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(54) **Titre : PEPTIDES HER-2**

(54) **Title: HER-2 PEPTIDES**

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1 melaalcrwg lllallppga astqvctgtd mklrlpaspe thldmlrhly qgcqvvggnl
61 eltylptnas lsflqdiqev qgyvliahnq vrqvplqlrl ivrgtqlfed nyalavldng
121 dplnnttpvt gaspgglrel qlrslteilk ggvligrnpq lcyqdtlwk difhknnqla
181 ltldtnrsr achpcspmk gsrgwesse dcqsltrtvc aggarckgp lptdccheqc
241 aagctgpkhs dclaclhfnh sgicelhcpa lvtyntdtfe smpnpegryt fgascvtacp
301 ynystdvgs ctlvcpnlhq evtaedgtqr cekcskpcar vcyglgmehl revravtsan
361 iqefagckki fgslafipes fdgdpasnta plqpeqlqv etleeitgyl yisawpdsip
421 dlsvfqnlqv irgrilhnga ysltlqglgi swlglrlsre lgsglalihh nthlcfvhtv
481 pwdqlfrnph qallhtanrp edecvgegla chqlcarghc wpggptqcvn csqflrgqec
541 veecrvlqgl preyvnrhc lpchpecqpq ngsvtcfge adqcvacahy kdppfcvarc
601 psgvkpdlly mpiwkfpdee gacqpcpinc thscvdlldk gcpaeqrasp ltsivsavg
661 illvvvlgvv fgilikkrrq kirkytmrrl lqetelvepl tpsgampnqa qmrilketel
721 rkvkvlgsa fgtvykigi pdgenkipv aikvlrents pkankeilde ayvmagvgsp
781 yvsrllgicl tstvqlvtql mpygclddhv renrgrlgsq dlnwcmqia kgmsyledvr
841 lvhrdlaarn vlvkspnhvk itdfglarll dideteyhad ggkvpikwma lesilrrrft
901 hqsdvwsygv tvwelmtfga kpydgipare ipdllekger lpqppictid vymimvkcwm
961 idsecrprfr elvsefsrma rdpqrfrvviq nedlgpaspl dstfyrslle dddmgdlvda
1021 eeylvpqqgf fcpdpapag gmvhhrhrss strsgggdlt lglepseee prsplapseg
1081 agsdvfdgdl gmgaakglqs lpthdpsplq rysedptvpl psetdgyvap ltcsppqeyv
1141 nqpdvrpqp spregplpaa rpagatlera ktlspgkngv vkdvfafgga venpeyltpq
1201 ggaapqphpp pafspafdnl yywdqdppe gappstfkgt ptaenpeylg ldvvp
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(57) **Abrégé/Abstract:**

Compositions, methods, and vaccines that may stimulate the immune system and that may be used for treating malignancies associated with overexpression of the HER-2 protein are provided. Such compositions include epitopes of the HER-2 proteins.



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1 melaalcwrg lllallppga astqvctgtd mklrlpaspe thldmlrhly ggcqvvggnl
61 eltylptnas lsflqdiqev qgyvliahnq vrqvplqrlr ivrgtqlfed nyalavldng
121 dplnnttpvt gaspgglrel qlrslteilk ggvligrnpq lcyqdtlwk difhknngla
181 ltldtnrsr achpcspmck gsrcwgesse dcqsltrtvc aggcarckgp lptdccheqc
241 aagctgpkhs dclaclhfnh sgicelhcpa lvtyntdtfe smpnpegryt fgascvtacp
301 ynylstdivgs ctlvcpnlhng evtaedgtqr cekcskpcar vcyglgmehl revravtsan
361 iqefagckki fgslafllpes fdgdpasnta plqpeqlqv etleeitgyl yisawpdsip
421 dlsvfqnlqv irgrilhnga ysltlqglgi swlglrlsre lgsglalihh nthlcfvhtv
481 pwdqlfrnph qallhtanrp edecvgegla chqlcarghc wpggptqcvn csqflrgqec
541 veecrvlqgl preyvnarhc lpchpecqpq ngsvctcfge adqcvacahy kdpffcvarc
601 psgvkpdlsy mpiwkfpdee gacqpcpinc thscvdlldk gcpaeqrasp ltsivsavg
661 illvvvlgvv fgilikrrrq kirkytmrrl lqetelvepl tpsgampnqa qmrilketel
721 rkvkvlgsa fgtvykigiwi pdgenvkipv aikvlrents pkankeilde ayvmagvgsp
781 yvsrllgicl tstvqlvtql mpygcldhv renrgrlgsq dllnwcmaia kgmsyledvr
841 lvhrdlaarn vlvkspnhvk itdfglarll dideteyhad ggkvpikwma lesilrrrft
901 hqsdvwsygv tvwelmtfga kpydgipare ipdllekger lpqppictid vymimvkcwm
961 idsecrprfr elvsefserma rdpqrfvviq nedlgpaspl dstfyrslle dddmgdlvda
1021 eeylvppqgf fcpdpapgag gmvhhrhrss strsgggdlt lglepseee prsplapseg
1081 agsdvfdgd1 gmgaakglqs lpthdpsplq rysedptvpl psetdgyvap ltcsppqeyv
1141 nqpdvrrppp spregplpaa rpagatlera ktlspgkngv vkdvfafgga venpeyltpq
1201 ggaapqphpp pafspafdn1 yywdqdpper gappstfkgt ptaenpeylg ldvvp

(57) Abstract: Compositions, methods, and vaccines that may stimulate the immune system and that may be used for treating malignancies associated with overexpression of the HER-2 protein are provided. Such compositions include epitopes of the HER-2 proteins.

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HER-2 PEPTIDES

BACKGROUND

Currently, the most common approaches to treating breast cancer involve surgery, chemical intervention, and/or radiotherapy. Unless the cancer is restricted to a defined area, surgery alone cannot eliminate the cancer. Accordingly, radiation treatment is often given after surgery to destroy cancer cells that are near the surgical site and that have evaded surgery. The side effects of such treatment include skin sensitivity or itchiness, interference with the immune system, sometimes queasiness and, rarely, radiation fibrosis where an affected portion of the lung becomes fibrous. Chemotherapy may also be employed following surgery. Chemotherapy utilizes drugs that are toxic to cancer cells. Since this is not a perfectly selective system, normal cells are affected as well. Negative side effects include nausea, tiredness, loss of appetite, hair loss and diarrhea.

In view of such present therapies, attempts have been made to find additional approaches for treating breast cancer. One such approach is immunotherapy. One of the targets for an immunotherapeutic approach is the HER-2 protein. The HER-2 protein, a

product of the HER-2 oncogene, is overexpressed in a variety of cancers. It is found in 50%-60% of ductal in situ carcinoma and 20%-40% of all breast cancers, as well as a substantial .

fraction of adenocarcinomas arising in the ovaries, prostate, colon and lung. Overexpression of the HER-2 protein is related to malignant transformation in humans. Overexpression of the HER-2 protein is also intimately associated with the aggressiveness of the malignancy, being found in one-fourth of all invasive breast cancers. Overexpression of HER-2 protein is correlated with a poor prognosis in both breast and ovarian cancer.

In recent studies, antibodies directed against the extracellular binding domain (ECD) of HER-2 have been shown to confer inhibitory effects on tumor growth *in vitro* and in animal models (Hudziak, R.M., et al., Mol. Cell. Biol., 9:11-65-72, 1989; Tagliabue, E., et al., Int. J. Cancer 47:933-7, 1991; Drebin, J.A., et al., Proc. Natl. Acad. Sci. USA 83:9129-33, 1986; Drebin, J.A., et al., Oncogene, 2:273-7, 1988; Drebin, J.A., et al., Oncogene, 2:387-94, 1988; and Katsumata, M., et al., Nat. Med. 1:644-8, 1995.) In addition, Phase II and III clinical trials of a recombinant humanized anti-HER-2 monoclonal antibody, Trastuzumab, in patients with metastatic, HER-2-overexpressing breast cancers produced an overall response rate of 15% as a single agent. Trastuzumab has also been shown to improve survival when combined with cytotoxic chemotherapeutics (Baselga, J., et al., J. Clin. Oncol. 14:737-44, 1996; Pegram, M.D., et al., J. Clin. Oncol., 16:2659-71, 1998.). A number of vaccine approaches targeting a recombinant HER-2 protein, the HER-2 ECD, or the ECD of rat neu, which is the rat homolog of HER-2 have also been evaluated. For example, strain NFS mice immunized with a *vaccinia* virus recombinant that expresses the ECD rat *neu* developed a protective antibody response against subsequent challenge with neu-transformed NIH 3T3 cells (Bernards, R., et al., Proc. Natl. Acad. Sci. USA, 84:6854-8, 1987.). Immunization of BDIX rats with the same immunogen, however, did not result in antibody response nor did it inhibit the growth of syngeneic neu-expressing B 104 neuroblastoma cells, suggesting that this strategy was insufficient to induce immune responses in the rat. A polysaccharide-oncoprotein complex vaccine, consisting of the 147 amino-terminal amino acids of HER-2 ECD complexed with cholesteryl group-bearing mannan and pullulan, induced cellular and humoral immune responses that mediated rejection of HER-2-expressing sarcomas in BALB/c mice (Gu, X. G., et al., Cancer Res., 58: 3385-90, 1998.). Partial protection was shown in rat *neu* transgenic mice destined to develop mammary tumors by immunizing with either a purified rat neu ECD (Esserman, L. J., Cancer Immunol. Immunother., 47:337-42, 1999.) or neu-transfected allogeneic mouse fibroblasts (Cefai, D., et al., Int. J. Cancer, 83:393-400, 1999.)

Despite the results of the studies described above, it is still uncertain whether effective immune responses can be generated in humans using cell-or protein-based vaccine strategies

targeting HER-2 or the HER-2 ECD, as HER-2 is a non-mutated, "self" antigen. Accordingly, it is desirable to have additional immunotherapeutic approaches for treating or preventing breast cancer and other malignancies with which overexpression of the HER-2 protein is associated.

SUMMARY

In accordance with embodiments, HER-2 B epitopes are provided. The Epitopes have a sequence of CHPECQPQNGSVTCFGPEADQCVACAHYKDPPFCVA (SEQ ID NO: 2); VACAHYKDPPFCVA (SEQ ID NO: 3); VARCPSGVKPDLSPYMPIWKFPDEEGACQPL (SEQ ID NO: 4); IWKFPDEEGACQPL (SEQ ID NO: 5); LHCPALVTYNTDTFESMPNPEGRTYTFGASCV (SEQ ID NO: 6); ACPYNYLSTDVGSTLVCPHNLQEVTAEDGTQRCEK (SEQ ID NO: 7); or CPLHNLQEVTAEDGTQRCEK (SEQ ID NO: 8).

Additional embodiments of the invention are described in more detail herein.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

The following detailed description of embodiments of the present invention can be best understood when read in conjunction with the following drawings, where like structure is indicated with like reference numerals and in which:

Figure 1 illustrates the HER-2 protein sequence;

Figure 2 shows the synthetic strategy for 3 disulfide pairings. Differential cysteine protection and selective removal and oxidation was used to generate the correct disulfide pairings as illustrated;

Figure 3 shows the immune response in FVB/n mice. Groups of four to ten FVB/n mice were immunized with linear (NC) or disulfide-bonded (SS) peptide constructs (A) MVF563-598, (B) MVF585-598, (C) MVF597-626, or the linear peptide (D) MVF613-626. Each mouse is represented as an individual bar. Note that the scale in A is different than B-D;

Figure 4 shows that trastuzumab specifically recognizes peptide epitopes designed to mimic the trastuzumab binding-site of HER-2. The peptide sequences are given on the x-axis. MVF316-339 is an Her-2 irrelevant control peptide;

Figure 5 shows the flow cytometry of peptide-specific antibodies with human breast cancer cells over-expressing HER-2. Flow cytometry was used to assess whether antibodies from FVB/n mice induced by various constructs recognize native HER-2. BT-474 human breast cancer cells (HER-2^{high}) were treated with 10 μ g/mL of normal mouse Ig (negative

control), mouse monoclonal Ab-2 (positive control), or peptide antibodies raised in FVB/n mice.

Figure 6 shows the pertuzumab binding sites with HER-2;

Figure 7 shows the 3-dimensional structure of Herceptin Peptide epitopes;

Figure 8 shows the structure of HER-2 bound to Omnitarg™ (Pertuzumab);

Figure 9 shows the HER-2-trastuzumab binding site. (A) Ribbon diagram of HER-2 and the heavy and light chain of trastuzumab complex. (B) The trastuzumab binding-site of HER-2. This region is disulfide-rich. The sequences of the three loops that interact with trastuzumab are indicated;

Figure 10 shows the binding of trastuzumab to peptides. Microtiter wells were coated overnight with 2µg/ml of various peptides and then blocked with 1% BSA for one hour. Trastuzumab was then added to plates at a concentration of 2000 µg/ml and serially diluted 1:2 with PBT. Bound trastuzumab was detected with HRP-conjugated anti-human IgG and then with substrate. (A) The OD₄₁₅ value for peptides from Table I and an irrelevant control peptide (MVF316-339) using 2000 µg/ml of trastuzumab. Values shown are the mean of duplicate samples. SEM are indicated by error bars. (B) Titration of trastuzumab with the disulfide-bound (CYC) and linear (NC) forms of MVF563-598 along with irrelevant control peptide (MVF316-339).

Figure 11 shows cell proliferation by MTT assay. BT474 cells were plated in 96-well microtiter plates at 2 x 10⁴ cells/well and incubated overnight at 37°C. PBS containing trastuzumab or normal human IgG (100µg/ml) with or without peptide at the indicated concentrations was added to the wells. The plates were incubated for three days at 37°C. The number of viable cells was measured with MTT by reading OD₅₇₀. The percentage of inhibition was calculated using the formula $(OD_{\text{normal human IgG}} - OD_{\text{trastuzumab+peptide}})/OD_{\text{normal human IgG}} \times 100$. Values shown are the mean of triplicate samples. SEM are indicated by error bars;

Figure 12 shows the antibody response against peptides in FVB/n (A) and Neu-N (B) transgenic mice. Direct ELISAs were performed on sera from mice immunized with the cyclized (CYC) and linear (NC) constructs to determine differences in immunogenicity. Antibody titers against the corresponding immunogen were defined as the reciprocal of the highest dilution with absorbance ≥ 0.2 . Each bar represents an individual mouse. Designation on the x-axis represents time at which sera was sampled, e.g. 1y+3 corresponds to serum collected three weeks after the first immunization. Neu-N mice have an FVB/n background and express normal rat *neu* proto-oncogene under control of a mammary-specific

promoter. These mice show tolerance to *neu* relative to non-transgenic mice (Cancer Research 60, 3569). B demonstrates that although these mice are tolerant to rat *neu* they are able to generate an immune response against the peptide immunogens;

Figure 13 shows the cross-reactivity of peptide antibodies to HER-2. The reactivity of purified antibodies from immunized mouse sera was tested with (A) BT474 and (B) SKBR-3 breast cancer cell lines using flow cytometric analysis. Ab binding was detected with goat-anti mouse FITC-conjugated abs. The x-axis represents fluorescent intensity, and the y-axis represents relative cell number. Each histogram contains an overlay of mouse pre IgG, peptide antibodies, and AB2, a mouse mAb that binds HER-2. Both cell lines demonstrate that Abs from epitopes 563-598 and 585-598 do not recognize HER-2, while Abs from epitopes 597-626 and 613-626 recognize HER-2;

Figure 14 shows a schematic representation of the chimeric peptide vaccine construct consisting of the 'promiscuous' Th-cell epitope MVF co-linearly synthesized with the B-cell epitope via a flexible linker (GPSL), allowing independent folding of MVF and the B-cell epitope. This combination may help to elicit optimal antibody production by activation of both the humoral and innate arms of the immune system;

Figure 15 shows that iodine oxidation was used to form the naturally occurring disulfide bond between Cys268 and Cys295;

Figure 16 shows the immunogenicity in NZW rabbits immunized with MVFHER2(266-296) non-cyclized (NC) and cyclized (CYC) peptides. Serum is collected weekly and antibodies purified for use in diagnostic studies. Antibody titers are determined by direct ELISA;

Figure 17 shows A) immunogenicity in WT FVB/n mice immunized with either MVFHER2(266-296) cyclized (CYC) or non-cyclized (NC) peptide (8 mice/group). B) immunogenicity in 3 Neu over-expressing mice with FVB/n background. Antibody titers are determined by direct ELISA;

Figure 18 shows the ribbon structure of the extracellular domain of HER-2 that interacts with herceptin. The arrows show the three loops where HER-2 makes contact with herceptin;

Figure 19 shows the CD spectroscopy measurements that were performed using 100 uM solution of Her-2 563-598 CYC and Her-2 563-598 NC in water. Epitope HER-2 563-598 CYC, which is constrained with three disulfide bonds shows CD ellipticity minima at 193 nm, while epitope HER-2 563-598 NC free peptide shows CD ellipticity minima at 204 nm, which demonstrate significant differences in secondary structure;

Figure 20 shows the HER-2 563-598 epitope, and strategy for selective oxidation, reduction and disulfide bond analysis using a biotinylation agent, which attacks free sulfhydryl groups and therefore can be used to determine the completion of disulfide pairing;

Figure 21 shows the regioselective disulfide formation. Side chain protection for residues 315 and 331 was trityl, which was conveniently removed upon cleavage from the resin. The side chain of cysteine residues at 299 and 311 was protected with AcM, which can be selectively removed and cyclized by oxidation (I2) after the first cyclization;

Figure 22 shows the antibody response against peptides in out bred NZW rabbits (A) and inbred FVB/n mice (B). Direct ELISAs were performed on sera from animals immunized with the cyclized (CYC) and linear (NC) constructs to determine differences in immunogenicity. Antibody titers against the corresponding immunogen were defined as the reciprocal of the highest dilution with absorbance ≥ 0.2 . Each bar represents an individual animal. Designation on the x-axis represents time at which sera was sampled, e.g. 1y+3w corresponds to serum collected three weeks after the first immunization;

Figure 23 shows the cross-reactivity of peptide antibodies to HER-2. The reactivity of purified antibodies from immunized rabbit sera was tested with (A) BT474 (HER-2^{high}) and (B) MDA468 (HER-2^{low}) breast cancer cell lines using flow cytometric analysis. Ab binding was detected with goat-anti rabbit FITC-conjugated abs. The x-axis represents fluorescent intensity, and the y-axis represents relative cell number. Each histogram contains an overlay of rabbit pre IgG, peptide antibodies, and herceptin, a human mAb that binds HER-2.

Figure 24 shows that peptide antibodies induce ADCC (antibody dependent cell-mediated cytotoxicity) against BT474 breast cancer cells *in vitro*. Target cell line BT474 was incubated with peptide antibodies from rabbits, normal rabbit IgG, or herceptin in the presence of Na⁵¹CrO₄ for one hour. After three washings target cells were cultured with human PBMC effector cells to give an effector:target (E:T) ratio of 100:1, 20:1, and 4:1 for four hours at 37°C. Supernatant was subsequently harvested and radioactivity determined using a γ -counter. Cytotoxicity was calculated from the formula $100 \times (A-B)/(C-B)$ where A represents ⁵¹Cr (cpm) from test supernatant, B represents ⁵¹Cr (cpm) from target alone in culture (spontaneous), and C represents maximum ⁵¹Cr release from cells lysed with 5% SDS. Results represent the average (\pm SEM) of triplicate samples;

Figure 25 shows a schematic representation of the chimeric peptide vaccine construct consisting of the 'promiscuous' TH-cell epitope derived from the measles virus fusion protein

(MVF, residues 288-302) co-linearly synthesized with the B-cell epitope (HER-2(266-296)) via a flexible linker (GPSL), allowing independent folding of MVF and the B-cell epitope;

Figure 26 shows solid-phase peptide synthesis was performed using preloaded Fmoc-Val-CLEAR Acid resin. Peptides were cleaved using Reagent B (TFA:Phenol:H₂O:TIS, 90:4:4:1) and crude peptide purified by RP-HPLC. Iodine oxidation was used to form the naturally occurring disulfide bond between Cys268 and Cys295;

Figure 27 shows A) Antibody titers of NZW rabbits mice immunized with MVF-HER-2(266-296) noncyclized and cyclized peptides. B) Antibody titers of wild-type FVB/n mice immunized with MVF-HER-2(266-296) noncyclized and cyclized peptides. C) Antibody titers of Neu overexpressing FVB/n mice immunized with MVF-HER-2(266-296). Serum was collected weekly and titers determined by direct ELISA;

Figure 28 shows the purified MVF-HER-2(266-296) cyclized and noncyclized antibodies tested for their ability to bind to the native protein on human BT474 HER-2 overexpressing tumor cells (A) and mouse NT2.5 neu-overexpressing tumor cells (B). Both antibodies were shifted compared to the normal IgG isotype control and had similar binding compared to the positive controls (Herceptin for BT474 and anti-c-ErbB2/c-Neu (Ab-4) for NT2.5);

Figure 29 shows antibody-dependent cell-mediated cytotoxicity determined by incubating BT474 cells with purified MVF-HER-2(266-296) cyclized and noncyclized antibodies and ⁵¹Cr, then exposing the antibody-bound cells to human PBMCs, which perform immunologic lysis on the BT474 cells; and

Figure 30 shows wild-type FVB/n mice from Fig. 3B subcutaneously challenged with 3×10⁶ NT2.5 cells and tumor growth monitored for 24 days. MVF-HER-2(266-296) cyclized- and noncyclized-treated mice had delayed tumor development (A) and growth (B) as compared to the MVF immunized mice only.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

The present invention will now be described with occasional reference to the specific embodiments of the invention. This invention may, however, be embodied in different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art.

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Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. The terminology used in the description of the invention herein is for describing particular embodiments only and is not intended to be limiting of the invention. As used in the description of the invention and the appended claims, the singular forms "a," "an," and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise.

