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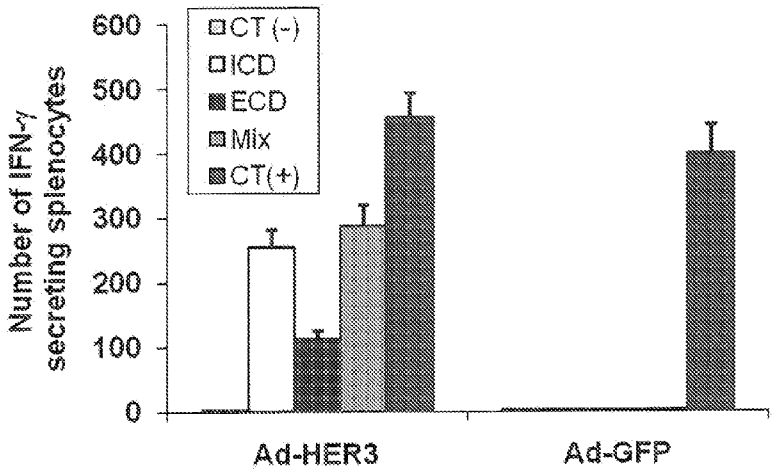
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(54) Title: VACCINES AGAINST ANTIGENS INVOLVED IN THERAPY RESISTANCE AND METHODS OF USING SAME



(57) Abstract: Methods of reducing the likelihood of a cancer or precancer developing resistance to a cancer therapeutic or prevention agent are provided herein. The methods include administering the cancer therapeutic or prevention agent and a vaccine comprising a polynucleotide encoding a polypeptide whose expression or activation is correlated with development of resistance of the cancer or precancer to the cancer therapeutic or prevention agent to a subject. The vaccine may include a polynucleotide encoding a HERS polyepptide. Methods of using the vaccine including the polynucleotide encoding the HER3 polypeptide to treat a cancer or precancer are also provided.

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VACCINES AGAINST ANTIGENS INVOLVED IN THERAPY RESISTANCE AND METHODS OF USING SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

This patent application claims the benefit of priority of United States Provisional Patent Application No. 61/588,449, filed January 19, 2012, which is incorporated herein by reference in its entirety.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

This invention was made with United States government support awarded by the National Cancer Institute grant numbers P50 CA89496-01, P50 CA068438 and R01 CA95447 and by Department of Defense grant number BC050221. The United States has certain rights in this invention.

INTRODUCTION

This application relates to a cancer vaccine, specifically a vaccine against antigens that are expressed in response to resistance to therapeutic intervention to cancer (or pre-cancers), with a proof of principle antigen, HER3, as an example. Methods of using the vaccines and methods of developing vaccines capable of blocking the development of resistance to cancer therapies are also provided.

Cancer vaccines target antigens expressed by tumors, but application of these vaccines has not been as effective as once hoped due to induction of immune tolerance by chronic overexpression of the targeted protein in the absence of co-stimulatory molecules and the induction of an immunomodulatory environment. Preventative cancer vaccines may be more promising, but cancers are highly variable, with multiple genetic changes, but few truly universal changes. Thus, it is difficult to predict what antigens will be overexpressed on any specific cancer or whether an individual should be vaccinated and if so, with what antigens. In contrast, a strategy is proposed here in which vaccination against the antigen(s) that will predictably be overexpressed in response to a therapy, but prior to that antigen's over-expression by the cancer cells is used to induce a robust anti-cancer immune response.

SUMMARY

Provided herein is a mechanism of revolutionizing cancer therapy or prevention by preventing the development of resistance to cancer therapeutic or cancer prevention agents by identifying which antigens are likely to be expressed in a cancer or precancer in response to treatment with a cancer therapeutic or prevention agent and thus which antigens may be targeted with a vaccine in patients. Also provided is a vaccine targeting a specific antigen involved in a resistance mechanism, namely HER3, and methods of using the vaccine. In one aspect, the vaccine includes a polynucleotide encoding a HER3 polypeptide. For example, a HER3 polypeptide of SEQ ID NO: 1 or 2 may be included in a vaccine.

In another aspect, methods of treating a cancer or precancer or reducing the likelihood of the cancer or precancer to develop resistance to a cancer therapeutic or prevention agent by administering the vaccine provided herein to a subject with cancer or precancer are provided. The vaccine may be administered before, concurrently with or after administration of the cancer therapeutic or prevention agent.

In yet another aspect, methods of reducing the likelihood of a cancer or precancer developing resistance to a cancer therapeutic or prevention agent by administering the cancer therapeutic or prevention agent and a vaccine to the subject are provided. The vaccine includes a polynucleotide encoding a polypeptide whose expression or activation correlates with development of resistance of the cancer or precancer to the cancer therapeutic or prevention agent. Co-administration of the cancer therapeutic or prevention agent and the vaccine inhibits the generation of resistance to the cancer therapeutic or prevention agent and increases the therapeutic potential of the cancer therapeutic agent and the prevention potential of the cancer prevention agent.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a set of figures showing HER3 specific T cell and B cell responses to Ad-HER3 *in vivo*. Figure 1A is a graph showing the number of IFN-γ secreting splenocytes by ELISPOT after 6-8 week old BALB/c mice were immunized once with 2.6×10^{10} Ad-HER3 or Ad-GFP via bilateral subcutaneous footpad injections. Two weeks following the vaccination mice were euthanized and splenocytes collected for

analysis in an Interferon-gamma ELISPOT assay. Splenocytes from Ad-HER3 vaccinated and not or Ad-GFP vaccinated (control) mice recognized HER3 intracellular domain (ICD) and extracellular domain (ECD) peptide libraries and the mixture of both libraries (Mix) in interferon-gamma ELISPOT assays. The mean from 5 mice per group is shown with error bars denoting standard deviation. CT-; splenocytes alone. CT+; Splenocytes plus PMA (50 ng/mL) and Ionomycin (1 ng/mL) as a control for the assay. Figure 1B is a set of FACS analysis histograms of peripheral blood serum from the mice was tested for the presence of antibodies capable of binding to tumor cell-expressed HER3. Flow cytometric analysis was used and histograms denote binding of HER3-vaccine induced antibodies (HER3-VIA) in serum to human breast cancer cell line BT474. Figure 1C is a graph showing the mean fluorescence intensity which was calculated for the binding of HER3-VIA against a panel of human breast cancer cell lines with dilutions of the serum. Figure 1D shows the results of epitope mapping of HER3-VIA using spotted 15mer peptide arrays and revealed recognition of 18 different epitopes.

Figure 2 is a set of figures showing that HER3-VIA mediate multiple mechanisms of action on human breast tumor cell lines *in vitro*. Figure 2A is a set of graphs showing that HER-3 VIA mediate complement dependent cytotoxicity (CDC) against HER3-expressing (BT474, T47D, MDA-MB-468, BT474M1) human breast cancer cell lines but not against the HER3-negative cell line (MDA-MB-231). Black bars, HER3-VIA; white bars, GFP-VIA; grey bars, Trastuzumab. Trastuzumab does not mediate CDC. Figure 2B is a graph showing that HER-3 VIA mediate antiproliferative activity against HER3-expressing (BT474, T47D, MDA-MB-468, BT474M1) human breast cancer cell lines but not against the HER3-negative cell line (MDA-MB-231) in a 72 hour assay. The antiproliferative effect implied receptor modulation and Figure 2C is a set of photographs showing that binding of HER3-VIA results in rapid internalization of endogenous HER3 receptor expressed on the surface of human breast cancer cell lines.

Figure 3 is a set of figures showing the *in vivo* effects of HER3-VIA on BT474M1 human breast tumor xenografts. Figure 3A is a cartoon showing the experiment schema. HER3-VIA or control GFP-VIA were transferred via tail vein injections. Figure 3B is a graph showing that HER3-VIA retarded the growth of

established BT474M1 breast cancers ($p < 0.005$ at *) Figure 3C is a set of photographs showing immunohistochemistry analysis of HER3 protein expression in excised tumors and revealed a dramatic loss of HER3 protein in the HER3-VIA-treated mice compared to GFP-VIA treated mice. GFP-VIA-treated mouse tumors retained HER3 protein levels seen in tumors from mice "treated" with saline. Figure 3D is a set of photographs of Western blot analysis of excised tumors for expression of the indicated proteins.

Figure 4is a set of figures showing the *in vivo* effects of HER3-VIA in lapatinib-refractory rBT474 SCID tumor xenografts. Figure 4A is a graph showing that passive transfer of HER3-VIA retarded the growth of established lapatinib-refractory BT474 tumors in SCID mice demonstrating that anti-HER3 immunity can treat therapy resistant tumors ($p < 0.025$ at *). Figure 4B is a set of photographs showing Western blot analysis of excised tumors to perform pathway analysis. Figure 4C is a set of photographs showing immunohistochemical analysis of excised tumors and revealed no significant change in HER3 levels compared to controls.

Figure 5 is a schematic representation of the primer binding sites on the human Her3 full length cDNA.

Figure 6 is a graph showing that Ad-HER3 vaccine inhibits JC-HER3 tumor growth. Balb/c mice were vaccinated twice (day-18, day-4) via footpad injection with Ad-GFP or Ad-hHER3 vectors (2.6×10^{10} particles/ mouse). Four days after boosting, at day 0, each mouse was implanted with 1,000,000 JC-HER3 mouse mammary tumor cells expressing human HER3. Tumor volume was measured, once it became palpable, every 3 days using calipers and is reported.

Figure 7 is a graph showing Ad-hHER3 vaccine induced HER3 specific T cell response. Splenocytes (500,000 cells/well) from vaccinated Balb/c mice in Figure 6 (x-axis) were collected at day 28 and stimulated with HER3 peptide mix (hHER3 peptides) (1μg/mL was used; JPT, Acton, MA) or HIV peptide mix (BD Bioscience) as a negative control (Negative CT) and analyzed in a interferon-gamma ELISpot assay.

Figure 8 is a set of photographs showing that Ad-hHER3 vaccination causes degradation of HER3 on JC-hHER3 tumor. Tumors were isolated from vaccinated and control Balb/c mice (as indicated on figure) and immediately flash frozen. Tissue

extracts were prepared by homogenization in RIPA buffer. Equal amounts of protein from each sample were used to visualize the indicated molecules by immunoblotting.

Figure 9 is a set of FACS histograms showing that Ad-hHER3 vaccination decreases HER3 expression on JC-hHER3 tumor cells. JC-HER3 tumors were collected from vaccinated and control Balb/c mice (as indicated on figure) at day 28 and pooled by group. The tissues were minced and digested with an enzymatic cocktail (Hyaluronalse, DNAse, and Collagenase) overnight. After 3 days culture, the cells were harvested and HER3 expression determined by flow cytometry using PE-anti-hHER3 antibody.

