We observed that select single and double stapling of HIV-1 fusion inhibitor peptides
15 conferred α -helical stabilization that was remarkably heat-resistant, sustaining an up to 2.3-fold enhancement in α -helicity even at 91 °C (Fig. 15).

A major limitation of peptides as therapeutics is their susceptibility to rapid proteolytic degradation. Biologically active peptides such as enfuvirtide that are lengthy, unfolded, and replete with protease sites are particularly vulnerable. One of
20 the potential benefits of a covalent crosslinking strategy to enforce peptide α -helicity is shielding of the vulnerable amide bonds from proteolysis. Because proteases require that peptides adopt an extended conformation to hydrolyze amide bonds, the structural constraint afforded by the hydrocarbon staple can render crosslinked peptides protease-resistant. To determine if hydrocarbon stapling, and especially
25 double stapling, could protect the 36 to 37-mer HIV-1 fusion peptides from proteolysis, we subjected enfuvirtide, T649v, and SAH-gp41 peptides to direct protease exposure in vitro. To especially challenge the stapled peptides, we selected chymotrypsin, which can cleave gp41 HR2 peptides at numerous consensus cleavage sites, including 9-11 locations for SAH-gp41(638-673) and 7 locations for SAH-
30 gp41(626-662).

In the presence of 0.5 ng/ μ L chymotrypsin, enfuvirtide and T649v (25 μ M) exhibited rapid degradation, with half-lives of 12 and 14 minutes, respectively (Fig.

16A-C). In comparison, singly stapled SAH-gp41 compounds displayed longer half-lives that ranged from 21 to 200 minutes. The majority of doubly stapled compounds markedly surpassed their singly stapled counterparts, with select doubly stapled peptides achieving half-lives of up to 1275 minutes. In most cases, double stapling had a stronger influence on proteolytic stability than overall peptide α -helicity, as select doubly stapled peptides had lower α -helicity than select singly stapled peptides, but still exhibited superior protease resistance. Almost all stapled peptides had the identical number of chymotrypsin cleavage sites as the corresponding unmodified peptides, emphasizing that the observed protease resistance derived from peptide stapling itself, rather than elimination of cleavage sites.

Peptides have poor oral bioavailability in part due to rapid acid hydrolysis in the proximal digestive tract. The compelling protease resistance of doubly stapled SAH-gp41 compounds at neutral pH prompted us to explore their stability under acidic conditions. In each case, acidification of the peptide solutions significantly enhanced their α -helical content as measured by CD (Fig. 16D-F). Upon exposure to pepsin at 0.5 ng/ μ L, enfuvirtide and T649v (25 μ M) exhibited rapid degradation, with half-lives of 4 and 11 minutes, respectively. Select doubly stapled SAH-gp41 compounds displayed half-lives ranging from approximately 80-800-fold greater than the unmodified peptides, and consistently surpassed their singly stapled counterparts. Remarkably, select doubly-stapled SAH-gp41 peptides remained 80% intact after exposure to pepsin at pH 2 for more than 12 hours. As observed for chymotrypsin resistance, double stapling itself, rather than overall peptide α -helicity or number of cleavage sites, correlated with the superior resistance to pepsin hydrolysis. These studies highlight the capacity of double stapling to generate HIV-1 fusion inhibitor peptides with unprecedented resistance to proteolytic hydrolysis at both neutral and acidic pH.

The compounds of the invention were also measured for their affinity to gp41 in a five-helix binding assay as described herein. As shown in FIG. 17 the modified compounds bound substantially better than the unmodified control polypeptides.

Example 10. SAH-gp41 compounds demonstrate anti-syncytial formation activity and anti-HIV viral fusion activity

The compounds of the invention were assayed for inhibition of syncytial

formation using methods well known to those skilled in the art. The results of the assay are shown in FIG. 18. Equal amounts of either T20/gp41₍₆₃₈₋₆₇₃₎ or SAH-gp41₍₆₂₆₋₆₄₅₎A were added to the media. As shown, the modified compounds inhibited syncytial formation more so than unmodified control polypeptides.

5 In order to determine the functional impact of hydrocarbon-stapling on gp41-based fusion inhibitor activity, SAH-gp41 compounds were tested and compared to their unmodified counterparts in a luciferase-based HIV infectivity assay (Si, Z.H., M. Cayabyab, and J. Sodroski, *Journal of Virology*, 2001. 75(9): p. 4208-4218; Si, Z.H., et al., *PNAS*, 2004. 101(14): p. 5036-5041). Recombinant HIV-1 bearing the envelope glycoproteins from three distinct HIV-1 strains, HXBc2, ADA, and HXBc2P 3.2, and a negative control virus bearing the amphotropic murine leukemia virus (A-MLV) envelope glycoproteins, were evaluated. Compared to enfuvirtide, select SAH-gp41₍₆₃₈₋₆₇₃₎ peptides exhibited a 3- to 15-fold enhancement of inhibitory activity across all three HIV-1 strains (Figure 19). T649v, an HR2 peptide that encompasses a 15 37-amino acid fragment terminating 11 residues upstream of enfuvirtide's C-terminus, displayed 26-, 40-, and 16-fold greater inhibitory activity than enfuvirtide against viruses with the HXBc2, ADA, and HXBc2P 3.2 envelope glycoproteins, respectively. Given the marked potency of T649v against these viral strains, we found that the corresponding SAH-gp41 peptides showed essentially comparable activity in infectivity assays. In order to probe for differential anti-viral potencies among T649v-based stapled peptides, we screened the compounds against viruses with envelope glycoproteins derived from the more resistant primary R5 isolate, YU2. Compared to T649v, select SAH-gp41₍₆₂₆₋₆₆₂₎ peptides demonstrated enhanced anti-YU2 activity (Fig. 19, 20B). The ability of SAH-gp41 peptides to overcome HIV-1 HR1 resistance mutations, was further underscored by the superior binding activity of select SAH-gp41 peptides to mutant HR1 peptides, as compared to unmodified gp41-based fusion peptides, when assayed by fluorescence scan of electrophoresed mixtures of HR1 and HR2/SAH-gp41 peptides (Fig. 20A).

30 These functional data reveal that insertion of one or more hydrocarbon staples can yield SAH-gp41 peptides with potent and broad anti-HIV-1 activity. The importance of striking a balance between α -helical stabilization, proteolytic stability, and anti-viral activity is underscored by the doubly stapled SAH-gp41₍₆₂₆₋₆₆₂₎(A, F)

peptide, which combines intermediate α -helical stabilization, the striking anti-proteolysis feature of double stapling, and potent anti-viral activity, to yield a pharmacologically optimized HIV-1 fusion inhibitor peptide.

Example 11. A doubly stapled SAH-gp41 peptide demonstrates striking enhancement of *in vivo* stability and bioavailability compared to the corresponding unmodified peptide.

5 Male C57/BL6 mice were administered intravenously or by oral gavage 10 mg/kg of either SAH-gp41₍₆₂₆₋₆₆₂₎(A,F) or the corresponding unmodified peptide. Blood samples withdrawn at 30 minutes by retro-orbital bleed were subjected to quantitation using LC/MS-based blood tests. The
10 level of SAH-gp41₍₆₂₆₋₆₆₂₎(A,F) measured in the blood was more than 6-fold greater than the measured level of the corresponding unmodified peptide. Strikingly, 30 minutes after oral administration, intact SAH-gp41₍₆₂₆₋₆₆₂₎(A,F) was detected in the blood at measurable levels, whereas the unmodified peptide was undetectable (Figure
15 21). These data emphasize that hydrocarbon stapling confers unique pharmacologic properties to gp41-based fusion peptide sequences, enhancing their *in vivo* stability and even conferring measurable oral bioavailability. This single dose experiment demonstrates that the SAH-gp41 peptides could be dosed at a level to provide serum levels of the compound comparable to the level of an unmodified peptide (e.g., enfuvirtide) suggesting that a therapeutically effective dose could be administered
20 orally.

Claims:

1. A modified polypeptide comprising a stabilized alpha helix of HIV gp41 heptad repeat domain, wherein said stabilized HIV gp41 heptad repeat domain is stabilized with two hydrocarbon staples, wherein said hydrocarbon staples are positioned so as to link amino acid residues i and $i + 4$.
2. The modified polypeptide of claim 1, wherein said modified polypeptide is 20 or more amino acids.
3. The modified polypeptide of claim 1, wherein said heptad repeat domain comprises the formula:
--W--W---I--Y---I--L---S--Q---N--E---L, or conservative amino acid substitutions thereof and wherein “-” can be any amino acid (SEQ ID NO: 44).
4. The modified polypeptide of claim 1, wherein said heptad repeat domain comprises the formula:
-TW--WDR-I--Y---I--LI---Q--QEK-E--L-EL, or conservative amino acid substitutions thereof and wherein “-” can be any amino acid (SEQ ID NO: 45).
5. The modified polypeptide of claim 1, wherein said modified polypeptide has at least 10%, 20%, 30%, 50%, 60%, 70%, 80%, or 90% alpha helicity in aqueous solution as determined by circular dichroism.
6. The modified polypeptide of claim 1, wherein said heptad repeat domain is a HIV-1 gp41 heptad repeat domain 1, an HIV-1 gp41 heptad repeat domain 2, an HIV-2 gp41 heptad repeat domain 1, or an HIV-2 gp41 heptad repeat domain 2.
7. The modified polypeptide of claim 1, wherein said modified polypeptide is a chimera comprising at least a portion of each of at least two different HIV gp41 heptad repeat domains.
8. The modified polypeptide of claim 7, wherein said chimera has the amino acid sequence of WQEWEQKITALLEQAQIQQEKNEYELQKLDKWASLWEWF (SEQ ID NO: 46).
9. The modified polypeptide of claim 1, wherein said heptad repeat domain forms an alpha helix

and is 30% or more identical to the amino acid sequence of
 YTSLIHSLIEESQNQQEKNEQELLELDKWASLWNWF (SEQ ID NO:1),
 NNLLRAIEAQQHLLQLTVWGIKQLQARILAVERYLQDQ (SEQ ID NO:2),
 BTWBEWDREINNYTSLIHSL (SEQ ID NO:3),
 MTWMEWDREINNYTSLIHSLIEESQNQQEKNEQELLE (SEQ ID NO:13),
 YTHIYSLIEQSQNQQEKNEQELLALDKWASLWNWF (SEQ ID NO:58), or
 MTMKWEREIDNYTHIYSLIEQSQNQQEKNEQELLA (SEQ ID NO:59).

10. The modified polypeptide of claim 1, wherein said modified polypeptide has a formula selected from the group consisting of:

BTWBXWDRXINNYTSLIHSLIEXSQNXQEKNEQELLE (SEQ ID NO: 20),
 BTWBXWDRXINNYTSLIHSLIEESQNQQXKNEXELLE (SEQ ID NO: 22),
 BTWBEWDXEINXYTSLIHSLIEESQNQQXKNEXELLE (SEQ ID NO: 23),
 BTWBEWDREINXYTSXIHSIEESQNQQXKNEXELLE (SEQ ID NO: 24),
 BTWBEWDREINNYTSXIHSXIEESQNQQXKNEXELLE (SEQ ID NO: 25),
 YTSLIHSLIEXSQNXQEKNEQXLLLEXDKWASLWNWF (SEQ ID NO: 35),
 YTSXIHSXIEESQNQQEKNEQELLELDKWASLWXWF (SEQ ID NO: 36),
 YTSLIHSLIEESQNQQXKNEXELLELDKWASLWXWF (SEQ ID NO: 37),
 YTSXIHSXIEESQNQQXKNEXELLELDKWASLWNWF (SEQ ID NO: 38),
 YTSXIHSXIEESQNQQEKNEQELLELDXWASXWNWF (SEQ ID NO: 39),
 YTSLIHSLIEXSQNXQEKNEQELLELDXWASXWNWF (SEQ ID NO: 40),
 BTWBXWDRXINNYTSLIHSLIEESQNQXEKNXQELLE (SEQ ID NO: 42),
 BTWBXWDRXINNYTSLIHSLIEESQNQXEKXEQELLE, (SEQ ID NO: 43) and
 BTWXEWDXEINNYTSLIHSLIEESQNQXEKNXQELLE (SEQ ID NO: 82);

wherein X is any amino acid and further identifies the amino acid residues which are linked by the hydrocarbon staple, and B is methionine or norleucine.

11. A kit comprising the modified polypeptide of claim 1 and instructions for use in inhibiting HIV.

FIGURE 1

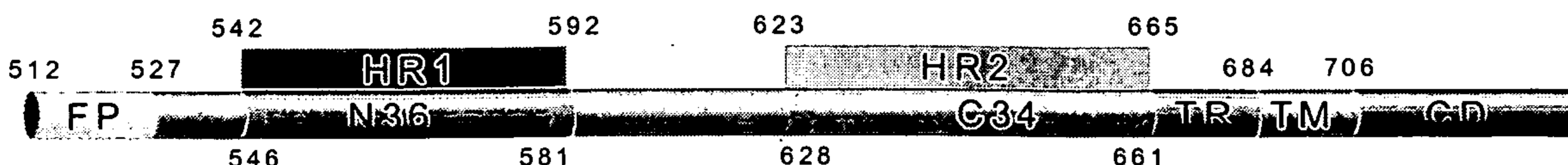


FIGURE 2A

MRVKEKYQHLWRWGWRWGTMLLGMLMICSATEKLWVTVYYGVPVWKEATTTLFCASD
 AKAYDTEVHNVWATHACVPTDPNPQEVVLVNVVTENFNMWKNMVEQMHEIDIISLWDQ
 SLKPCVKLTPLCVSLKCTDLKNDTNTNSSSGRMIMEKGEIKNCSFNISTSIIRGKVQK
 EYAFFYKLDIIPIDNDTTSYKLTSCNTSVITQACPKVSFEPPIPIHYCAPAGFAILKC
 NNKTFNGTGPCTNVSTVQCTHGIRPVVSTQLLNGSLAESEEVVIRSVNFTDNAKTIIVQLN
 TSVEINCTRPNNNTRKRIRIQRGPGRFVTIGKIGNMRQAHCNISRAKWNNTL
 KQIASKLREQFGNNKTIIFKQSSGGDPEIVTHSFNCGGEFFYCNSTQLFNSTWFNST
 WSTEGSNTEGSDTITLPCRIKQIINMWQKVGKAMYAPPISGQIRCSSNITGLLLTR
 DGGNSNNESEIFRPGGGDMRDNRSELYKYKVVKIEPLGVAPTAKARRVVQREKRAV
 GIGALFLGFLGAAGSTMGAASMTLTVQARQLLSGIVQQQNNLLRAIEAQQHLLQLTV
WGIKQLQARILAVERYLKDQQLLGIWGC SGKLICTTAVPWNASWSNKSLEQIWNHTT
WMEWDREINNYTSLIHSLIEESQNQQEKNEQELLELDK WASLWNWFNITNWLWYIKL
 FIMIVGGLVGLRIVFAVLSIVNRVRQGYSPFSFQTHLPTPRGPDRPEGIEEEGGERD
 RDRSIRLVNGSLALIWDLLRSLCLFSYHRLRDLILLIVTRIVELLGRRGWVWVLYKWWN
 LLQYWSQELKNSAVSLLNATAIAVAEGTDRVIEVVQGACRAIRHIPRRIRQGLERIL
 L

FIGURE 2B

MRATEIRKNYQHLWKGGTLLLGMLMICSAAEQWLWVTVYYGVPVWKEATTTLFCASDA
 KAYDTEVHNVWATHACVPTDPNPQEVKLENTENFNMWKNMVEQMHEIDIISLWDQS
 LKPCVKLTPLCVTLNCTDLRNATNTTSSSWETMEKGEIKNCSFNITTSIRDKVQKEY
 ALFYNDVVPIDNASYRLISCNTSVITQACPKVSFEPPIPIHYCAPAGFAILKCNDKK
 FNGTGPCTNVSTVQCTHGIRPVVSTQLLNGSLAESEEVVIRSENFTNNAKTIIVQLN
 ESVVINCTRPNNNTRKSINIGPGRALYTTGEIIGDIRQAHCNLSKTQWENTLEQIAI
 KLKEQFGNNKTIIFNPSSGGDPEIVTHSFNCGGEFFYCNSTQLFTWNDTRKLNNTGR
 NITLPCRIKQIINMWQEVGKAMYAPPIRGQIRCSSNITGLLLTRDGGKDTNGTEIFR
 PGGGDMRDNRSELYKYKVVKIEPLGVAPTAKARRVVQREKRAVGLGALFLGFLGAA
 GSTMGAASITLTVQARQLLSGIVQQQNNLLRAIEAQQHLLQLTVWGIKQLQARVLAV
ERYLRDQQLLGIWGC SGKLICTTTPWNTSWSNKSLEIWDNMTWMKWEREIDNYTH
IYSLIEQSQNQQEKNEQELLALDK WASLWNWFDITKWLWYIKIFIMIVGGLIGLRI
 VFVLSIVNRVRQGYSPFSFQTHLPAQRGPDRPDGIEEEGGERDRDRSGPLVDGFLA
 IIVDLRSLCLFSYHRLRDLILLIVTRIVELLGRRGWVWVLYKWWNLLQYWIQELKNSA
 VSLNATAIAVAEGTDRVIEILQRAFRVAVLHIPVRRIRQGLERALL