The present invention provides isolated polypeptides of the HER-2 protein, referred to hereinafter as HER-2 B epitopes. In some embodiments, the HER-2 B epitopes are immunogenic. The present invention additionally provides compositions that include one or more chimeric peptides, and the chimeric peptides include the HER-2 B epitopes. Additionally, compositions having one or more multivalent peptides are provided. These multivalent peptides include two or more of the HER-2 B epitopes. Methods of stimulating an immune response and methods of treating cancer in a subject are additionally provided. Vaccines are also provided for therapeutic and prophylactic use. The HER-2 B epitopes, either alone or in the context of chimeric peptides, as described herein, may be capable of invoking a humoral response which results in the production of antibodies that are immunoreactive with the extracellular domain of the HER-2 protein. According to some embodiments, the HER-2 B epitopes or chimeric peptides confer a protective effect.

HER-2 protein, and its rat homolog neu, are transmembrane proteins with a relative molecular mass of 185 kd that is approximately 1255 amino acids (aa) in length. HER-2/neu protein has an extracellular binding domain (ECD) of approximately 645 aa, with 40% homology to epidermal growth factor receptor (EGFR), a highly hydrophobic transmembrane anchor domain (TMD), and a carboxyterminal cytoplasmic domain (CD) of approximately 580 aa with ~80% homology to EGFR. The amino acid sequence of the HER-2 protein and a nucleotide sequence which encodes such amino acid sequence are shown GenBank Accession No. M11730. Fig. 1 shows the amino acid sequence of the HER-2 protein (SEQ ID NO. 1).

The HER-2 B epitopes encompass peptides having one of the sequences, referred to hereinafter as the "reference sequences", and the sequences are:

CHPECQPQNGSVTCEGPEADQCVACAHYKDPPFCVA, SEQ ID NO. 2;

VACAHYKDPPFCVA, SEQ ID NO. 3;

VARCPSGVKPDLSYMPIWKFPDEEGACQPL, SEQ ID NO. 4;

IWKFPDEEGACQPL, SEQ ID NO. 5;
 LHCPALVTYNTDTFESMPNPEGRYTFGASCV, SEQ ID NO. 6;
 ACPYNYLSTDVGSCITLVCPLHNQEVTAE~~D~~GTQRCEK, SEQ ID NO 7;
 CPLHNQEVTAE~~D~~GTQRCEK, SEQ ID NO. 8; or
 CPINCTHSCVDLDDKGCPAEQRAS, SEQ ID NO. 9.

The HER-2 B epitopes may be cyclized or linear. When cyclized, the epitopes may be cyclized in any suitable manner. For example, disulfide bonds may be formed between selected cysteine (Cys) pairs in order to provide a desired confirmation. It is believed that the formation of cyclized epitopes may provide conformations that improve the humoral response, thus improving the protective effect.

The HER_2 B epitopes identified by SEQ ID NOS. 2-5 contain at least one region of the three regions that make contact with trastuzumab in the trastuzumab binding region of the HER-2 extracellular domain (SEQ ID NO. 1). In 2003, the crystal structure of the extracellular region of HER-2 alone and complexed to the Fab fragment of trastuzumab was published. Trastuzumab was shown to interact with three loops in subdomain IV comprising residues from SEQ ID NO. 1 in loop 1:579-583 (2 disulfide pairings between C563-C576, and between C567-C584), loop 2: 592-595 (cysteine disulfide pairing between C587-C596), and loop 3:615-625 (cysteine disulfide between C600-C623). Loops 1 and 3 are further stabilized by interaction with trastuzumab mainly through electrostatic interactions, whereas loop 2 take part in hydrophobic interactions.

The HER-2 B epitope identified by SEQ ID NO. 2 represents positions 563-598 of the HER-2 protein (SEQ ID. NO. 1). The HER-2 B epitope identified by SEQ ID NO. 2 may be cyclized by the formation of a disulfide bonds between Cys-563 and Cys-576, Cys-567 and Cys-584, and/or Cys-587 and Cys-596. The HER-2 B epitope identified by SEQ ID. NO. 3 represents positions 585-598. The HER-2 B epitope identified by SEQ ID NO. 3 may be cyclized by the formation of a disulfide bond between Cys-587 and Cys-596. The HER-2 B epitope identified by SEQ ID NO. 4 represents positions 597-626, and the underlined leucine (Leu) amino acid was mutated from Cys to Leu in order not to interfere with disulfide bond formation. The HER-2 B epitope identified by SEQ ID NO. 4 may be cyclized by the formation of a disulfide bond between Cys-600 and Cys-623. The HER-2 B epitope identified by SEQ ID NO. 5 represents positions 613-626, and the bold Leu amino acid was mutated from Cys to Leu in order not to interfere with disulfide bond formation as will be

discussed further herein. It will be understood that the indicated Leu amino acids in SEQ ID NOS. 4 and 5 may alternatively be Cys.

The HER-2 B epitopes identified by SEQ ID NOS. 6-8 represent sequences designed to elicit antibody similar to the pertuzmab binding site of HER-2 (SEQ ID No. 1). The HER-2 B epitope identified by SEQ ID NO. 6 represents positions 315-333 of the HER-2 protein (SEQ ID NO. 1). The HER-2 B epitope identified by SEQ ID NO. 6 may be cyclized by the formation of a disulfide bond between Cys-315 and Cys-331. The HER-2 B epitope identified by SEQ ID NO. 7 represents positions 298-333. The HER-2 B epitope identified by SEQ ID NO. 7 may be cyclized by the formation of disulfide bonds between Cys-299 and Cys-311 and/or Cys-315 and Cys-331. The HER-2 B epitope identified by SEQ ID NO. 8 represents positions 266-296. The HER-2 B epitope identified by SEQ ID NO. 8 may be cyclized by the formation of a disulfide bond between Cys-268 and Cys-295.

The HER-2 B epitope identified by SEQ ID NO. 9 represents positions 626-649. This sequence may have disulfide bonds between Cys-626 and Cys-634 and/or Cys-630 and Cys-634. It will be understood that each of epitopes having more than one Cys may be cyclized or linear.

As described herein, the HER-2 B epitopes also encompass peptides that are functional equivalents of the peptides identified by SEQ ID NOS. 2-9. Such functional equivalents have an altered sequence in which one or more of the amino acids in the corresponding HER-2 B epitope sequence is substituted or in which one or more amino acids are deleted from or added to the corresponding reference sequence. For example 1 to 3 amino acids may be added to the amino terminus, carboxy terminus, or both. In some examples, the HER-2 B epitopes are glycosylated.

In other examples, the HER-2 B epitopes may be the retro-inverso isomers of the HER-2 B epitopes. The retro-inverso modification comprises the reversal of all amide bonds within the peptide backbone. This reversal may be achieved by reversing the direction of the sequence and inverting the chirality of each amino acid residue by using D-amino acids instead of the L-amino acids. This retro-inverso isomer form may retain planarity and conformation restriction of at least some of the peptide bonds. For example, the nonretro-inverso form of SEQ ID NO. 5 may be indicated as NH₂-L[IWKFPDEEGACQPL]-COOH. The retro-inverso form of SEQ ID NO. 5 may be indicated as NH₂-D[LPQCAGEEDPFKWI]-COOH.

Nonconservative amino acid substitutions and/or conservative substitutions may be made. Substitutions are conservative amino acid substitutions when the substituted amino

acid has similar structural or chemical properties with the corresponding amino acid in the reference sequence. By way of example, conservative amino acid substitutions involve substitution of one aliphatic or hydrophobic amino acids, e.g., alanine, valine, leucine and isoleucine, with another; substitution of one hydroxyl-containing amino acid, e.g., serine and threonine, with another; substitution of one acidic residue, e.g., glutamic acid or aspartic acid, with another; replacement of one amide-containing residue, e.g., asparagine and glutamine, with another; replacement of one aromatic residue, e.g., phenylalanine and tyrosine, with another; replacement of one basic residue, e.g., lysine, arginine and histidine, with another; and replacement of one small amino acid, e.g., alanine, serine, threonine, methionine, and glycine, with another.

In some examples, the deletions and additions are located at the amino terminus, the carboxy terminus, or both, of one of the sequences shown above. For example, the HER-2 B epitope equivalent has an amino acid sequence which is at least 70% identical, at least 80% identical, at least 90% identical, or at least 95% identical to the corresponding HER-2 B epitope sequences. Sequences which are at least 90% identical have no more than 1 alteration, i.e., any combination of deletions, additions or substitutions, per 10 amino acids of the reference sequence. Percent identity is determined by comparing the amino acid sequence of the variant with the reference sequence using MEGALIGN project in the DNA STAR program.

For functional equivalents that are longer than a corresponding HER-2 B epitope sequence, the functional equivalent may have a sequence which is at least 90% identical to the HER-2 B epitope sequence and the sequences which flank the HER-2 B epitope sequences in the wild-type HER-2 protein.

Functional equivalents of the HER-2 B epitopes may be identified by modifying the sequence of the epitope and then assaying the resulting polypeptide for the ability to stimulate an immune response, e.g., production of antibodies. For example, such assays may generally be performed by preparing a chimeric peptide which comprises the modified polypeptide and a Th epitope, injecting the chimeric peptide into a test animal and assaying for antibodies. Such antibodies may be found in a variety of body fluids including sera and ascites. Briefly, a body fluid sample is isolated from a warm-blooded animal, such as a human, for whom it is desired to determine whether antibodies specific for HER-2/neu polypeptide are present. The body fluid is incubated with HER-2/neu polypeptide under conditions and for a time sufficient to permit immunocomplexes to form between the polypeptide and antibodies specific for the protein and then assayed, preferably using an ELISA technique. In such

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technique, the colorimetric change is measured at 490 nm. Epitopes which induce production of antibodies that exhibit a titer equal to 10,000 or greater for HER-2/neu protein, may be useful. As used herein a titer of 10,000 refers to an absorbance value of 0.2 above background.

In accordance with other embodiments of the present invention, chimeric peptides and compositions comprising one or more chimeric peptides are provided. According to various embodiments, the chimeric peptides comprise a HER-2 B epitope, a T helper (Th) epitope, and a linker joining the HER-2 B epitope to the Th epitope. It will be understood that any suitable Th epitope may be used. For example, a promiscuous Th epitope may be used. As used herein a "promiscuous" Th epitope is one which promotes release of cytokines that assists in bypassing MHC restriction. It will be further understood that any suitable linker may be used. For example, depending upon the Th epitope used, the HER-2 B epitope may be linked to either the amino or the carboxy terminus of the Th epitope. The location and selection of the Th epitope depends on the structural characteristics of the HER-2 B epitope, whether alpha helical or beta-turn or strand. Methods for selecting suitable Th epitopes are described in Kaumaya et al., "DE NOVO" ENGINEERING OF PEPTIDE IMMUNOGENIC AND ANTIGENIC DETERMINANTS AS POTENTIAL VACCINES, in *Peptides, Design, Synthesis and Biological Activity* (1994), pp. 133-164.

A summary of the immune responses elicited a variety of Th epitopes containing B-cell epitope chimeras was presented in a review titled "Synthetic Peptides: Dream or Reality" by Kaumaya et al., and published in *PEPTIDES IN IMMUNOLOGY*, Wiley and Sons, Ltd. (1996).

In some examples, the Th epitope may be from about 14 to about 22, about 15 to 21, or 16 amino acids in length. In other embodiments, examples of suitable Th epitopes include, but are not limited to:

KLLSLIKGVTVHRLEGVE, SEQ ID NO. 10;
 NSVDDALINSTIYSYFPSV, SEQ ID NO. 11;
 PGINGKAIHLVNNQSSE, SEQ ID NO. 12;
 QYIKANSKFIGITEL, SEQ ID NO. 13;
 FNNFTVSFWLRVPKVSASHLE, SEQ ID NO. 14;
 LSEIKGVIVHRLEGV, SEQ ID NO. 15;
 FFLLTRILTIPQSLN, SEQ ID NO. 16; or
 TCGVGVRVRSRVNAANKKPE, SEQ ID NO. 17.

In other examples, the linker may be a peptide of from about 2 to about 15 amino acids, about 2 to about 10 amino acids, or from about 2 to about 6 amino acids in length. For example, the linker may be a peptide having the amino acid sequence Gly-Pro-Ser-Leu, SEQ ID NO. 18. The chimeric peptides may be linear or cyclized. Additionally, the HER-2 B epitopes, the Th epitopes, and/or the linker may be in retro-inverso form. Thus the HER-2 B epitope alone could be in retro inverso form. Alternatively, the HER-2 B epitope and the Th epitope could be in retro inverso form. In another example, the HER-2 B epitope, the Th epitope, and the linker could be in retro inverso form.

Examples of suitable chimeric peptides include but are not limited to:

KLLSLIKGVIVHRLEGVE-GPSL-

CHPECQPQNGSVTCFGPEADQCVACAHYKDPPFCVA, SEQ ID NO. 19;

KLLSLIKGVIVHRLEGVE-GPSL-VACAHYKDPPFCVA, SEQ ID NO. 20;

KLLSLIKGVIVHRLEGVE-GPSL-VARCPSGVKPDLSYMPIWKFPDEEGACQPL, SEQ ID NO. 21;

KLLSLIKGVIVHRLEGVE-GPSL-IWKFPDEEGACQPL, SEQ ID NO. 22;

KLLSLIKGVIVHRLEGVE-GPSL-LHCPALVTYNTDTFESMPNPEGRYTFGASCV, SEQ ID NO. 23;

KLLSLIKGVIVHRLEGVE-GPSL-

ACPYNYLSTDVGSCITLVCPLHNQEVTAEDGTQRCEK, SEQ ID NO. 24;

KLLSLIKGVIVHRLEGVE-GPSL-CPLHNQEVTAEDGTQRCEK, SEQ ID NO. 25; or

KLLSLIKGVIVHRLEGVE-GPSL-CPINCTHSCVDLDDKGCPAEQRAS, SEQ ID NO. 26.

The peptides of SEQ ID NOS. 19-26 have a Th epitope, a GPSL linker and a HER-2 B epitope.

The chimeric peptides and compositions comprising the peptides may be useful immunogens for inducing production of antibodies that interact with and bind to the extracellular domain of the HER-2 protein. The chimeric peptides may also be useful as laboratory tools for detecting antibodies to HER-2 protein in a subject's sera. The chimeric peptides may invoke an antibody response in a subject and that such antibodies may (a) immunoprecipitate HER-2 protein, (b) bind to intact HER 2 receptor on ER-2 overexpressing cells in culture, and (c) reduce proliferation of HER-2 overexpressing cells in vitro. The chimeric peptides may also be used to immunize a subject and retard or prevent tumor development. The chimeric peptides may be used in vaccines to provide a protective effect.

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In accordance with additional embodiments of the present invention, compositions comprising a mixture of two or more of the chimeric peptides are provided. In some examples, the HER-2 B epitope of each of the two or more chimeric peptides are different. In other examples, one of the HER-2 B epitopes is selected from SEQ ID NOS. 2-5 and another one of the HER-2 B epitopes is selected from SEQ IDS NOS. 6-8.

The HER-2 B epitopes and chimeric peptides may be synthesized using commercially available peptide synthesizers. For example, the chemical methods described in Kaumaya et al., "DE NOVO" ENGINEERING OF PEPTIDE IMMUNOGENIC AND ANTIGENIC DETERMINANTS AS POTENTIAL VACCINES, in *Peptides, Design, Synthesis and Biological Activity* (1994), pp 133-164.

For example, HER-2 B-cell epitopes may be synthesized co-linearly with the Th epitope to form a chimeric peptide. Peptide synthesis may be performed using Fmoc/t-But chemistry. The HER-2 B epitopes and chimeric peptides may be cyclized in any suitable manner. For example, disulfide bonds may be achieved using differentially protected cysteine residues, iodine oxidation, the addition of water to boost Acn removal and the concomitant formation of a disulfide bond, and/or the silyl chloride-sulfoxide method.

The HER-2 B epitopes and chimeric peptides may also be produced using cell-free translation systems and RNA molecules derived from DNA constructs that encode the epitope or peptide. Alternatively, the epitopes or chimeric peptides are made by transfecting host cells with expression vectors that comprise a DNA sequence that encodes the respective epitope or chimeric peptide and then inducing expression of the polypeptide in the host cells. For recombinant production, recombinant constructs comprising one or more of the sequences which encode the epitope, chimeric peptide, or a variant thereof are introduced into host cells by conventional methods such as calcium phosphate transfection, DEAE-dextran mediated transfection, transvection, microinjection, cationic lipid-mediated transfection, electroporation, transduction, scrape lading, bolistic introduction or infection.

The HER-2 B epitope and chimeric peptide may be expressed in suitable host cells, such as for example, mammalian cells, yeast, bacteria, insect cells or other cells under the control of appropriate promoters using conventional techniques. Suitable hosts include, but are not limited to, *E. coli*, *P. pastoris*, Cos cells and 293 HEK cells. Following transformation of the suitable host strain and growth of the host strain to an appropriate cell density, the cells are harvested by centrifugation, disrupted by physical or chemical means, and the resulting crude extract retained for further purification of the epitope or chimeric peptide.

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Conventional procedures for isolating recombinant proteins from transformed host cells, such as isolation by initial extraction from cell pellets or from cell culture medium, followed by salting-out, and one or more chromatography steps, including aqueous ion exchange chromatography, size exclusion chromatography steps, and high performance liquid chromatography (HPLC), and affinity chromatography may be used to isolate the recombinant polypeptide.

To produce glycosylated epitopes and chimeric peptides, recombinant techniques may be used. For example, mammalian cells such as, Cos-7 and Hep-G2 cells be employed in the recombinant techniques. Alternatively, glycosylated epitopes and chimeric peptides may be produced using standard Fmoc/tBut synthesis. For example, one or more sugar units can be added to peptides using a chemoenzymatic approach employing *endo- β -N*-acetylglucosaminidases as the key enzyme for oligosaccharide transfer.

Naturally occurring variants of the HER-2 B epitopes may also be isolated by, for example, by screening an appropriate cDNA or genomic library with a DNA sequence encoding the polypeptide.

In accordance with further embodiments, multivalent peptides which comprise a plurality, i.e., at least two of the HER 2-B epitopes or functional equivalents thereof and a Th epitope are provided. The HER-2 B epitopes and Th epitope are connected to a template. For example, the HER-2 B epitopes and the Th epitope may be connected to a core β sheet template. In another example, the template may be two strands of alternating leucine and lysine residues, which are connected by a linker. The linker is an amino acid or a peptide of from about 2 to about 15 amino acids, from about 2 to about 10 amino acids, or from about 2 to about 6 amino acids in length. For example, the linker may be the amino acid sequence Gly-Pro-Ser-Leu, SEQ ID NO. 18.

Multivalent peptides may be synthesized in any suitable manner. For example, multivalent peptides may be prepared by employing a combinatorial Fmoc/tbutyl, Fmoc/benzyl and Boc benzyl strategy as well as a fourth level of differential protecting group (Npys) strategy. Details of such approach are presented in Larimore et al. (1995) Journal of Virology 69:6077-6089.

In accordance with yet other embodiments of the present invention, isolated polynucleotides which encode the HER-2 B epitopes and the chimeric peptides discussed herein are provided. The present polynucleotides also encompass polynucleotides having sequences that are capable of hybridizing to the nucleotide sequences of the HER-2 B

epitopes or the chimeric peptides under stringent conditions, and/or highly stringent conditions. Hybridization conditions are based on the melting temperature (T_m) of the nucleic acid binding complex or probe, as described in Berger and Kimmel (1987) *Guide to Molecular Cloning Techniques, Methods in Enzymology*, vol 152, Academic Press. The term "stringent conditions, as used herein, is the "stringency" which occurs within a range from about T_m-5 (5° below the melting temperature of the probe) to about 20° C below T_m . As used herein "highly stringent" conditions employ at least 0.2 x SSC buffer and at least 65° C. As recognized in the art, stringency conditions can be attained by varying a number of factors such as the length and nature, i.e., DNA or RNA, of the probe; the length and nature of the target sequence, the concentration of the salts and other components, such as formamide, dextran sulfate, and polyethylene glycol, of the hybridization solution. All of these factors may be varied to generate conditions of stringency which are equivalent to the conditions listed above.

Polynucleotides comprising sequences encoding a HER-2 B epitope or a chimeric peptide of the present invention may be synthesized in whole or in part using chemical methods or recombinant methods which are suitable. Polynucleotides which encode a HER-2 B epitope may be obtained by screening a genomic library or cDNA library with antibodies immunospecific for the HER-2 protein to identify clones containing such polynucleotide.

The polynucleotides are useful for producing a HER-2 B epitope or a chimeric peptide. For example, an RNA molecule encoding a multivalent chimeric peptide may be used in a cell-free translation systems to prepare such polypeptides. Alternatively, a DNA molecule encoding a HER-2 B epitope or a chimeric peptide may be introduced into an expression vector and used to transform cells. Suitable expression vectors include, but are not limited to, chromosomal, nonchromosomal and synthetic DNA sequences, e.g., derivatives of SV40, bacterial plasmids, phage DNAs; yeast plasmids, vectors derived from combinations of plasmids and phage DNAs, viral DNA such as vaccinia, adenovirus, fowl pox virus, pseudorabies, baculovirus, and retrovirus. The DNA sequence may introduced into the expression vector by any suitable procedure.

In accordance with further embodiments, recombinant constructs comprising one or more of the polynucleotides encoding one or more HER-2 B epitopes or chimeric peptides are provided. Suitable constructs include, for example, vectors, such as a plasmid, phagemid, or viral vector, into which a sequence that encodes the HER-2 B cell epitope or the chimeric peptide has been inserted. In the expression vector, the DNA sequence which encodes the

epitope or chimeric peptide is operatively linked to an expression control sequence, i.e., a promoter, which directs mRNA synthesis. Representative examples of such promoters, include the LTR or SV40 promoter, the *E. coli* lac or trp, the phage lambda PL promoter and other promoters known to control expression of genes in prokaryotic or eukaryotic cells or in viruses. The expression vector may also contain a ribosome binding site for translation initiation and a transcription terminator. For example, the recombinant expression vectors also may include an origin of replication and a selectable marker, such as for example, the ampicillin resistance gene of *E. coli* to permit selection of transformed cells, i.e., cells that are expressing the heterologous DNA sequences. The polynucleotide sequence encoding the HER-B cell epitope or the chimeric peptide may be incorporated into the vector in frame with translation initiation and termination sequences. For example, the polynucleotide may further encode a signal sequence which is operatively linked to the amino terminus of the HER-2 B epitope or chimeric peptide.