DETAILED DESCRIPTION

As a novel alternative to vaccines targeting well established tumor antigens, we hypothesized that the antigen-specific immune non-responsiveness to conventional tumor-associated antigens may be avoided by targeting tumor antigens that are induced after exposure to a cancer therapeutic or prevention agent as a mechanism of developing therapeutic resistance. Although there may be many potential antigens overexpressed in response to a cancer therapeutic or prevention agent, those antigens that are likely critical components of specific therapeutic resistance mechanisms would be attractive targets, as immunologic ablation of clones expressing such antigens should eliminate the clinical recurrence of therapy resistant tumor cells. One such antigen thought to be essential to therapeutic resistance is a member of the HER family of receptor tyrosine kinases (RTKs), and to endocrine therapies, HER3.

HER3, although lacking catalytic kinase activity, is thought to function as a signaling substrate for other HER proteins with which it heterodimerizes. Although not transforming by itself, HER3 has tumor promoting functions in some cancers, including a role as a co-receptor for amplified HER2 with which it is synergistically co-transforming and rate-limiting for transformed growth. Treatment of HER2-amplified breast cancers with HER2-targeting tyrosine kinase inhibitors (TKIs) leads to an increase in HER3 expression and downstream signaling that results in therapeutic resistance.

The pivotal role of HER3 as a hub for HER family signaling has made it an attractive therapeutic target, but its' lack of kinase activity prevents small molecule HER3 specific TKIs from being generated. Nonetheless, HER3 may be targeted with antibodies which have diverse functional consequences depending on their binding site. For example, the anti-HER2 monoclonal antibody pertuzumab disrupts neuregulin-induced HER2-HER3 dimerization and signaling; however, it is less effective at disrupting the elevated basal state of ligand-independent HER2-HER3 interaction and signaling in HER2-overexpressing tumor cells. Other HER3-specific antibodies under development bind to, and cause internalization of, HER3, inhibiting downstream signaling. As an alternative to monoclonal antibodies, we have recently demonstrated that polyclonal antibodies induced by vaccination against receptors such as HER2 can mediate profound receptor internalization and degradation, providing a therapeutic effect *in vitro* and *in vivo* (Ren et al., Breast cancer Research 2012 14: R89).

Therefore, we generated a recombinant adenoviral vector expressing human HER3 (Ad-HER3) and demonstrated that it elicited HER3 specific B and T cell immune responses as shown in the Examples. Furthermore, we demonstrated that HER3 specific antibodies recognized multiple HER3 epitopes, bound to tumor membrane expressed HER3, mediated complement dependent lysis and altered downstream signaling mediated by receptor heterodimers involving HER3. In addition, we found that HER3 specific polyclonal antisera had specific activity in mediating HER3 internalization and degradation. Finally, we demonstrated that HER3 specific polyclonal antisera was well tolerated when transferred to tumor bearing animals, yet retarded tumor growth *in vivo*, including retarding the growth of HER2 therapy-resistant tumors. These data suggest that Ad-HER3 is an effective vaccine which should be tested for therapeutic efficacy in clinical trials targeting cancers that overexpress HER3 in response to a targeted therapy. The general application of this vaccination strategy can be applied to other antigens expressed in HER therapy resistant tumors, as well as antigens induced by other resistance mechanisms, and represents a new conceptual framework for cancer immunotherapy.

As described in the appended examples, generation of resistance to cancer therapeutic or prevention agents is a common problem in the treatment of cancer or

precancer and in several cases the mechanism of resistance to the therapeutic agent is known. Resistance is often the result of changes in gene expression (over-expression or blocked expression of a protein), change in the gene by mutation, or altered sequences by altered splicing or translocation or altered activation of a protein in the cells (over-activation or blocked activation of a protein).

In those cases where over-expression or over-activation of a protein, or a new sequence in the protein is responsible for increasing the resistance of the cancer or precancer cells to the therapeutic or prevention agent, we report a method for reducing the likelihood that the cancer or precancer will develop resistance to the cancer therapeutic or prevention agent. As used herein, resistance to a cancer therapeutic or prevention agent indicates that the cancer therapeutic or prevention agent is not as effective at inhibiting the growth of, or killing, cancer or precancer cells in response to the cancer therapeutic or prevention agent. The method may even block the development of resistance to the cancer therapeutic or prevention agent or may reverse resistance to the cancer therapeutic or prevention agent after it has developed. The methods include administering the cancer therapeutic or prevention agent and administering a vaccine to the subject in need of treatment for a cancer. The vaccine comprises a polynucleotide encoding a polypeptide whose expression or activation is correlated with or results in development of resistance of the cancer or precancer to the cancer therapeutic or prevention agent.

The vaccine may be administered before, during or after treatment with the cancer therapeutic or prevention agent or may be administered simultaneously with the cancer therapeutic or prevention agent. The administration of the vaccine and the cancer therapeutic or prevention agent to the subject reduces the likelihood that the subject's cancer or precancer will develop resistance to the therapeutic or prevention agent as compared to a control subject with a similar cancer or precancer not administered the vaccine or as compared to the general likelihood of a population of subjects having the cancer or precancer. In some embodiments, the cancer or precancer in individuals administered both the vaccine and the therapeutic or prevention agent does not develop resistance to the cancer therapeutic or prevention agent and is treated. Alternatively, the growth of the cancer or precancer may be inhibited or the growth rate reduced. The

administration of the vaccine and cancer therapeutic or prevention agent may also reverse resistance to the cancer therapeutic or prevention agent if the cancer or precancer is already resistant to the cancer therapeutic or prevention agent. In some embodiments, administration of the vaccine is sufficient to treat the cancer or inhibit the growth or kill the cancer. In other embodiments, the vaccine must be administered in conjunction with the cancer therapeutic or prevention agent or prior to development of resistance to the cancer therapeutic or prevention agent by the cancer.

The vaccine may include a polynucleotide encoding a HER3 polypeptide. The mature HER3 protein sequence is provided in SEQ ID NO: 1 and the complete HER3 protein precursor sequence is provided in SEQ ID NO: 2. Polynucleotide sequences for HER3 are provided in SEQ ID NO:3 (mRNA) and SEQ ID NO: 4 (DNA). The vaccine may comprise full-length HER3 or portions thereof. For example, the vaccine may comprise only the extracellular domain or the extracellular domain plus the ransmembrane domain or other portions of the HER3 polypeptide. Suitably the vaccine is capable of eliciting an immune response to HER3 in a subject administered the vaccine. The immune response may be a B cell or T cell response. Suitably the immune response includes an antibody response directed to HER3. The immune response may be a polyclonal antibody response in which multiple epitopes of HER3 are recognized by antibodies.

As reported in the examples, in a mouse model a HER3 vaccine was able to generate a robust polyclonal antibody response to HER3 and several epitopes were identified. See Figure 1D. The epitopes identified in Figure 1D include the polypeptides identified in SEQ ID NOs: 5-22, which represents portions of SEQ ID NO:2. It is expected that some of these epitopes may be immunogenic in humans as well. Those of skill in the art will appreciate that a vaccine including polynucleotides encoding only portions of full-length HER3, i.e. antigenic epitopes, may be used in the vaccines described herein.

The vaccine may include a vaccine vector. The vaccine vector may be a bacterial, yeast, viral or liposomal vaccine vector. The vaccine may be a DNA vaccine as well and not include a vaccine vector. The vaccine vector may be an adenovirus or adeno-associated virus. In the Examples an adenovirus was used as the vaccine vector. The

vaccine vector may contain the HER3 polynucleotide or portions thereof. The vaccine vector may contain the HER3 polypeptide or portions thereof. The vaccine vector may express the HER3 polypeptide or portions thereof. HER3 polypeptide or portions thereof may be expressed on the surface or interior of the vaccine vector. HER3 polynucleotide or portions thereof may be carried within the vaccine vector and the HER3 polypeptide or portions thereof may be expressed only after vaccination. HER3 polypeptides or portions thereof may be expressed as a fusion protein or in conjunction with adjuvants or other immunostimulatory molecules to further enhance the immune response to the polypeptide.

Methods of treating a cancer or precancer, or of reducing the likelihood of the cancer or precancer developing resistance to a cancer therapeutic or prevention agent, are also provided. The methods include administering the vaccine as described above to a subject having cancer or precancer. The subject may be any mammal, suitably a human, domesticated animal such as a dog or cat, or a mouse or rat. A cancer therapeutic or prevention agent may be administered concurrently with, before or after administration of the vaccine.

The cancer therapeutic or prevention agents may be any agent capable of treating the cancer or inhibiting growth of cancer cells. Suitable agents include those which target HER2, HER1/EGFR, estrogen receptor or IGF1R. The therapeutic agent may be trastuzumab, lapatinib, pertuzumab or another HER2 targeting therapeutic agent or it may be an EGFR targeting therapeutic agent such as cetuximab or erlotanib, or it may be an antiestrogen, or an agent that prevents estrogen synthesis such as an aromatase inhibitor. In particular, the Examples demonstrate that a HER3 vaccine can treat a HER2 positive cancer when used in combination with a therapeutic agent targeting HER2. Cancer cells often develop resistance to HER2 targeting therapeutic agents. Addition of vaccination with a HER3 vaccine or passively transferred polyclonal antibodies specific for HER3 resulted in blocking resistance, inhibited cancer cell growth and resulted in treatment of the cancer.

Suitably the vaccinated subject develops an immune response to HER3 in response to administration of the vaccine. The immune response may be an antibody or T cell immune response. For example the immune response may include antibody-

dependent cellular cytotoxicity, polyclonal antibody response, complement dependent cellular cytotoxicity, cellular cytotoxicity, disruption of ligand binding, disruption of dimerization, mimicking ligand binding causing internalization of HER3, or degradation of HER3. The immune response may comprise an antibody response directed to at least one of SEQ ID NOs: 5-22. As shown in the Examples, transfer of HER3 specific antibodies was sufficient to treat the cancer and inhibit the development of resistance to the therapeutic agent.

Reduction of the development of resistance can be measured in several ways. The resistance of the vaccinated subject may be compared to a similar subject that was not vaccinated as in the Examples. Alternatively, the reduction may be measured based on statistics generated regarding the likelihood of an individual being treated with the therapeutic agent to develop resistance versus that of individuals treated with the therapeutic agent and vaccinated with HER3. The reduction in the likelihood of resistance of the cancer may also be measured by measuring the level of HER3 expression on the surface of cancer cells. HER3 expression is reduced on cancer cells after effective administration of the vaccine. The effectiveness of the vaccine in treating the cancer or reducing the likelihood of resistance can be measured by tracking the growth of the tumor or the growth rate of the tumor or cancer cells. A decrease in tumor size or in the rate of tumor growth is indicative of treatment of the cancer.

The cancer may be selected from any cancer capable of developing resistance to a therapeutic agent by increasing expression or activation of a protein by the cancer cells. In particular the cancer may be any cancer capable of developing resistance to a therapeutic agent which targets a HER family tyrosine kinase, suitably HER2 or EGFR or the estrogen receptor, suitably anti-estrogens. The cancer may develop resistance by increasing the expression of HER3, which although not a kinase, will dimerize with another HER family kinase and allow for signaling to occur. Suitably the cancers are selected from breast, prostate, lung, ovarian, colon, rectal, pancreas, bladder, head and neck or liver cancers or precancers. The resistance may be due to a single or multiple changes, and the vaccine can target one or more of these changes, and/or include multiple antigens likely found in resistance cells, but not necessarily in all resistance cells.