FIGURE 3

Heptad-repeat domain 1 (HR1)

SARS coronavirus spike protein₅₄₂ RQLLSGIVQÖQNNLLRAIEAQÖHLLQLLTWVGIKÖLQARILAVERYLÖDDÖL₅₉₂

Ebolavirus spike protein₅₄₆ DGLICGLRQLANETTQALQLFLRATTELRTFPSILNRKAIIDFL₅₉₄

Human parainfluenza virus₁₅₀ SGIADVSKVLIHLEGEVNIKKNALLSTNKAVVSLSNVSVLTSKVLDDKSYINNÖLLPI₂₀₆

T-cell leukemia virus₃₃₈ MSIASGKSLLHEVDKDISÖLTAIVKNNHKNLLKIAQYAAQÖNRRGLDLLFW₃₈₇

Marburg virus₅₅₃ NNLVCRRLRLANQTAKSLELLLRVTTTEERTFSLINRHAIDFL₅₉₄

Heptad-repeat domain 2 (HR2)

SARS coronavirus spike protein₆₂₃ WNNMTWMEWEKEIDNYTSIIYTLLETSONQÖEKNEQELLEDK₆₆₅

Ebolavirus spike protein₆₁₄ DWTKNITDKIDQIIHDFVDKTLPPD₆₃₇

Human parainfluenza virus₄₇₃ PIINYYDPLVFPSEDFDASISQÖVNEKINQSLAFIRRSDELLHNVTGKSTTNIM₅₂₆

T-cell leukemia virus₄₀₀ CCFLNITNSHVSILQÖERPPIENRVLLTGWGL₄₂₉

Marburg virus₆₁₃ IEDLSRNISEQÖIDQIKKDEQ₆₃₂

FIGURE 4A

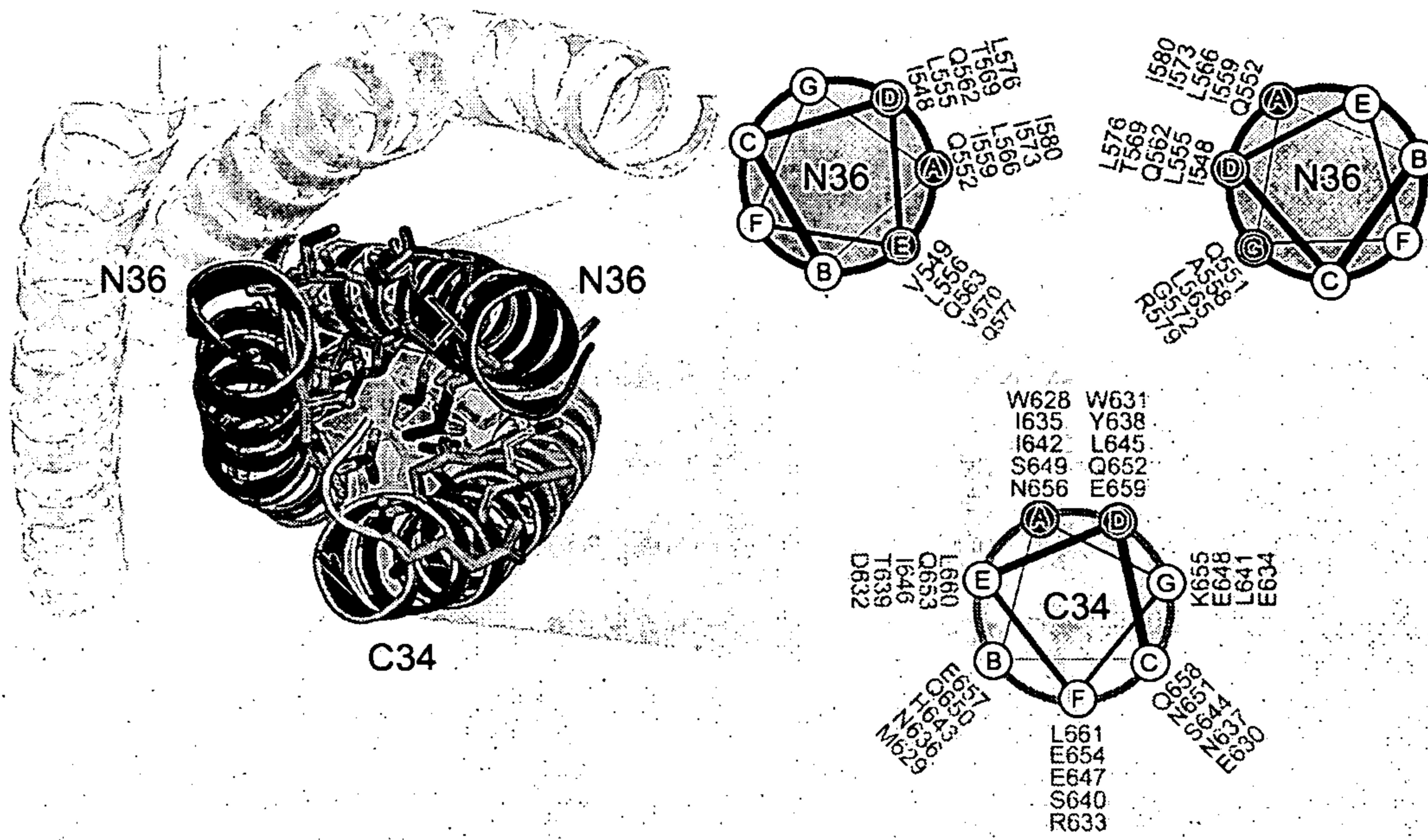


FIGURE 4B

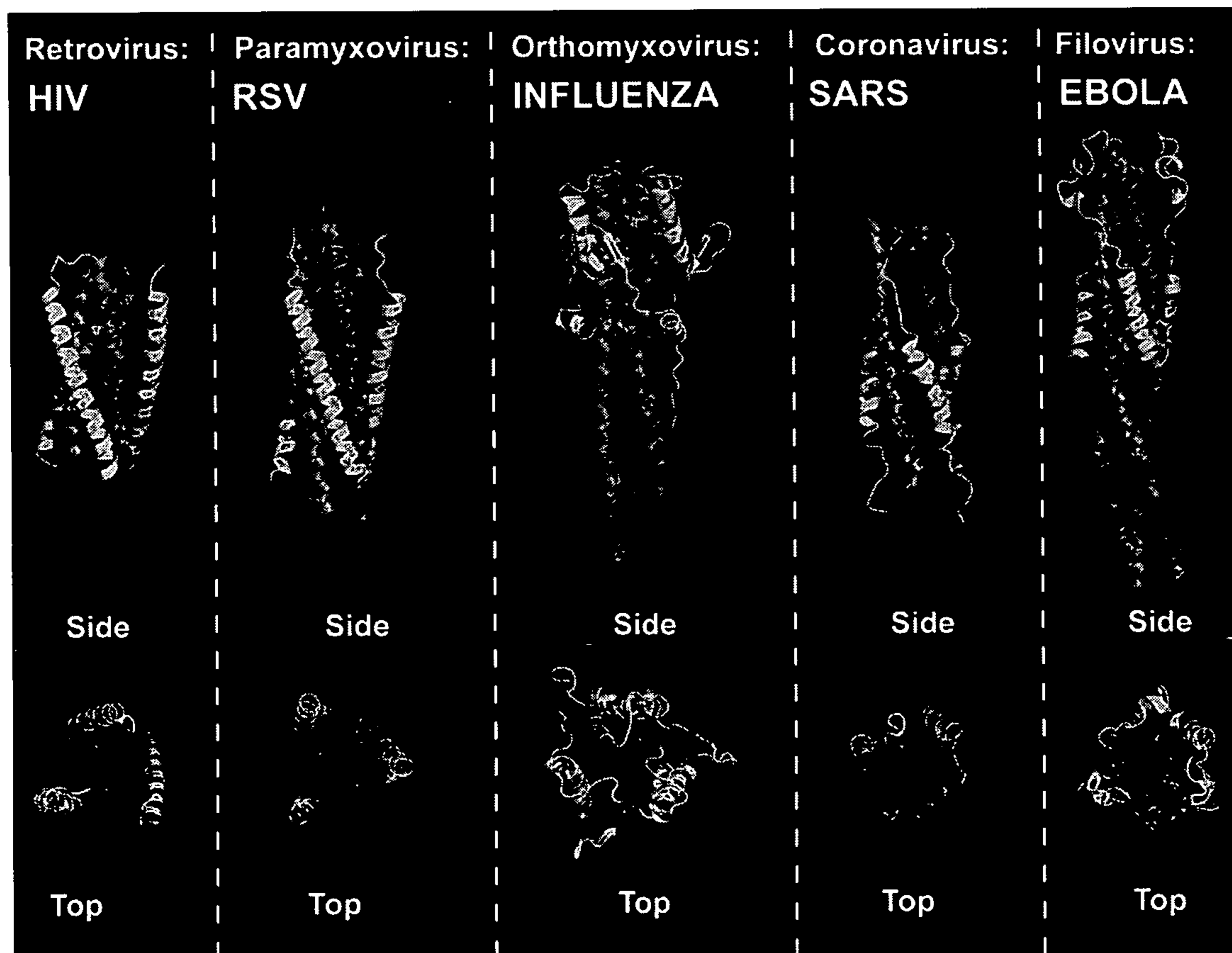


FIGURE 5A (1)

YTS
YTSL
YTSLI
YTSLIH
YTSLIHS
YTSLIHSL
YTSLIHSLI
YTSLIHSLIE
YTSLIHSLIEE
YTSLIHSLIEES
YTSLIHSLIEESQ
YTSLIHSLIEESQN
YTSLIHSLIEESQNNQ
YTSLIHSLIEESQNNQQ
YTSLIHSLIEESQNNQQE
YTSLIHSLIEESQNNQQEK
YTSLIHSLIEESQNNQQEKN
YTSLIHSLIEESQNNQQEKNE
YTSLIHSLIEESQNNQQEKNEQ
YTSLIHSLIEESQNNQQEKNEQE
YTSLIHSLIEESQNNQQEKNEQEL
YTSLIHSLIEESQNNQQEKNEQELL
YTSLIHSLIEESQNNQQEKNEQELLE
YTSLIHSLIEESQNNQQEKNEQELLEL
YTSLIHSLIEESQNNQQEKNEQELLELD
YTSLIHSLIEESQNNQQEKNEQELLELDK
YTSLIHSLIEESQNNQQEKNEQELLELDKW
YTSLIHSLIEESQNNQQEKNEQELLELDKWA
YTSLIHSLIEESQNNQQEKNEQELLELDKWAS
YTSLIHSLIEESQNNQQEKNEQELLELDKWASL
YTSLIHSLIEESQNNQQEKNEQELLELDKWASLW
YTSLIHSLIEESQNNQQEKNEQELLELDKWASLWN
YTSLIHSLIEESQNNQQEKNEQELLELDKWASLWNW
YTSLIHSLIEESQNNQQEKNEQELLELDKWASLWNWF

FIGURE 5A (2)

MTW
MTWM
MTWME
MTWMEW
MTWMEWD
MTWMEWDR
MTWMEWDRE
MTWMEWDREI
MTWMEWDREIN
MTWMEWDREINN
MTWMEWDREINNY
MTWMEWDREINNYT
MTWMEWDREINNYTS
MTWMEWDREINNYTSL
MTWMEWDREINNYTSLI
MTWMEWDREINNYTSLIH
MTWMEWDREINNYTSLIHS
MTWMEWDREINNYTSLIHSL
MTWMEWDREINNYTSLIHSLI
MTWMEWDREINNYTSLIHSLIE
MTWMEWDREINNYTSLIHSLIEE
MTWMEWDREINNYTSLIHSLIEES
MTWMEWDREINNYTSLIHSLIEESQ
MTWMEWDREINNYTSLIHSLIEESQN
MTWMEWDREINNYTSLIHSLIEESQNQ
MTWMEWDREINNYTSLIHSLIEESQNQQ
MTWMEWDREINNYTSLIHSLIEESQNQQE
MTWMEWDREINNYTSLIHSLIEESQNQQEK
MTWMEWDREINNYTSLIHSLIEESQNQQEKN
MTWMEWDREINNYTSLIHSLIEESQNQQEKNE
MTWMEWDREINNYTSLIHSLIEESQNQQEKNEQ
MTWMEWDREINNYTSLIHSLIEESQNQQEKNEQE
MTWMEWDREINNYTSLIHSLIEESQNQQEKNEQEL
MTWMEWDREINNYTSLIHSLIEESQNQQEKNEQELL

FIGURE 5A (3)

YTH
YTHI
YTHII
YTHIIY
YTHIIYS
YTHIIYSL
YTHIIYSLI
YTHIIYSLIE
YTHIIYSLIEQ
YTHIIYSLIEQS
YTHIIYSLIEQSQ
YTHIIYSLIEQSQN
YTHIIYSLIEQSQNQ
YTHIIYSLIEQSQNQQ
YTHIIYSLIEQSQNQQE
YTHIIYSLIEQSQNQQEK
YTHIIYSLIEQSQNQQEK
YTHIIYSLIEQSQNQQEKNE
YTHIIYSLIEQSQNQQEKNEQ
YTHIIYSLIEQSQNQQEKNEQE
YTHIIYSLIEQSQNQQEKNEQEL
YTHIIYSLIEQSQNQQEKNEQELL
YTHIIYSLIEQSQNQQEKNEQELLA
YTHIIYSLIEQSQNQQEKNEQELLAL
YTHIIYSLIEQSQNQQEKNEQELLALD
YTHIIYSLIEQSQNQQEKNEQELLALDK
YTHIIYSLIEQSQNQQEKNEQELLALDKW
YTHIIYSLIEQSQNQQEKNEQELLALDKWA
YTHIIYSLIEQSQNQQEKNEQELLALDKWAS
YTHIIYSLIEQSQNQQEKNEQELLALDKWASL
YTHIIYSLIEQSQNQQEKNEQELLALDKWASLW
YTHIIYSLIEQSQNQQEKNEQELLALDKWASLWN
YTHIIYSLIEQSQNQQEKNEQELLALDKWASLWNW
YTHIIYSLIEQSQNQQEKNEQELLALDKWASLWNWF

FIGURE 5A (4)

MTM
MTMK
MTMKW
MTMKWE
MTMKWER
MTMKWERE
MTMKWEREI
MTMKWEREID
MTMKWEREIDN
MTMKWEREIDNY
MTMKWEREIDNYT
MTMKWEREIDNYTH
MTMKWEREIDNYTHI
MTMKWEREIDNYTHII
MTMKWEREIDNYTHIIY
MTMKWEREIDNYTHIIYS
MTMKWEREIDNYTHIIYSL
MTMKWEREIDNYTHIIYSLI
MTMKWEREIDNYTHIIYSLIE
MTMKWEREIDNYTHIIYSLIEQ
MTMKWEREIDNYTHIIYSLIEQS
MTMKWEREIDNYTHIIYSLIEQSQ
MTMKWEREIDNYTHIIYSLIEQSQN
MTMKWEREIDNYTHIIYSLIEQSQNQ
MTMKWEREIDNYTHIIYSLIEQSQNQQ
MTMKWEREIDNYTHIIYSLIEQSQNQQE
MTMKWEREIDNYTHIIYSLIEQSQNQQEK
MTMKWEREIDNYTHIIYSLIEQSQNQQEK
MTMKWEREIDNYTHIIYSLIEQSQNQQEKNE
MTMKWEREIDNYTHIIYSLIEQSQNQQEKNEQ
MTMKWEREIDNYTHIIYSLIEQSQNQQEKNEQE
MTMKWEREIDNYTHIIYSLIEQSQNQQEKNEQEL
MTMKWEREIDNYTHIIYSLIEQSQNQQEKNEQELL
MTMKWEREIDNYTHIIYSLIEQSQNQQEKNEQELLA

FIGURE 5B (1)

NWF
WNWF
LWNWF
SLWNWF
ASLWNWF
WASLWNWF
KWASLWNWF
DKWASLWNWF
LDKWASLWNWF
ELDKWASLWNWF
LELDKWASLWNWF
LLELDKWASLWNWF
ELLELDKWASLWNWF
QELLELDKWASLWNWF
EQELLELDKWASLWNWF
NEQELLELDKWASLWNWF
KNEQELLELDKWASLWNWF
EKNEQELLELDKWASLWNWF
QEKNEQELLELDKWASLWNWF
QQEKNEQELLELDKWASLWNWF
NQQEKNEQELLELDKWASLWNWF
QNQQEKNEQELLELDKWASLWNWF
SQNQQEKNEQELLELDKWASLWNWF
ESQNQQEKNEQELLELDKWASLWNWF
EESQNQQEKNEQELLELDKWASLWNWF
IEESQNQQEKNEQELLELDKWASLWNWF
LIEESQNQQEKNEQELLELDKWASLWNWF
SLIEESQNQQEKNEQELLELDKWASLWNWF
HSLIEESQNQQEKNEQELLELDKWASLWNWF
IHSLIEESQNQQEKNEQELLELDKWASLWNWF
LIHSLIEESQNQQEKNEQELLELDKWASLWNWF
SLIHSLIEESQNQQEKNEQELLELDKWASLWNWF
TSLIHSLIEESQNQQEKNEQELLELDKWASLWNWF
YTSLIHSLIEESQNQQEKNEQELLELDKWASLWNWF