The polynucleotides encoding the HER-2 B epitope or the chimeric peptides comprising such epitopes may be used to express recombinant peptide using suitable techniques. Such techniques include, but are not limited to, those described in Sambrook, J. et al (1989) Molecular Cloning A Laboratory Manual, Cold Spring Harbor Press, Plainview, N.Y. and Ausubel, F. M. et al. (1989) Current Protocols in Molecular Biology, John Wiley & Sons, New York, NY. Polynucleotides encoding the HER-2 B epitope or the chimeric peptides comprising such epitopes may also be used to immunize subjects.

In accordance with yet further embodiments, methods of treating cancer are provided. The methods comprise administering a pharmaceutical composition to a subject. In other embodiments, vaccines comprising at least one chimeric peptide, multivalent peptide, or both, of the polynucleotide which encodes the same are provided. The pharmaceutical composition comprises a pharmaceutically acceptable vehicle and at least one chimeric peptide, multivalent peptide, or both, or the polynucleotide which encodes the same, as described herein. Pharmaceutically acceptable vehicles, include, but are not limited to pharmaceutically acceptable carriers, excipients or diluents. These vehicles are generally nontoxic to subjects at the dosages and concentrations employed.

In addition to the epitopes, multivalent peptides, and chimeric peptides or the polynucleotide which encodes the same, other components, such as a vehicle for antigen delivery and immunostimulatory substances designed to enhance the protein's immunogenicity are included in the pharmaceutical composition. Examples of vehicles for

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antigen delivery include aluminum salts, water-in-oil emulsions, biodegradable oil vehicles, oil-in-water emulsions, biodegradable microcapsules, and liposomes. For the vaccines which comprise the chimeric peptide, a suitable vehicle for antigen delivery is a biodegradable microsphere, which may be comprised of poly (D, L- lactide-co-glycolide) (PLGA).

While any suitable vehicle may be employed in the pharmaceutical compositions of this invention, the type of carrier will vary depending on the mode of administration and whether a substantial release is desired. For parenteral administration, such as subcutaneous injection, the carrier may be water, saline, alcohol, a fat, a wax, or a buffer. Biodegradable microspheres (e.g., polylactic galactide) may also be employed as vehicles for the pharmaceutical compositions of this invention. According to some embodiments, the pharmaceutical composition comprises an adjuvant.

The HER-2 chimeric and multivalent peptides and the polynucleotides which encode the same may be useful for enhancing or eliciting, in a subject or a cell line, a humoral response and, preferably, a cellular immune response (e.g., the generation of antigen-specific cytolytic T cells). In some examples the subject is a human. A subject may be afflicted with cancer or other cancer involving HER-2, such as breast cancer, or may be normal (i.e., free of detectable disease and infection). The pharmaceutical compositions and vaccines may be useful for treating women who have a family history of breast cancer or who have had breast tumors removed. According to some embodiments, "treating" means inhibiting or slowing or retarding the growth of the tumor. Such cancers include, but are not limited to, breast, lung, ovarian, bladder and prostate. In some examples, multiple intramuscular injections, at three week intervals, are used to administer the pharmaceutical composition.

Examples

Exemplary methods are described below, although methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present peptides, compositions and methods.

The materials, methods, and examples are illustrative only and not intended to be limiting.

Peptide Synthesis and HPLC Purification. Peptides were synthesized as previously described (Kaumaya 1994). Briefly, peptides were synthesized on a Milligen/Bioscience 9600 peptide synthesizer, using a 4-methylbenzhydrylamine resin as the solid support (substitution 0.54mm/g). The Fmoc/t-butyl synthetic method was employed using 4-(hydroxymethyl) phenoxyacetic acid as the linker. After the final deprotection step, protecting groups and peptide resin bond were cleaved with 90% TFA, 5% anisole, 3% thioanisole, 2%

ethanedithiol. Crude peptide was purified by semipreparative HPLC using a Vydac C4 (10mm x 25cm) column at 32.5°C. Buffers were 0.1% TFA in H₂O and 0.1% TFA in acetonitrile. Peptides incorporate a "promiscuous" T cell epitopes MVF 288-302 (Kaumaya 1994): DW1MVF (HER-2 376-395), MVFDW4 (628-647), DW5MVF (115-136), DW6MVF (410-429).

Gel Filtration. 20mg/ml acidified peptide solution (.1mg/ml in DTT) was loaded onto a Sephadex G-25 column and 5ml fractions eluted with 0.1M HOAc. Peptide samples were measured spectrophotometrically at 235nm and absorbance values plotted vs. time. Samples with absorbance values above 0.1 and eluting before DTT were pooled and lyophilized. The reaction was monitored for completion by Ellman's reagent at 410nm.

Capillary Zone Electrophoresis. CZE was performed on a Beckman P/ACE System 2100 interfaced with an IBM computer. Sample was voltage separated (15kV) in 100mM sodium borate using a 50cm capillary over 20min. Eluant was monitored at 214nm.

Circular Dichroism and mass spectrometry. Measurements were performed on a JASCO J-500 spectropolarimeter interfaced with an IBM computer. The instrument was calibrated in 0.06% (w/v) solution of ammonium-d-10-camphorsulfonate. The CD spectra of the peptides (62.5- 250uM by dilution of peptide stocks in water) were measured at ambient temperature in a 0.1cm path length cylindrical quartz cuvette (Hellma). Mean residue ellipticity (mdeg) was calculated using the relationship $[\theta] = 100 \theta / c n l$ where θ is the ellipticity, c is the peptide concentration (mM), n is the number of amino acids in the peptide, and l is the path length (cm). Fast atom bombardment (FAB) mass spectrometry measurements were carried out on a inneganMat-900 instrument.

Mercuric Acetate. Peptide was dissolved in a minimal amount of water and 100mg/mm S-tBu solution (2- 10 fold excess) added. Peptide was placed under vacuum and precipitated by 2-Mercaptoethanol in a 55°C water bath under stirring. After filtering through dampened Celite, the filtrate was rotary evaporated, acidified with 0.1% TFA in water and lyophilized.

Biological Procedures

Immunizations and animals. Female New Zealand white rabbits were obtained from Mohican Valley Rabbitry (Loudenville, OH). Rabbits were immunized subcutaneously at multiple sites with a total of 1mg of peptide emulsified in CFA. Subsequent booster injections (1mg and 500µg in PBS) were given three and six weeks after the primary immunization. Sera were collected and complement inactivated by heating to 56°C for

30min. Sera aliquots were stored at -5 to -15°C. Antibodies were purified by ammonium sulfate precipitation: A stock solution of saturated ammonium sulfate solution (SAS) was prepared, autoclaved and cooled to 4°C. Antibody was allowed to precipitate by slowly adding SAS to 35% v/v under stirring in cold room. Samples were centrifuged 14,000 xg 20min and the supernate stored at -20°C. The pellet was dissolved with 0.1M PBS in ½ original volume. Fractions were then placed in Slide-a-lyzer cassettes (Pierce) and dialyzed against frequent changes of >200 volumes pH 8, 0.15M NaCl. The saline was brought to pH 8 with a few drops of 0.1M NaOH. IgG concentration was determined by radial immunodiffusion (RID) (The Binding Site, UK). Monoclonal antibodies were purchased from Oncogene Science.

Direct ELISA. U-bottom polyvinyl chloride plastic assay plates were coated with 100µl of antigen at 2µg/ml in PBS overnight at 4°C. Nonspecific binding sites were blocked for 1 hour with 200µl PBS-1% BSA and plates were washed with PBT (phosphate-buffered saline containing 0.05% Tween 20 and 1% horse serum). Rabbit antiserum 1/500 or mouse antiserum 1/50 in PBT was added to antigen coated plates, serially diluted 1:2 in PBT, and incubated 2hr at room temperature. After washing the plates, 50µl of 1/500 goat anti-rabbit or goat anti-mouse IgG conjugated to horseradish peroxidase (Pierce Chemical Co.) was added to each well. Excess antibody conjugate was removed, and bound antibody was detected using 50µl of 0.15% H₂O₂ in 24mM citric acid, 5mM sodium phosphate buffer, pH 5.2, with 0.5 mg/ml 2,2'-aminobis(3-ethylbenzthiazoline-6-sulfonic acid) as the chromophore. Color development was allowed to proceed for 10min and the reaction was stopped with 25µl of 1% sodium dodecylsulfate. Absorbance was determined at 410nm using a Dynatech MR700 ELISA reader. Results are expressed as the mean absorbance of duplicate wells after subtraction of background.

Cell Culture. Stock cultures were maintained at 37°C in a 5% CO₂ incubator. All cell culture media, FCS, and supplements were purchased from GEBCO (Grand Island, NY). The human breast adenocarcinoma cell lines SKBR-3 and MCF-7 were obtained from the American Type Culture Collection and was subcultured in McCoy's 5A or DMEM supplemented with 10% FCS and L-glutamine. Cav-1 was maintained in RPMI 1640 with 10% FCS and L-glutamine. Cav-1 was derived from a fresh colon tumor specimen which was cryopreserved and subsequently cultured; it does not express detectable levels of HER-2/*neu*. SKBR3 is a breast tumor cell line which overexpresses the HER-2 protein while MCF-7 expresses the normal concentration of protein.

Immunoprecipitation and Western Blotting. On day zero, 1.0×10^7 SKBR3 cells were plated in 75cm^3 cell culture flasks and allowed to adhere overnight. Anti-peptide antibodies were added ($100\text{ }\mu\text{g/ml}$) for 4 hrs. The reaction was stopped by aspirating the media and immediately adding ice cold 0.1M phosphate buffered saline (PBS). Cells were trypsinized and washed twice with cold Hank's Balanced Salts Solution (HBSS). Cold lysis buffer (150mM NaCl; 50 mM Tris, pH 8; 10mM EDTA, 10mM sodium pyrophosphate, 10mM sodium fluoride; 1% NP-40, 0.1% SDS) containing 3mM Na_3VO_4 , $10\mu\text{g/ml}$ each aprotinin and leupeptin was added to cells resuspended in $100\mu\text{l}$ HBSS. Lysis was achieved by gentle rotation at 4°C for 20min. After centrifugation ($14,000\times g$, 20min) to remove cell debris, lysates were incubated with $3\text{-}5\mu\text{g}$ antibody and $30\mu\text{l}$ Protein A/Protein G (Oncogene Science) overnight. Beads were pelleted by centrifugation ($14,000\times g$ 30sec), washed twice in lysis buffer containing 1mM Na_3VO_4 and boiled in SDS sample buffer 5 min.

Proteins were resolved by 7.5% SDS-PAGE, transferred to nitrocellulose and probed with antibody. Protein transfer was monitored with prestained molecular mass standards (BioRad). Immunoreactive bands were detected using horse radish peroxidase conjugated goat anti rabbit immunoglobins by enhanced chemiluminescence (Amersham).

Indirect Binding Assay. SKBR3 cells or MCF-7 cells were plated at 5,000 cells/well in V-bottom plates (Linbro, McLean VA). The cells were incubated with various concentrations of antibodies. After being washed with Hank's Balanced Salts Solution (HBSS) the cells were incubated for one hour with fluorescein isothiocyanate (FITC)-conjugated goat anti-rabbit or goat anti-mouse antibody and fixed with formalin. A mouse monoclonal Ab (Oncogene Science, Cambridge, MA) was used as the positive control and an anti-CD3 Ab as the negative control. The cells were analyzed by a Coulter ELITE flow cytometer (Coulter, Hialeah, FL), which has an argon laser for excitation at 488nm , and a 525nm band pass filter for FITC fluorescence 5.0×10^3 cells were counted for each sample and final processing was performed. Debris, cell clusters and dead cells were gated out by light scattered assessment before single parameter histograms were drawn.

Effect of Abs on cell proliferation. SKBR3, MCF7 and CAVI cells were plated 5,000 cells/well in V-bottom plates along with various concentrations of Ab on day zero. On day 3, cells were pulsed with $[^3\text{H}]$ thymidine ($1\text{ }\mu\text{Ci/well}$) at which time they were placed in a 20°C freezer for 1h. After thawing at room temperature cells were harvested in a PHD cell harvester (Cambridge Tech, Inc.). Samples were incubated in 5ml Ready Safe liquid

scintillation cocktail (Beckman) and radioactivity determined by beta counter. Results are expressed as the mean CPM +/- the standard deviation (SD).

CTL Assay: In vitro stimulation. Inguinal and periaortic lymph nodes (LN) are removed 7-10 days after immunization. LN cells (4×10^6 - 5×10^6) are then stimulated *in vitro* by coculturing with 1.5×10^5 irradiated (10 000 rad) P815 cells prepulsed for 1h with $1 \mu\text{M}$ of the appropriate CTL peptide. The culture medium used is cDMEM (DMEM supplemented with 10% FCS). Supernatant containing 30 U/ml (final) of IL-2, 2mM L-glutamine, 10mM Hepes and 5×10^5 M-2-mercaptoethanol).

Seven days after *in vitro* stimulation, the CTL activity is tested in a standard chromium-release assay. P815 cells (10^6) are labeled with 150 μCi sodium [^{51}Cr] chromate for 1h at 37°C in the presence or absence of the appropriate peptide ($1 \mu\text{M}$) and washed three times. Labeled targets (2×10^3) are co-incubated with stimulated LN cells at predetermined ratios in 200 μl volumes in V-bottom 96 well plates. After a 4h incubation at 37°C, the supernatants (100 μl) are harvested for γ -counting. The % specific lysis is calculated as $100 \times [(\text{experimental-spontaneous release})/(\text{total-spontaneous release})]$ (Valmori, et al. 1994).

Effect of antibodies in vivo. HER2 cells (3×10^6) were suspended in 250 μl PBS, mixed with 250 μl MATRIGEL (Beckton Dickinson) on ice and injected subcutaneously into mice. Polyclonal antibodies to a total concentration of 2mg/mouse, were injected i.p. on days 9 and 11. Tumor volume was measured twice weekly with calipers and calculated by the formula (length x width x height).

Example 1 – A Conformational HER-2 B-Cell Epitope Incorporating of Two Native Disulfide Bonds Show Enhanced Tumor Cell Binding.

The human EGFR disulfide pairings have been defined. Based on the high homology between EGFR and HER-2, the 628-647 epitope to 626-649 to incorporate two disulfide bonds between Cys-626 and Cys-634, and Cys-630 and Cys-642. Differential side chain protection and a specialized deprotection and oxidation successfully generated the cyclized product with a desired secondary structural characteristics as determined by CD measurements. Both linear and cyclized constructs were highly immunogenic (titers >200,000) in outbred mice. Flow cytometry analysis showed that the antibodies against the cyclized epitope bound the HER-2 protein with a higher affinity than the non-cyclized epitope (mean log fluorescence 2.29 and 1.65 respectively). Antibodies against both the cyclized and non-cyclized epitopes were able to cause a reduction of growth in cells overexpressing HER-2 as measured in an anchorage-independent growth assay (31 and 58%

inhibition, respectively). Antibodies against both constructs were able to elicit IFN- γ release in the presence of effector human PBMCs, with the cyclized antibodies inducing 25% higher levels of IFN- γ compared to the linear antibodies. Cyclized antibodies elicited twice the level of specific lysis compared to non-cyclized antibodies in an ADCC assay (11 and 5.6% respectively). To investigate the *in vivo* effect of these peptide vaccines, inbred FVB/N mice were immunized with the constructs. Both constructs were immunogenic in these mice with the cyclized construct generating higher titers. These mice were then challenged with the NT2.5 tumor cell line which has an FVB/N background. The mice immunized with the cyclized conformational construct had a reduction in tumor volume compared to both the linear and control MVF immunized mice. Cyclized vaccinated mice had the longest doubling time (6.63 days), thereby demonstrating the greatest ability to impede tumor growth compared to linear or MVF control peptide (4.31 and 4.48 days, respectively). Thus, these results show that conformational peptides for eliciting high affinity Abs has immediate application for the design of effective Her-2 vaccines.

Example 2 - Design and Synthesis of Novel HER-2 B-cell epitopes

Four new constructs were selected for synthesis as shown in Table 1. All four constructs contain at least one region of the three regions that make contact with trastuzumab. HER-2 B epitopes were synthesized co-linearly with the MVF promiscuous Th epitope. Peptide synthesis was performed using Fmoc/t-But chemistry. The formation of three disulfide bonds for epitope 563-598 was achieved using differentially protected cysteine residues shown in Figure 2. The first disulfide bond is formed using iodine oxidation. The addition of water boosts AcM removal and the concomitant formation of a disulfide bond between C567 and C584. The final disulfide bond between C563 and C576 was formed using the silyl chloride-sulfoxide method.

Designation	Peptide	Sequence	M.Wt. (da)
MVF 563 SS	563-598 peptide with 3 disulfide bonds	H ₂ N-KLLSLIKGVIVHRLEGVE-GPSL-CHPECQPGNGSVTCFGPEADQCVACAHYKDPPFCVA-COOH	6181
MVF 585 SS	585-598 peptide with one disulfide bond	H ₂ N-KLLSLIKGVIVHRLEGVE-GPSL-VACAHYKDPPFCVA-COOH	3856
MVF 597 SS	597-626 peptide with one disulfide bond	H ₂ N-KLLSLIKGVIVHRLEGVE-GPSL-VARCPSGVKPDLSYMPIWKFPDEEGACQPL-COOH	5872
MVF 613	613-626 peptide	H ₂ N-KLLSLIKGVIVHRLEGVE-GPSL-IWKFPDEEGACQPL-COOH	3977

Table 1 shows candidate peptide vaccines from the HER-2/Herceptin structure. The promiscuous T-helper epitope sequence, shown in italics, is linked to the B-cell epitope via a four residue turn sequence (GPSL). Underlined amino acids were mutated from Cys to Leu so as not to interfere with natural disulfide formation.

Example 3 - Immunogenicity of HER-2 Peptides

The immunogenicity of the 4 constructs listed in Table 1 was determined using both the disulfide-bonded and linear constructs by immunizing groups of FVB/n mice (n=4-9) 6-8 weeks old. Both 563-598 cyclized and non-cyclized constructs was highly immunogenic (Fig. 3A); by three weeks after the third immunization all mice had titers above 120,000 and two mice with the cyclized construct (MVF563SS) had titers above 250,000. The 585-598 construct proved to be the least immunogenic (Fig. 3B), three weeks after the third immunization only one mouse from both the cyclized (SS) and linear (NC) groups had a titer above 120,000 with a mean titer around 58,000. Both the 597-626 and 613-626 peptide constructs were highly immunogenic (Fig. 3 C, D). Three mice that received the cyclized form of 597-626 had titers above 120,000, while no mouse that received the linear form had titers above 120,000.

Second, we tested the immunogenicity of the B-cell epitopes in *neu*-N transgenic mice developed by Guy *et al.*. The *neu*-N transgenic mice elicited high titers of Abs (data not shown) to the peptide constructs similar to those seen in FVB/n mice even though these mice have low basal levels of neu specific IgG upon vaccination with a neu-specific whole-cell vaccine.

Example 4 - Cross reactivity of Herceptin binding peptides with Herceptin (trastuzumab)

Whether the conformational peptides from trastuzumab binding sites could recognize herceptin by ELISA was tested. As shown in Fig. 4, various peptides in the binding region of 563-626 bound trastuzumab. Maximum binding occurred with cyclized epitope 563-598 which possesses the 3 disulfide pairings. This result is in contrast with the FACS binding of antibodies to HER-2 due to glycosylation.

Example 5 - Cross-reactivity of Peptide Antibodies with HER-2 protein

To determine if antibodies elicited by the Herceptin-peptide epitopes show differences in their ability to recognize the HER-2 receptor, the binding of FVB/n purified antibodies to the HER-2 over-expressing human breast cancer cell line BT474 was tested. Figure 5 C, D shows that both the 597-626 and the 613-626 construct are shifted relative to normal mouse antibodies. However the 563-598 and the 585-598 constructs showed little shift compared to normal mouse antibodies (Fig. 5 A, B). The 563-598 contains two of the three contacts that HER-2 makes with trastuzumab. The 597-626 epitope, which contains the last contact point with trastuzumab consist of 11 amino acids that recognize the native protein (Fig. 5C). The shorter version of this sequence 613-626 also recognizes the native protein in a similar manner (Fig. 5D). A plausible explanation for the lack of recognition of epitope 563-598 and 585-598 is that there is a potential glycosylation site at residues 571-573 (NGS) with the large bulky sugar moiety interfering sterically and prevents binding of that epitope.

Example 6 - Tumor Challenge

To better understand the potential clinical benefit associated with introducing conformational constraints into B-cell epitope vaccines, both FVB/n and *neu*-N transgenic mice were challenged with the tumor cell line NT2.5 derived from a spontaneous mammary tumor isolated from a *neu*-N transgenic mouse. As a consequence of *neu* over-expression these mice develop spontaneous mammary adenocarcinomas in a manner similar to that observed in human breast cancer patients, and are therefore a suitable model for human breast cancer studies. Groups of FVB/n mice were challenged with 5×10^6 NT2.5 cells s.c. (lower abdomen) two weeks after final immunization. Tumor measurements were taken twice weekly until day 55. Tumor volumes were calculated by the formula (long measurement x short measurement²)/2. Note that after day 30 the tumors in FVB/n mice begin to regress, indicative of rejection of the tumor. With subsequent tumor studies using FVB/n mice, tumors were measured to day 30. Mice immunized with the 563-598 NC and SS constructs

had mean tumor volumes at day 30 of 166.517 and 173.7292 mm³ respectively while unimmunized mice had a mean tumor volume of 346.6563 mm³ (data not shown). By day 33 mice immunized with the 613-626 and 585-598CYC showed a reduction in tumor volume compared to both unimmunized and MYF immunized mice. While there appears to be some moderate success in terms of reduction in tumor burden of mice immunized with the trastuzumab B-cell epitopes, nearly all mice developed tumors.