Treating cancer includes, but is not limited to, reducing the number of cancer cells or the size of a tumor in the subject, reducing progression of a cancer to a more aggressive form (i.e. maintaining the cancer in a form that is susceptible to a therapeutic agent), reducing proliferation of cancer cells or reducing the speed of tumor growth, killing of cancer cells, reducing metastasis of cancer cells or reducing the likelihood of recurrence of a cancer in a subject. Treating a subject as used herein refers to any type of treatment that imparts a benefit to a subject afflicted with cancer or at risk of developing cancer or facing a cancer recurrence. Treatment includes improvement in the condition of the subject (e.g., in one or more symptoms), delay in the progression of the disease, delay in the onset of symptoms or slowing the progression of symptoms, etc.

Co-administration, or administration of more than one composition (i.e. a vaccine and a therapeutic agent) to a subject, indicates that the compositions may be administered in any order, at the same time or as part of a unitary composition. The two compositions may be administered such that one is administered before the other with a difference in administration time of 1 hour, 2 hours, 4 hours, 8 hours, 12 hours, 16 hours, 20 hours, 1 day, 2 days, 4 days, 7 days, 2 weeks, 4 weeks or more.

An effective amount or a therapeutically effective amount as used herein means the amount of a composition that, when administered to a subject for treating a state, disorder or condition is sufficient to effect a treatment (as defined above). The therapeutically effective amount will vary depending on the compound, formulation or composition, the disease and its severity and the age, weight, physical condition and responsiveness of the subject to be treated.

The compositions (i.e. the vaccines and the therapeutic agents) described herein may be administered by any means known to those skilled in the art, including, but not limited to, oral, topical, intranasal, intraperitoneal, parenteral, intravenous, intramuscular, subcutaneous, intrathecal, transcutaneous, nasopharyngeal, or transmucosal absorption. Thus the compositions may be formulated as an ingestable, injectable, topical or suppository formulation. The compositions may also be delivered with in a liposomal or time-release vehicle. Administration of the compositions to a subject in accordance with the invention appears to exhibit beneficial effects in a dose-dependent manner. Thus, within broad limits, administration of larger quantities of the compositions is expected to

achieve increased beneficial biological effects than administration of a smaller amount. Moreover, efficacy is also contemplated at dosages below the level at which toxicity is seen.

It will be appreciated that the specific dosage administered in any given case will be adjusted in accordance with the composition or compositions being administered, the disease to be treated or inhibited, the condition of the subject, and other relevant medical factors that may modify the activity of the compositions or the response of the subject, as is well known by those skilled in the art. For example, the specific dose for a particular subject depends on age, body weight, general state of health, diet, the timing and mode of administration, the rate of excretion, medicaments used in combination and the severity of the particular disorder to which the therapy is applied. Dosages for a given patient can be determined using conventional considerations, e.g., by customary comparison of the differential activities of the compositions described herein and of a known agent, such as by means of an appropriate conventional pharmacological or prophylactic protocol.

The maximal dosage for a subject is the highest dosage that does not cause undesirable or intolerable side effects. The number of variables in regard to an individual prophylactic or treatment regimen is large, and a considerable range of doses is expected. The route of administration will also impact the dosage requirements. It is anticipated that dosages of the compositions will reduce the growth of the cancer at least 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 100% or more as compared to no treatment or treatment with only the therapeutic agent. It is specifically contemplated that pharmaceutical preparations and compositions may palliate, block further growth or alleviate symptoms associated with the cancer without providing a cure, or, in some embodiments, may be used to cure the cancer and rid the subject of the disease.

The effective dosage amounts described herein refer to total amounts administered, that is, if more than one composition is administered, the effective dosage amounts correspond to the total amount administered. The compositions can be administered as a single dose or as divided doses. For example, the composition may be administered two or more times separated by 4 hours, 6 hours, 8 hours, 12 hours, a day, two days, three days, four days, one week, two weeks, or by three or more weeks.

The vaccine vector may be administered one time or more than one time to the subject to effectively boost the immune response against HER3. If the vaccine is provided as a vaccine vector, the vaccine vector may be administered based on the number of particles delivered to the subject (i.e. plaque forming units or colony forming units). The subject may be administered 10^{12}, 10^{11}, 10^{10}, 10^{9}, 10^{8}, 10^{7} or 10^{6} particles.

The examples provided herein are meant only to be illustrative and are not meant as limitations on the scope of the invention or of the appended claims. All references cited herein are hereby incorporated by reference in their entireties.

EXAMPLES

Materials and Methods

Cell lines and cell culture reagents.

The human breast cancer cell lines BT474, MCF-7, MDA-MB-231, MDA-MB-468, SKBR3, and T47D were obtained from the ATCC and grown in recommended media. The BT474M1 human breast tumor cell line was a gift from Dr. Mien-Chie Hung at The University of Texas M. D. Anderson Cancer Center and was grown in DMEM/F12 with 10% FBS. Laptinib-resistant BT474 (rBT474) were generated as previously described. Xia et al. A model of acquired autoresistance to a potent ErbB2 tyrosine kinase inhibitor and a therapeutic strategy to prevent its onset in breast cancer. Proc Natl Acad Sci U S A 2006;103:7795-800. Trastuzumab (Herceptin™, Genentech, San Francisco, CA) was purchased from the Duke Pharmacy.

Adenovirus vector preparation.

The human HER3 cDNA was excised from a pCMVSport6-HER3-HsIMAGE6147464 plasmid (cDNA clone MGC:88033/IMAGE:6147464) from the ATCC (Manassas, VA) , and construction of first-generation [E1-, E3-] Ad vectors containing human full length HER3 under control of human CMV promoter/enhancer elements was performed using the pAdEasy system (Agilent technologies, Santa Clara, CA) as previously described. Morse et al. Synergism from combined immunologic and pharmacologic inhibition of HER2 in vivo. Int J Cancer 2010;126:2893-903; Amalfitano et al. Production and characterization of improved adenovirus vectors with the E1, E2b,

and E3 genes deleted. J Virol 1998;72:926-33; Hartman et al. An adenoviral vaccine encoding full-length inactivated human Her2 exhibits potent immunogenicty and enhanced therapeutic efficacy without oncogenicity. Clin Cancer Res 2010;16:1466-77; and He et al. A simplified system for generating recombinant adenoviruses. Proc Natl Acad Sci U S A 1998;95;2509-14.

Mice.

BALB/c and NOD.CB17-*Prkdc*^{scid}/J mice were purchased from Jackson Labs (Bar Harbor, ME). All work was conducted in accordance with Duke IACUC-approved protocols. Induction of VIA: BALB/c mice were vaccinated on day 0 and day 14 via footpad injection with Ad-GFP, or Ad-HER3 vectors ($2.6x10^{10}$ particles/ mouse). Fourteen days after the second vaccination, mice were euthanized and sera were collected and stored at -80°C.

MTT assay to detect cell proliferation.

The effect of VIA-HER3 on the proliferation of human breast cancer cell lines was measured as previously described. Morse et al. Synergism from combined immunologic and pharmacologic inhibition of HER2 in vivo. Int J Cancer 2010;126:2893-903. Briefly, 5000 cells per well in a 96-well plate were cultured with HER3-VIA (1:33 dilution) or control serum GFP-VIA (1:33 dilution) or Trastuzumab 20 µg/ml for 3 days and proliferation was assessed by MTT assay.

Western blotting to analyze pathway inhibition.

Tumors were isolated from euthanized mice and immediately flash frozen. Tissue extracts were prepared by homogenization in RIPA buffer as previously described by Morse et al. 2010. Equal amounts of proteins (50 ug) were resolved by 4-15% gradient SDS PAGE After transfer membranes were probed with specific antibodies recognizing target proteins: pTyr (Sigma), ErbB2, ErbB3, Akt, pAkt473, Erk 1/2, pErk1/2, (Cell Signaling, Beverly, MA) survivin, and actin (Sigma, St. Louis, MO), 4EBP-1, p4EBP-1, s6, ps6 (Santa Cruz Biotech.,Santa Cruz, CA) and IRDye 800 conjugated anti-rabbit or mouse IgG or Alexa Fluor 680 anti-rabbit IgG and were visualized using the Odyssey Infrared Imaging System (LI-COR, Lincoln, NE).

ELISPOT analysis.

IFN-gamma ELISPOT assays (Mabtech, Cincinnati, OH) performed as previously described by Morse et al, 2010. HER3 peptide mix (1 mcg/mL was used; Jerini Peptide Technologies, Berlin, Germany), HIVgag peptide mix (BD Bioscience), or a mixture of PMA (50 ng/mL) and Ionomycin (1 ng/mL) were used. Six replicate wells for each condition were scored using the KS ELISPOT Reader with the KS ELISPOT 4.9 Software (Carl Zeiss, München-Hallbergmoos, Germany), reporting responses as the mean of the replicate 6 wells.

Analysis of anti-HER3 antibody binding by Flow cytometry.

We have adapted a methodology reported by Piechocki et al. to measure anti-HER3 vaccine induced antibodies in vaccinated mouse serum by flow cytometry. Hartman et al. An adenoviral vaccine encoding full-length inactivated human Her2 exhibits potent immunogenicty and enhanced therapeutic efficacy without oncogenicity. Clin Cancer Res 2010;16:1466-77 and Piechockiet al. Quantitative measurement of anti-ErbB-2 antibody by flow cytometry and ELISA. J Immunol Methods 2002;259:33-42. Briefly, 3 x 10^5 human breast cancer cells were incubated with diluted (1:100 to 1:51,200) mouse serum antibodies (HER3-VIA or GFP-VIA) for 1h at 4°C and then washed with 1% BSA-PBS. The cells were further stained with PE-conjugated anti-mouse IgG (Dako, Cat # R0480) for 30 minutes at 4°C, and washed again. Samples were analyzed on a BD LSRII flow cytometer (Becton Dickenson, San Jose, CA) and mean fluorescence intensity (MFI) reported.

Complement dependent cytotoxicity assay.

We performed complement dependent cytotoxicity assays using our previously published protocol in Morse et al. 2010. Briefly, target cells were incubated with rabbit serum (1:100) as a source of complement and the HER3-VIA or GFP-VIA in sera from mice immunized as above diluted (1:100), or Trastuzumab (20 mcg/ml) at 37°C for 2 hrs. After incubation, cytotoxicity was measured using the CytoTox 96 Nonradioactive Cytotoxicity Assay (Promega; per manufacturer's instructions) to measure LDH release in the culture media as evidence of cytotoxicity.