FIGURE 5B (2)

LLE
ELLE
QELLE
EQELLE
NEQELLE
KNEQELLE
EKNEQELLE
QEKNEQELLE
QQEKNEQELLE
NQQEKNEQELLE
QNQQEKNEQELLE
SQNQQEKNEQELLE
ESQNQQEKNEQELLE
EESQNQQEKNEQELLE
IEESQNQQEKNEQELLE
LIEESQNQQEKNEQELLE
SLIEESQNQQEKNEQELLE
HSLIEESQNQQEKNEQELLE
IHSLIEESQNQQEKNEQELLE
LIHSLIEESQNQQEKNEQELLE
SLIHSLIEESQNQQEKNEQELLE
TSLIHSLIEESQNQQEKNEQELLE
YTSLIHSLIEESQNQQEKNEQELLE
NYTSLIHSLIEESQNQQEKNEQELLE
NNYTSLIHSLIEESQNQQEKNEQELLE
INNYTSLIHSLIEESQNQQEKNEQELLE
EINNYTSLIHSLIEESQNQQEKNEQELLE
REINNYTSLIHSLIEESQNQQEKNEQELLE
DREINNYTSLIHSLIEESQNQQEKNEQELLE
WDREINNYTSLIHSLIEESQNQQEKNEQELLE
EWDREINNYTSLIHSLIEESQNQQEKNEQELLE
MEWDREINNYTSLIHSLIEESQNQQEKNEQELLE
WMEWDREINNYTSLIHSLIEESQNQQEKNEQELLE
TWMEWDREINNYTSLIHSLIEESQNQQEKNEQELLE
MTWMEWDREINNYTSLIHSLIEESQNQQEKNEQELLE

FIGURE 5B (3)

NWF
WNWF
LWNWF
SLWNWF
ASLWNWF
WASLWNWF
KASLWNWF
DKASLWNWF
LDKASLWNWF
ALDKASLWNWF
LALDKASLWNWF
LLALDKASLWNWF
ELLALDKASLWNWF
QELLALDKASLWNWF
EQELLALDKASLWNWF
NEQELLALDKASLWNWF
KNEQELLALDKASLWNWF
EKNEQELLALDKASLWNWF
QEKNEQELLALDKASLWNWF
QQEKNEQELLALDKASLWNWF
NQQEKNEQELLALDKASLWNWF
QNQQEKNEQELLALDKASLWNWF
SQNQQEKNEQELLALDKASLWNWF
EQSQNQQEKNEQELLALDKASLWNWF
IEQSQNQQEKNEQELLALDKASLWNWF
LIEQSQNQQEKNEQELLALDKASLWNWF
SLIEQSQNQQEKNEQELLALDKASLWNWF
YSLIEQSQNQQEKNEQELLALDKASLWNWF
IYSLIEQSQNQQEKNEQELLALDKASLWNWF
HIIYSLIEQSQNQQEKNEQELLALDKASLWNWF
THIIYSLIEQSQNQQEKNEQELLALDKASLWNWF
YTHIIYSLIEQSQNQQEKNEQELLALDKASLWNWF

FIGURE 5B (4)

LLA
ELLA
QELLA
EQELLA
NEQELLA
KNEQELLA
EKNEQELLA
QEKNEQELLA
QQEKNEQELLA
NQQEKNEQELLA
QNQQEKNEQELLA
SQNQQEKNEQELLA
QSQNQQEKNEQELLA
EQSQNQQEKNEQELLA
IEQSQNQQEKNEQELLA
LIEQSQNQQEKNEQELLA
SLIEQSQNQQEKNEQELLA
YSLIEQSQNQQEKNEQELLA
IYSLIEQSQNQQEKNEQELLA
IIYSLIEQSQNQQEKNEQELLA
HIIYSLIEQSQNQQEKNEQELLA
THIIYSLIEQSQNQQEKNEQELLA
YTHIIYSLIEQSQNQQEKNEQELLA
NYTHIIYSLIEQSQNQQEKNEQELLA
DNYTHIIYSLIEQSQNQQEKNEQELLA
IDNYTHIIYSLIEQSQNQQEKNEQELLA
EIDNYTHIIYSLIEQSQNQQEKNEQELLA
REIDNYTHIIYSLIEQSQNQQEKNEQELLA
EREIDNYTHIIYSLIEQSQNQQEKNEQELLA
WEREIDNYTHIIYSLIEQSQNQQEKNEQELLA
KWEREIDNYTHIIYSLIEQSQNQQEKNEQELLA
MKWEREIDNYTHIIYSLIEQSQNQQEKNEQELLA
TMKWEREIDNYTHIIYSLIEQSQNQQEKNEQELLA
MTMKWEREIDNYTHIIYSLIEQSQNQQEKNEQELLA

FIGURE 6 (1)

SQNQQEKNEQELLE
SQNQQEKNEQELLEL
ESQNQQEKNEQELLEL
ESQNQQEKNEQELLELD
EESQNQQEKNEQELLELD
EESQNQQEKNEQELLELDK
IEESQNQQEKNEQELLELDK
IEESQNQQEKNEQELLELDKW
LIEESQNQQEKNEQELLELDKW
LIEESQNQQEKNEQELLELDKWA
SLIEESQNQQEKNEQELLELDKWA
SLIEESQNQQEKNEQELLELDKWA
HSLIEESQNQQEKNEQELLELDKWA
HSLIEESQNQQEKNEQELLELDKWA
IHSLIEESQNQQEKNEQELLELDKWA
IHSLIEESQNQQEKNEQELLELDKWA
LIHSLIEESQNQQEKNEQELLELDKWA
LIHSLIEESQNQQEKNEQELLELDKWA
SLIHSLIEESQNQQEKNEQELLELDKWA
SLIHSLIEESQNQQEKNEQELLELDKWA
TSLIHSLIEESQNQQEKNEQELLELDKWA
TSLIHSLIEESQNQQEKNEQELLELDKWA
YTSLIHSLIEESQNQQEKNEQELLELDKWA

FIGURE 6 (2)

NYTSLIHSLIEESQN
NYTSLIHSLIEESQNO
NNYTSLIHSLIEESQNO
NNYTSLIHSLIEESQNOQ
INNYTSLIHSLIEESQNOQ
INNYTSLIHSLIEESQNOQE
EINNYTSLIHSLIEESQNOQE
EINNYTSLIHSLIEESQNOQEK
REINNYTSLIHSLIEESQNOQEK
REINNYTSLIHSLIEESQNOQEK
DREINNYTSLIHSLIEESQNOQEK
DREINNYTSLIHSLIEESQNOQEKNE
WDREINNYTSLIHSLIEESQNOQEKNE
WDREINNYTSLIHSLIEESQNOQEKNEQ
EWDREINNYTSLIHSLIEESQNOQEKNEQ
EWDREINNYTSLIHSLIEESQNOQEKNEQE
MEWDREINNYTSLIHSLIEESQNOQEKNEQE
MEWDREINNYTSLIHSLIEESQNOQEKNEQEL
WMEWDREINNYTSLIHSLIEESQNOQEKNEQEL
WMEWDREINNYTSLIHSLIEESQNOQEKNEQELL
TWMEWDREINNYTSLIHSLIEESQNOQEKNEQELLE
MTWMEWDREINNYTSLIHSLIEESQNOQEKNEQELLE

FIGURE 6 (3)

SONQQEKNEQELLA
SONQQEKNEQELLAL
QSONQQEKNEQELLAL
QSONQQEKNEQELLALD
EQSONQQEKNEQELLALD
EQSONQQEKNEQELLALDK
IEQSONQQEKNEQELLALDK
IEQSONQQEKNEQELLALDKW
LIEQSONQQEKNEQELLALDKW
LIEQSONQQEKNEQELLALDKWA
SLIEQSONQQEKNEQELLALDKWA
SLIEQSONQQEKNEQELLALDKWAS
YSLIEQSONQQEKNEQELLALDKWAS
YSLIEQSONQQEKNEQELLALDKWASL
IYSLIEQSONQQEKNEQELLALDKWASL
IYSLIEQSONQQEKNEQELLALDKWASLW
IIYSLIEQSONQQEKNEQELLALDKWASLW
HIIYSLIEQSONQQEKNEQELLALDKWASLWN
HIIYSLIEQSONQQEKNEQELLALDKWASLWNW
THIIYSLIEQSONQQEKNEQELLALDKWASLWNW
THIIYSLIEQSONQQEKNEQELLALDKWASLWNWF
YTHIIYSLIEQSONQQEKNEQELLALDKWASLWNWF

FIGURE 6 (4)

NYTHIIYSLIEQSQN
 NYTHIIYSLIEQSQNQ
 DNYTHIIYSLIEQSQNQ
 DNYTHIIYSLIEQSQNQQ
 IDNYTHIIYSLIEQSQNQQ
 IDNYTHIIYSLIEQSQNQQE
 EIDNYTHIIYSLIEQSQNQQE
 EIDNYTHIIYSLIEQSQNQQEKN
 REIDNYTHIIYSLIEQSQNQQEKN
 REIDNYTHIIYSLIEQSQNQQEKN
 EREIDNYTHIIYSLIEQSQNQQEKN
 EREIDNYTHIIYSLIEQSQNQQEKN
 WEREIDNYTHIIYSLIEQSQNQQEKN
 WEREIDNYTHIIYSLIEQSQNQQEKN
 KWEREIDNYTHIIYSLIEQSQNQQEKN
 KWEREIDNYTHIIYSLIEQSQNQQEKN
 MKWEREIDNYTHIIYSLIEQSQNQQEKN
 MKWEREIDNYTHIIYSLIEQSQNQQEKN
 TMKWEREIDNYTHIIYSLIEQSQNQQEKN
 TMKWEREIDNYTHIIYSLIEQSQNQQEKN
 MTMKWEREIDNYTHIIYSLIEQSQNQQEKN

FIGURE 7

gp41₍₆₂₆₋₆₄₅₎ BTWBEWDREINNYTSLIHSL
 SAH-gp41₍₆₂₆₋₆₄₅₎(A) BTW~~E~~W~~D~~EINNYTSLIHSL

FIGURE 8

WQEWERKVDLFLEENITALLEEAAQIQQEK

SIV

HX strain of gp160:

YTSLIHSLIEESQNQQEKNEQELLELDKWASLWNWF HIV(T20)
 MTWMEWDREINNYTSLIHSLIEESQNQQEKNEQELLE
 HIV(T649)

YU2 strain of gp160:

YTHIIYSLIEQSQNQQEKNEQELLALDKWASLWNWF HIV(T20)
 MTMKWEREIDNYTHIIYSLIEQSQNQQEKNEQELLA HIV(T649)

Chimera	WQEWEQKITALLEQAQIQQEKNEYELQKLDKWASLWEWF (T1249)
T20	-----I--LLE--Q-QQEKNE-EL--LDKWASLW-WF
T649	W-EW---I-----
SIV	WQEWE-K-----

FIGURE 9A (heptad repeat domain)

--abcdefgabcdefgabcdefgabcdefgabcdefg

FIGURE 9B HIV gp41 (626-663)

MTWMEWDREINNYTSLIHSLIEESQNQQEKNEQELLEL

FIGURE 9C (heptad position a, d)