Example 7 - Design and evaluation of novel pertuzumab-binding conformational B-cell epitopes

The 3 peptide sequence listed in the Table 2 were designed to further delineate the minimal sequence to elicit an antibody similar to the pertuzumab binding site. These complex conformational peptide epitopes have been synthesized, successfully purified, and cyclized with the correct disulfide pairings. Epitope 266-296 (SH bond between Cys268-Cys295, Epitope 298-333 (SH bond between Cys 299-Cys311, and Epitope 315-333 (SH bond Cys 315-Cys 331) should allow us to delineate the minimal pertuzumab binding epitope.

Designation	Peptide	Sequence
MVF 266 CYC	266-296	H2N-KLLSLIKGVIVHRLEGVE-GPSL-LHCPALVTYNTDTFESMPNPEGRTFGASCV-COOH
MVF 298 CYC	298-333	H2N-KLLSLIKGVIVHRLEGVE-GPSL-ACPYNYLSTDVGSCTLVCP LHNQEVTAEDGTQRCEK-COOH
MVF 315 CYC	315-333	H2N-KLLSLIKGVIVHRLEGVE-GPSL-CPLHNQEVTAEDGTQRCEK-COOH

Table 2 shows engineered HER-2 B chimeric peptides. The peptide designated MVF 266 CYC is SEQ ID NO: 23, MVF 298 CYC is SEQ ID NO: 24 and MVF 315 CYC is SEQ ID NO: 25.

Additional results are shown in Figs. 6-30.

The scope of the claims should not be limited by the preferred embodiments set forth in the description, but should be given the broadest interpretation consistent with the description as a whole.

Claims

1. A chimeric peptide, wherein the chimeric peptide comprises a HER-2 B epitope, a T helper (Th) epitope, and a linker joining the HER-2 B epitope to the Th epitope, wherein:
the sequence of the HER-2 B epitope is LHCPALVTYNTDTFESMPNPEGRYTFGASCV (SEQ ID NO: 6);
the Th epitope comprises a sequence wherein the sequence is: KLLSLIKGVIVHRLEGVE (SEQ ID NO: 10); NSVDDALINSTIYSYFPSV (SEQ ID NO: 11); PGINGKAIHLVNNQSSE (SEQ ID NO: 12); QYIKANSKFIGITEL (SEQ ID NO: 13); FNNFTVSFWLRVPKVSASHLE (SEQ ID NO: 14); LSEIKGVIVHRLEGV (SEQ ID NO: 15); FLLTRILTIPQSLN (SEQ ID NO: 16); or TCGVGVRVRSRVNAANKKPE (SEQ ID NO: 17); and
the linker is from 1 to 15 amino acids.
2. A composition comprising a mixture of two or more chimeric peptides wherein one chimeric peptide is as defined in claim 1 wherein the sequence of the HER-2 B epitope is LHCPALVTYNTDTFESMPNPEGRYTFGASCV (SEQ ID NO: 6), and wherein the HER-2 B epitope of each of the two or more chimeric peptides are different and wherein one of the HER-2 B epitopes is CHPECQPQNGSVTCFGPEADQCVACAHYKDPPFCVA (SEQ ID NO: 2); VACAHYKDPPFCVA (SEQ ID NO: 3); VARCPSGVKPDLSEMPIWKFPDEEGACQPL (SEQ ID NO: 4); or IWKFPDEEGACQPL (SEQ ID NO: 5).
3. The chimeric peptide as claimed in claim 1 wherein at least one of the HER-2 B epitope, the Th epitope, or the linker is in retro-inverso form.
4. The chimeric peptide as claimed in claim 1 wherein the linker comprises 2 to 15 amino acids.
5. The chimeric peptide as claimed in claim 1 wherein the linker comprises a sequence of GPSL.
6. The chimeric peptide as claimed in claim 1 wherein the Th epitope comprises a sequence of KLLSLIKGVIVHRLEGVE (SEQ ID NO: 10).
7. The chimeric peptide as claimed in claim 1 wherein the Th epitope comprises a sequence of NSVDDALINSTIYSYFPSV (SEQ ID NO: 11).

8. The chimeric peptide as claimed in claim 1 wherein the Th epitope comprises a sequence of PGINGKAIHLVNNQSSE (SEQ ID NO: 12).
9. The chimeric peptide as claimed in claim 1 wherein the Th epitope comprises a sequence of QYIKANSKFIGITEL (SEQ ID NO: 13).
10. The chimeric peptide as claimed in claim 1 wherein the Th epitope comprises a sequence of FNNFTVSFWLRVPKVSASHLE (SEQ ID NO: 14).
11. The chimeric peptide as claimed in claim 1 wherein the Th epitope comprises a sequence of LSEIKGVIVHRLEGV (SEQ ID NO: 15).
12. The chimeric peptide as claimed in claim 1 wherein the Th epitope comprises a sequence of FLLTRILTIPQSLN (SEQ ID NO: 16).
13. The chimeric peptide as claimed in claim 1 wherein the Th epitope comprises a sequence of TCGVGVRVRSRVNAANKKPE (SEQ ID NO: 17).
14. A chimeric peptide for stimulating an immune response to HER-2 protein, wherein said chimeric peptide is a multivalent peptide and comprises two or more HER-2 B epitopes, a Th cell epitope, and a template, wherein:
 - each of said two or more HER-2 B epitopes are different from the others; and wherein the sequence of one of said two or more HER-2 B epitopes is
LHCPALVTYNTDTFESMPNPEGRYTFGASCV (SEQ ID NO: 6);
 - and the sequence(s) of each of the other of said two or more HER-2 B epitopes is:
CHPECQPQNGSVTCFGPEADQCVACAHYKDPPFCVA (SEQ ID NO: 2);
VACAHYKDPPFCVA (SEQ ID NO: 3); VARCPSGVKPDL SYMPIWKFPDEEGACQPL (SEQ ID NO: 4);
IWKFPDEEGACQPL (SEQ ID NO: 5);
ACPYNYLSTDVGSCTLVCP LHNQEVT AEDGTQRCEK (SEQ ID NO: 7); or
CPLHNQEVT AEDGTQRCEK (SEQ ID NO: 8);
 - the Th epitope comprises a sequence, wherein the sequence is: KLLSLIKGVIVHRLEGVE (SEQ ID NO: 10); NSVDDALINSTIYSYFPSV (SEQ ID NO: 11); PGINGKAIHLVNNQSSE (SEQ ID NO: 12); QYIKANSKFIGITEL (SEQ ID NO: 13); FNNFTVSFWLRVPKVSASHLE (SEQ ID NO: 14);

LSEIKGVIVHRLEGV (SEQ ID NO: 15); FLLTRILTIPQSLN (SEQ ID NO: 16); or
TCGVGVRVRSRVNAANKKPE (SEQ ID NO: 17);

the HER-2 B epitopes and the Th cell epitope are attached to the template; and
the template comprises two strands of alternating leucine and lysine residues connected by a
linker of 1 to 15 amino acids.

15. A use of a chimeric peptide that comprises a HER-2 B epitope, a T helper (Th) epitope, and
a linker joining the HER-2 B epitope to the Th epitope, to stimulate an immune response in a subject,
wherein:

the sequence of the HER-2 B epitope is:

LHCPALVTYNTDTFESMPNPEGRTYFGASCV (SEQ ID NO: 6);

the Th epitope comprises a sequence, wherein the sequence is: KLLSLIKGVIVHRLEGVE (SEQ ID
NO: 10); NSVDDALINSTIYSYFPSV (SEQ ID NO: 11); PGINGKAIHLVNNQSSE (SEQ ID NO: 12);
QYIKANSKFIGITEL (SEQ ID NO: 13); FNNFTVSFWLRVPKVSASHLE
(SEQ ID NO: 14); LSEIKGVIVHRLEGV (SEQ ID NO: 15); FLLTRILTIPQSLN (SEQ ID NO: 16); or
TCGVGVRVRSRVNAANKKPE (SEQ ID NO: 17); and

the linker is from 2 to 15 amino acids.

16. A use of a multivalent peptide, wherein the multivalent peptide comprises two or more HER-2
B epitopes, a Th cell epitope, and a template, to stimulate an immune response in a subject,
wherein:

each of the two or more HER-2 B epitopes are different from the others; and wherein the
sequence of one of said two or more HER-2B epitopes is

LHCPALVTYNTDTFESMPNPEGRTYFGASCV (SEQ ID NO: 6); and

the sequence of each of the further HER-2 B epitopes is selected from:

CHPECQPQNGSVTCFGPEADQCACAHYKDPPFCVA (SEQ ID NO: 2);

VACAHYKDPPFCVA (SEQ ID NO: 3); VARCPSGVKPDLSYMPIWKFPDEEGACQPL (SEQ ID NO:
4);

IWKFPDEEGACQPL (SEQ ID NO: 5);

ACPYNYLSTDVGSCTLVCPHLNQEVTAEDGTQRCEK (SEQ ID NO: 7); or

CPLHNQEVTAEDGTQRCEK (SEQ ID NO: 8);

the Th epitope comprises a sequence selected from: KLLSLIKGVIVHRLEGVE (SEQ ID NO:
10); NSVDDALINSTIYSYFPSV (SEQ ID NO: 11); PGINGKAIHLVNNQSSE (SEQ ID NO: 12);
QYIKANSKFIGITEL (SEQ ID NO: 13); FNNFTVSFWLRVPKVSASHLE (SEQ ID NO: 14);

LSEIKGVIVHRLEGV (SEQ ID NO: 15); FLLTRILTIPQSLN (SEQ ID NO: 16); or
TCGVGVRVRSRVNAANKKPE (SEQ ID NO: 17);

the HER-2 epitopes and the Th cell epitope are attached to the template; and

the template comprises two strands of alternating leucine and lysine residues connected by a linker of 1 to 15 amino acids.

17. A use of a pharmaceutical composition, said pharmaceutical composition comprising a pharmaceutically acceptable vehicle, and a chimeric peptide that comprises a HER-2 B epitope, a T helper (Th) epitope, and a linker joining the HER-2 B epitope to the Th epitope, for the prevention or treatment of cancer expressing a HER-2 B protein,

wherein:

the sequence of the HER-2 B epitope is LHCPALVTYNTDTFESMPNPEGRTFGASCV (SEQ ID NO: 6);

the Th epitope comprises a sequence wherein the sequence is: KLLSLIKGVIVHRLEGVE (SEQ ID NO: 10); NSVDDALINSTIYSYFPSV (SEQ ID NO: 11); PGINGKAIHLVNNQSSE (SEQ ID NO: 12); QYIKANSKFIGITEL (SEQ ID NO: 13); FNNFTVSFWLRVPKVSASHLE (SEQ ID NO: 14); LSEIKGVIVHRLEGV (SEQ ID NO: 15); FLLTRILTIPQSLN (SEQ ID NO: 16); or TCGVGVRVRSRVNAANKKPE (SEQ ID NO: 17); and the linker is from 2 to 15 amino acids.

18. The use as claimed in claim 17 wherein the cancer is: breast cancer, ovarian cancer, lung cancer, prostate cancer, or colon cancer.

19. The use as claimed in claim 18 wherein the cancer is breast cancer.

20. The use as claimed in claim 17 wherein:

the pharmaceutical composition further comprises a mixture of chimeric peptides:

the mixture comprises two or more chimeric peptides; and

each of the two or more chimeric peptides comprise the HER-2 B epitope, the T helper (Th) epitope; and the linker joining the HER-2 B epitope to the Th epitope; wherein the HER-2 B epitope of each of the two or more chimeric peptides are different from the others and wherein the sequence of one of said two or more HER-2 B epitopes is LHCPALVTYNTDTFESMPNPEGRTFGASCV (SEQ ID NO: 6); and wherein the sequence of each of the further HER-2 B epitopes is CHPECQPQNGSVTCFGPEADQCVACAHYKDPPFCVA (SEQ ID NO: 2);

VACAHYKDPPFCVA (SEQ ID NO: 3); VARCPSGVKPDLSYMPIWKFPDEEGACQPL (SEQ ID NO: 4);
 IWKFPDEEGACQPL (SEQ ID NO: 5);
 ACPYNYLSTDVGSCTLCPLHNQEVTAE DGTQRCEK (SEQ ID NO: 7); or
 CPLHNQEVTAE DGTQRCEK (SEQ ID NO: 8).

21. A vaccine, comprising a HER-2 B epitope, a T helper (Th) epitope, and a linker joining the HER-2 B epitope to the Th epitope, wherein:

the sequence of the HER-2 B epitope is LHCPALVTYNTDTFESMPNPEG RYTFGASCV (SEQ ID NO: 6);

the Th epitope comprises a sequence selected from: KLLSLIKGVIVHRLEGVE (SEQ ID NO: 10);
 NSVDDALINSTIYSYFPSV (SEQ ID NO: 11); PGINGKAIHLVNNQSSE (SEQ ID NO: 12);
 QYIKANSKFIGITEL (SEQ ID NO: 13); FNNFTVSFWLRVPKVSASHLE (SEQ ID NO: 14);
 LSEIKGVIVHRLEGV (SEQ ID NO: 15); FLLTRILTIPQSLN (SEQ ID NO: 16); or
 TCGVGVRVRSRVNAANKKPE (SEQ ID NO: 17); and
 the linker is from 1 to 15 amino acids.

22. The vaccine as claimed in claim 21 further comprising at least one additional HER-2 B epitope, T helper (Th) epitope, and linker joining the additional HER-2 B epitope to the Th epitope, wherein the at least one additional HER-2 B epitope is different from the HER-2 B epitope.

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1 melaalcrwg lllallppga astqvctgtd mklrlpaspe thldmlrhly qgcqvvggnl
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481 pwdqlfrnph qallhtanrp edecvgegla chqlcarghc wpggptqcvn csqflrgqec
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FIGURE 1