Assessment of HER3 internalization

Human HER3+ breast cancer cells (SKBR3 and BT474M1) were incubated with 1:100 HER3-VIA or GFP-VIA at 37°C for 60 minutes. After washing, fixation with 4% PFA, and permeabilization with permeabilizing solution 2 (Becton Dickenson), nonspecific binding was blocked with 2.5% Goat Serum at 37°C for 30 min. Cells were incubated with 1:100 Red™-conjugated anti-mouse IgG (H+L) (Jackson ImmunoResearch Laboratories Inc. West Grove, PA) in a dark chamber for 1 hour at room temperature and washed with PBS. Slides were mounted in VectaShield containing DAPI (Vector Laboratories, Burlingame, CA) and images acquired using a Zeiss Axio Observer widefield fluorescence microscope (Carl Zeiss, München-Hallbergmoos, Germany).

Treatment of established HER3+ BT474M1 human tumor xenografts by passive transfer of vaccine induced antibodies.

Eight to 10 week old NOD.CB17-*Prkdc*^{scid}/J mice (Jackson Labs., Bar Harbor, ME) were implanted in the back with 17 Beta-Estradiol pellets (0.72 mg 60day continuous release pellets; Innovative Research of American, Sarasota, FL) two days prior to tumor implantation. Five million BT474M1 tumor cells in 50% Matrigel were injected into the mammary fat pad. Tumors were allowed to develop for 14 days and then mice were randomized to receive iv injection of either GFP-VIA or HER3-VIA (5 mice per group). 100-150 microliters of VIA was injected at 2-3 day intervals for a total of 10 administrations. Tumor growth was measured in two dimensions using calipers and tumor volume determined using the formula volume = ½ [(width)^2 x (length)].

Treatment of established HER3+ lapatinib-resistant rBT474 human tumor xenografts by passive transfer of vaccine induced antibodies.

Eight to 10 week old NOD.CB17-*Prkdc*^{scid}/J mice (Jackson Labs., Bar Harbor, ME) were implanted in the mammary fat pad with 1 million lapatinib-resistant rBT474 tumor cells in 50% Matrigel. Tumors were allowed to develop for two months and then mice were randomized to receive iv injection of either GFP-VIA or HER2-VIA (5 mice per group). 100-150 microliters of VIA was injected at 2-3 day intervals for a total of 10 administrations. Tumor growth was measured as described above.

Statistical analyses.

Tumor volume measurements for *in vivo* models were analyzed under a cubic root transformation to stabilize the variance as in Morse et al. 2010. Welch t-tests were used to assess differences between mice injected with HER3-VIA or control GFP-VIA. Analyses were performed using R version 2.10.1. For all tests, statistical significance was set at $p < 0.05$.

Results

Ad-HER3 elicits anti-HER3 T cell and antibody responses in vivo

We developed a recombinant E1-, E3- adenovirus serotype 5 vector (Ad-HER3) expressing full length human HER3 (Ad-HER3). Wild type BALB/c mice were vaccinated with Ad-HER3, splenocytes from vaccinated mice were harvested and demonstrated by ELISPOT to specifically recognize HER3 using an overlapping human HER3 peptide mix as a source of antigens, whereas splenocytes from mice receiving control Ad-GFP vaccine or saline showed no reactivity to the HER3 peptide mix (**Fig. 1A**). To detect HER3-specific antibodies capable of detecting membrane associated HER3, binding of vaccine induced antibodies (VIA) in mouse serum was tested using a series of human HER3 expressing breast tumor cells lines, including the high HER3 expressing BT474M1, BT474, SKBR3 andT47D and the low to negatively expressing MDA-231 tumor cell line (**Fig. 1B and 1C**). The serum of mice vaccinated with the Ad-HER3 had binding titers of >1:800, whereas the serum of mice receiving the control Ad-LacZ vaccine showed only background levels of binding. Thus, HER3-VIA are able to bind to endogenous HER3 expressed on human breast cancer lines.

To confirm that multiple HER3 epitopes were recognized, we demonstrated VIA binding to a series of HER3 peptides. The HER3-VIA recognized at least 18 epitopes in both the intracellular and extracellular domain, demonstrating that the antibody responses are polyclonal (**Fig. 1D** and SEQ ID NOs: 5-22). It should be noted that peptide arrays do not recapitulate conformationally correct protein structure, so they often underestimate the true number of epitopes recognized.

HER3 specific antibodies induced by vaccination (HER3-VIA) mediate complement dependent lysis of HER3+ breast tumor cell lines *in vitro*

Direct antibody-mediated tumor cell killing is a powerful potential mechanism of action of antibodies induced by vaccination. We evaluated the capacity HER3-VIA to mediate complement-dependent cytotoxicity (CDC). HER3-VIA exhibited strong CDC against HER3-expressing human breast tumor cells but not the HER3 negative MDA-231 cell line, while control GFP-VIA showed no effect (**Fig. 2A**). Trastuzumab is known not to mediate CDC and this was confirmed in our assays.

Anti-proliferative effects of HER3 VIA *in vitro*

Although immunization with Ad-HER3 was able to efficiently induce humoral immunity *in vivo* and mediate complement dependent tumor cell cytotoxicity, we also wished to determine whether these antibodies could inhibit tumor cell proliferation. We found that when HER3-expressing human breast cancer cells were cultured with HER3-VIA from the sera of Ad-HER3 vaccinated mice, their proliferation was significantly inhibited compared with cells cultured with control GFP-VIA (**Fig. 2B**). Of interest, despite the much high levels of HER2 expressed on these tumor cells, compared to HER3, the inhibition of tumor cell proliferation mediated by HER3-VIA was similar to the effects of the clinically effective monoclonal antibody trastuzumab.

Loss of HER3 expression on tumor cell lines mediated by HER3-VIA *in vitro*

Growth factor receptor internalization, degradation, and down regulation has been proposed as a mechanism for the inhibition of tumor growth mediated by monoclonal antibodies. To ascertain whether receptor down regulation was caused by HER3-VIA as a result of receptor internalization, we visualized cell membrane associated HER3 receptor on SKBR3 and BT474M1 tumor cells. When exposed to serum containing HER3-VIA or GFP-VIA, dramatic internalization and aggregation of the receptor was observed within 1 hr after exposure to HER3-VIA, but not with exposure to control GFP-VIA (**Fig. 2C**).

Inhibition of tumor growth by HER3 VIA *in vivo* is associated with loss of HER3 expression and anti-signaling effects

After finding that HER3 specific antibodies could inhibit HER3+ tumor cell proliferation *in vitro*, we sought to demonstrate the effects of HER3 VIA *in vivo*. At this time, there are no murine breast tumors dependent on human HER3 for growth, and attempts to establish 4T1 tumors expressing HER3 have been unsuccessful. Consequently, we employed a human xenograft model using the BT474M1 cell line that expresses both HER2 and HER3, with adoptive transfer of antibodies to demonstrate the *in vivo* activity of HER3-VIA. The study design is illustrated in **Fig. 3A**. We found that passive immunotherapy with HER3-VIA retarded the growth of established HER3+ BT474M1 human tumor xenografts *in vivo* ($p<0.005$ after Day 28) when compared to the control GFP-VIA treated mice (Fig. 3B). At the termination of the study tumor size was compared and was significantly reduced in the HER3-VIA-treated mice ($p=0.005$).

In addition to demonstrating anti-tumor effects *in vivo*, we also wanted to document the anti-HER3 signaling effects of HER3 VIA *in vivo*. Analysis of excised tumors allowed us to determine HER3 expression following treatment *in vivo*. We found that mice treated with HER3-VIA showed decreased levels of HER3 in their residual tumor by immunohistochemistry (**Fig. 3C**), consistent with antigen downregulation as the basis of immunologic escape. We also examined the impact of treatment with HER3-VIA on downstream effectors of HER3 signaling, and found a reduction of pHER (pTyr), HER3, and pErk1/2, compared to tumors treated with GFP-VIA (**Fig. 3D**).

Inhibition of therapy-resistant tumor growth by HER3 VIA *in vivo*

While the antitumor efficacy against established HER3+ BT474M1 tumors was encouraging, we know that a major unmet need for breast cancer patients is for therapies to overcome therapeutic resistance to HER2 targeted therapies. For example, therapeutic resistance to trastuzumab, can be overcome by treatment with a small molecule inhibitor of HER2, lapatinib, but patients whose tumors initially respond ultimately experience therapeutic resistance and disease progression. Of interest is the persistent overexpression of HER2 in the tumors from these patients, and the emerging recognition that signaling from the HER2/HER3 heterodimer, and other heterodimers involving HER3, was a significant resistance mechanism. Consequently, we tested the effects of HER3-VIA in a model of lapatinib resistance derived from the rBT474 cell line that we

have previously reported. Xia et al. A model of acquired autoresistance to a potent ErbB2 tyrosine kinase inhibitor and a therapeutic strategy to prevent its onset in breast cancer. Proc Natl Acad Sci U S A 2006;103:7795-800. This rBT474 cell line expresses HER2 and HER3 at similar levels to the BT474M1 tumor line. We demonstrate that the HER3-VIA was effective at retarding the growth of established tumors (**Fig. 4**) (p 0.025 for all time points from Day 4 to Day 25), confirming the therapeutic potential of an Ad-HER3 vaccine for patients who have experienced disease progression on lapatinib.

Inhibition of lapatinib-resistant tumor growth by HER3 VIA *in vivo* is associated with loss of HER3 expression and broader anti-signaling effects than lapatinib-sensitive tumors

Tumors excised from the mice at the termination of the study described above, were examined for signaling pathway modulation. Whole tumor lysates from 5 mice per group were studied, since we expected some mouse-to-mouse variation and wanted to capture the spectrum of responses (Fig. 4B). Total HER2 and HER3 levels are decreased in the HER3-VIA treated tumors, suggesting receptor degradation may be occurring. pTyr is also consequently reduced, indicating decreased HER2:HER3 signaling. pAkt473(S473) and pS6 are also decreased for the HER3-VIA treated tumors, as are pErk1/2, p4EBP1, and survivin relative to the control GFP-VIA treated tumors. In contrast to the data in the lapatinib-sensitive BT474M1 tumors, immunohistochemistry analysis of excised rBT474 tumors did not show a marked decrease in HER3 in tumors treated with HER3-VIA compared to GFP-VIA controls (Fig. 4C), suggesting that HER3 degradation was more modest and anti-proliferative effects mediated through the HER3 heterodimers were therefore more prominent.

Generate Ad5(E2b-)HER3 and Ad5(E2b-)HER3 C1C2 constructs (Y1, Q1-2)

Adenoviral vectors expressing HER3 using the Ad5(E2b-) platform have been constructed and have been used to generate virus. We now wanted to assess whether other HER3 expressing adenovirus vectors would have similar effects. We have modified the adenovirus construction methods to facilitate the construction of (E1- , E2b-, E3-) Ad5 vector.

The human HER3 full length cDNA was obtained from OriGene (Rockville, MD). The truncated HER3 extracellular domain (ECD) and HER3 ECD plus transmembrane (TM) sequence were created using HER3 full length as templates in a PCR reaction using primers (see Table 1 below) and Figure 5.