--W--W---I--Y---I--L---S--Q---N--E---L

(residues as per Dwyer et al. *PNAS*, 104: 12772, 2007)**FIGURE 9D**

-TW--WDR-I--Y---I--LI---Q--QEK-E--L-EL

17/34

FIGURE 10A

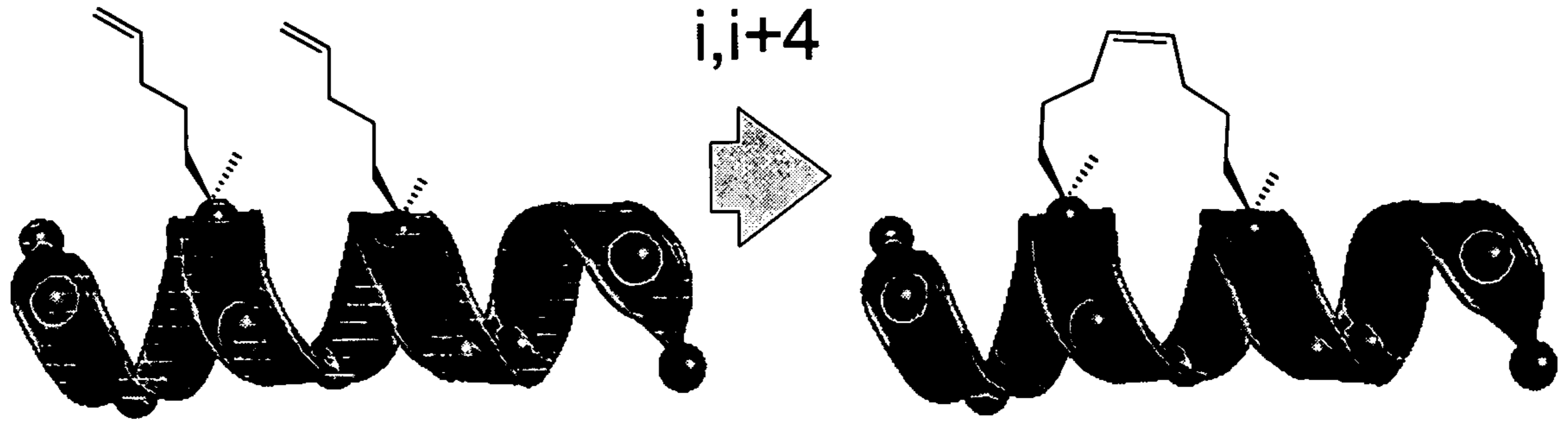


FIGURE 10B

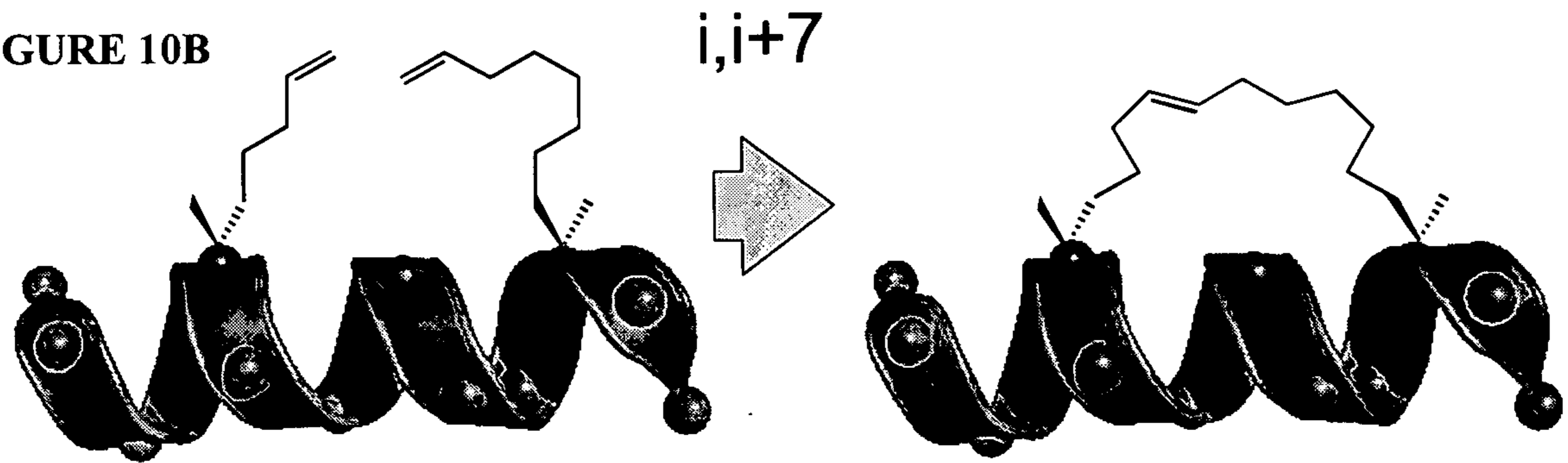
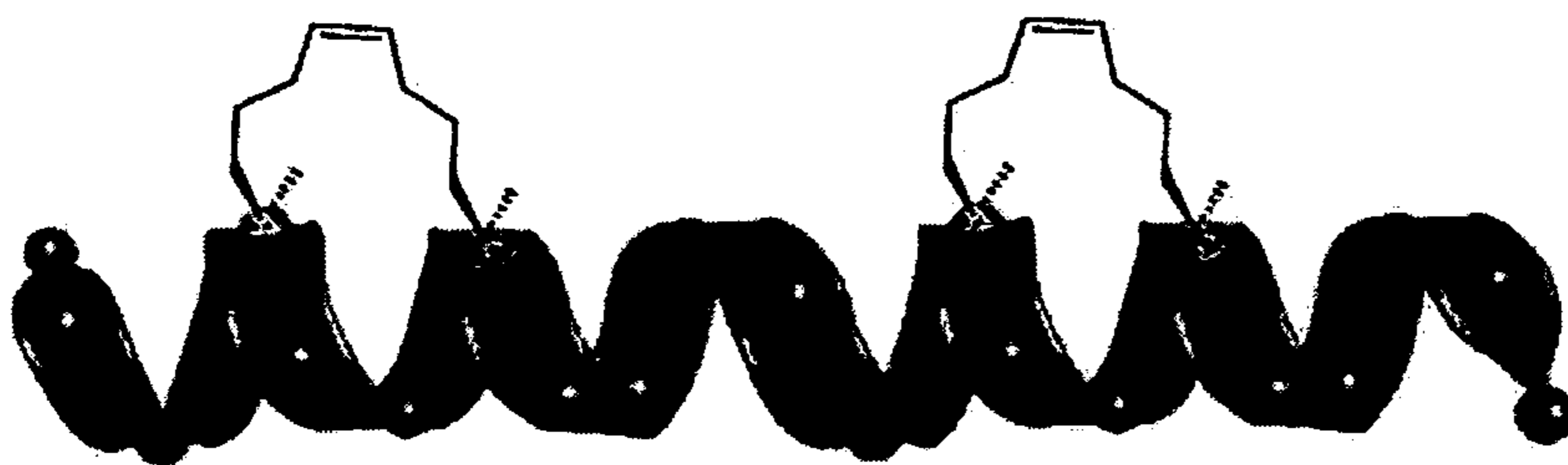
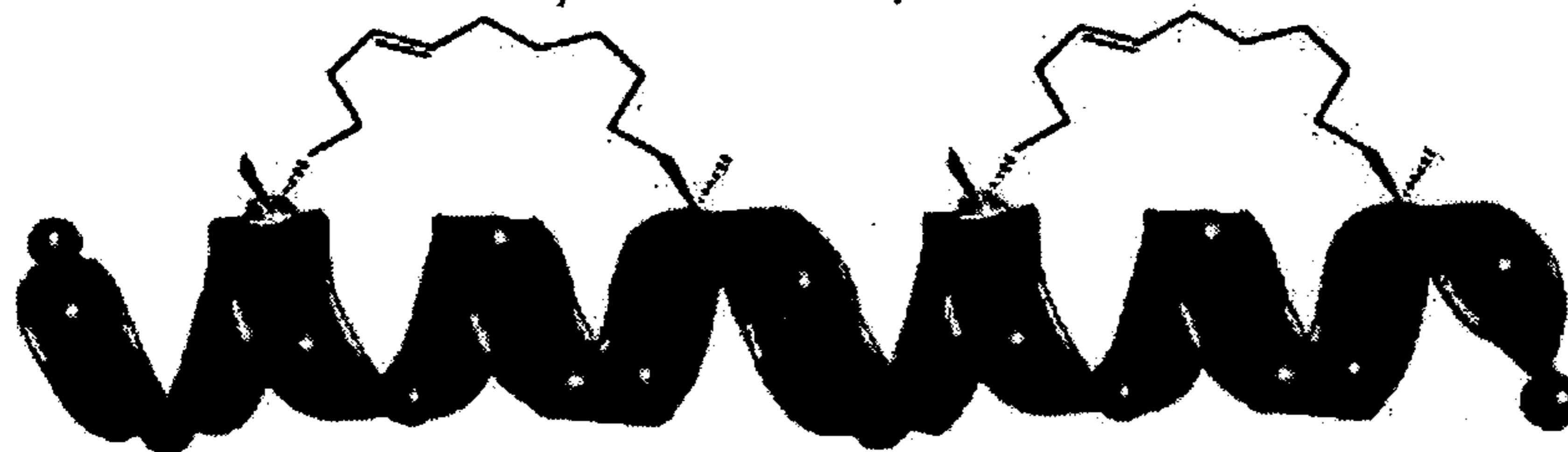


FIGURE 10C

$i, i+4$ and $i, i+4$



$i, i+7$ and $i, i+7$



$i, i+4$ and $i, i+7$

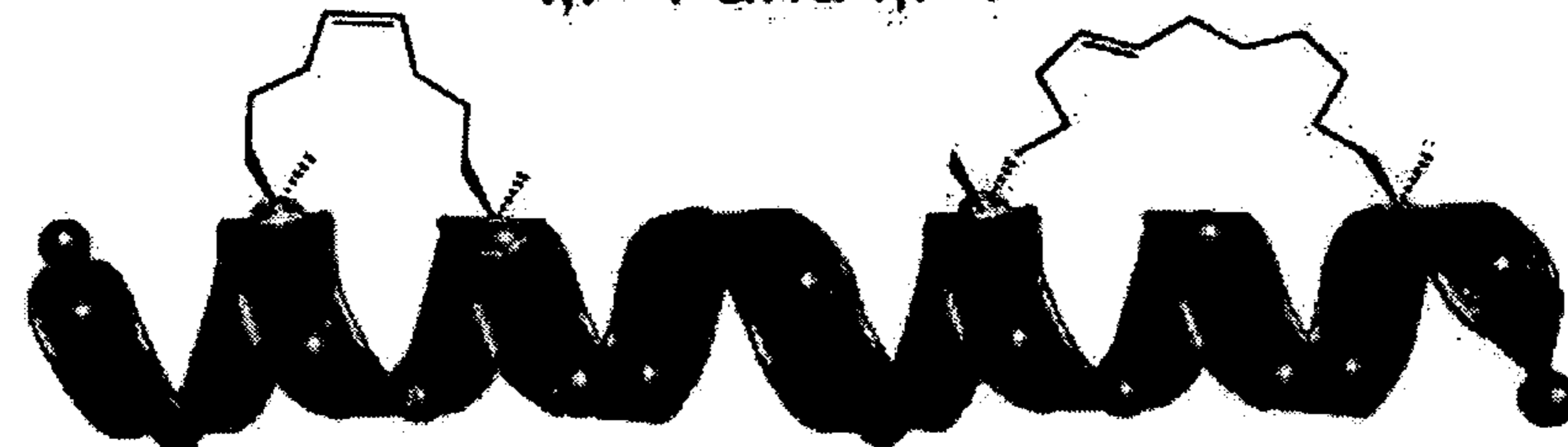


FIGURE 10D

$i, i+4$ and $i, i+4$ and $i, i+4$

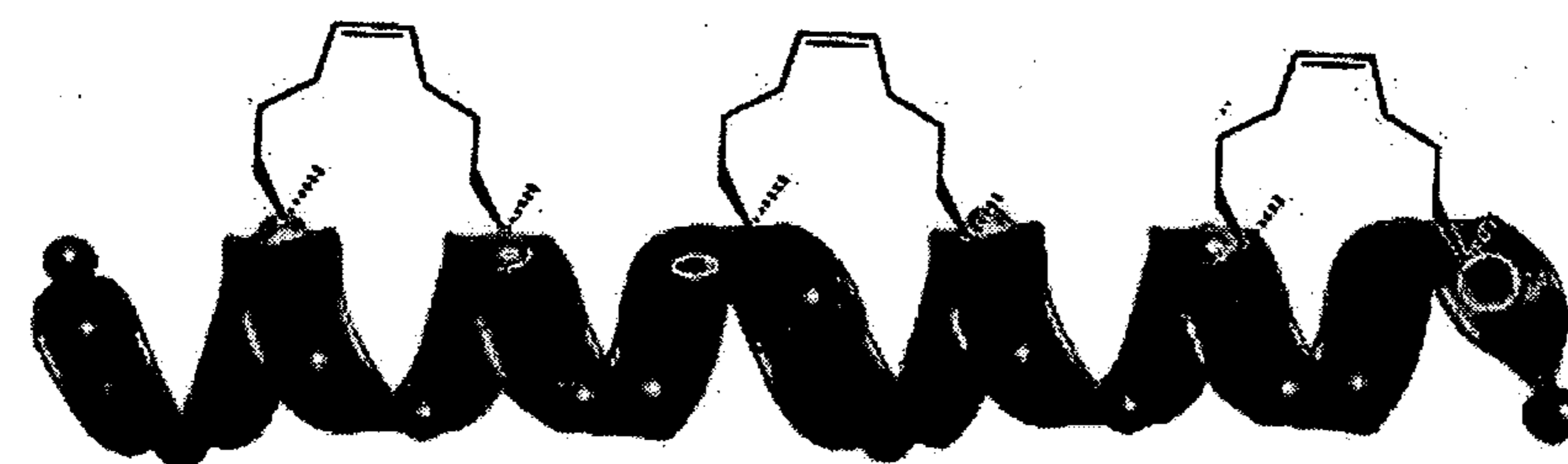
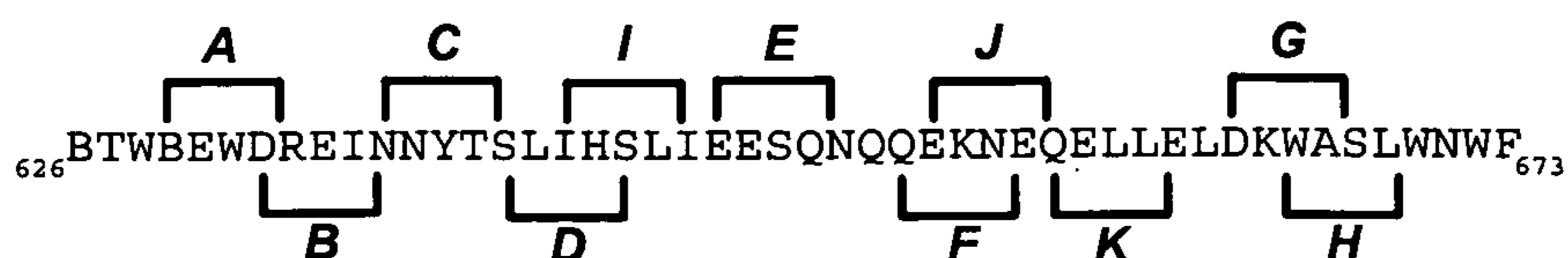


FIGURE 11



FIGURE 12



BTWBEWDREINNYTSLIHSLIEESQNQQEKNEQELLE
 BTWXEWDXEINNYTSLIHSLIEESQNQXEKNXQELLE
 BTWBEWXREIXNYTSLIHSLIEESQNQXEKNXQELLE
 BTWBEWDREIXNYTXLIHSLIEESQNQXEKNXQELLE
 BTWBEWDREINNYTXLIHXLIEESQNQXEKNXQELLE
 BTWXEWDXEINNYTSLIHSLIXESQQEKNEQELLE
 BTWXEWDXEINNYTXLIHXLIEESQNQXEKNXQELLE

gp41₍₆₂₆₋₆₆₂₎
 SAH-gp41₍₆₂₆₋₆₆₂₎(A, F)
 SAH-gp41₍₆₂₆₋₆₆₂₎(B, F)
 SAH-gp41₍₆₂₆₋₆₆₂₎(C, F)
 SAH-gp41₍₆₂₆₋₆₆₂₎(D, F)
 SAH-gp41₍₆₂₆₋₆₆₂₎(A, E)
 SAH-gp41₍₆₂₆₋₆₆₂₎(A, D, F)

YTSLIHSLIEESQNQQEKNEQELLELDKWASLWNWF
 YTXLIHXLIEESQNQQEKNEQELLELDKXASLXNWF
 YTXLIHXLIEESQNQQEKNEQELLELXKWAXLWNWF
 YTSLIHSLIEESQNQXEKNXQELLELDKXASLXNWF
 YTXLIHXLIEESQNQXEKNXQELLELDKWASLWNWF
 YTSLIHSLIXESQQEKNEQELLELXKWAXLWNWF
 YTSLIHSLIXESQQEKNEXELLXLDKWASLWNWF
 YTXLIHXLIEESQNQXEKNXQELLELXKWAXLWNWF

gp41₍₆₃₈₋₆₇₃₎
 SAH-gp41₍₆₃₈₋₆₇₃₎(D, H)
 SAH-gp41₍₆₃₈₋₆₇₃₎(D, G)
 SAH-gp41₍₆₃₈₋₆₇₃₎(F, H)
 SAH-gp41₍₆₃₈₋₆₇₃₎(D, F)
 SAH-gp41₍₆₃₈₋₆₇₃₎(E, G)
 SAH-gp41₍₆₃₈₋₆₇₃₎(E, K)
 SAH-gp41₍₆₃₈₋₆₇₃₎(D, F, G)

BTWBXWDRXINNYTSLIHSLIEESQNQQEKNEQELLE
 BTWBEWDREINNYTSLIHSLIEESQNXQEKXEQELLE
 BTWBXWDRXINNYTSLIHSLIEESQNQXEKNXQELLE
 BTWBXWDRXINNYTSLIHSLIEESQNXQEKXEQELLE

SAH-gp41₍₆₂₆₋₆₆₂₎(A')
 SAH-gp41₍₆₂₆₋₆₆₂₎(F')
 SAH-gp41₍₆₂₆₋₆₆₂₎(A', F)
 SAH-gp41₍₆₂₆₋₆₆₂₎(A', F')

FIGURE 13

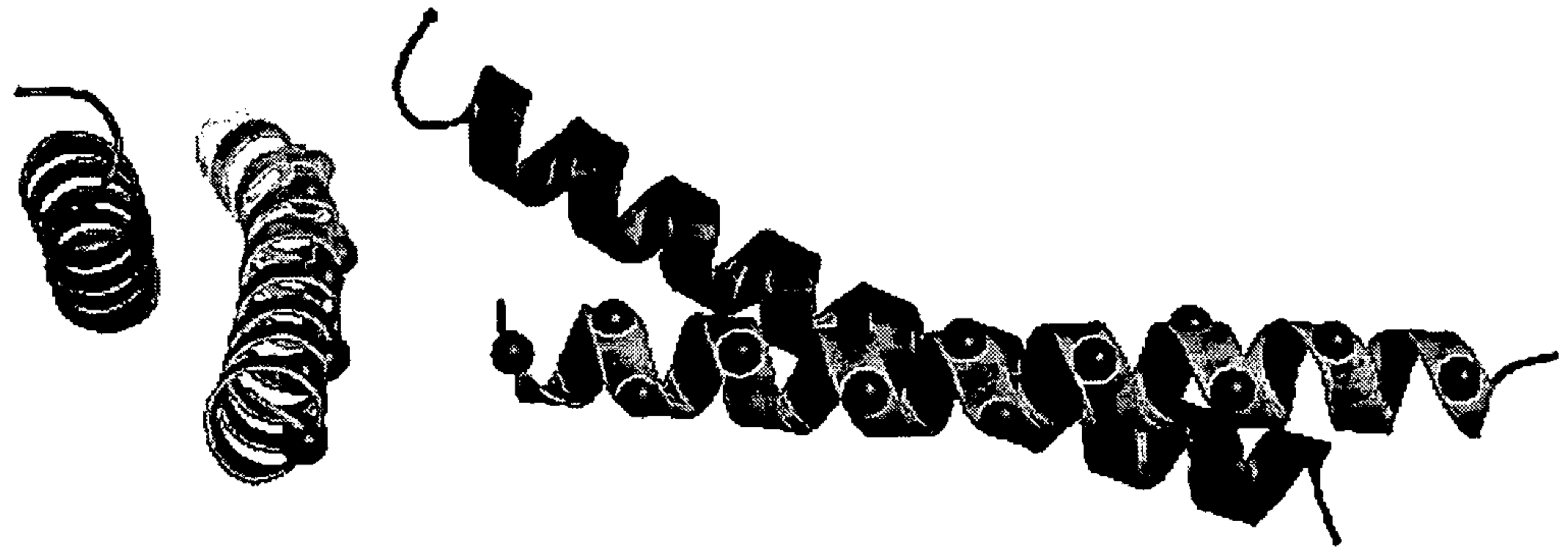
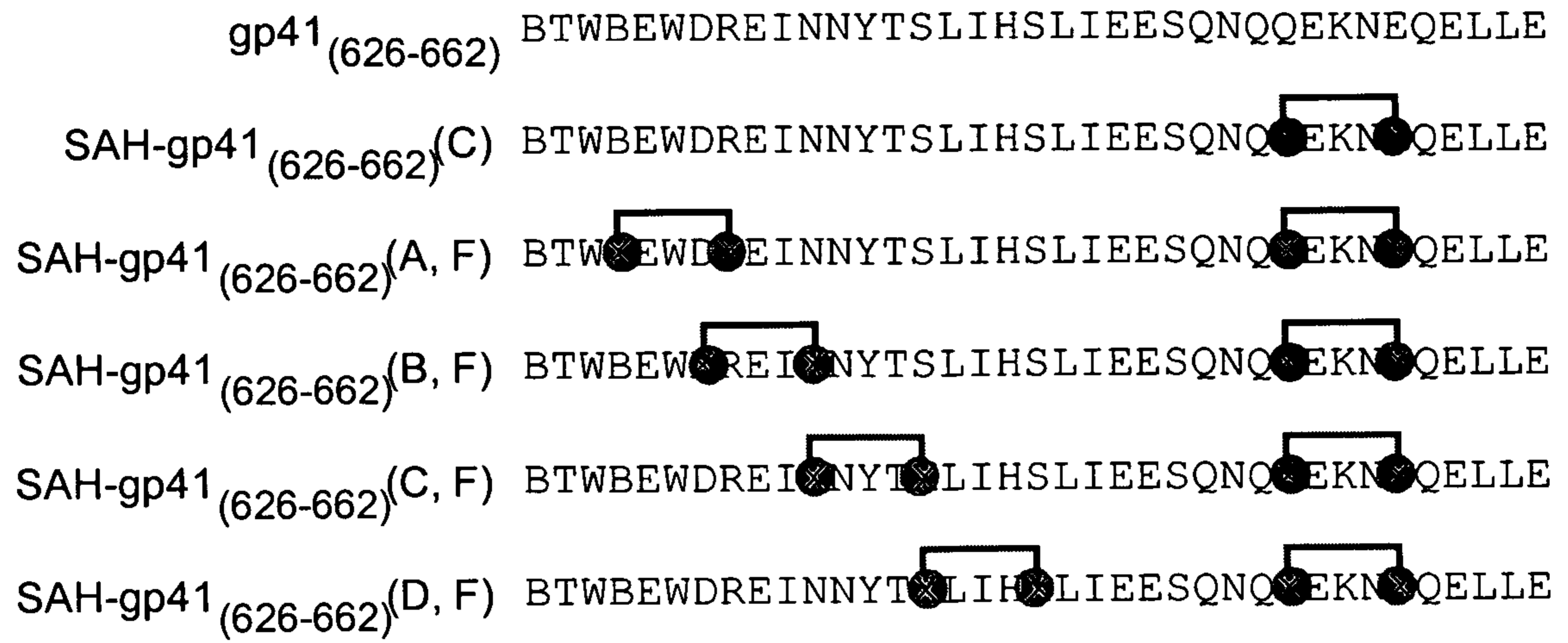