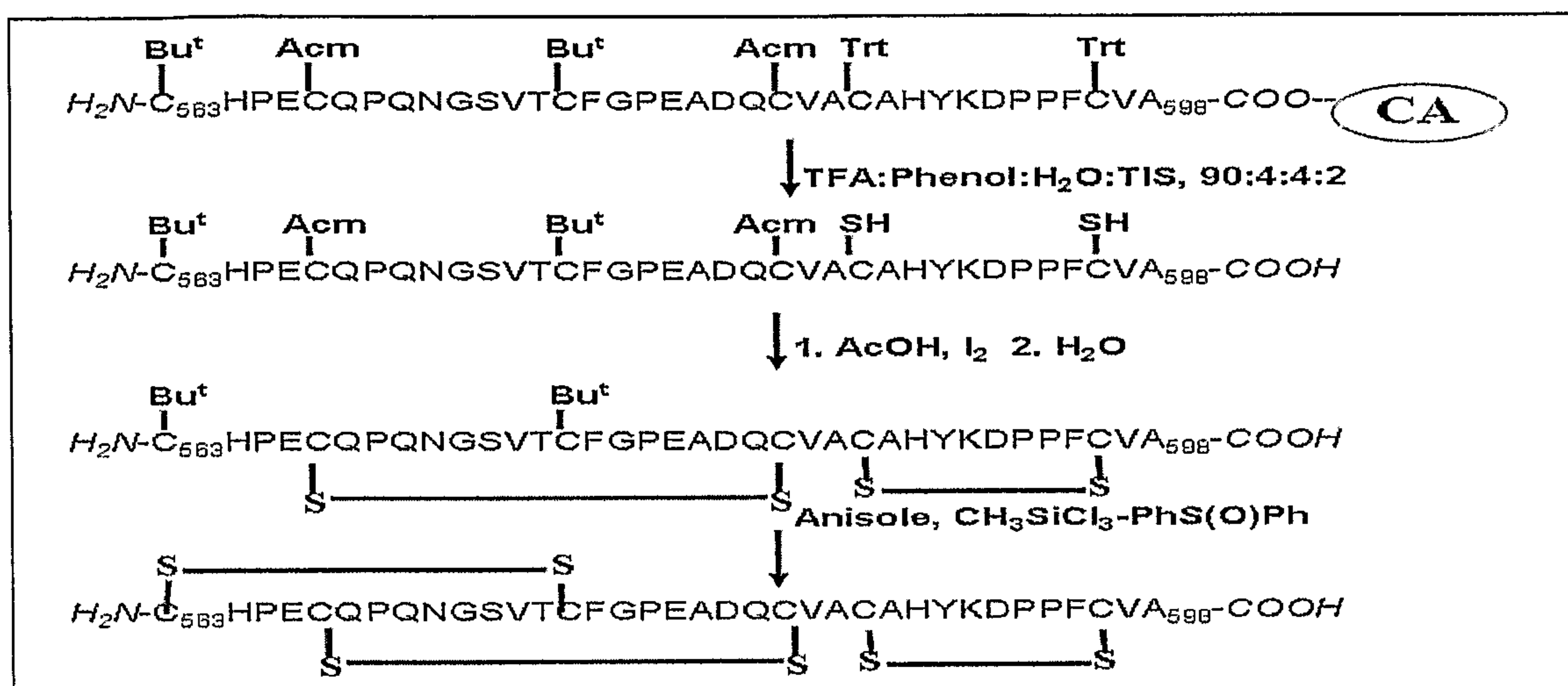


FIGURE 2

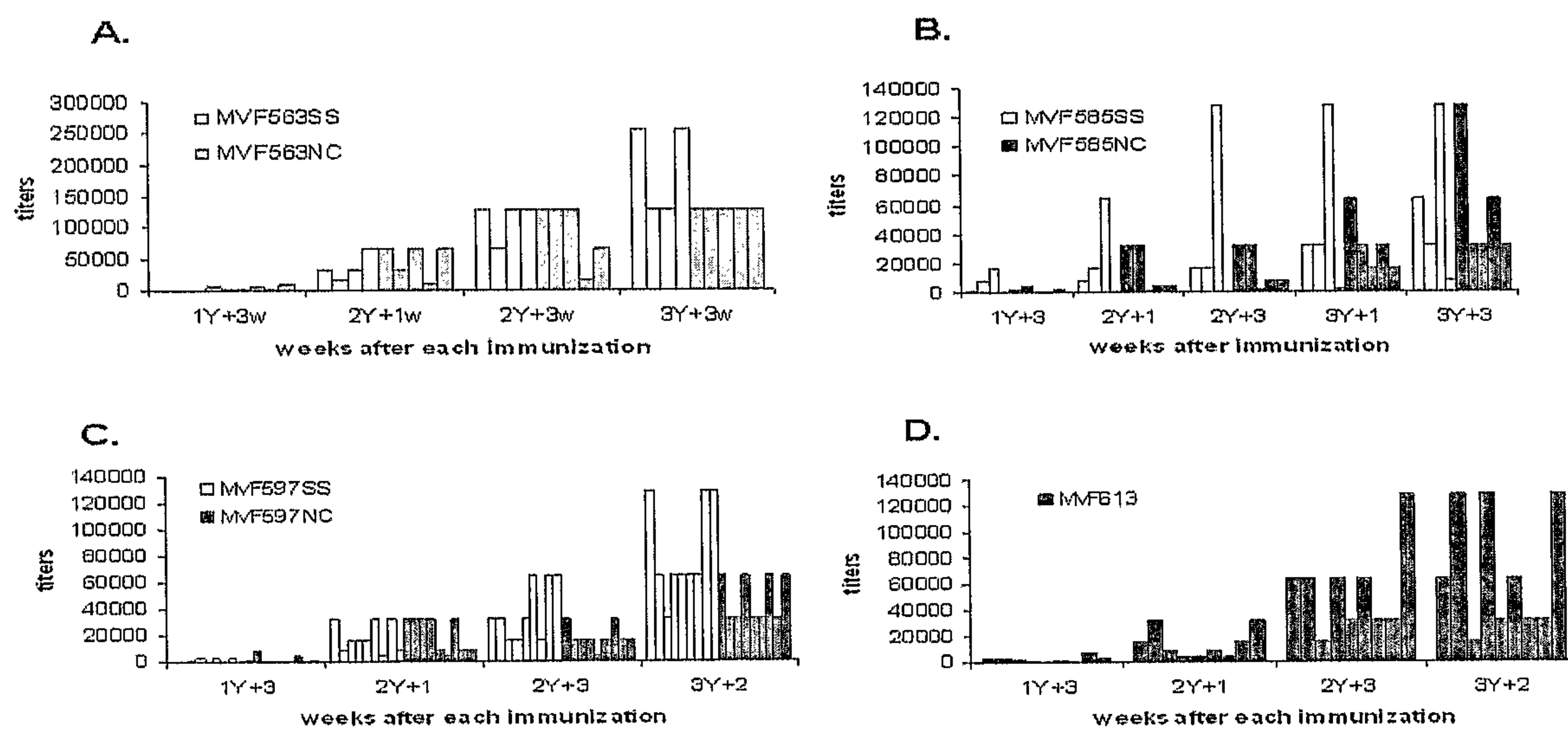
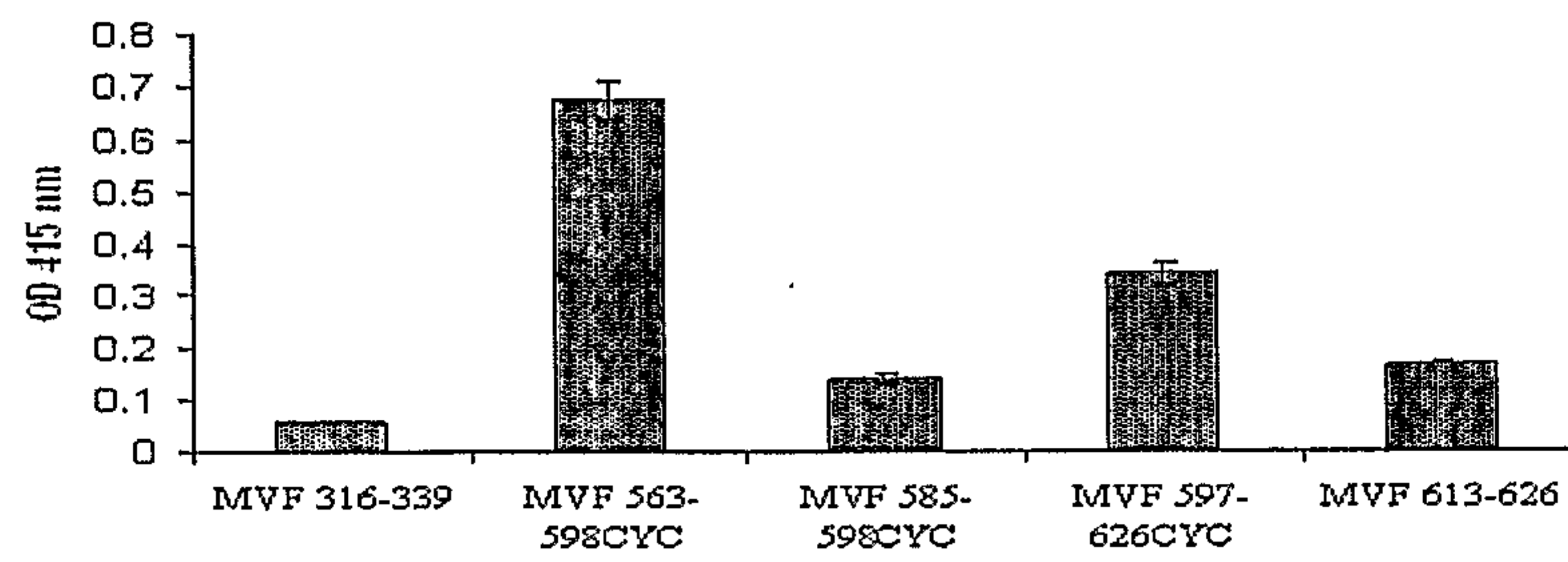
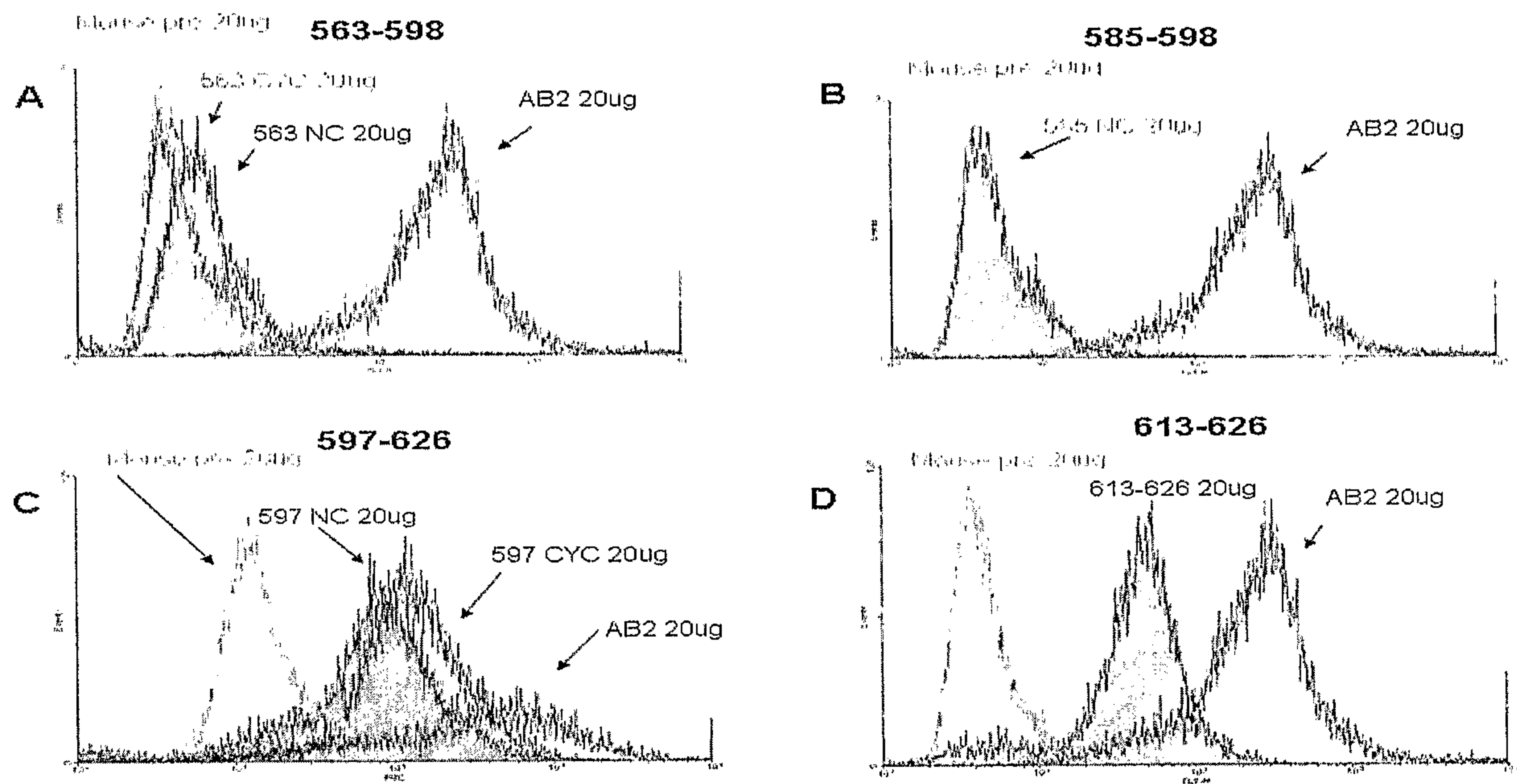
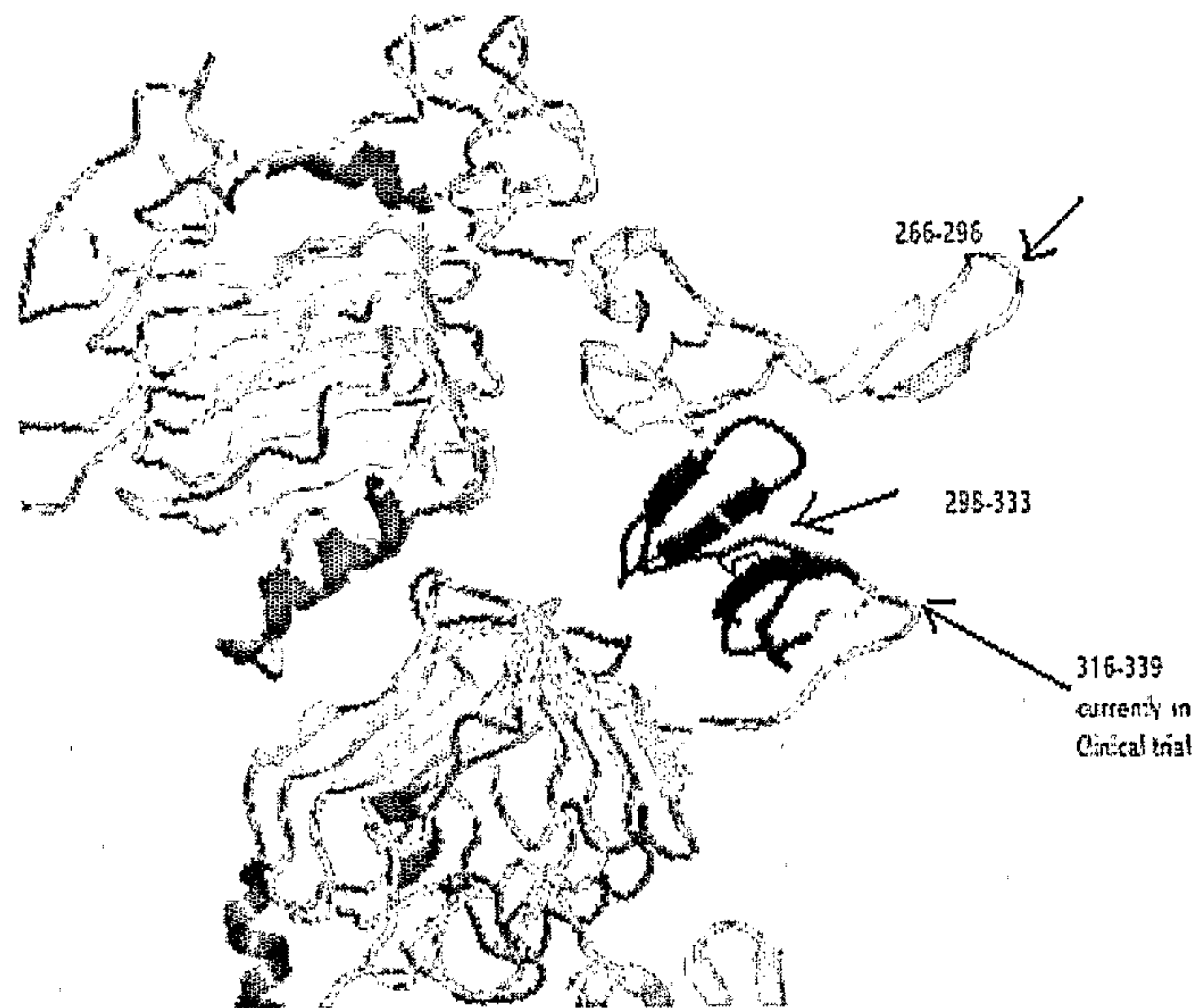
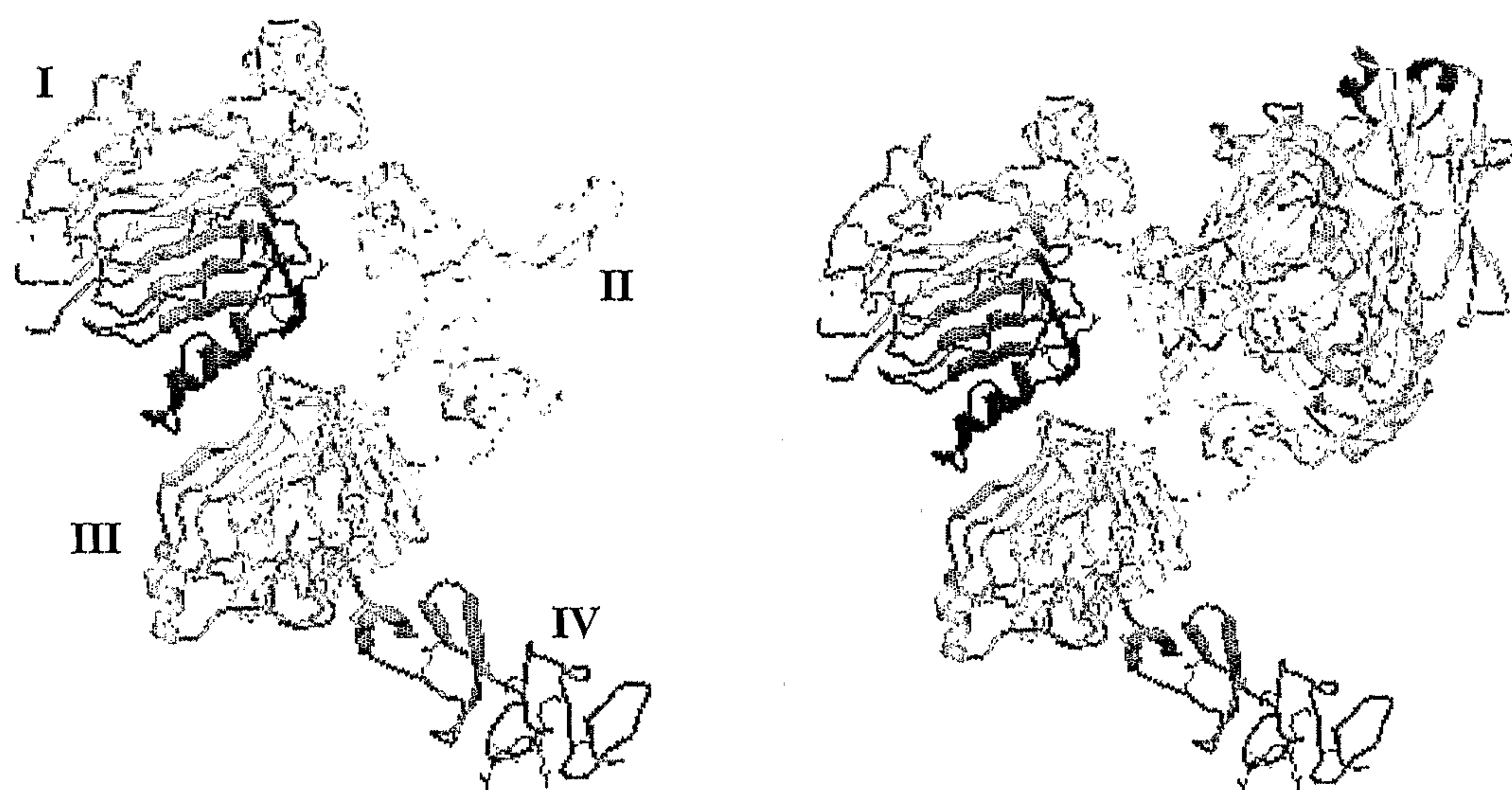
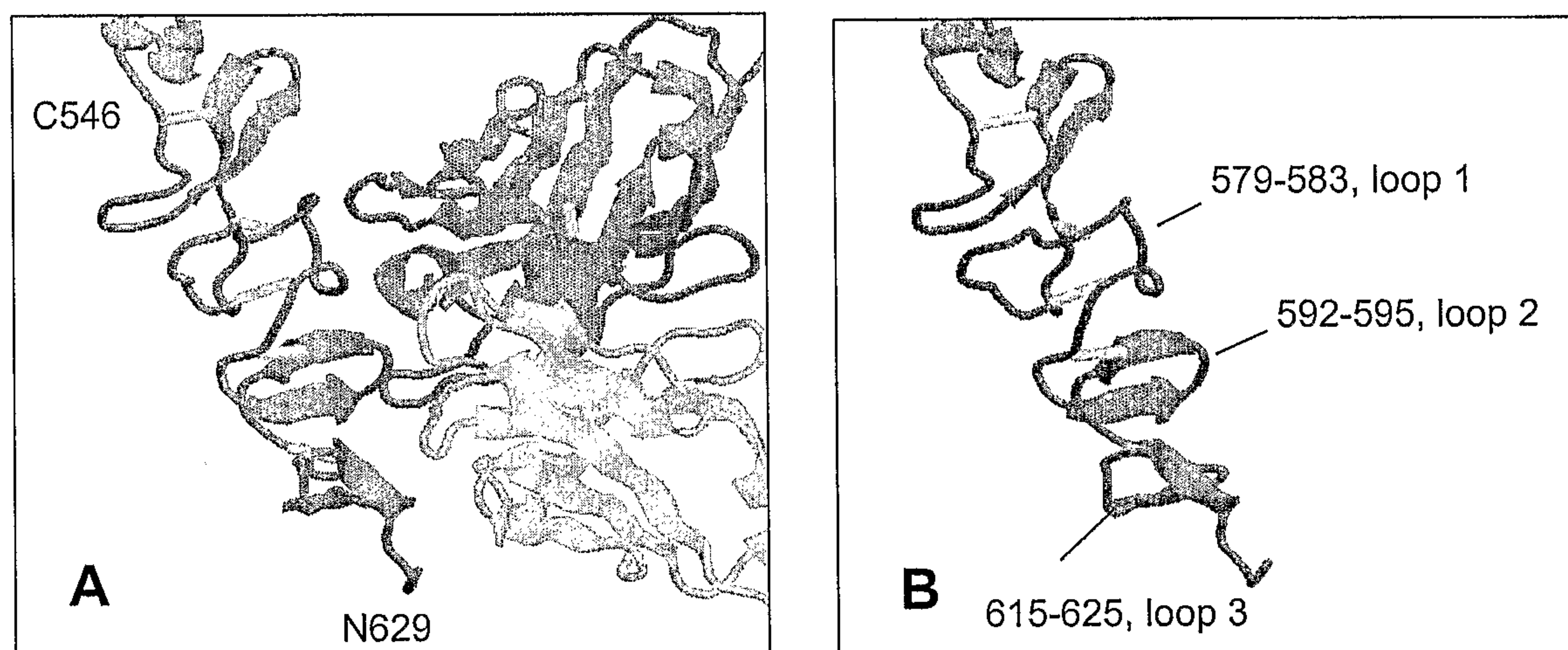