Table 1: Primers used in construction of truncated Ad5-human HER3

Primer	Sequence (SEQ ID NO:)
hHER3-F	5'-cagggcggccgcaccatgagggcgaacgacgctct-3' (SEQ ID NO: 23)
hHER3-ECDTM-R	5'-acaagcggccgcagttaaaaagtgccgcccagcatca-3'(SEQ ID NO: 24)
hHER3-ECD-R	5'-acaagcggccgcatttatgtcagatgggttttgccgatc-3' (SEQ ID NO: 25)
hHER3-ECDC1C2-R	5'-acaagcggccgcattgtcagatgggttttgccg-3' (SEQ ID NO: 26)

Briefly, full length HER3 cDNA and the PCR product are cut by restrict enzyme *Not I* and subcloned into *Not I* digested pShuttle-CMV or pShuttleCMV-C1C2 plasmid. Confirmation of correct insert of the full length and truncated DNA within pShuttle-CMV or pShuttle-CMV-C1C2 was confirmed by DNA sequencing. The pShuttle-CMV-her3-FL (full-length), pShuttle-Her3ECD, pShuttle-Her3ECDTM and pShuttle-Her3ECDC1C2 were then linearized using digestion with *Pme I,* recombined into linearized (E1-,E2b-,E3-) serotype 5 pAd construct in BJ 5183 bacterial recombination-based system (Stratagene), and propagated in XL10-Gold Ultracompetent cells (Stratagene). Complementing C7 cell (which express E1 and E2b) were used to produce high titers of these replication-deficient Ad5 vectors, and cesium chloride density gradient was done to purify the Ad5-vectors. All Ad vectors stocks were evaluated for replication-competent adenovirus via PCR-based replication-competent adenovirus assay.

The next generation human HER3 (E1-,E2b- , E3-) Adenovirus vectors are as follows:

1. Ad5 (E2b-)HER3 FL; express human HER3 full length.
2. Ad5 (E2b-)HER3ECDTM; express human HER3 ECD and trans-membrane domain
3. Ad5 (E2b-)HER3ECD; express human HER3 ECD
4. Ad5 (E2b-)HER3ECDC1C2; express human HER3 ECD and C1C2 domain

The ability of each vector to induce a HER3 specific immune responses will be tested, but was expected based on the earlier results and epitopes identified above.

Human HER3 specific immune responses to the vectors will be measured in Balb/c mice and in human HER3 transgenic mice.

To determine the preventive effect of HER3 vacccination, we have established a HER3 prevention model using JC-HER3 mouse mammary tumor cells in Balb/c mice. As shown in Figure 6, only vaccination with the HER3 encoding vector prevented growth of the hHER3 expressing tumors *in vivo*. We next sought to demonstrate development of HER3 specific immune response by ELISPOT. Results are shown in Figure 7.

Due to the induction of HER3 specific immune responses, we sought evidence whether those tumors that did grow in the HER3 vaccinated mice expressed HER3. In other words, we sought evidence of loss of HER3 in those tumors capable of growth in the vaccinated mice. As shown in Figure 8, immunization with Ad-hHER3 led to a reduction of HER3 expression in the tumors that did develop. Of interest, immunization with Ad-GFP or Ad-hHER2 did not change HER3 expression.

We then tested for surface HER3 expression in the tumors that grew in the HER3 vaccinated mice. As demonstrated in Figure 9, the surface expression of HER3 was dramatically reduced in the tumors that did grow in the HER3 vaccinated mice.

In summary, we created a HER3 vaccine by generating a recombinant adenovirus encoding human HER3 (Ad-HER3). The Ad-HER3 was highly effective in eliciting significant HER3 specific T-cell and polyclonal antibody responses in mouse models, with the vaccine induced antibodies (VIA) binding multiple HER3 epitopes as well as tumor-expressed HER3 and mediating complement dependent lysis. In addition, the HER3-VIA caused HER3 internalization and degradation, significantly inhibited signaling mediated by receptor heterdimers involving HER3, and retarded tumor growth *in vitro* and *in vivo*. Critically, we also showed that the HER3-VIA retarded the growth of human breast cancer refractory to HER2 small molecule inhibitors (lapatinib) in SCID xenografts, providing a compelling argument for the Ad-HER3 vaccine to be tested in patients whose cancer has progressed on HER2 targeted therapy, and in combination with HER2 targeted therapy.

It is interesting to note that the lapatinib-resistant rBT474 clone is much more sensitive to HER3-VIA *in vivo* than the lapatinib-sensitive BT474M1 clone yet they express equivalent levels of HER3 on the cell surface, which may be a result of increased reliance on HER3 as a driver of tumor growth in the lapatinib resistant BT474 cells. In fact, treatment of the lapatinib resistant BT474 cells leads to decreased HER3, pHER3 and pERK1/2 as expected, but also decreased HER2, pAkt(S473), pS6, p4EPB1, and survivin expression. In contrast, treatment of the lapatinib sensitive BT474 cells with HER3 VIA decreases only HER3, pHER3 and pErk1/2, suggesting that HER3 VIA will have more profound biologic and clinical effects in lapatinib refractory tumors. The lapatinib-resistant BT474 cells also continue to express HER3 protein after treatment with HER3-VIA *in vivo*, suggesting that antigen loss is not an escape mechanism for lapatinib resistant tumors because HER3 is critical to the tumor survival. Thus, persistent expression of HER3 because of it' role in lapatinib resistance, ensures that tumors will remain targets for vaccine induced T cell and antibody response.

The decrease in the inhibitor of apoptosis protein survivin suggests that a mechanism of resistance to tumor cell killing is also being diminished. We observed similar effects on the expression of survivin in the mouse 4T1-HER2 tumor model which is relatively resistant to trastuzumab, but relatively sensitive to lapatinib. When the 4T1-HER2 expressing tumors were treated with lapatinib or HER2 VIA alone, we observed no change in survivin expression, but when these tumors were treated with a combination of lapatinib and HER2-VIA we observed a decrease in survivin expression, implying that complete HER2 signaling blockade decreased survivin expression. In an analogous fashion, it suggested that complete blockade of HER2:HER3 signaling in lapatinib refractory tumors is accomplished by treatment with HER3-VIA, resulting in the decreased expression of survivin in these studies.

We believe our findings have relevance for counteracting the development of resistance to HER2 targeted therapies. Although HER3 is non-transforming alone, recent data suggests that HER3 expression or signaling is associated with drug resistance to targeted therapies directed against other HER family members. In particular, the acquired resistance to HER2 inhibitors in HER2-amplified breast cancers, trastuzumab resistance in breast cancer, with EGFR inhibitors in lung cancers, with pertuzumab

resistance in ovarian cancers, and with EGFR inhibitors in head and neck cancers. The overexpression of HER2:HER3 heterodimers is also negatively correlated with survival in breast cancer. Our approach of targeting HER3 may also have advantages over other HER family targeting strategies. For example, data suggest that trastuzumab is effective against HER1:HER2 heterodimers but not HER2:HER3 heterodimers. HER3 may play a role in therapeutic resistance to other therapies including anti-estrogen therapies in ER positive breast cancers, with hormone resistance in prostate cancers, and with IGF1R inhibitors in hepatomas. Therefore, targeting HER3 may have relevance for counteracting resistance to other pathway inhibitors.

These data suggest that it may be possible to begin a "resistance prophylaxis" vaccination against overexpressed or mutated proteins that will predictably arise to mediate therapeutic resistance, such as HER3. Immunization against these proteins prior to their overexpression as a mediator of therapeutic resistance may avoid immune tolerance induced by their prolonged expression in an immunosuppressive microenvironment. The resulting pre-existing immune response would be much more effective in mediating anti-tumor responses to tumors overexpressing antigen, and/or prevent these mediators from being expressed.

CLAIMS

We claim:

1. A vaccine comprising a polynucleotide encoding a HER3 polypeptide.
2. The vaccine of claim 1, wherein the vaccine is capable of eliciting an immune response to a HER3 polypeptide when administered to a subject.
3. The vaccine of any one of claims 1-2, wherein the HER3 polypeptide comprises SEQ NO: 1 or SEQ ID NO: 2 or portions thereof.
4. The vaccine of claim 3, wherein the portion of the HER3 polypeptide comprises the extracellular domain of HER3.
5. The vaccine of claim 3, wherein the portions of HER3 are selected from at least one of SEQ ID NOs: 5-22.
6. The vaccine of any one of claims 1-5, further comprising a vaccine vector.
7. The vaccine of claim 6, wherein the vaccine vector comprises the HER3 polypeptide.
8. The vaccine of claim 6 or 7, wherein the vaccine vector is selected from adenovirus or adeno-associated virus (AAV).
9. A method of treating a cancer or precancer or of reducing the likelihood of the cancer developing resistance to a cancer therapeutic or prevention agent comprising administering the vaccine of any one of claims 1-8 to a subject having the cancer or precancer, wherein administration of the vaccine to the subject treats the cancer or precancer, reduces the likelihood of the cancer or precancer developing resistance to the cancer therapeutic or prevention agent or reverses resistance of the cancer or precancer to the cancer therapeutic or prevention agent.
10. The method of claim 9, wherein the cancer is HER2 positive.
11. The method of claim 9 or 10, wherein the vaccine is administered concurrently with, before or after administration of the cancer therapeutic or prevention agent.
12. The method of claim 11, wherein the cancer therapeutic or prevention agent is an agent targeting HER2, HER1, estrogen receptor, EGFR, or IGF1R.
13. The method of any one of claims 9-12, wherein the cancer or precancer is selected from a breast, prostate, lung, ovarian, colon, rectal, pancreas, bladder, head and neck or liver cancer or precancer.

14. The method of any one of claims 9-13, wherein the subject develops an immune response to HER3.

15. The method of claim 14, wherein the immune response comprises an antibody response or a T cell mediated response.

16. The method of claim 13, wherein the immune response includes at least one of antibody-dependent cellular cytotoxicity, polyclonal antibody response, complement dependent cellular cytotoxicity, cellular cytotoxicity, disruption of ligand binding, disruption of dimerization, mimicking ligand binding causing internalization of HER3, or degradation of HER3.

17. The method of claim 14, wherein the immune response comprises an antibody response directed to at least one of SEQ ID NOs: 5-22.

18. The method of any one of claims 9-17, wherein administration of the vaccine results in a reduction of HER3 expression on cancer or precancer cells after administration of the vaccine as compared to the level of HER3 on the cells prior to vaccination.

19. The method of any one of claims 9-18, wherein administration results in decreased tumor growth rate or decreased tumor size after administration as compared to prior to administration.

20. The method of any one of claims 9-19, wherein the cancer therapeutic or prevention agent is selected from trastuzumab, lapatinib, cetuximab, pertuzumab and erlotanib.