FIGURE 14A

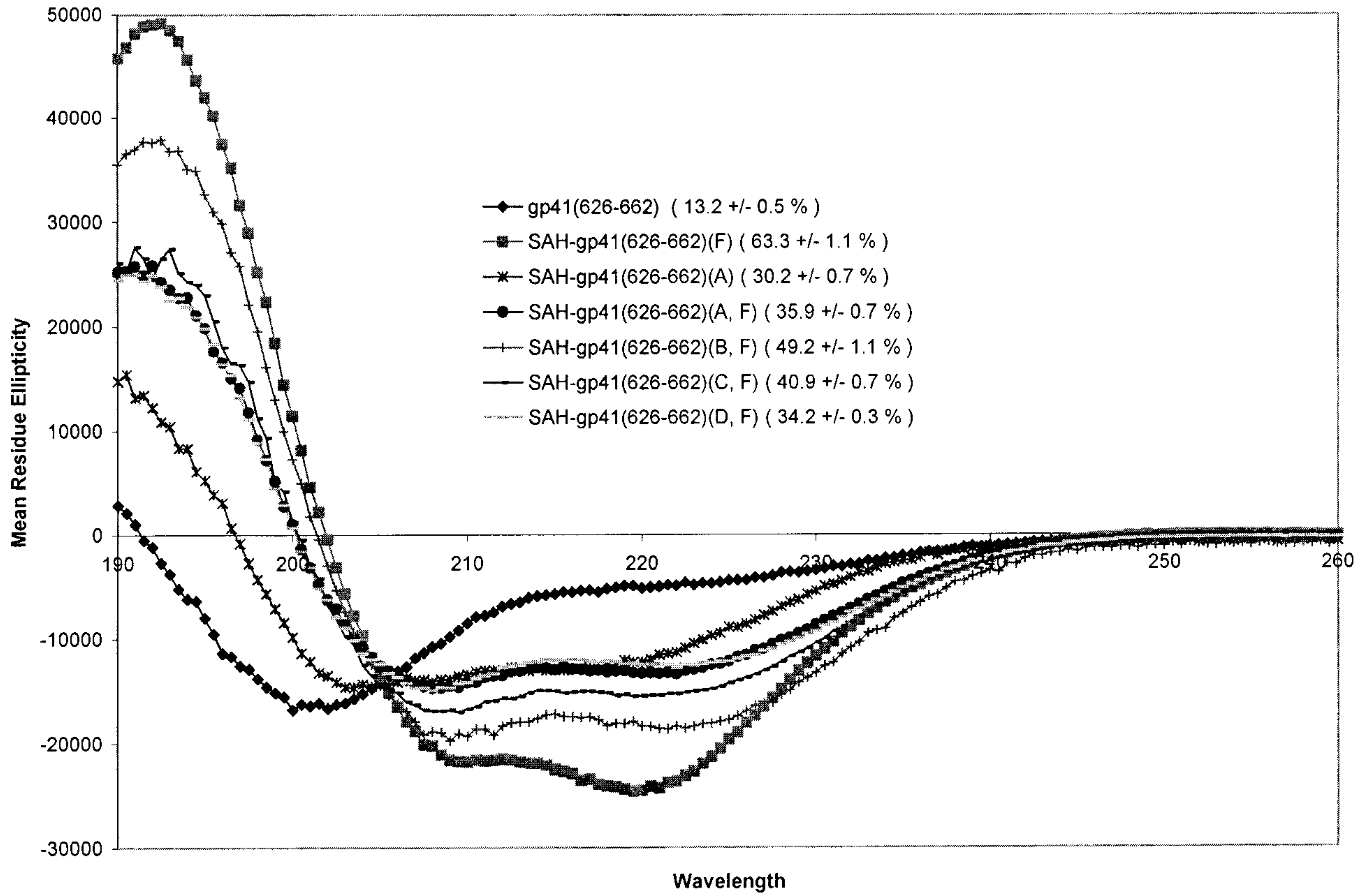


FIGURE 14B

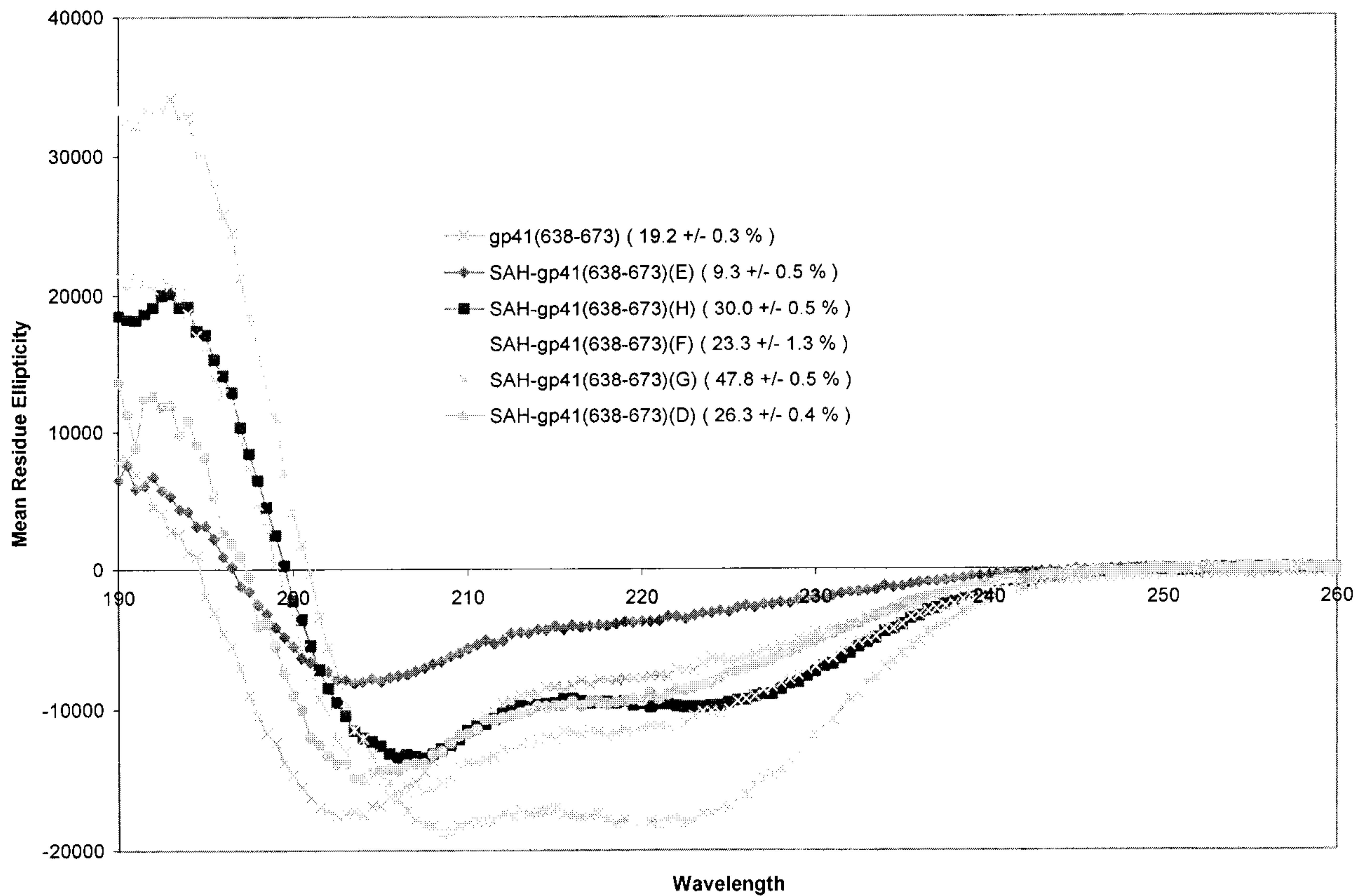


FIGURE 14C

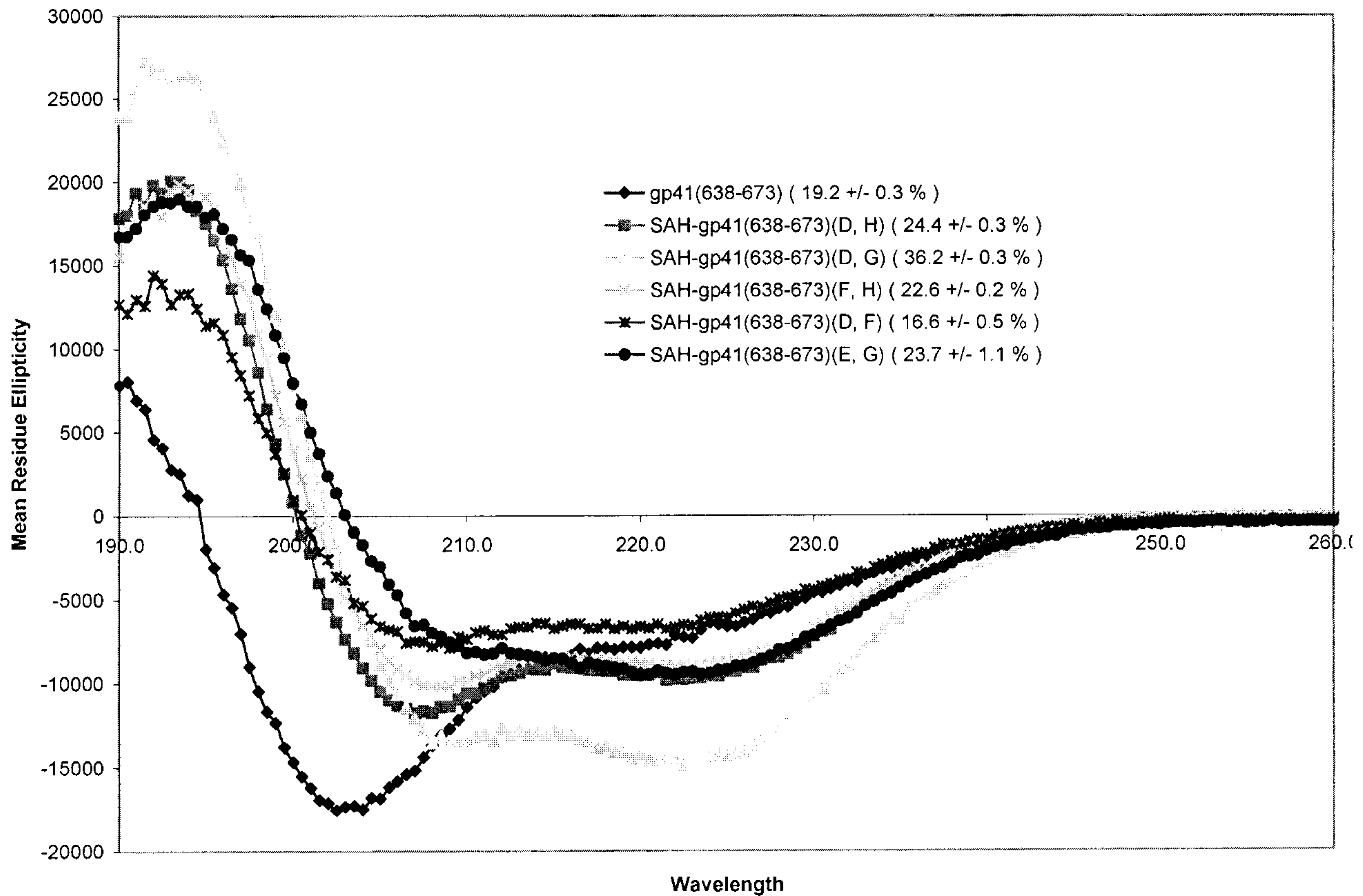


FIGURE 14D

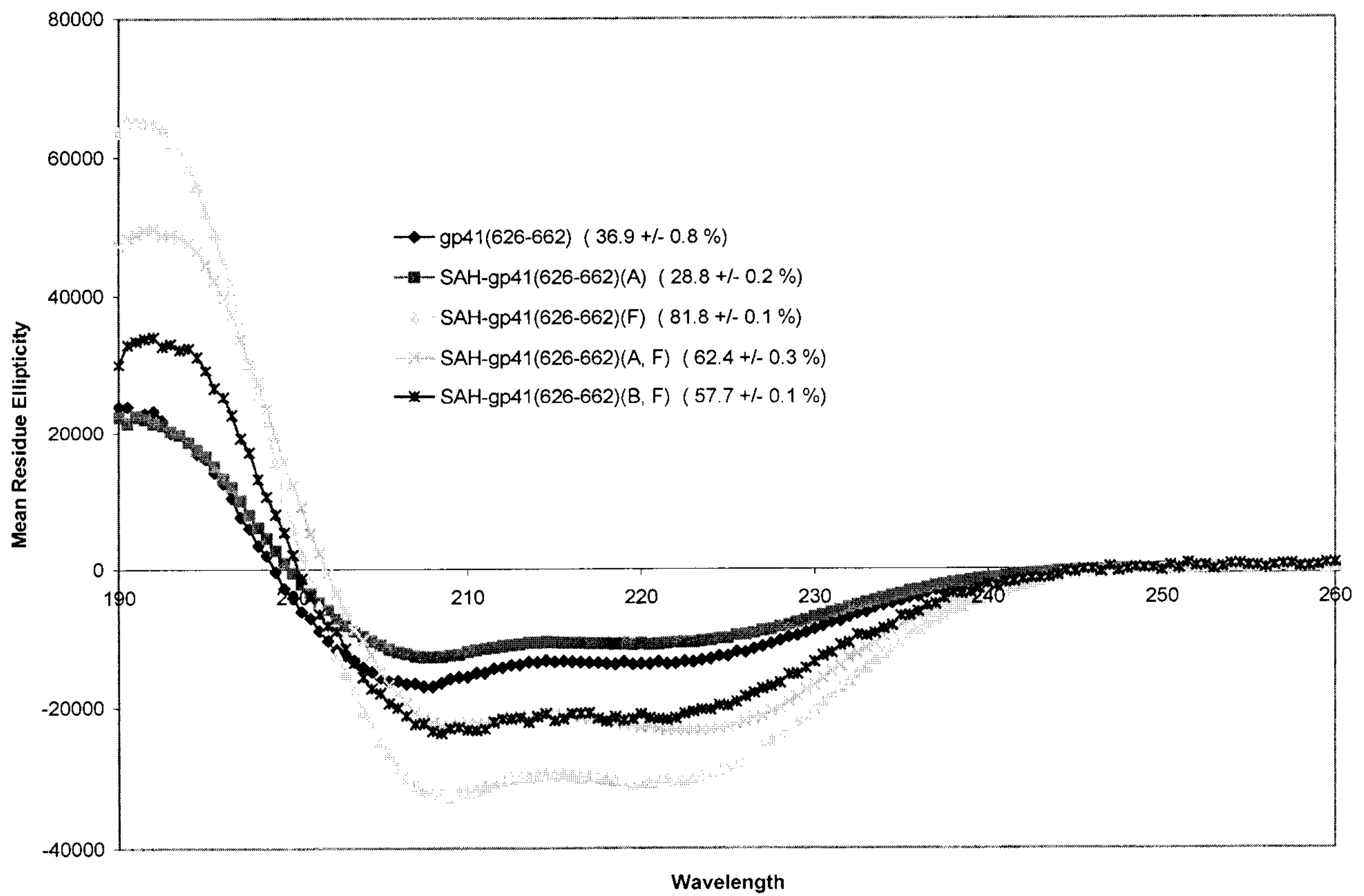


FIGURE 14E

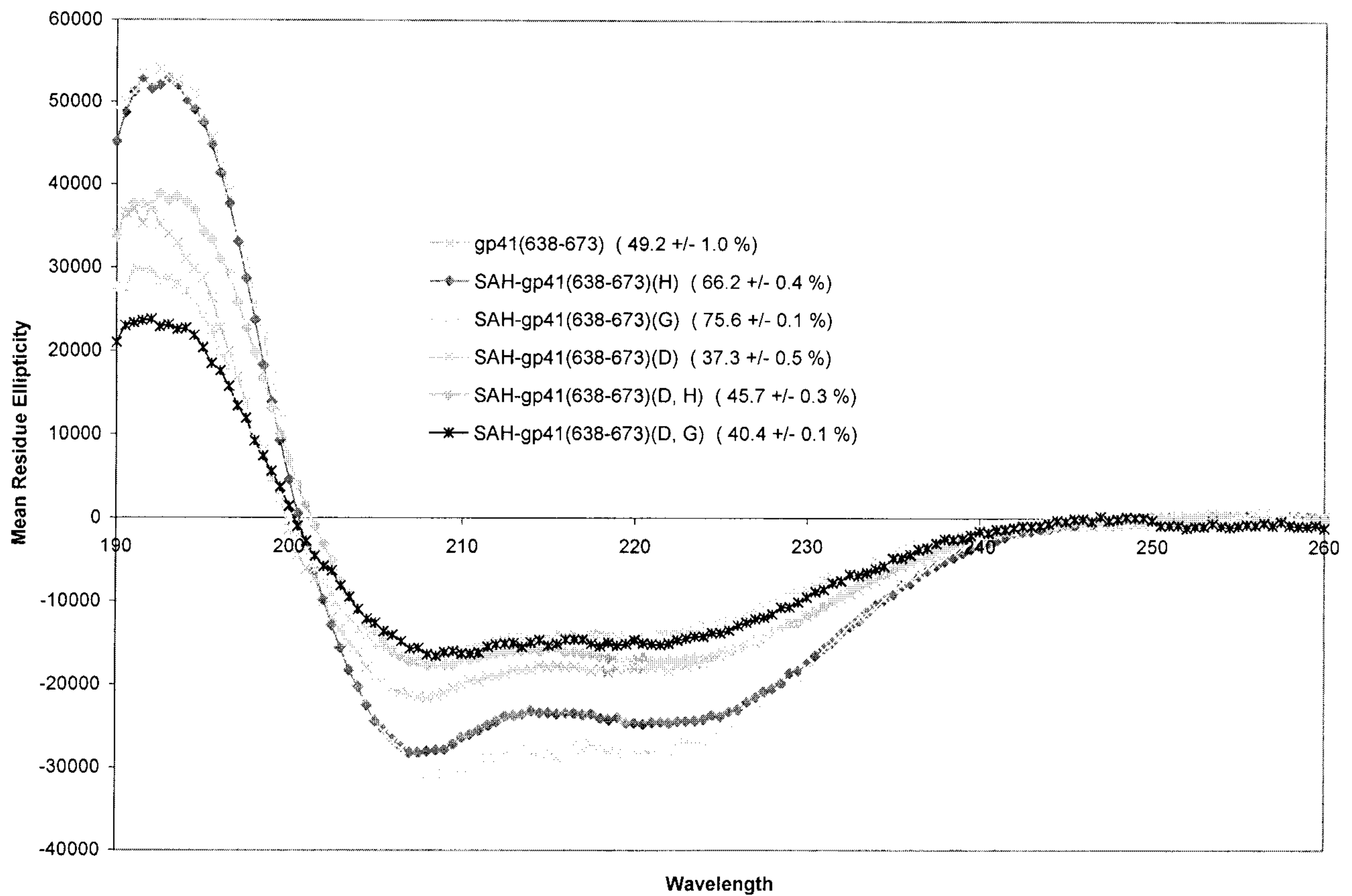


FIGURE 14F

Compound	%-helicity at pH 2	%-helicity at pH 7
SAH-gp41(626-662)	37	13
SAH-gp41(626-662)(F)	82	63
SAH-gp41(626-662)(C, F)	55	41
SAH-gp41(638-673)	49	19