FIGURE 3

**FIGURE 4****FIGURE 5**

**FIGURE 6****FIGURE 7**

**FIGURE 8****FIGURE 9**

6/20

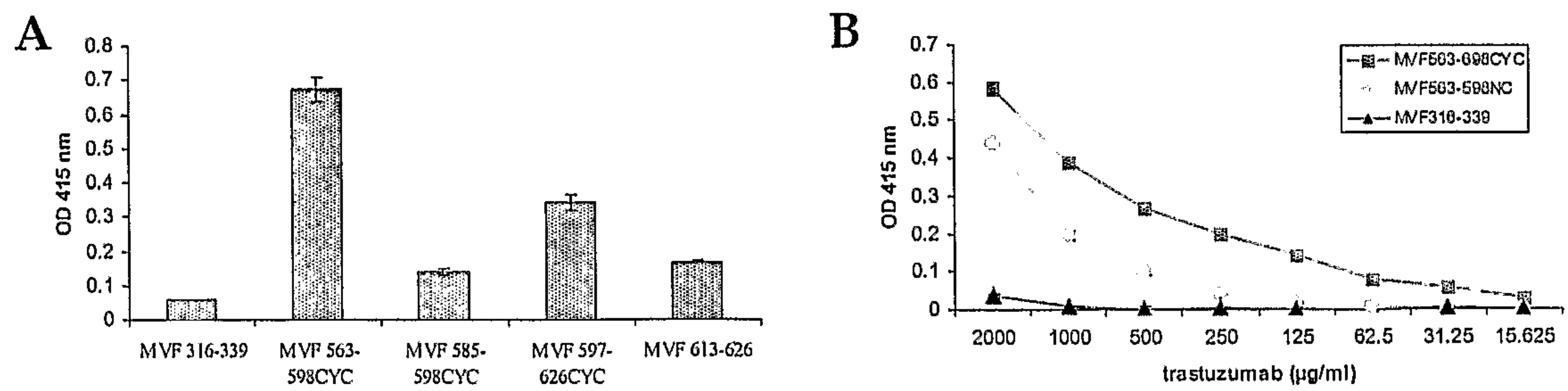


FIGURE 10

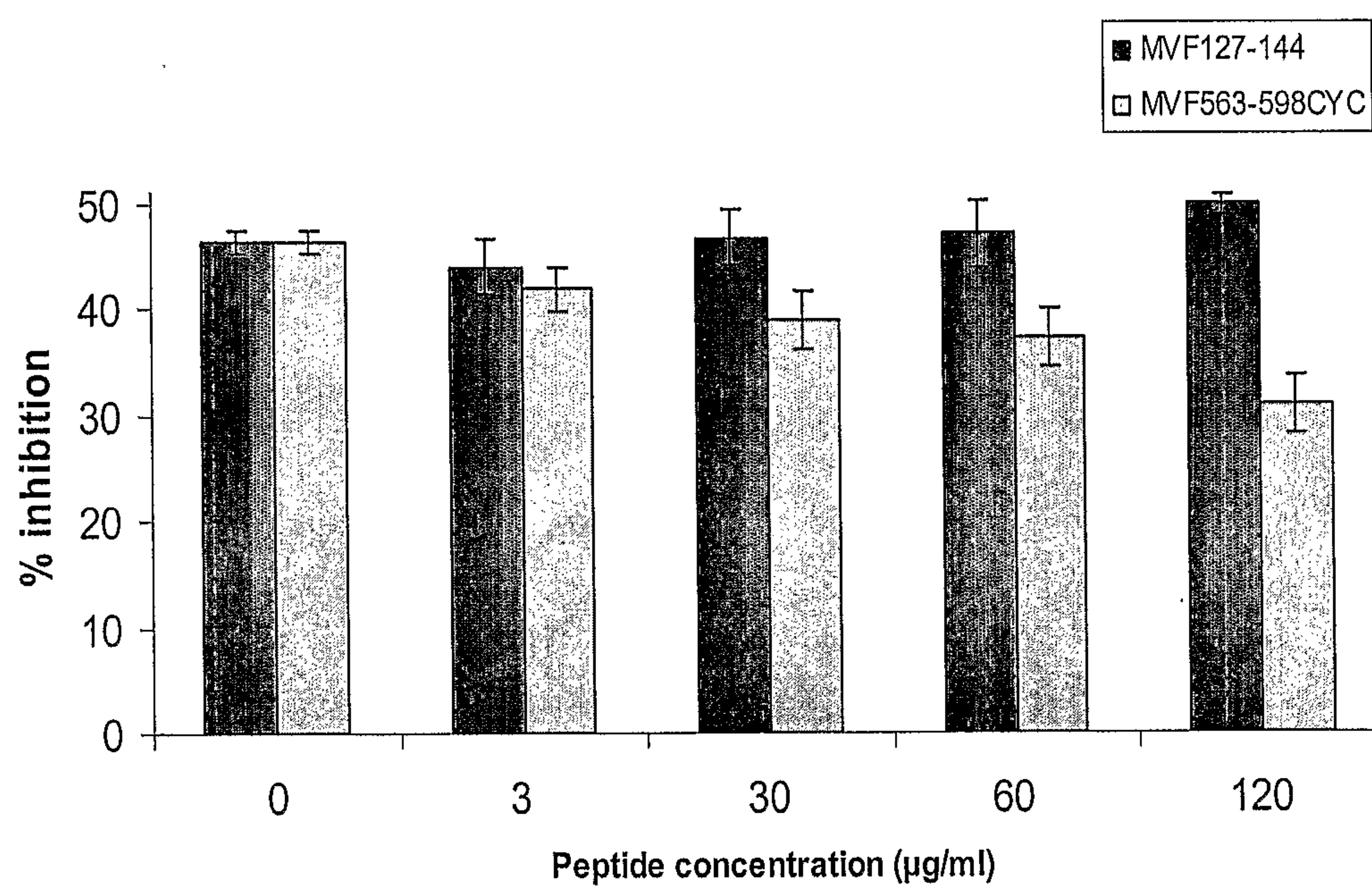


FIGURE 11

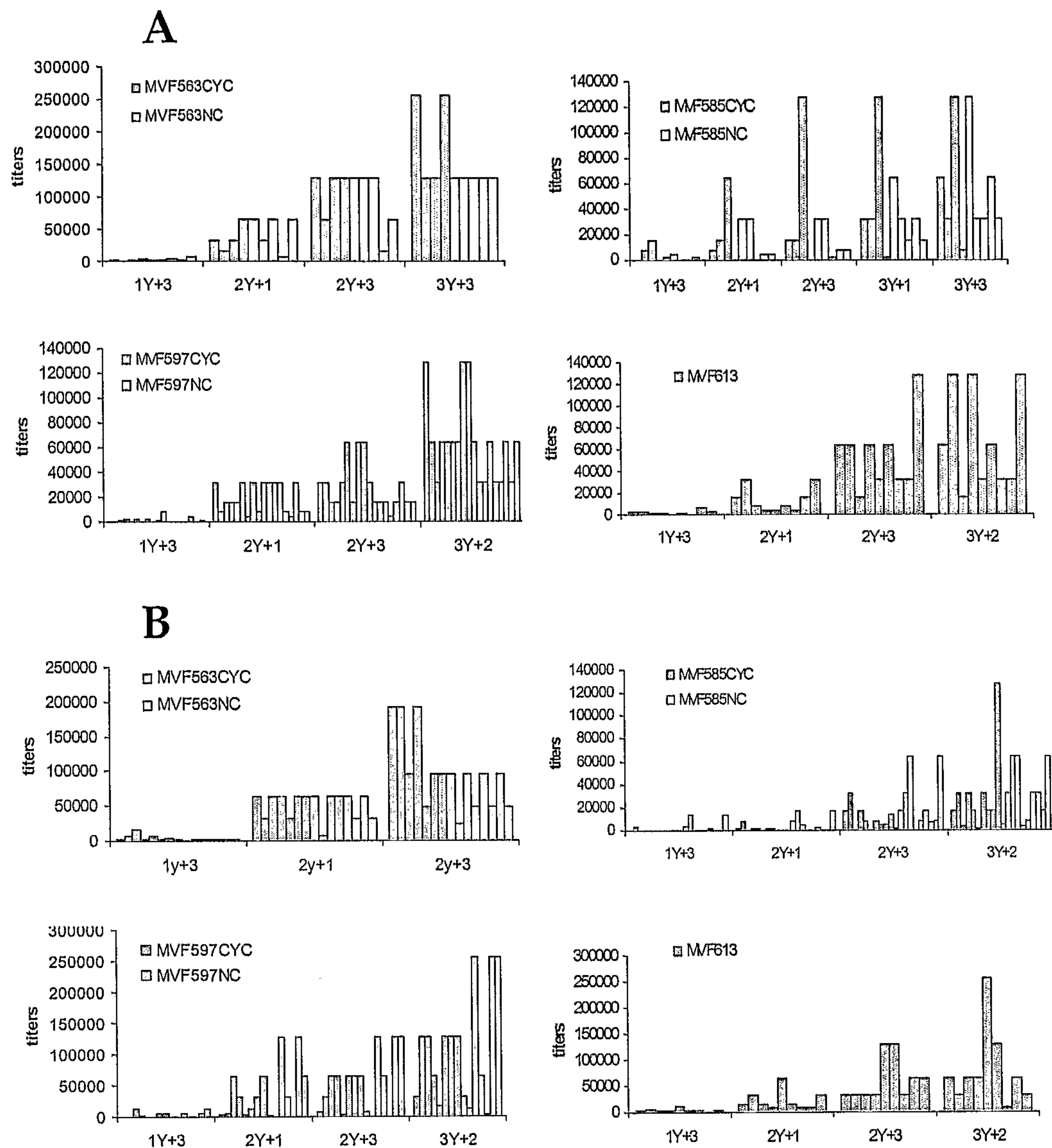


FIGURE 12

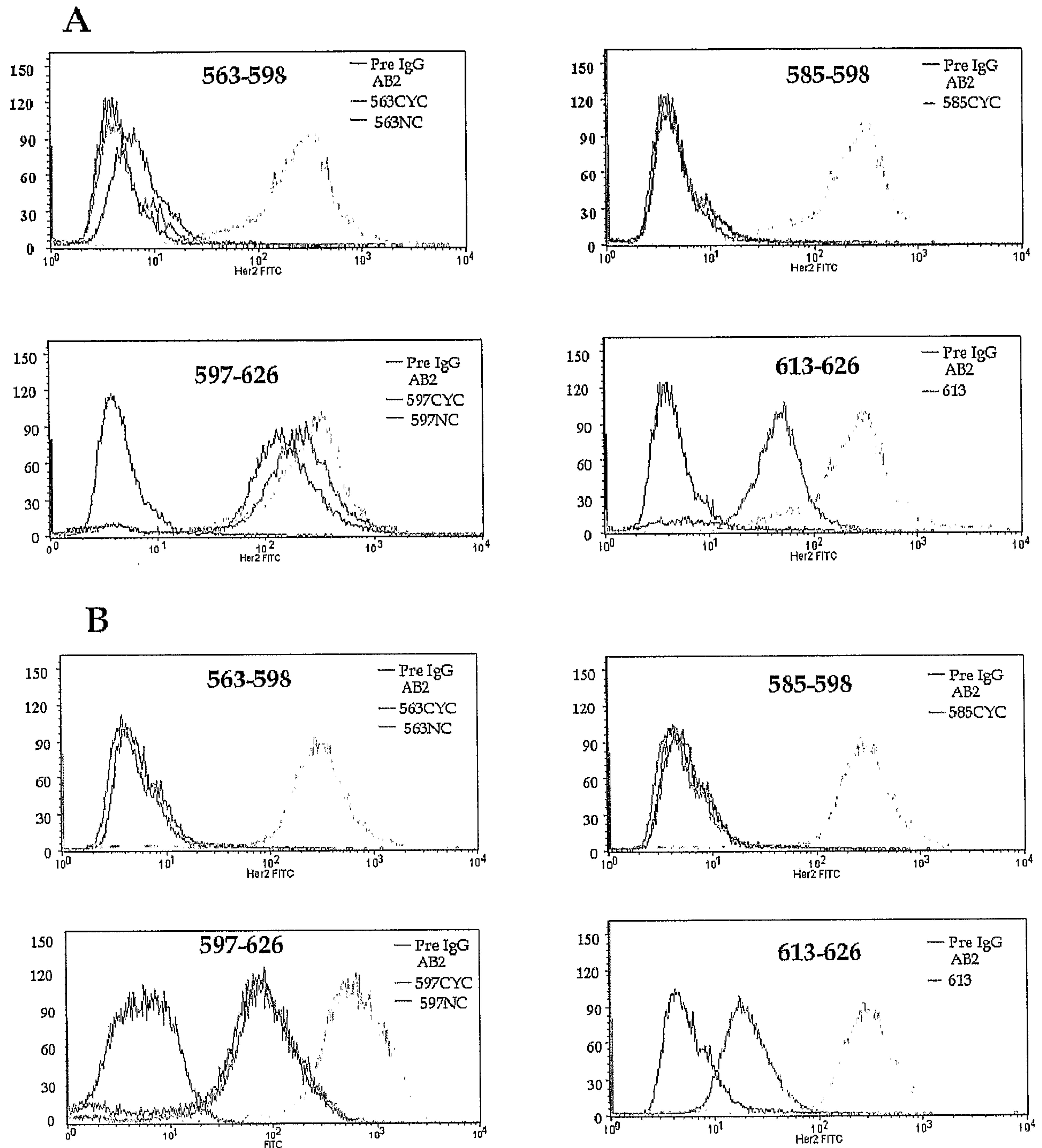


FIGURE 13

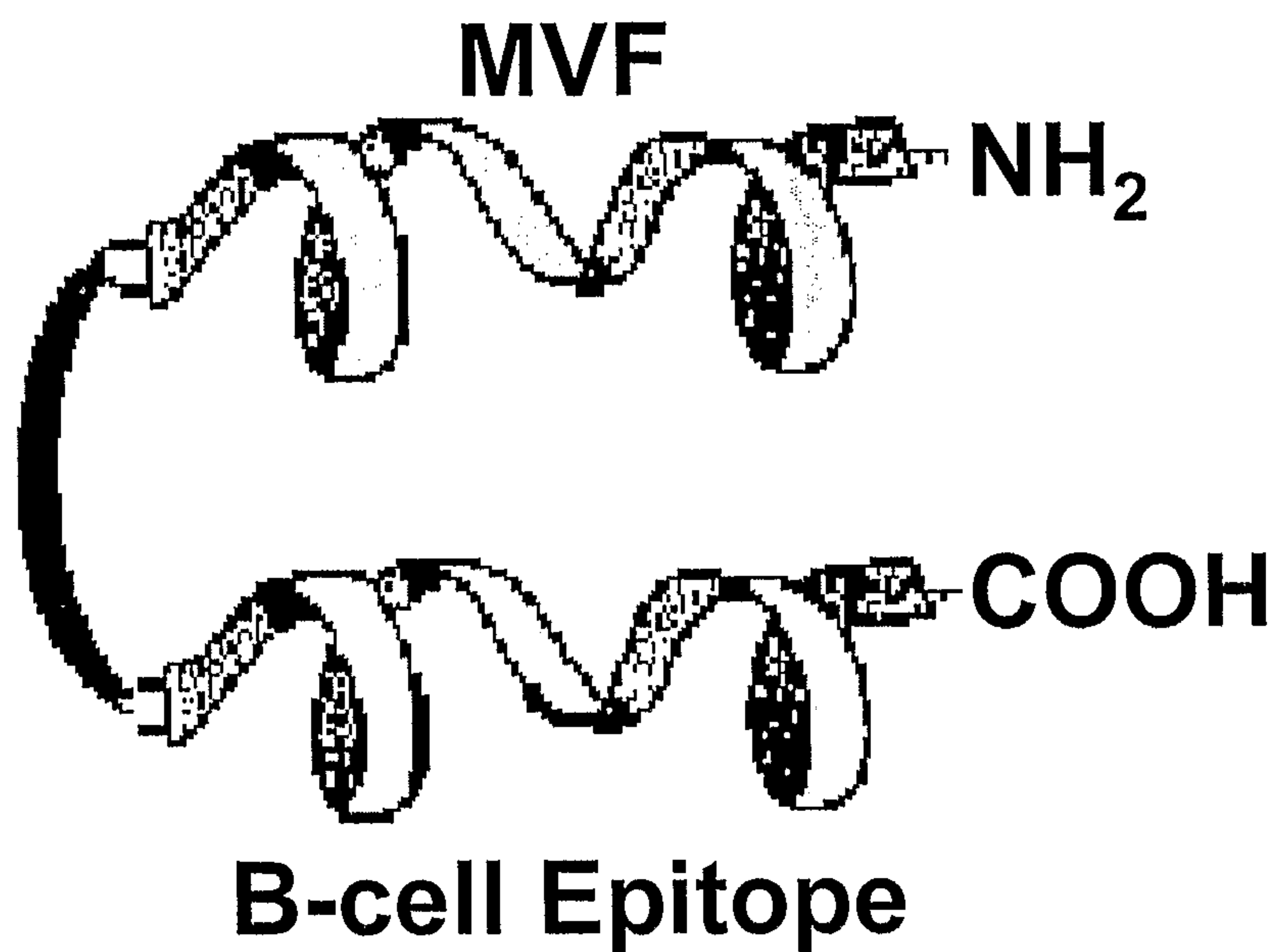


FIGURE 14

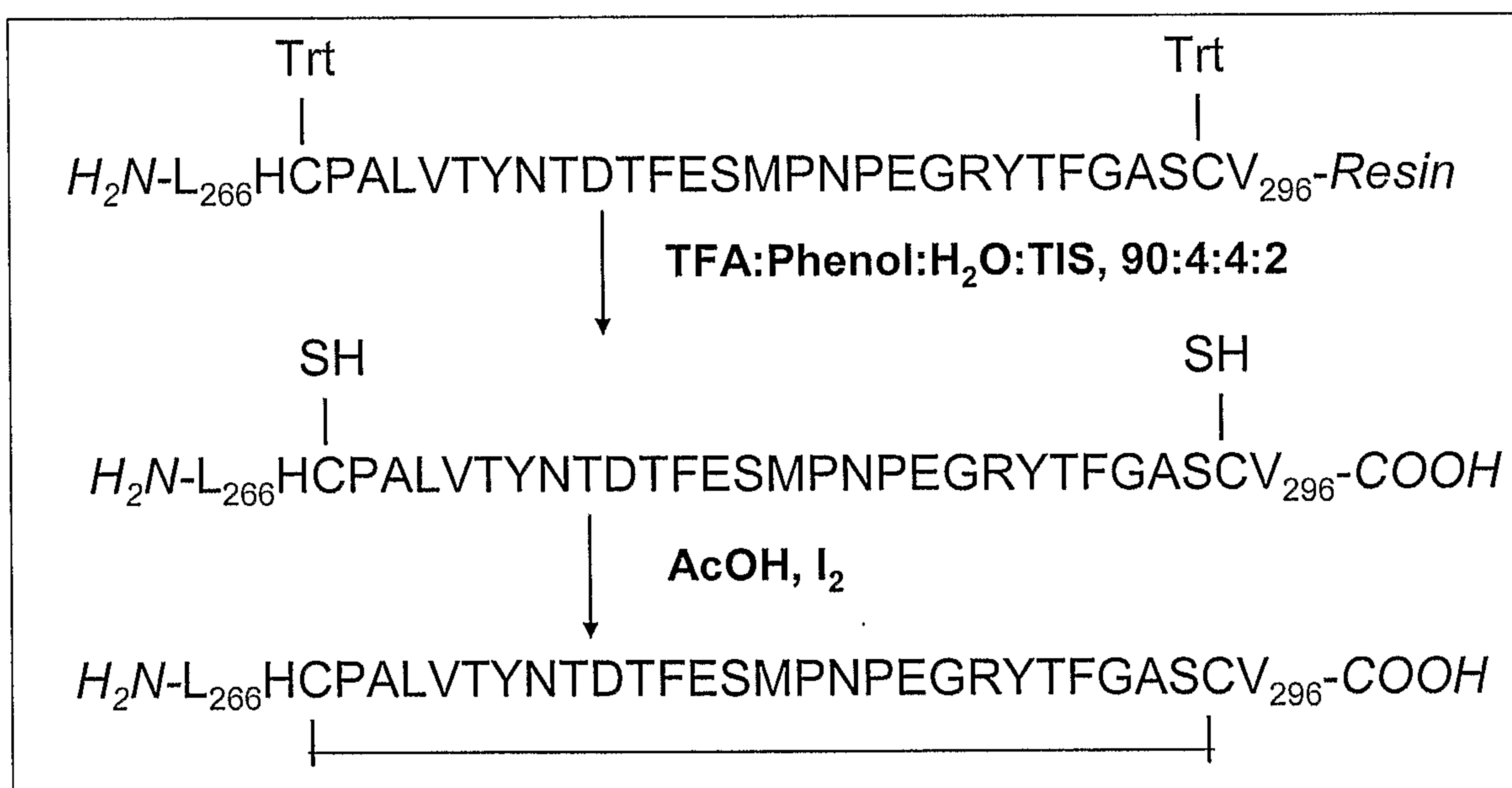


FIGURE 15

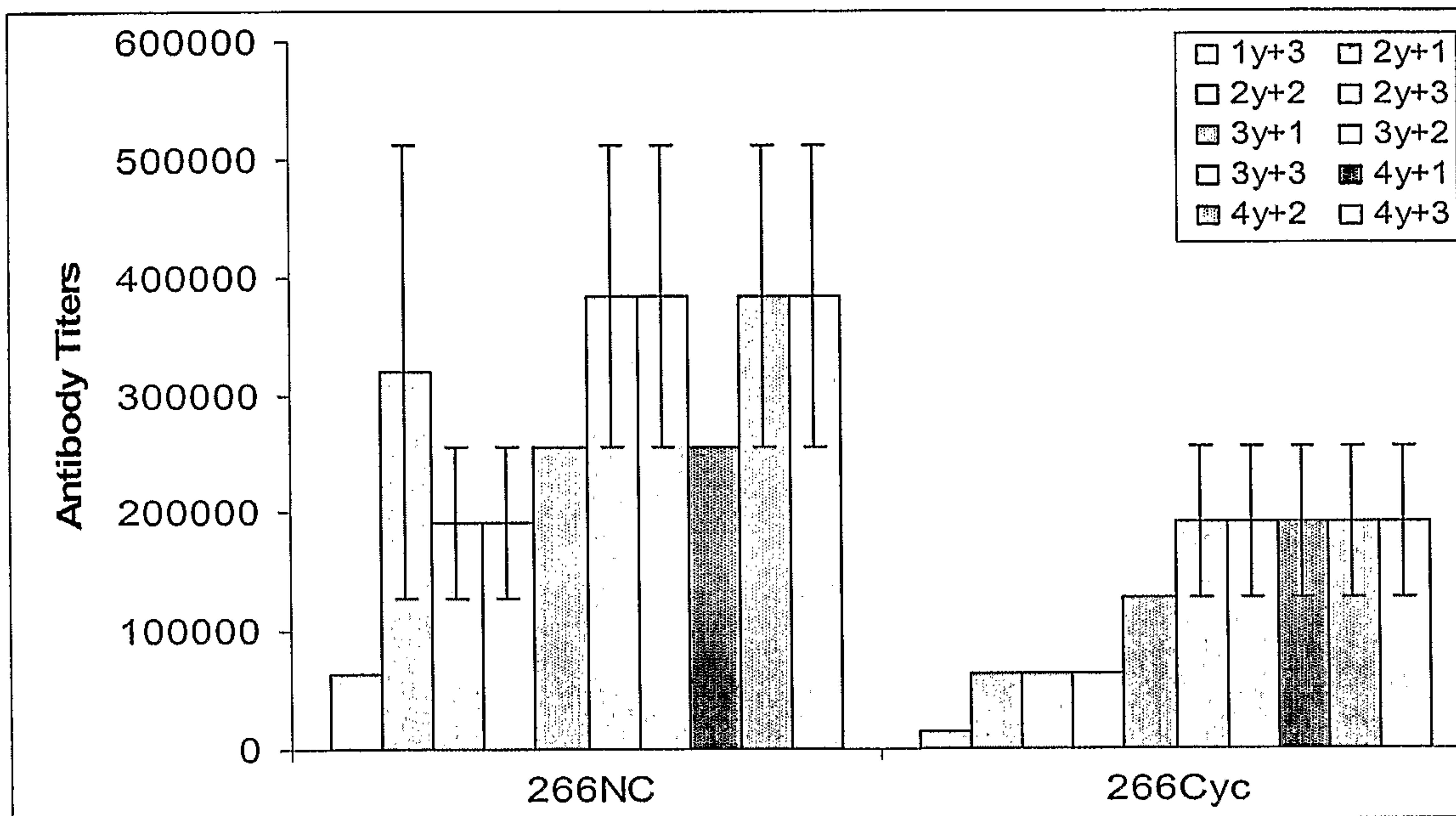
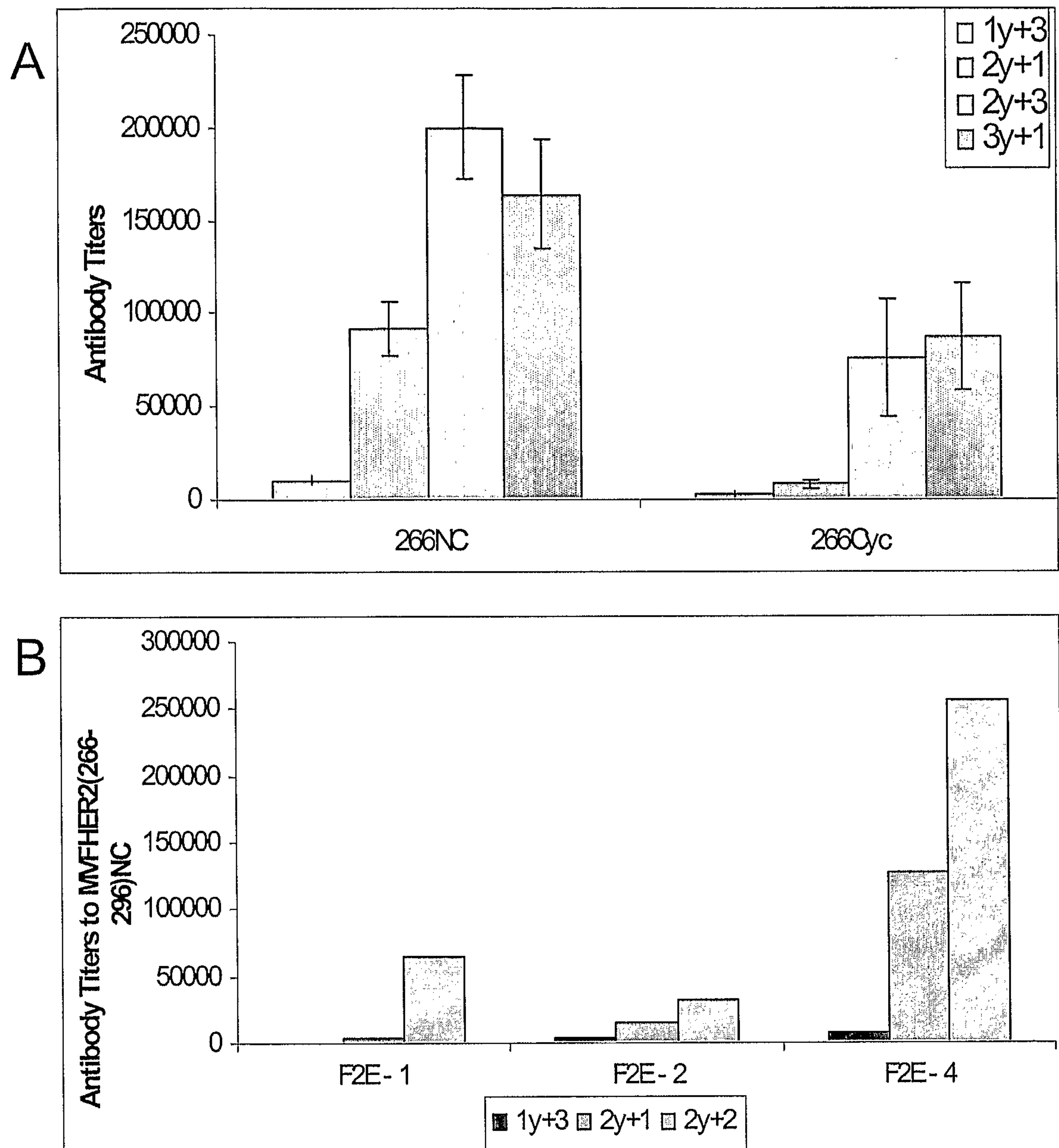