21. A method of reducing the likelihood of a cancer or precancer developing resistance to a cancer therapeutic or prevention agent comprising administering the cancer therapeutic or prevention agent and a vaccine comprising a polynucleotide encoding a polypeptide whose expression or activation is correlated with development of resistance of the cancer or precancer to the cancer therapeutic or prevention agent to a subject having a cacner or precancer.

22. The method of claim 21, wherein administration reduces the growth of the cancer or precancer.

23. The method of claim 21 or 22, wherein the vaccine is the vaccine of any one of claims 1-8.

24. The method of any one of claims 21-23, wherein the cancer does not develop resistance to the cancer therapeutic or prevention agent.

25. The method of any one of claims 21-24, wherein cancer or precancer that is resistant to the cancer thereapeutic or prevention agent becomes more sensitive to the cancer thereapeutic or prevention agent after administration of the vaccine.

26. The method of any one of claims 21-25, wherein the vaccine is administered concurrently with, before or after administration of the cancer therapeutic or prevention agent

Fig. 1A

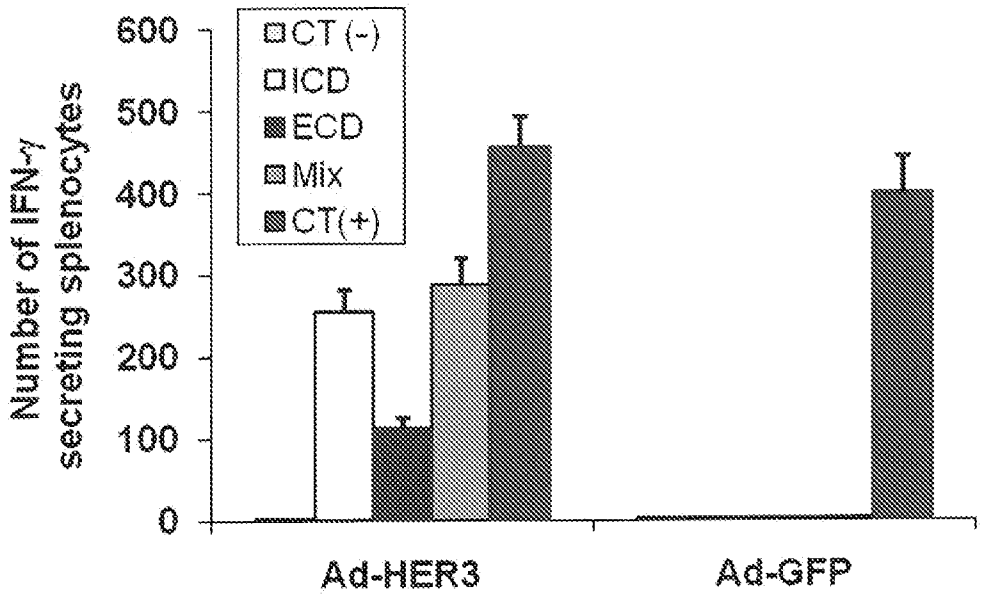

CT (-)
ICD
ECD
Mix
CT(+)
Number of IFN-γ secreting splenocytes
600
500
400
300
200
100
0
Ad-HER3
Ad-GFP

Fig. 1C

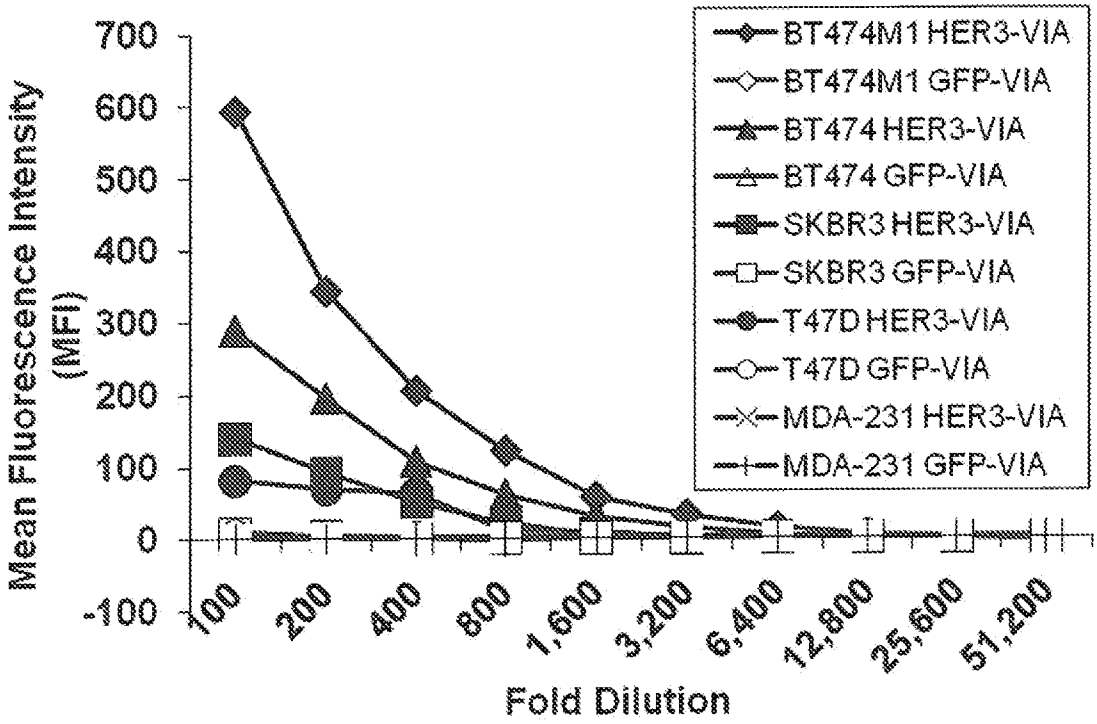

BT474M1 HER3-VIA
BT474M1 GFP-VIA
BT474 HER3-VIA
BT474 GFP-VIA
SKBR3 HER3-VIA
SKBR3 GFP-VIA
T47D HER3-VIA
T47D GFP-VIA
MDA-231 HER3-VIA
MDA-231 GFP-VIA
Mean Fluorescence Intensity (MFI)
700
600
500
400
300
200
100
0
-100
100
200
400
800
1,600
3,200
6,400
12,800
25,600
51,200
Fold Dilution

Fig. 1B

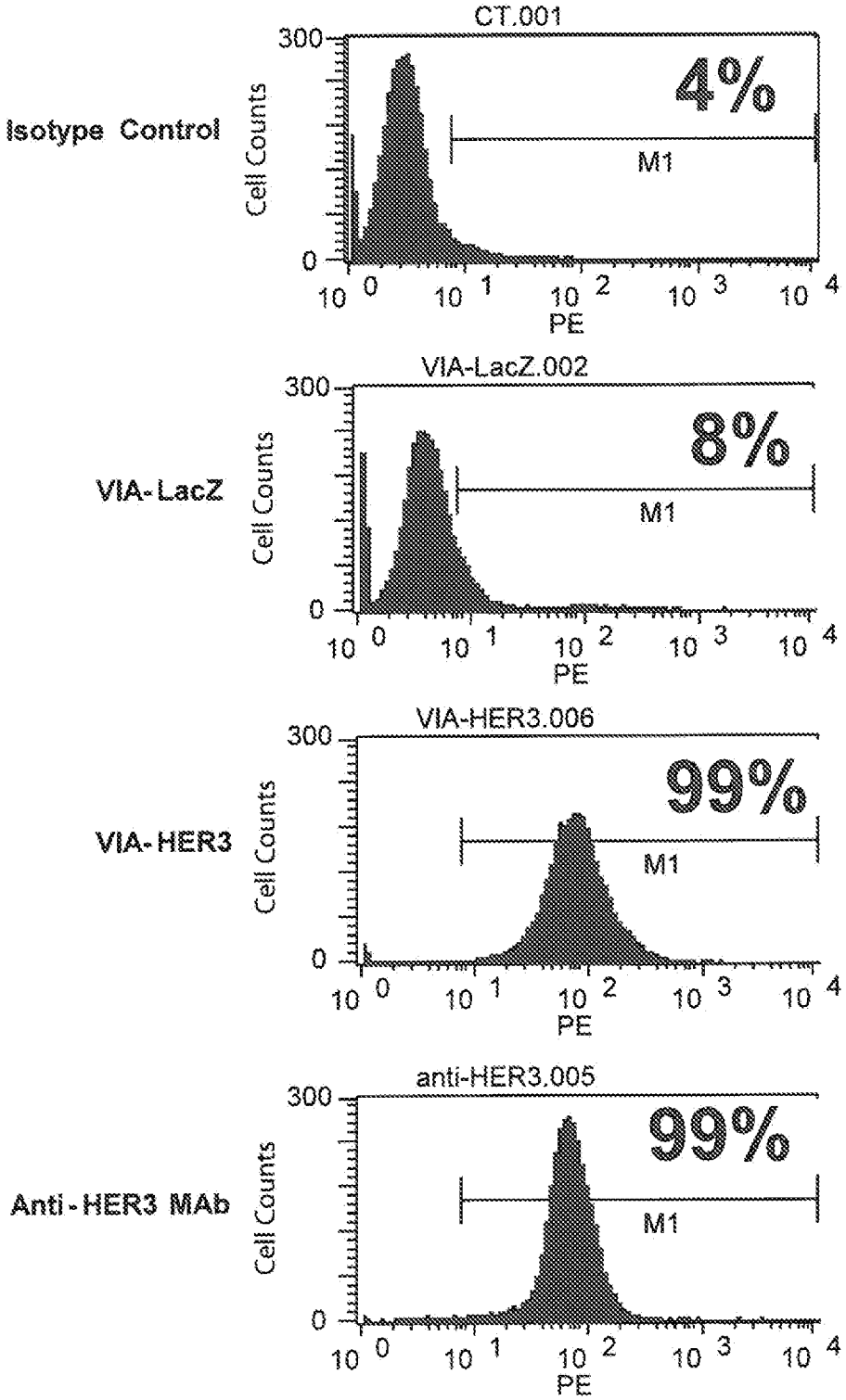

Isotype Control
CT.001
4%
M1
Cell Counts
300
0
10 0 10 1 10 2 10 3 10 4
PE
VIA-LacZ
VIA-LacZ.002
8%
M1
Cell Counts
300
0
10 0 10 1 10 2 10 3 10 4
PE
VIA-HER3
VIA-HER3.006
99%
M1
Cell Counts
300
0
10 0 10 1 10 2 10 3 10 4
PE
Anti-HER3 MAb
anti-HER3.005
99%
M1
Cell Counts
300
0
10 0 10 1 10 2 10 3 10 4
PE

Fig. 1D

HER3-VIA Antibody epitopes	
Epitope(s) position	Protein region
101-111	ECD
153-167	ECD
185-191	ECD
209-223	ECD
369-375	ECD
501-511	ECD
589-599	ECD
649-663	TM
681-691	ICD
865-875	ICD
881-895	ICD
901-915	ICD
981-988	ICD
1037-1051	ICD
1105-1119	ICD
1153-1163	ICD
1249-1255	ICD
1268-1279	ICD