SAH-gp41(638-673)(D)	79	23
SAH-gp41(638-673)(F)	57	30
SAH-gp41(638-673)(G)	61	48
SAH-gp41(638-673)(H)	66	26

FIGURE 15A

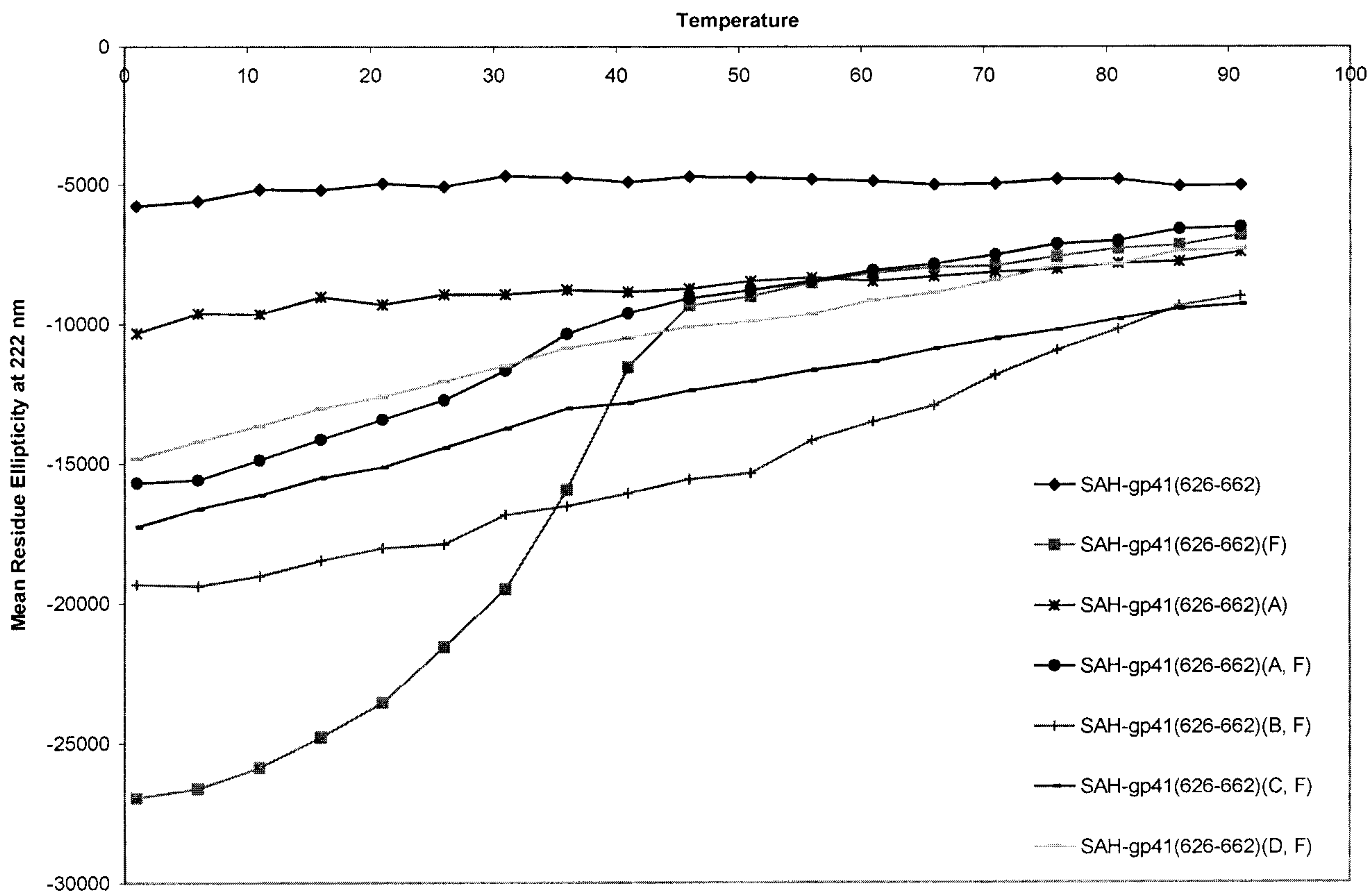


FIGURE 15B

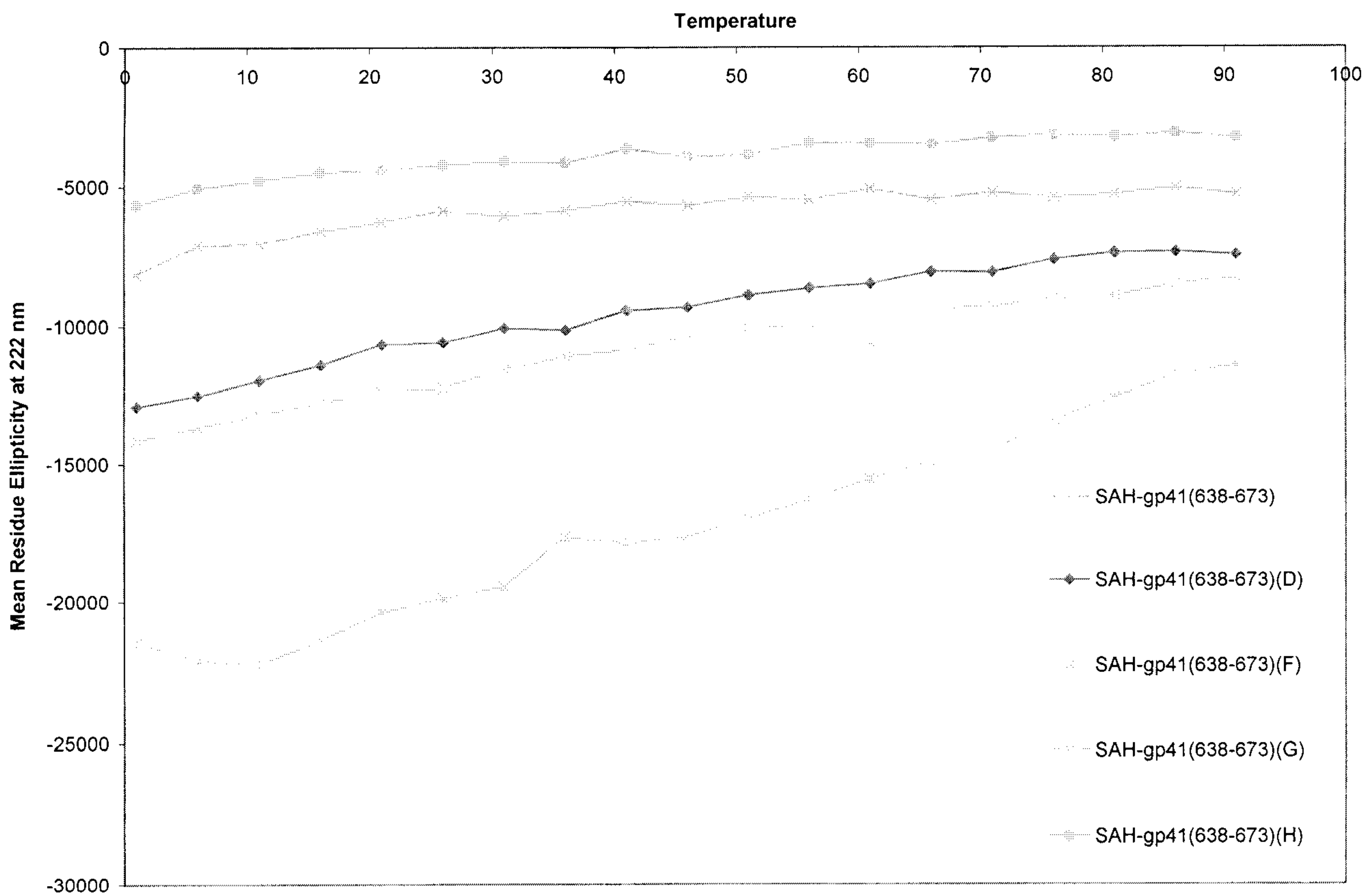


FIGURE 15C

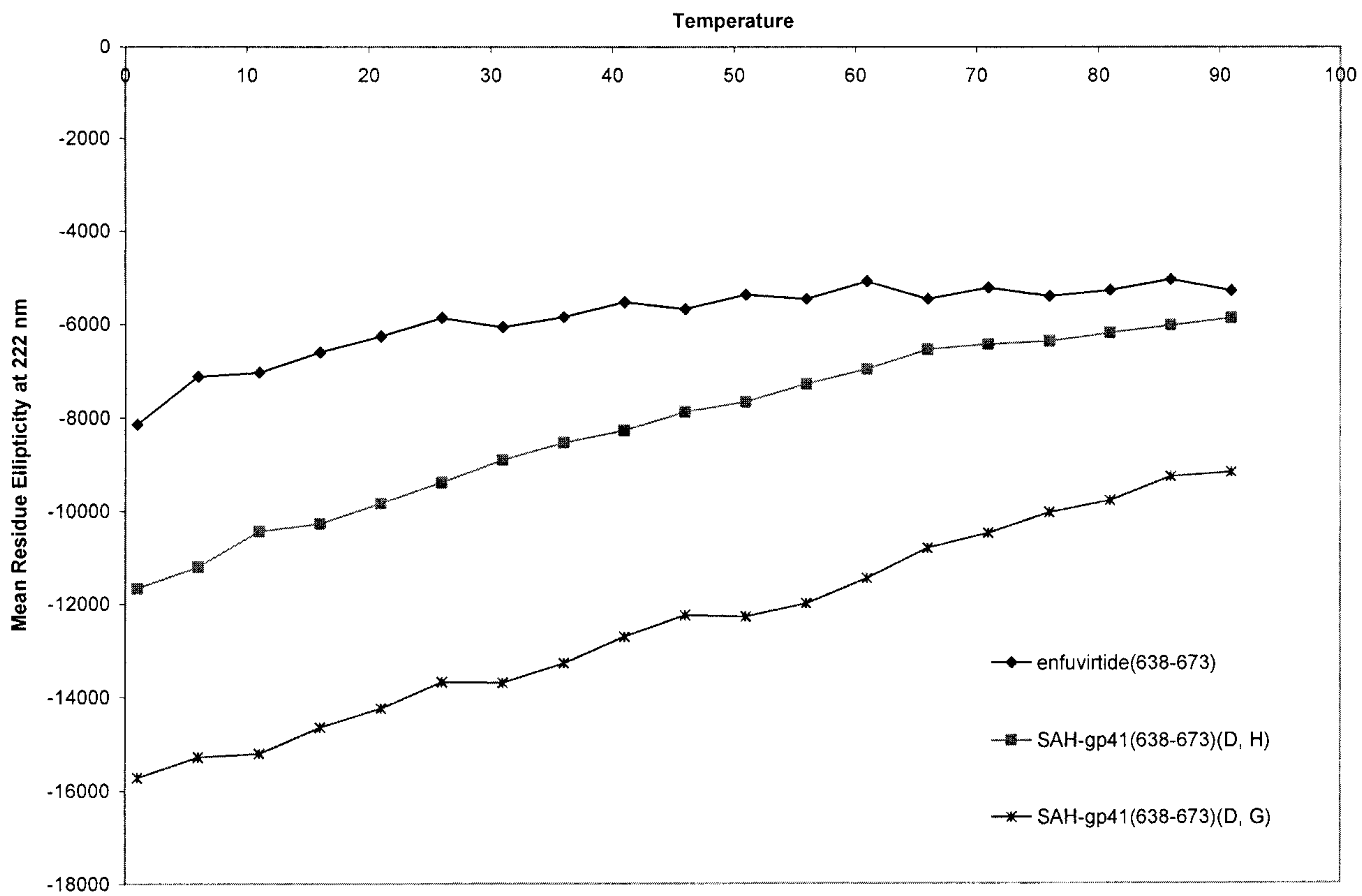


FIGURE 16A

Conditions = 195 μ L buffer (50 mM phos, pH 7.1 mM CaCl₂, 100 μ M AcTrpNH₂) + 5 μ L of 1 mM T20 peptide, then 2 μ L of 500 ng / μ L chymotrypsin