FIGURE 16

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**FIGURE 17**

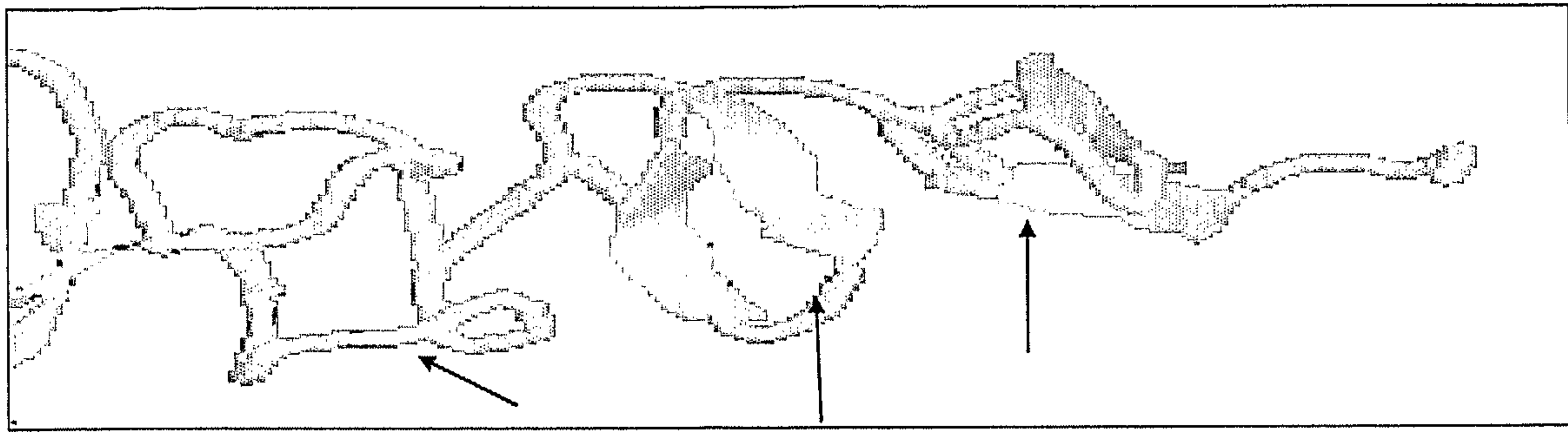


FIGURE 18

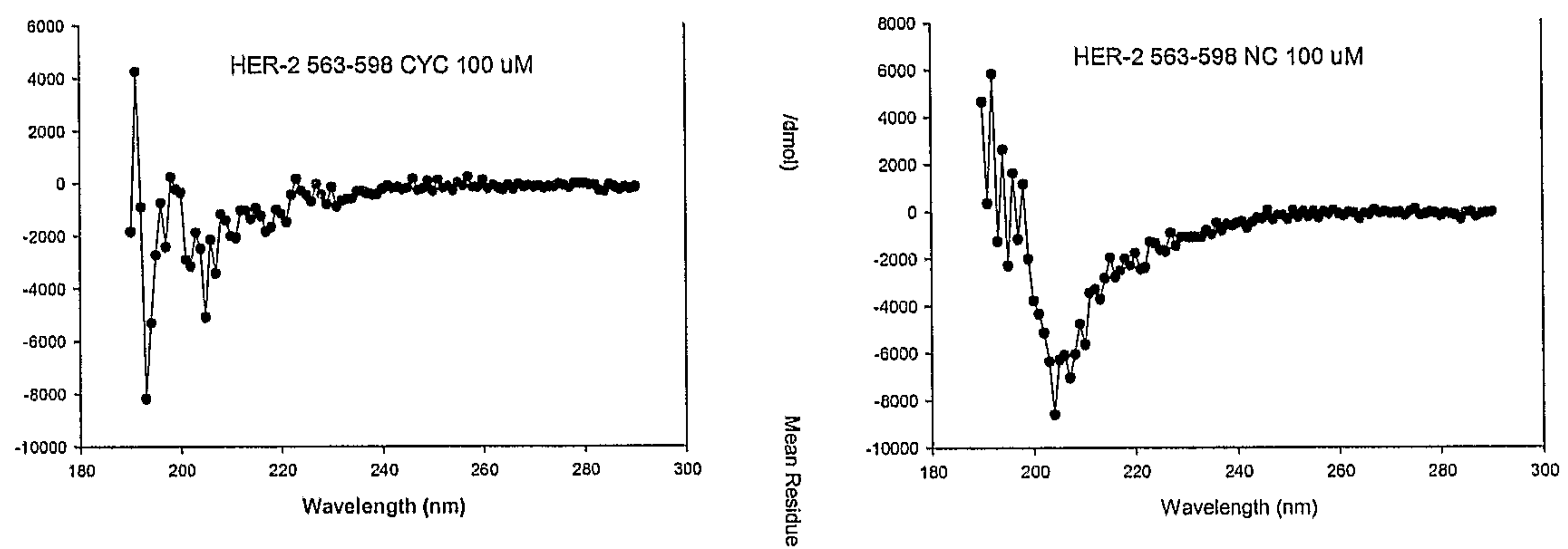


FIGURE 19

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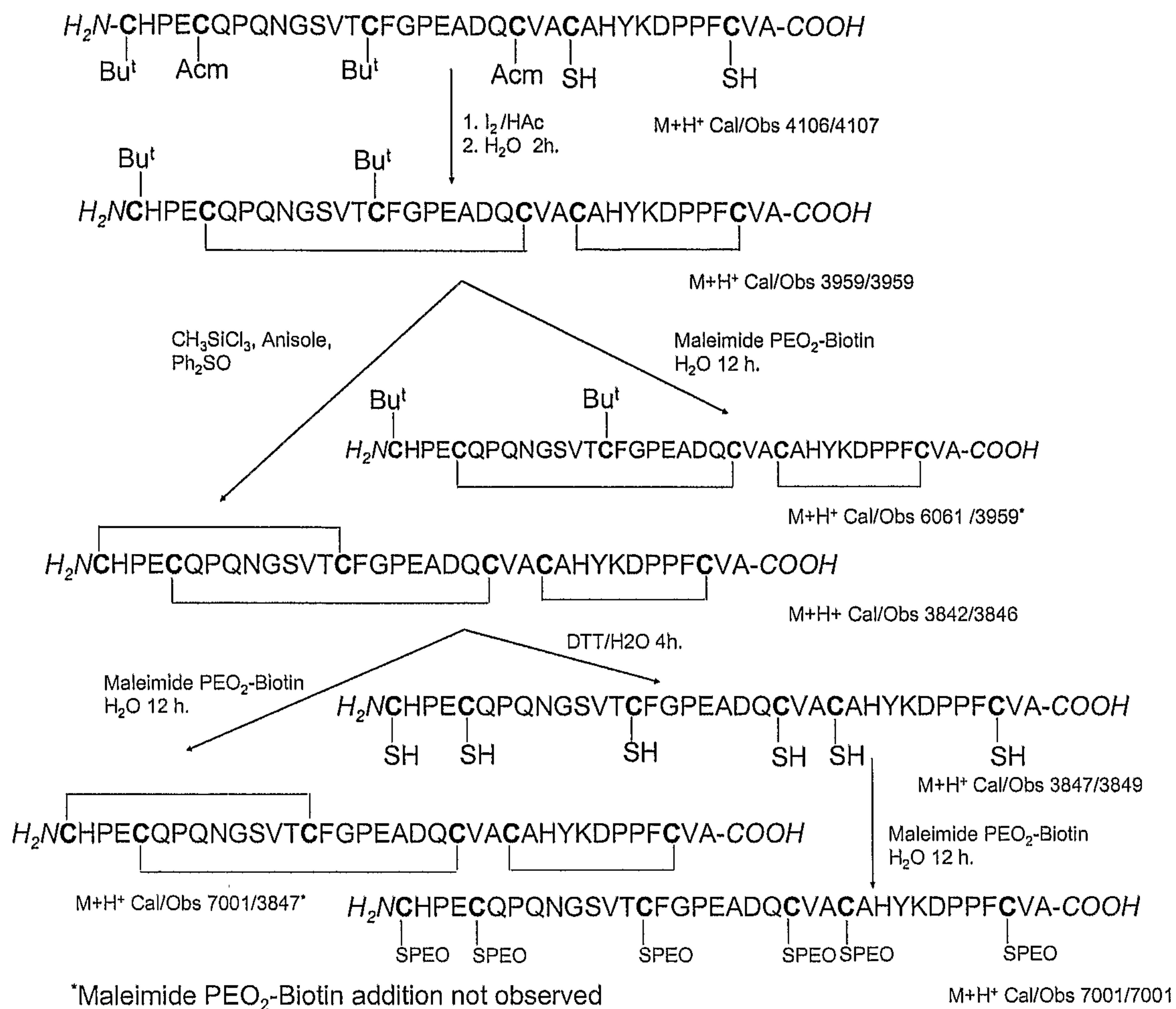


FIGURE 20

Figure 2 consists of four bar charts arranged in a 2x2 grid, labeled A and B. Each chart shows the virus titer (Y-axis, 0 to 140,000) for two conditions: MVF298-333CYC (white bars) and MVF298-333NC (hatched bars) in panel A, and MVF315-333CYC (white bars) and MVF315-333NC (hatched bars) in panel B. The X-axis represents time points in weeks (w) and days (d).

Panel A:

- Left Chart (MVF298-333CYC vs MVF298-333NC):** Shows titers for MVF298-333CYC (white bars) and MVF298-333NC (hatched bars) across time points: 1y+3w, 2y+1w, 2y+2w, 2y+3w, 3y+1w, 3y+2w, 3y+3w, 4y+1w, 4y+2w, and 4y+3w. MVF298-333CYC generally shows higher titers than MVF298-333NC, especially at 3y+1w and 3y+2w.
- Right Chart (MVF315-333CYC vs MVF315-333NC):** Shows titers for MVF315-333CYC (white bars) and MVF315-333NC (hatched bars) across time points: 1y+3w, 2y+1w, 2y+2w, 2y+3w, 3y+1w, 3y+2w, 3y+3w, 4y+1w, 4y+2w, and 4y+3w. MVF315-333CYC generally shows higher titers than MVF315-333NC, especially at 4y+1w.

Panel B:

- Left Chart (MVF298-333CYC vs MVF298-333NC):** Shows titers for MVF298-333CYC (white bars) and MVF298-333NC (hatched bars) across time points: 1y+3w, 2y+1w, 2y+3w, 3y+1w, and 3y+5w. MVF298-333CYC shows a significant peak at 3y+5w.
- Right Chart (MVF315-333CYC vs MVF315-333NC):** Shows titers for MVF315-333CYC (white bars) and MVF315-333NC (hatched bars) across time points: 1y+3w, 2y+1w, 2y+3w, 3y+1w, and 3y+5w. MVF315-333CYC shows a significant peak at 2y+3w.

FIGURE 22

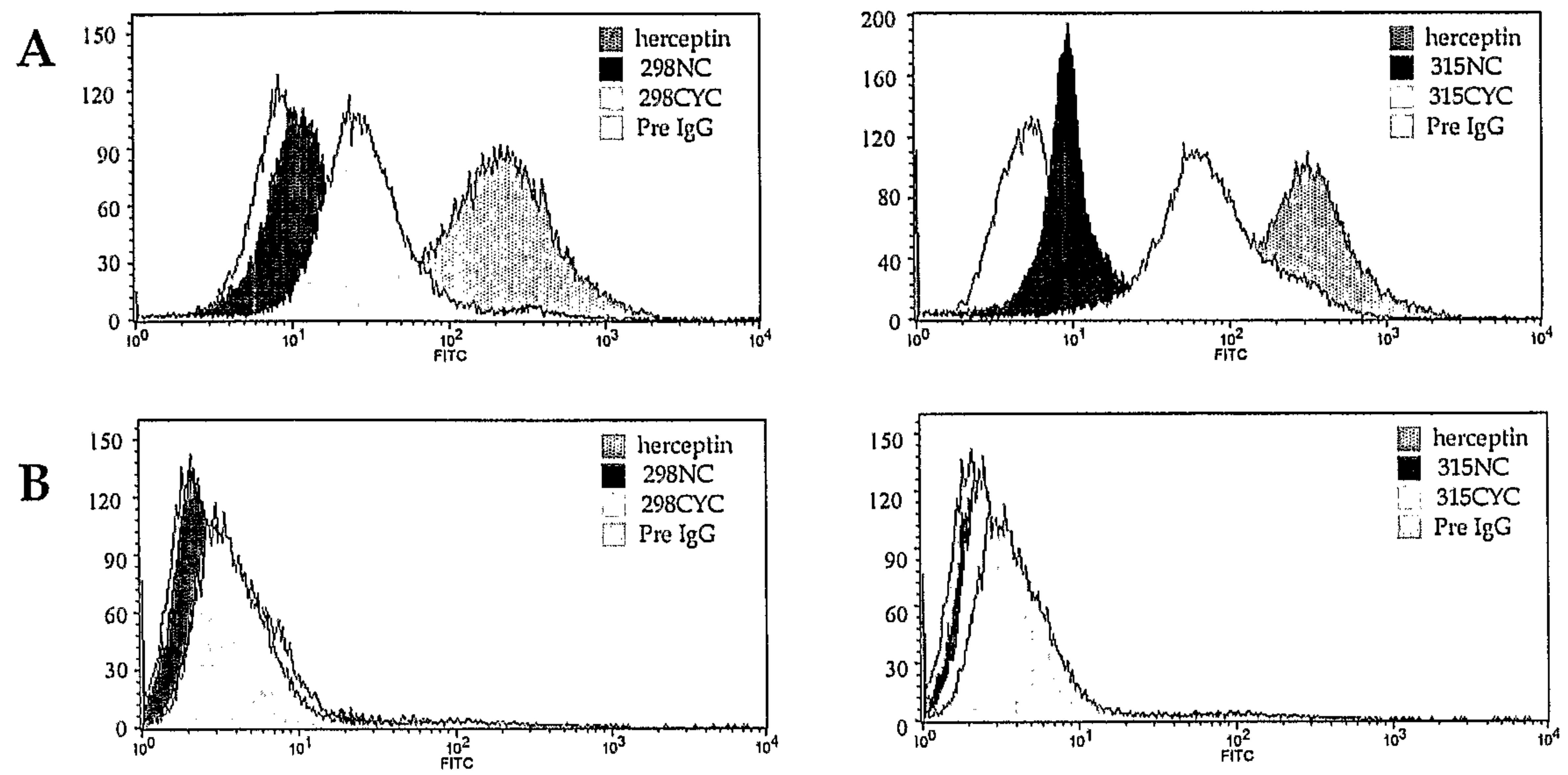


FIGURE 23

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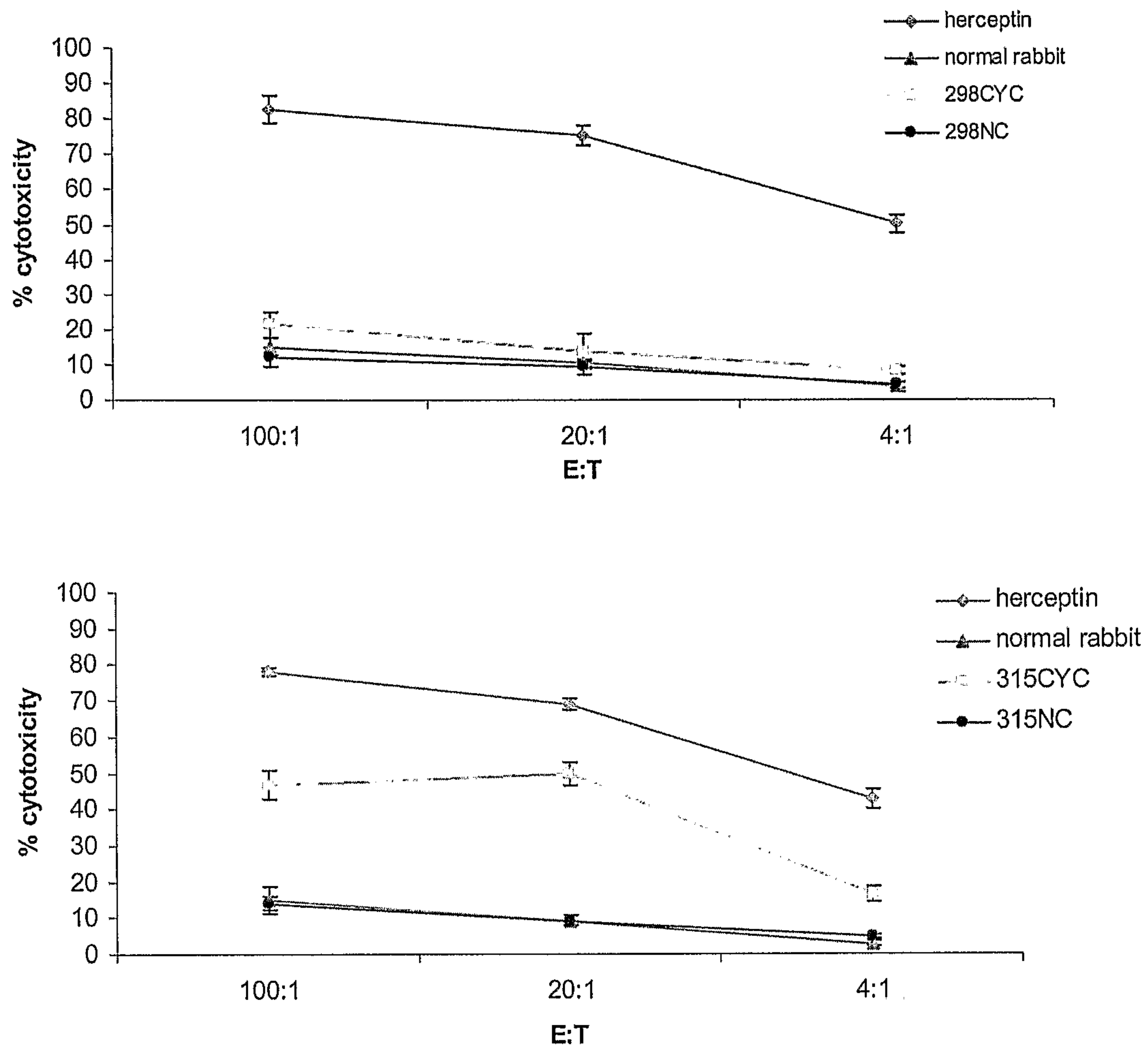
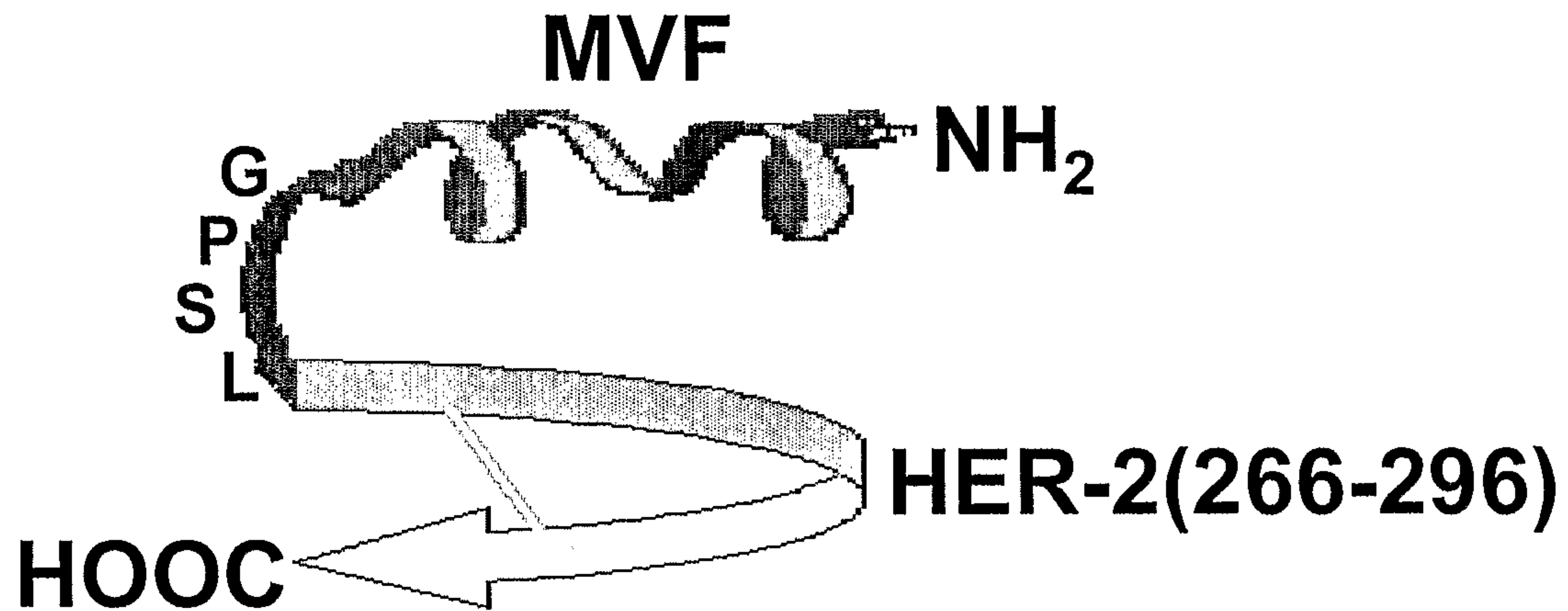
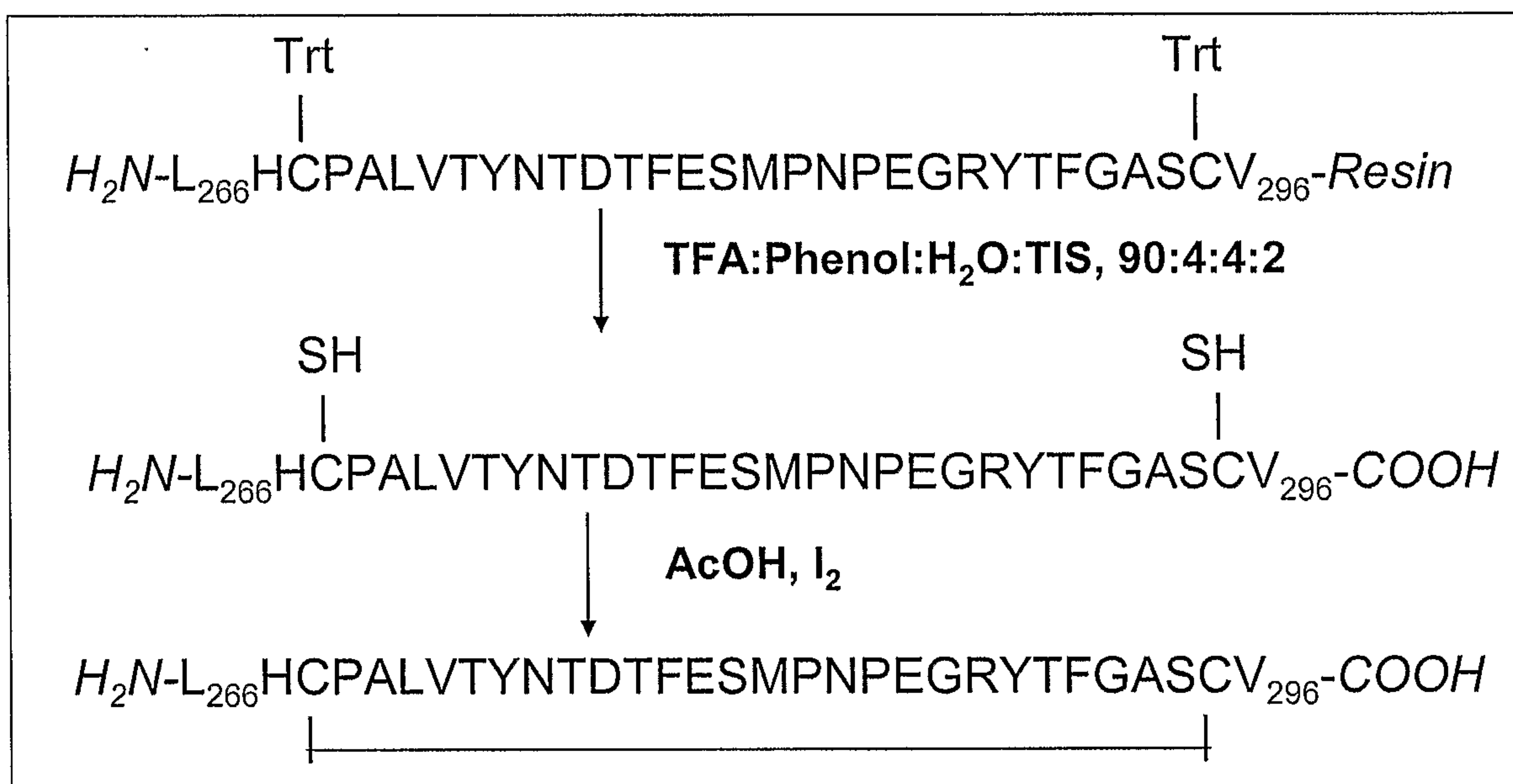