Fig. 2A

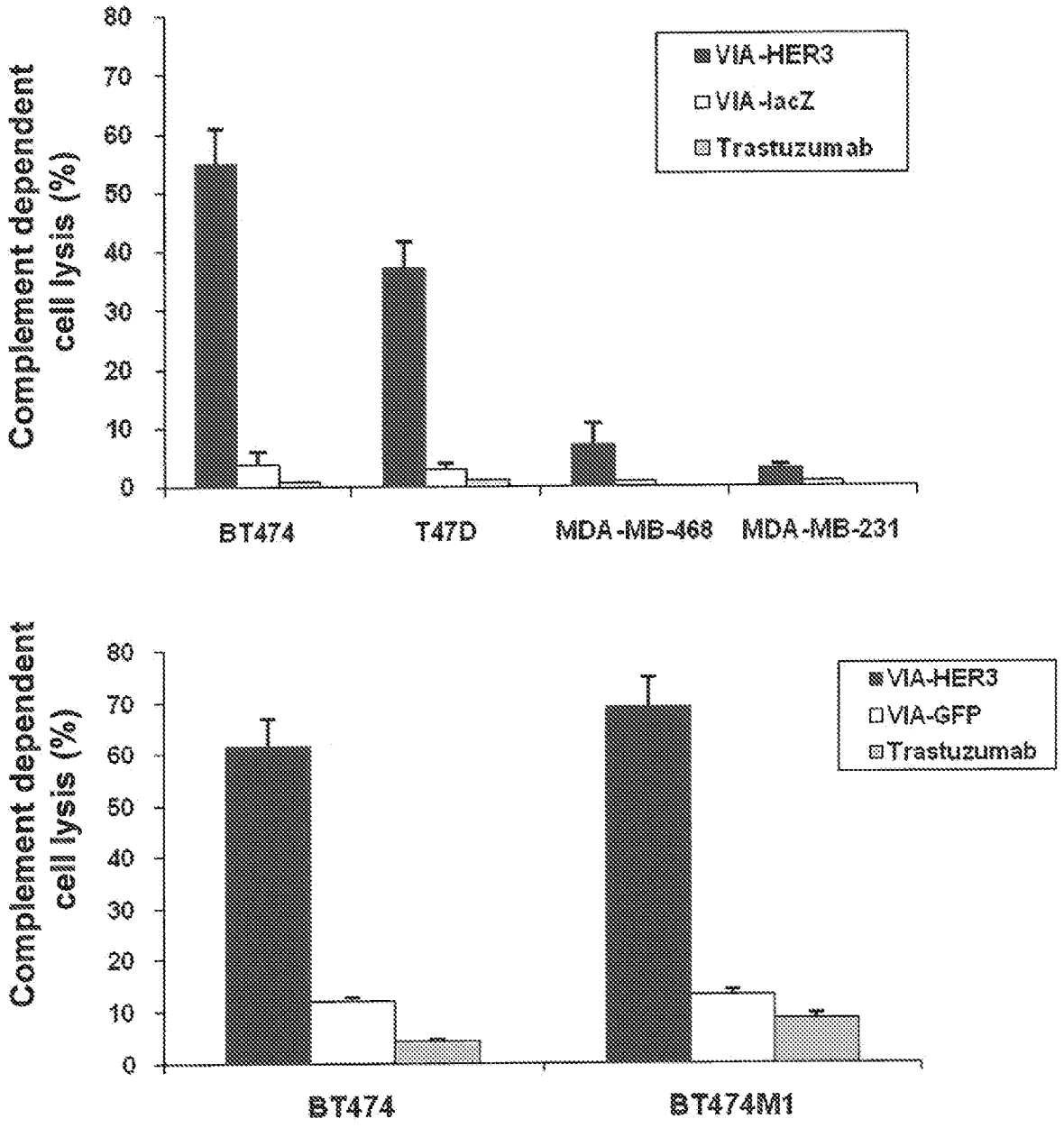

Complement dependent cell lysis (%)
80
70
60
50
40
30
20
10
0
VIA-HER3
VIA-lacZ
Trastuzumab
BT474
T47D
MDA-MB-468
MDA-MB-231
Complement dependent cell lysis (%)
80
70
60
50
40
30
20
10
0
VIA-HER3
VIA-GFP
Trastuzumab
BT474
BT474M1

Fig. 2B

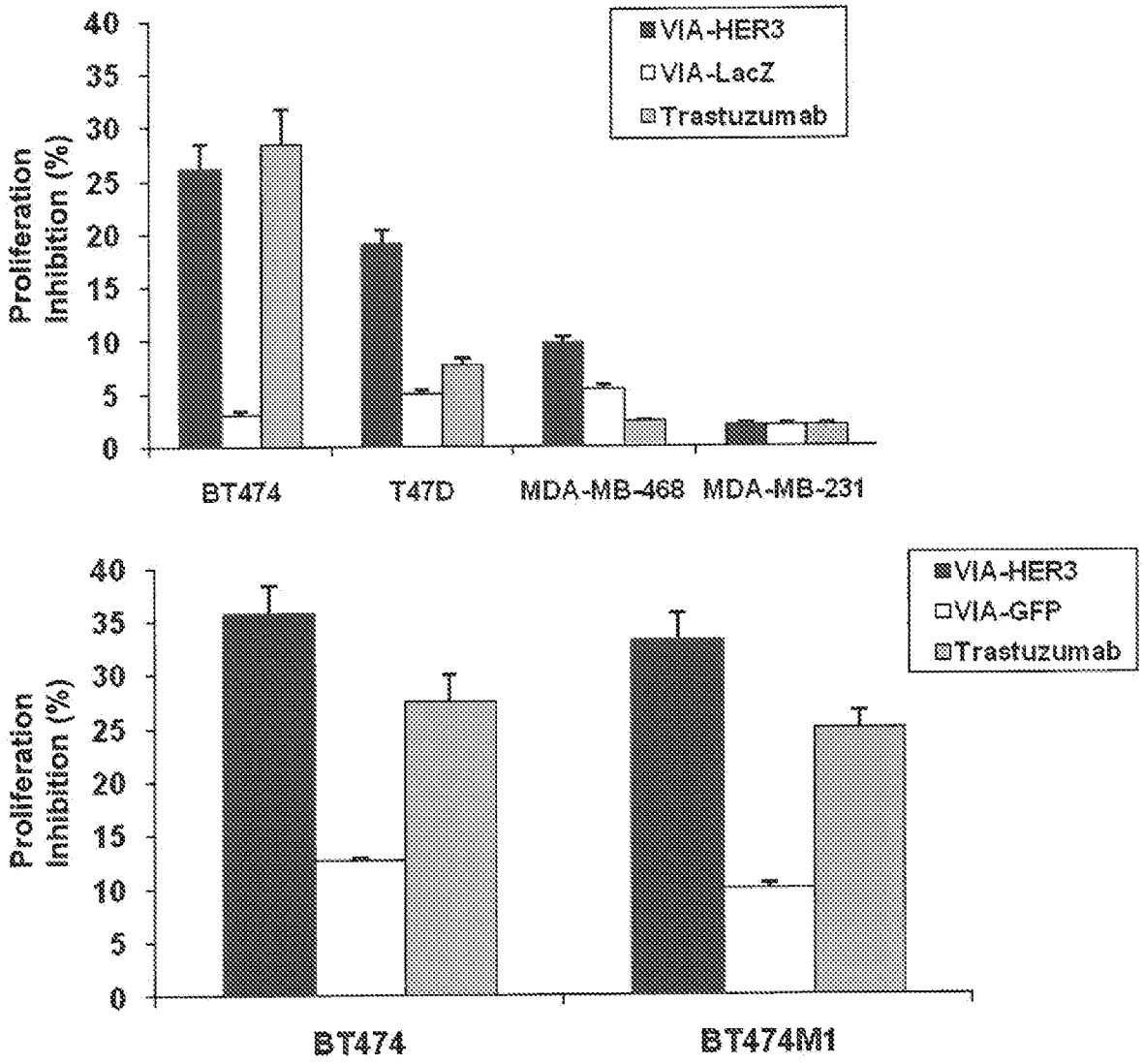

VIA-HER3
VIA-LacZ
Trastuzumab
Proliferation Inhibition (%)
40
35
30
25
20
15
10
5
0
BT474
T47D
MDA-MB-468
MDA-MB-231
VIA-HER3
VIA-GFP
Trastuzumab
Proliferation Inhibition (%)
BT474
BT474M1