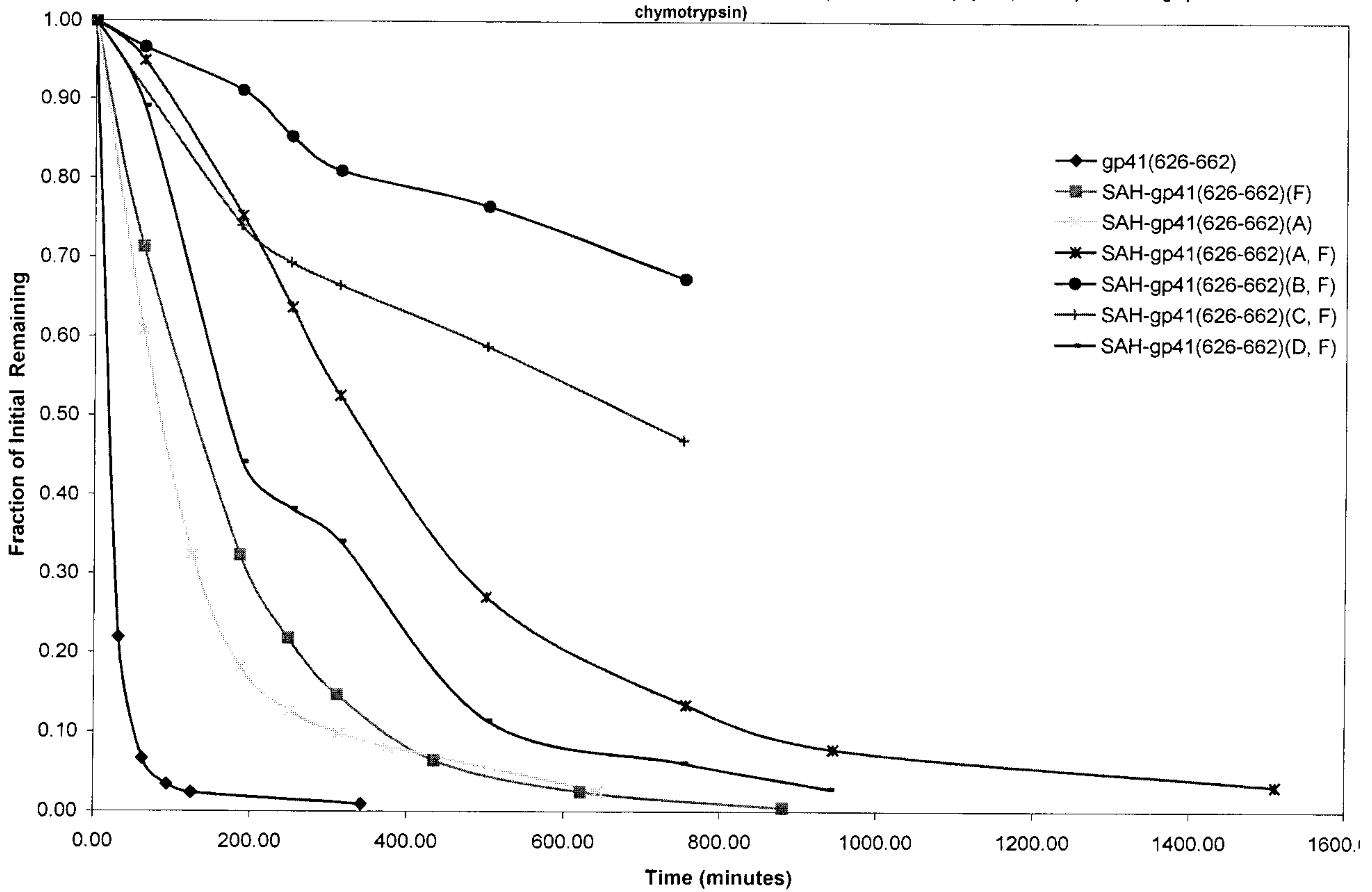


FIGURE 16B

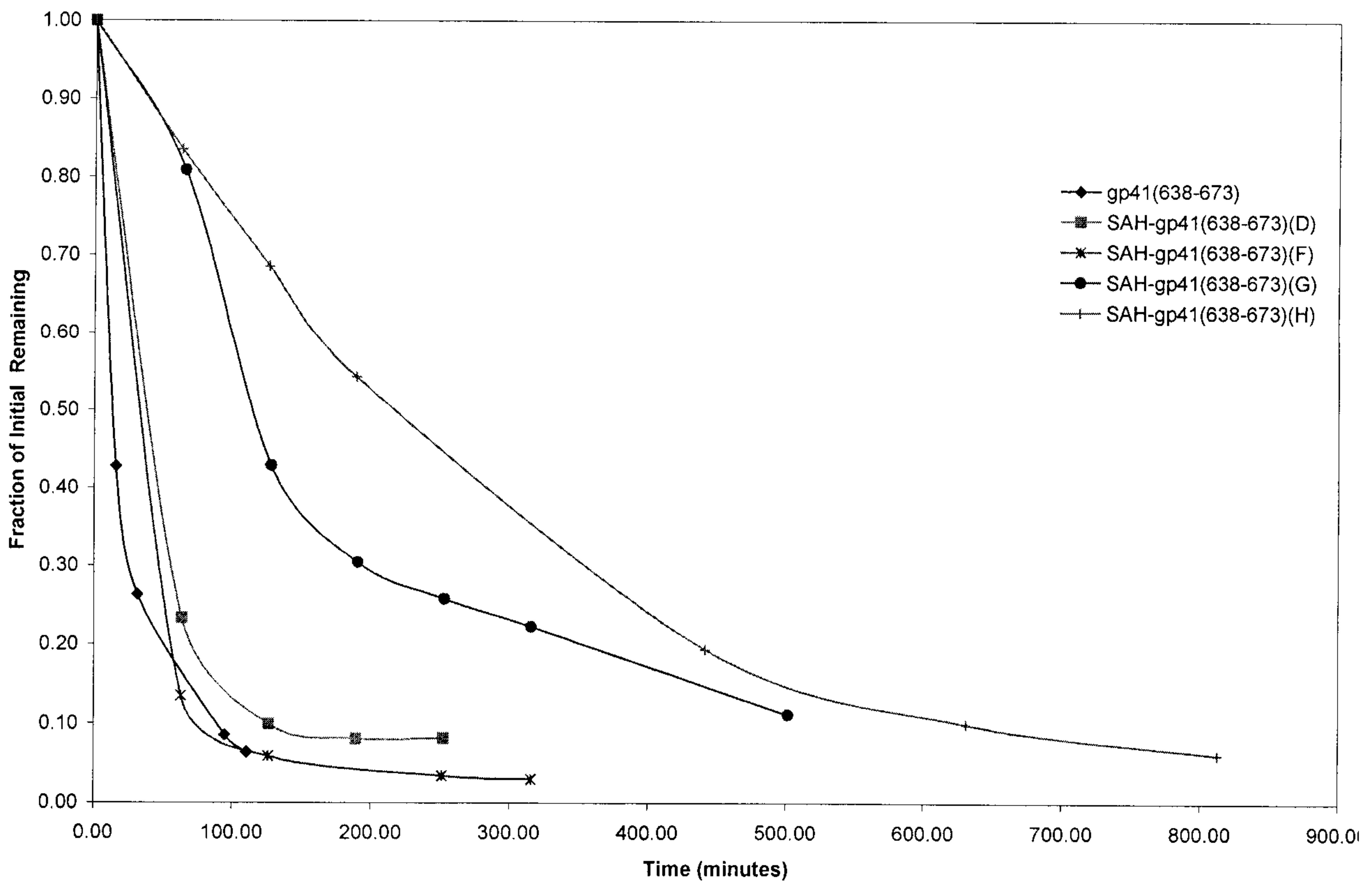


FIGURE 16C

compound	half-life, minutes
gp41 ₍₆₂₆₋₆₆₂₎	14
SAH-gp41 ₍₆₂₆₋₆₆₂₎ (F)	102
SAH-gp41 ₍₆₂₆₋₆₆₂₎ (A)	79
SAH-gp41 ₍₆₂₆₋₆₆₂₎ (A,F)	301
SAH-gp41 ₍₆₂₆₋₆₆₂₎ (B,F)	1275
SAH-gp41 ₍₆₂₆₋₆₆₂₎ (C,F)	494
SAH-gp41 ₍₆₂₆₋₆₆₂₎ (D,F)	181
gp41 ₍₆₃₈₋₆₇₃₎	15
SAH-gp41 ₍₆₃₈₋₆₇₃₎ (D)	32
SAH-gp41 ₍₆₃₈₋₆₇₃₎ (F)	21
SAH-gp41 ₍₆₃₈₋₆₇₃₎ (G)	128
SAH-gp41 ₍₆₃₈₋₆₇₃₎ (H)	201
SAH-gp41 ₍₆₃₈₋₆₇₃₎ (D, H)	510
SAH-gp41 ₍₆₃₈₋₆₇₃₎ (D, G)	1710
SAH-gp41 ₍₆₃₈₋₆₇₃₎ (F, H)	132
SAH-gp41 ₍₆₃₈₋₆₇₃₎ (D, F)	652
SAH-gp41 ₍₆₃₈₋₆₇₃₎ (E, G)	483

FIGURE 16D

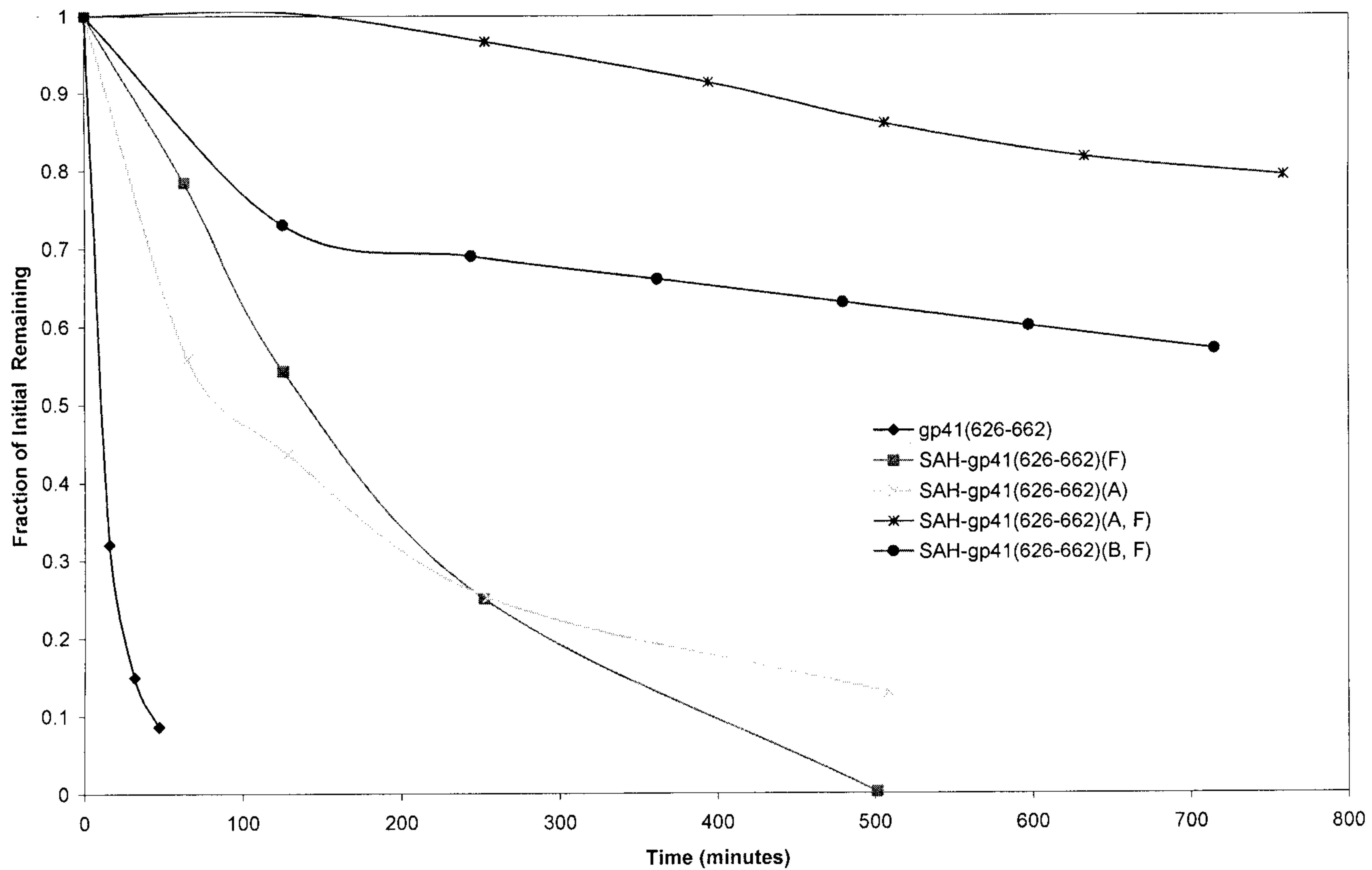


FIGURE 16E

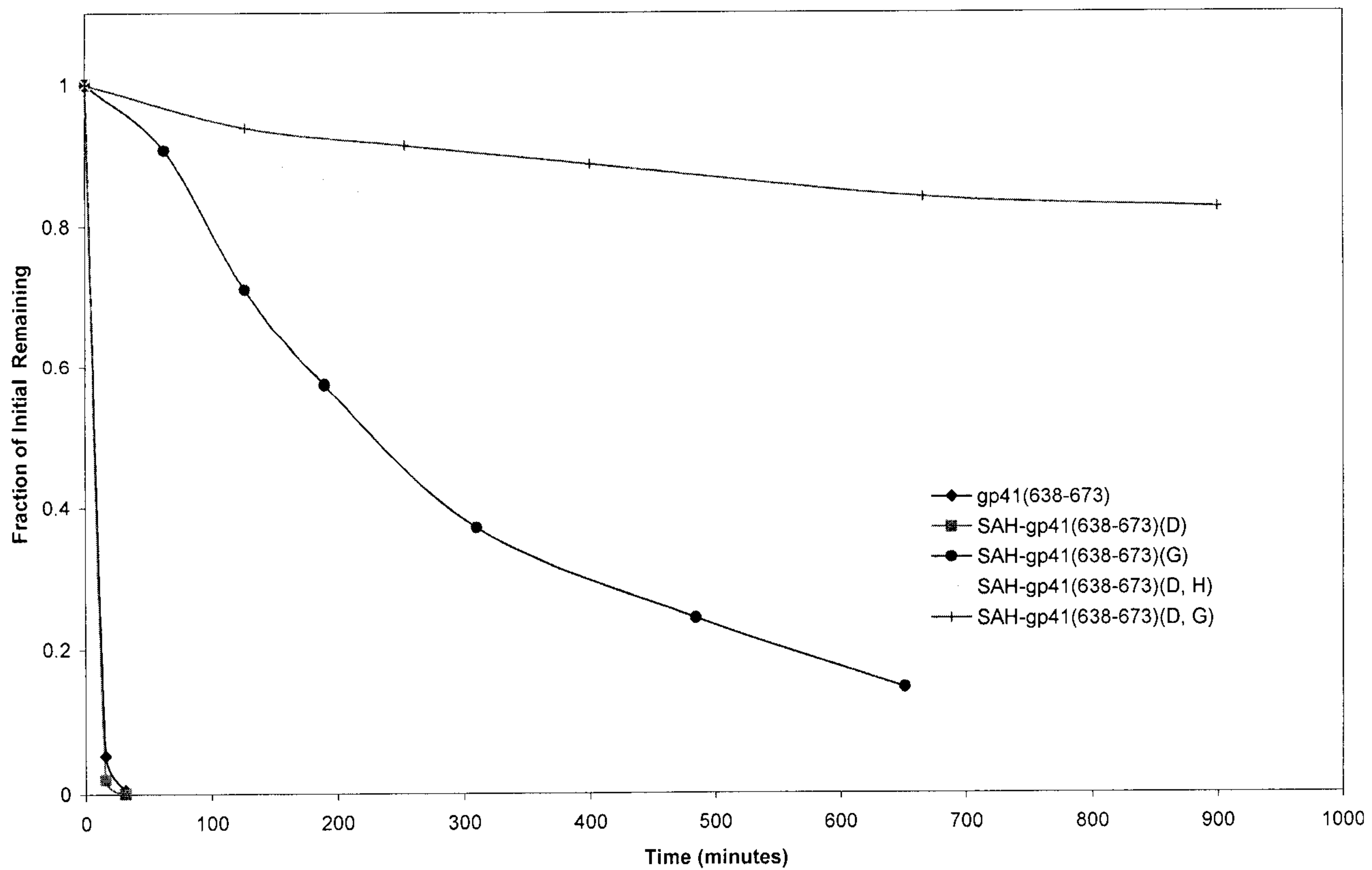


FIGURE 16F

compound	half-life, minutes
gp41 ₍₆₂₆₋₆₆₂₎	11
SAH-gp41 ₍₆₂₆₋₆₆₂₎ (F)	129
SAH-gp41 ₍₆₂₆₋₆₆₂₎ (A)	118
SAH-gp41 ₍₆₂₆₋₆₆₂₎ (A,F)	2040
SAH-gp41 ₍₆₂₆₋₆₆₂₎ (B,F)	930
gp41 ₍₆₃₈₋₆₇₃₎	4
SAH-gp41 ₍₆₃₈₋₆₇₃₎ (D)	3
SAH-gp41 ₍₆₃₈₋₆₇₃₎ (G)	227
SAH-gp41 ₍₆₃₈₋₆₇₃₎ (D, G)	3320
SAH-gp41 ₍₆₃₈₋₆₇₃₎ (D, H)	920