FIGURE 24

**FIGURE 25****FIGURE 26**

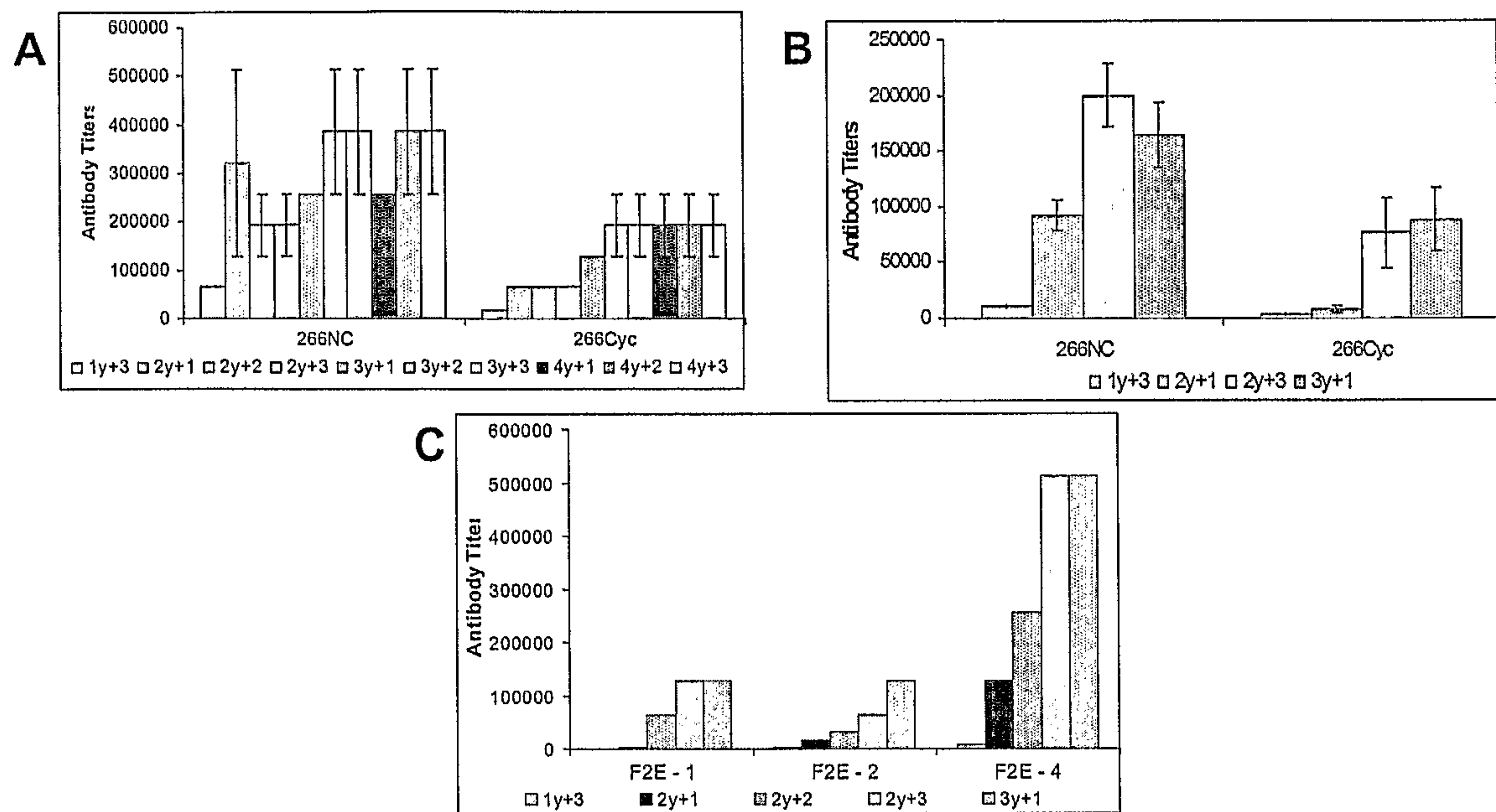


FIGURE 27

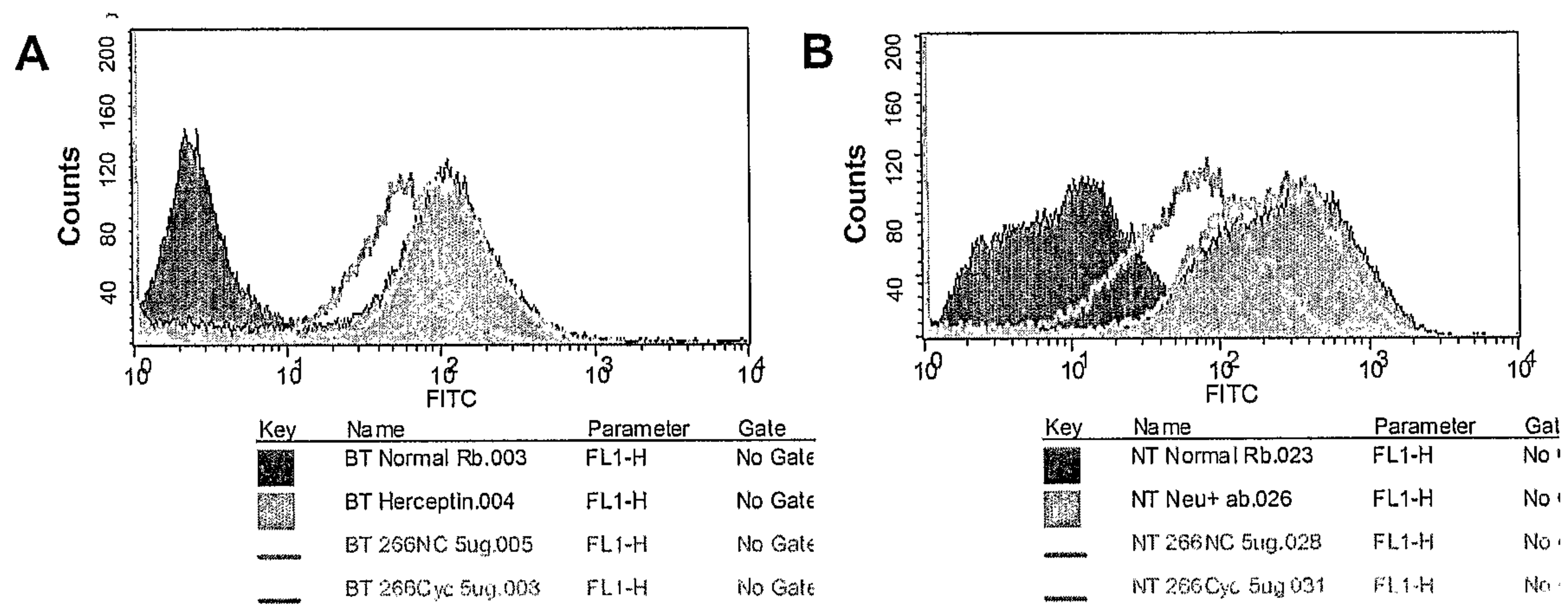
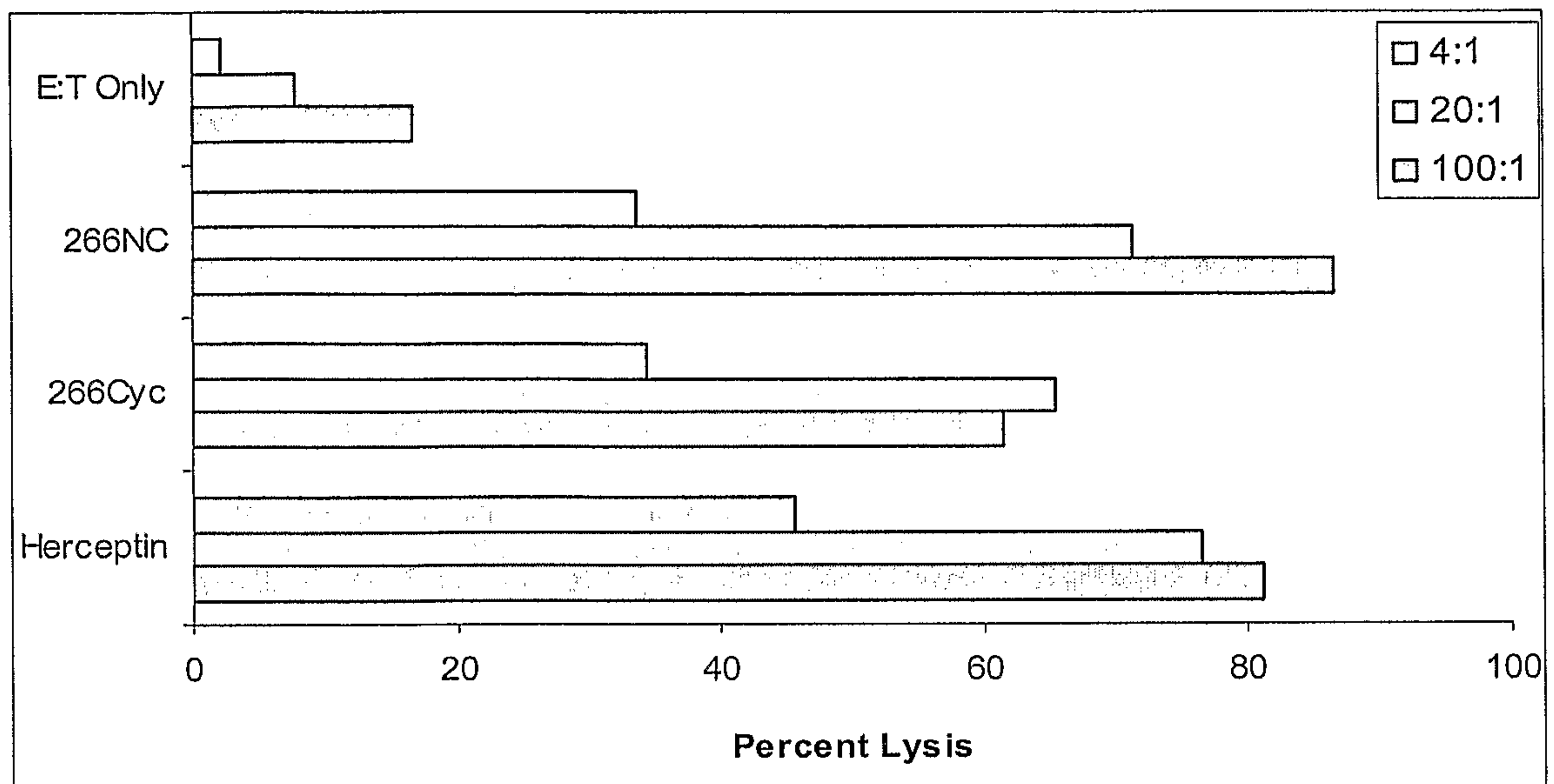
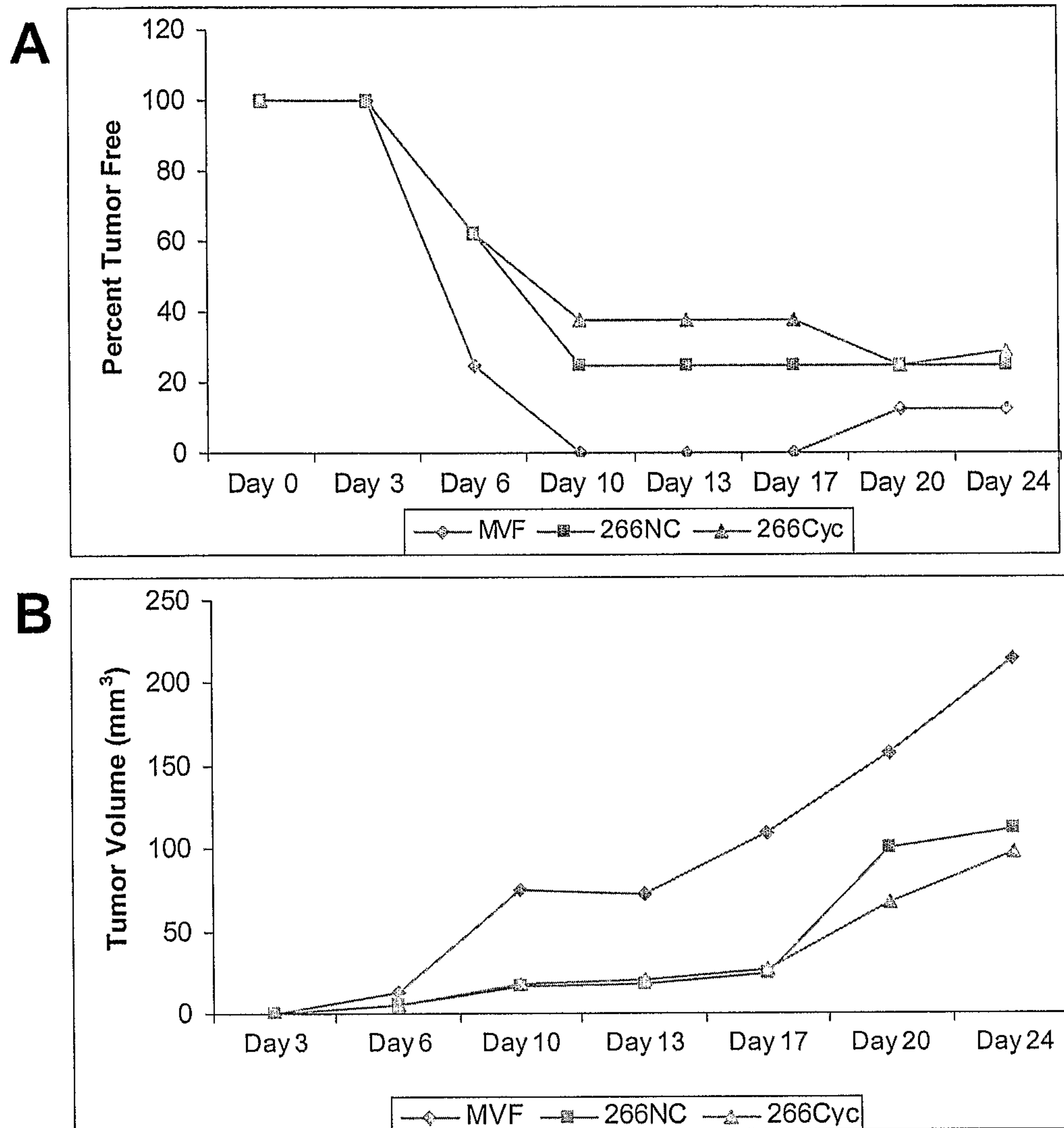


FIGURE 28

**FIGURE 29**

**FIGURE 30**

1	melaalcrwg	lllallppga	astqvctgtd	mklrlpaspe	thldmlrhly	qgcqvvggnl
61	eltylptnas	lsflqdiqev	qgyvliahnq	vrqvplqrlr	ivrgtqlfed	nyalavldng
121	dplnnttpvt	gaspzglrel	qlrslteilk	ggvliqrnpq	lcyqdtlwk	difhknnqla
181	ltlidtnrsr	achpcspmck	gsrwwgesse	dcqsltrtvc	aggcarckgp	lptdccheqc
241	aagctgpkhs	dclaclhfnh	sgicelhcpa	lvtyntdtfe	smpnpegryt	fgascvtacp
301	ynylstdvgs	ctlvcplhnq	evtaedgtqr	cekcskpcar	vcyglgmehl	revravtsan
361	iqefagckki	fgslaflpes	fdgdpasnta	plqpeqlqv	etleeitgyl	yisawpdsip
421	dlsvfqnlqv	irgrilhnga	ysltlqglgi	swlglsrlre	lgsglalihh	nthlcfvhtv
481	pwdqlfrnph	qallhtanrp	edecvgegla	chqlcarghc	wpgpqtqcvn	csqflrgqec
541	veecrvlqgl	preyvnaahc	lpchpecqpq	ngsvtcfqpe	adqcvacahy	kdppfcvarc
601	psgvkpdlsy	mpiwkfpdee	gacqpcpinc	thscvdlldk	gcpaeqrasp	ltsivsavg
661	illvvvlgvv	fgilikrrqq	kirkytmrrl	lqetelvepl	tpsgampnqa	qmrilketel
721	rkvkvlsga	fgtvykgiwi	pdgenvkipv	aikvlrents	pkankeilde	ayvmagvgsp
781	yvsrllgicl	tstvgqlvtql	mpygclldhv	renrgrlgsq	dllnwcmqia	kgmsyledvr
841	lvhrdlaarn	vlvkspnhvk	itdfglarll	dideteyhad	ggkvpikwma	lesilrrrft
901	hqsdvwsygv	tvwelmtfga	kpydgipare	ipdllekger	lpqppictid	vymimvkcwm
961	idsecrprfr	elvsefsrma	rdpqrfrvviq	nedlgpaspl	dstfyrslle	dddmgdlvda
1021	eeylvpqqgf	fcpdpapgag	gmvhhrhrss	strsgggdlt	lglepseeee	prsplapseg
1081	agsdvfdgd	gmgaakglqs	lpthdpsplq	rysedptvpl	psetdgyvap	ltcspqpeyv
1141	nqpdvrpqp	spregplpaa	rpagatlera	ktlspgkngv	vkdvfafgga	venpeyltpq
1201	ggaapqphpp	pafspafdn	yywdqdpper	gappstfkgt	ptaenpeylg	ldvpv