FIGURE 17

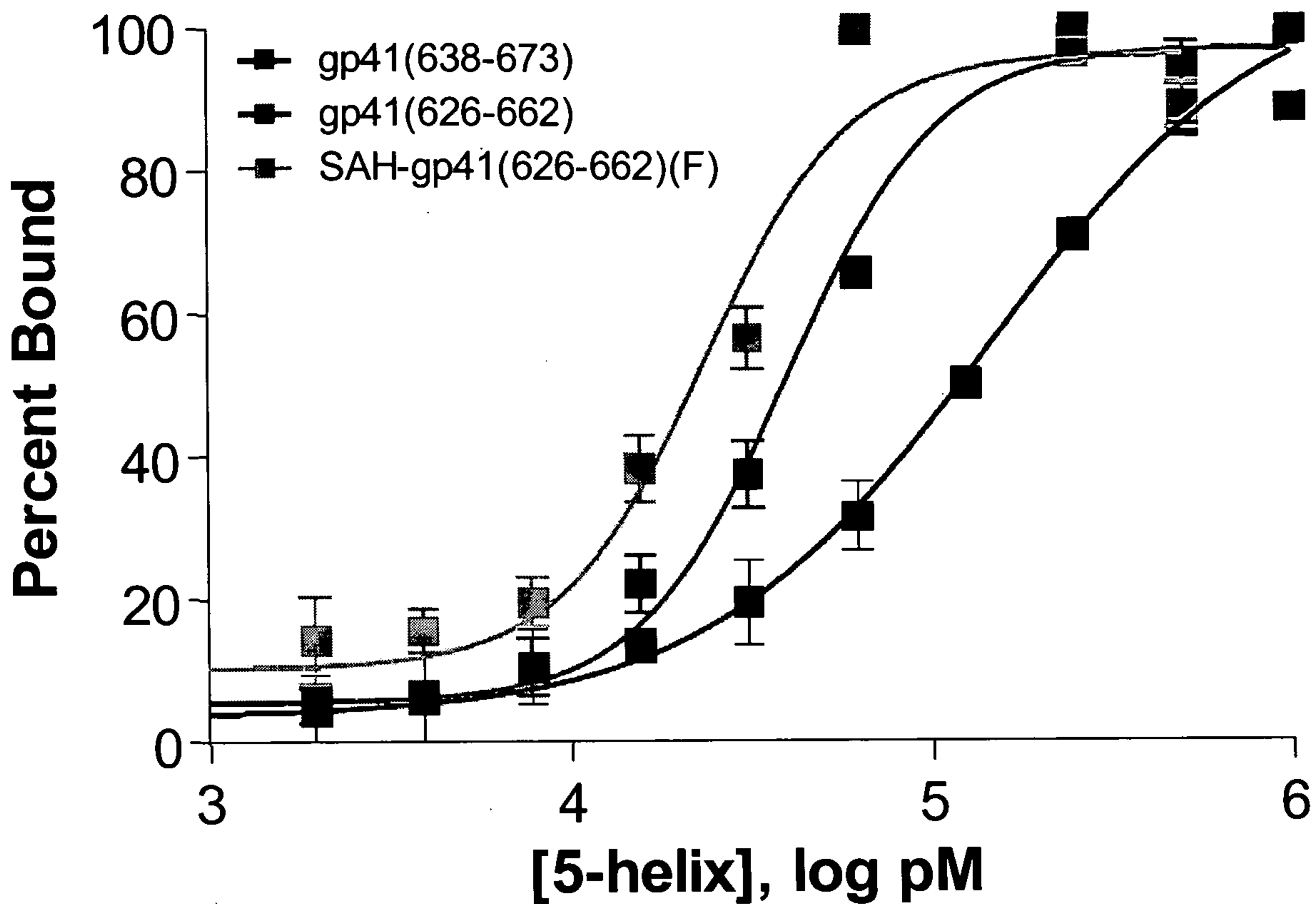


FIGURE 18

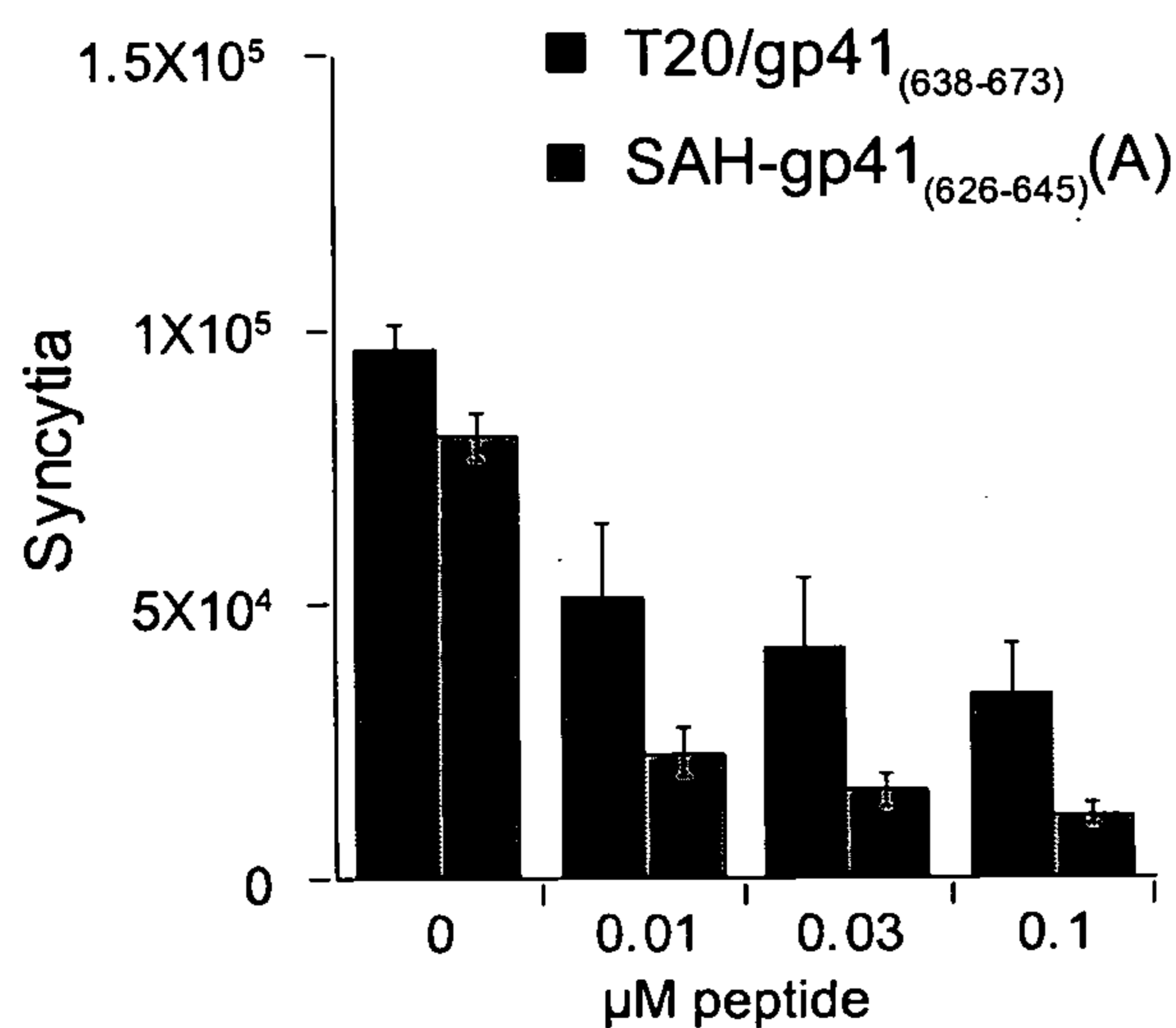


FIGURE 19

IC50,
nM

	gp41(638-673)	SAH-gp41(638-673)(D)	SAH-gp41(638-673)(G)	SAH-gp41(638-673)(D, G)	SAH-gp41(638-673)(D, H)
ADA	762 +/- 492	129 +/- 51	600 +/- 194	161 +/- 34	>3000 nM
HX	446 +/- 191	30 +/- 12	802 +/- 66	146 +/- 58	978 +/- 540
3.2	330 +/- 103	77 +/- 6	662 +/- 38	87 +/- 29	833 +/- 441
AMLV	>3000	>3000	>3000	>3000	>3000
YU2	>3000				

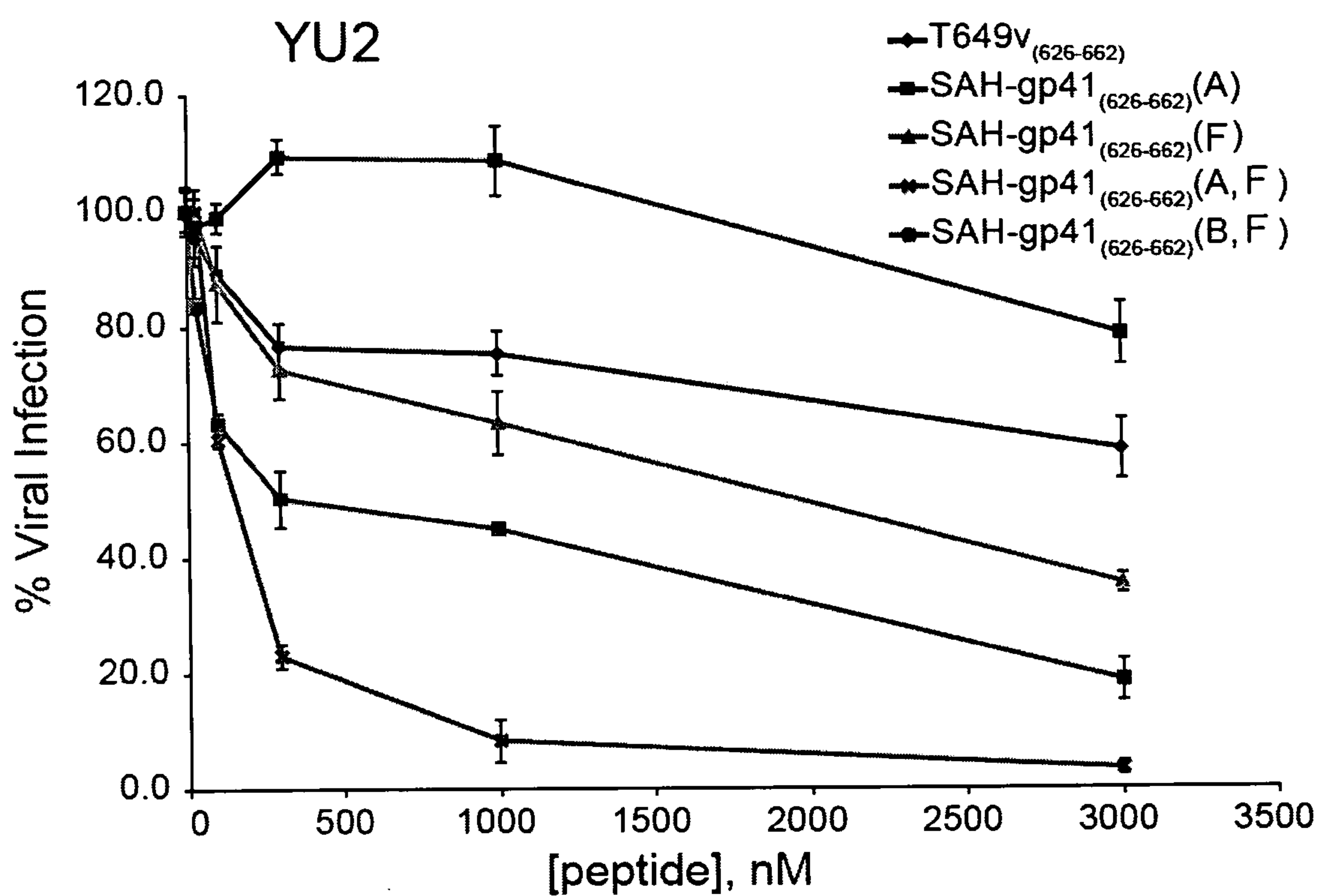
IC50,
nM

	gp41(626-662)	SAH-gp41(626-662)(A)	SAH-gp41(626-662)(F)	SAH-gp41(626-662)(A, F)	SAH-gp41(626-662)(B, F)
ADA	19 +/- 1	20 +/- 4	23 +/- 5	21 +/- 2	218 +/- 95
HX	17 +/- 2	16 +/- 1	19 +/- 3	18 +/- 1	1045 +/- 87
3.2	20 +/- 3	18 +/- 1	29 +/- 3	20 +/- 4	282 +/- 15
YU2	>3000	339 +/- 162	1958 +/- 259	87 +/- 30	>3000
AMLV	>3000	>3000	>3000	>3000	>3000

FIGURE 20A

	T865	T865(V38A,N42T)
gp41(638-673)	0.58	0.36
gp41(626-662)	0.84	0.37
SAH-gp41(626-662)(A,F)	0.80	0.73
SAH-gp41(626-662)(F)	0.95	0.84
SAH-gp41(626-662)(A)	0.65	0.39

FIGURE 20B



IC50,
nM

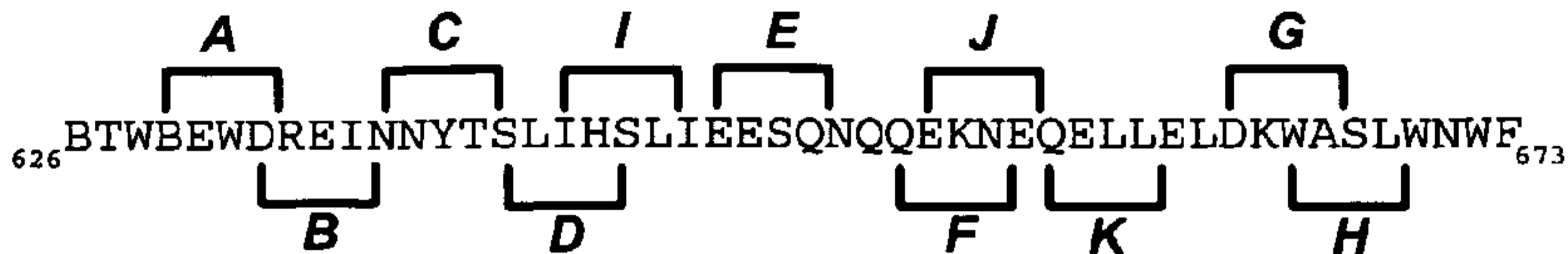
	gp41 (626-662)	SAH-gp41 (626-662)(A)	SAH-gp41 (626-662)(F)	SAH-gp41 (626-662)(A, F)	gp41 (638-673)
YU2	>3000	339 +/- 162	1958 +/- 259	87 +/- 30	>3000

FIGURE 21

Sample no.	Dose (mg/kg)	Route	Collection time (h)	Concentration in plasma (µg/mL) ^a	
				gp41(626-662) (µg/mL)	SAH-gp41(626-662)(A,F) (µg/mL)
7227	10	oral	0.5	<LOD	
7228	10	oral	0.5	<LOD	
7229	10	oral	0.5	<LOD	
7230	10	intravenous	0.5	7.1	
7231	10	intravenous	0.5	6.2	
7232	10	intravenous	0.5	7.8	
7206	10	oral	0.5		1.7
7207	10	oral	0.5		1.4
7208	10	oral	0.5		1.3
7209	10	intravenous	0.5		47.3
7210	10	intravenous	0.5		45.4
7226	10	intravenous	0.5		40.3

^a Lower limit of quantitation, 1.25 µg/mL; <LOD, undetectable.

FIGURE 11



BTWBEWDREINNYTSLIHSLIEESQNQQEKNEQELLE
 BTWBEWDREINNYTSLIHSLIEESQNQQEKKNXQELLE
 BTWXEWDXEINNYTSLIHSLIEESQNQQEKNEQELLE
 BTWBEWDREINNYTSLIHSLIXESQXQQEKNEQELLE

gp41₍₆₂₆₋₆₆₂₎
 SAH-gp41₍₆₂₆₋₆₆₂₎(F)
 SAH-gp41₍₆₂₆₋₆₆₂₎(A)
 SAH-gp41₍₆₂₆₋₆₆₂₎(E)

YTSLIHSLIEESQNQQEKNEQELLELDKWASLWNWF
 YTLIHXLIEESQNQQEKNEQELLELDKWASLWNWF
 YTSLIHSLIEESQI EKNXQELLELDKWASLWNWF
 YTSLIHSLIEESQNQQEKNEQELLELXKWAXLWNWF
 YTSLIHSLIEESQNQQEKNEQELLELDKXASLXNWF
 YTSLLXHSLXEESQNQQEKNEQELLELDKWASLWNWF
 YTSLIHSLIXESQXQQEKNEQELLELDKWASLWNWF
 YTSLIHSLIEESQNQQXKNEXELLELDKWASLWNWF
 YTSLIHSLIEESQNQQEKNEEXELLXLDKWASLWNWF

gp41₍₆₃₈₋₆₇₃₎
 SAH-gp41₍₆₃₈₋₆₇₃₎(D)
 SAH-gp41₍₆₃₈₋₆₇₃₎(F)
 SAH-gp41₍₆₃₈₋₆₇₃₎(G)
 SAH-gp41₍₆₃₈₋₆₇₃₎(H)
 SAH-gp41₍₆₃₈₋₆₇₃₎(I)
 SAH-gp41₍₆₃₈₋₆₇₃₎(E)
 SAH-gp41₍₆₃₈₋₆₇₃₎(J)
 SAH-gp41₍₆₃₈₋₆₇₃₎(K)