Fig. 2C

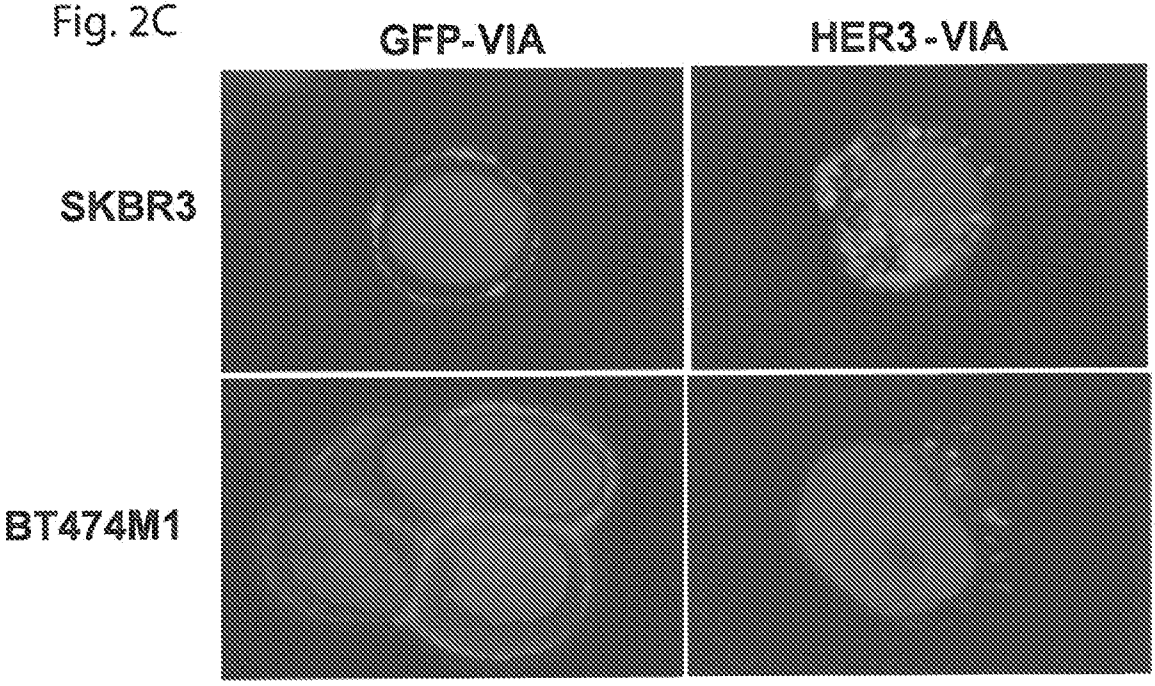

GFP-VIA
HER3-VIA
SKBR3
BT474M1

Fig. 3A

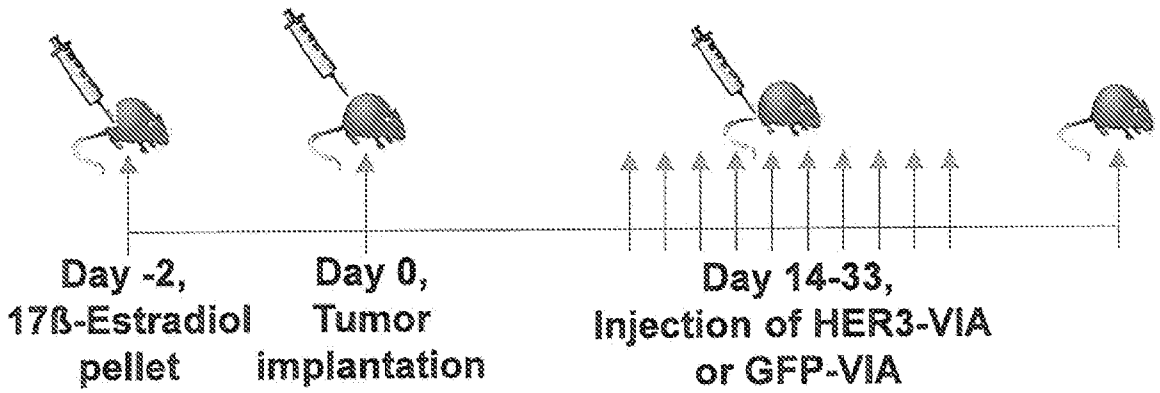

Day -2,
17ß-Estradiol
pellet
Day 0,
Tumor
implantation
Day 14-33,
Injection of HER3-VIA
or GFP-VIA

Fig. 3B

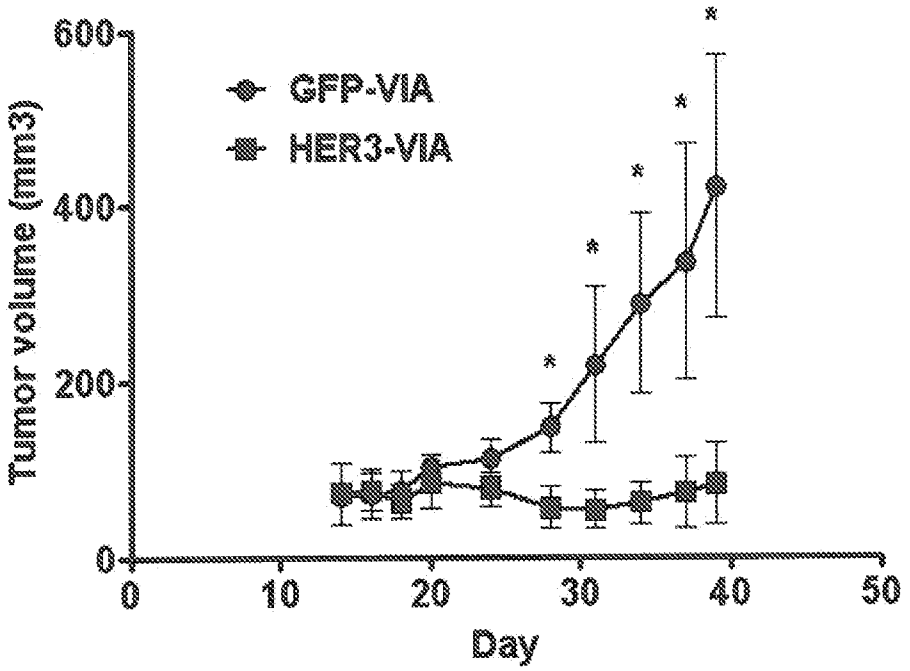
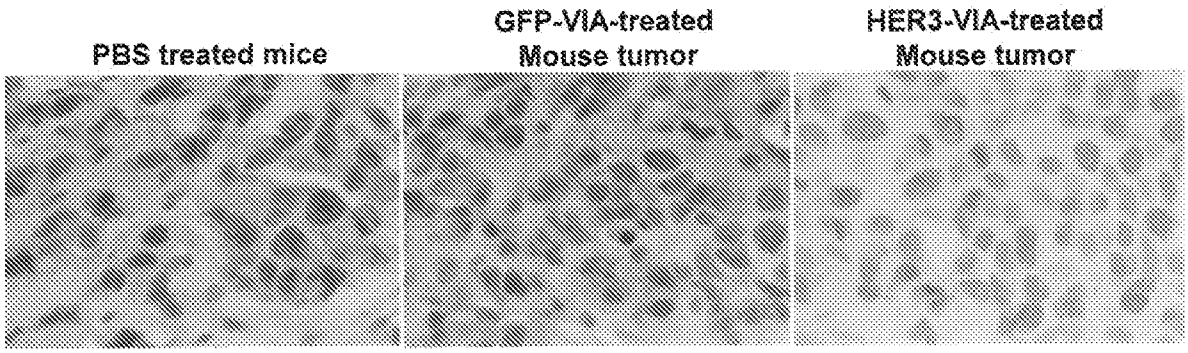

600
400
200
0
Tumor volume (mm3)
GFP-VIA
HER3-VIA
*
*
*
*
*
0
10
20
30
40
50
Day

Fig. 3C


PBS treated mice
GFP-VIA-treated Mouse tumor
HER3-VIA-treated Mouse tumor

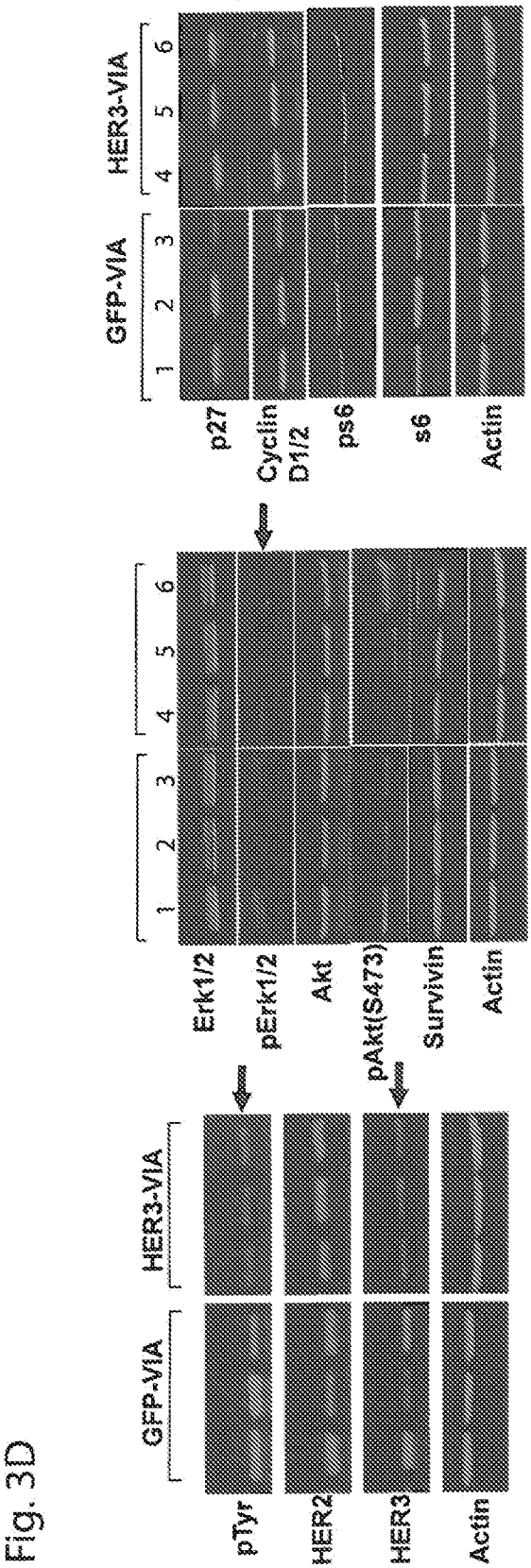

GFP-VIA
HER3-VIA
1
2
3
4
5
6
pTyr
HER2
HER3
Actin
Erk1/2
pErk1/2
Akt
pAkt(S473)
Survivin
Actin
p27
Cyclin D1/2
ps6
s6
Actin

Fig. 3D

Fig. 4A

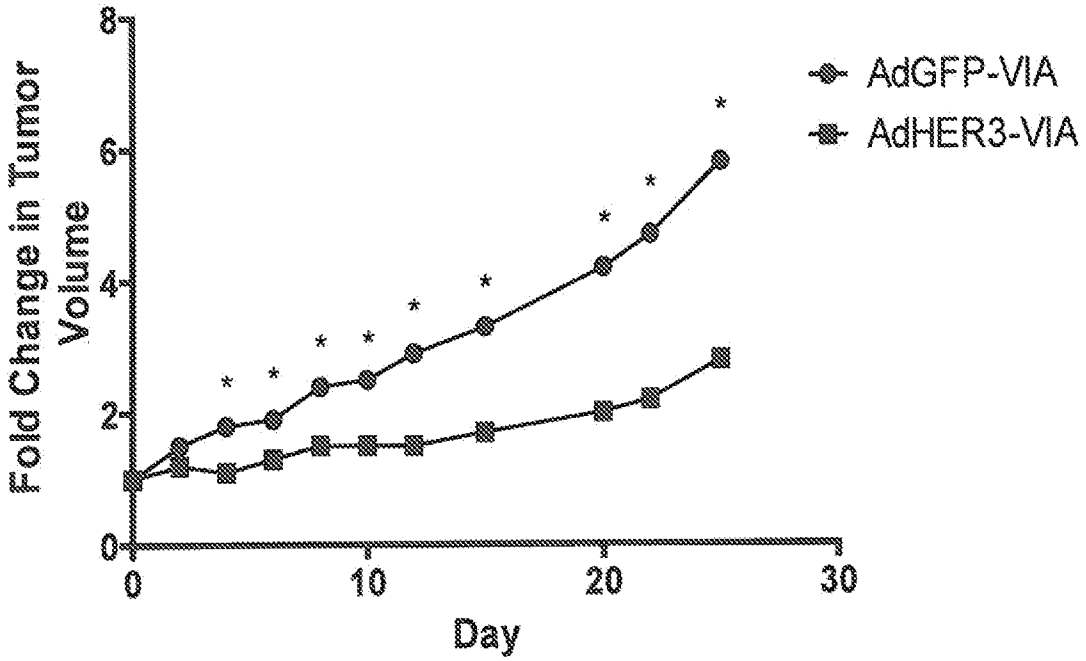

Fold Change in Tumor Volume
8
6
4
2
0
0
10
20
30
Day
AdGFP-VIA
AdHER3-VIA
*
*
*
*
*
*
*
*

Fig. 4C

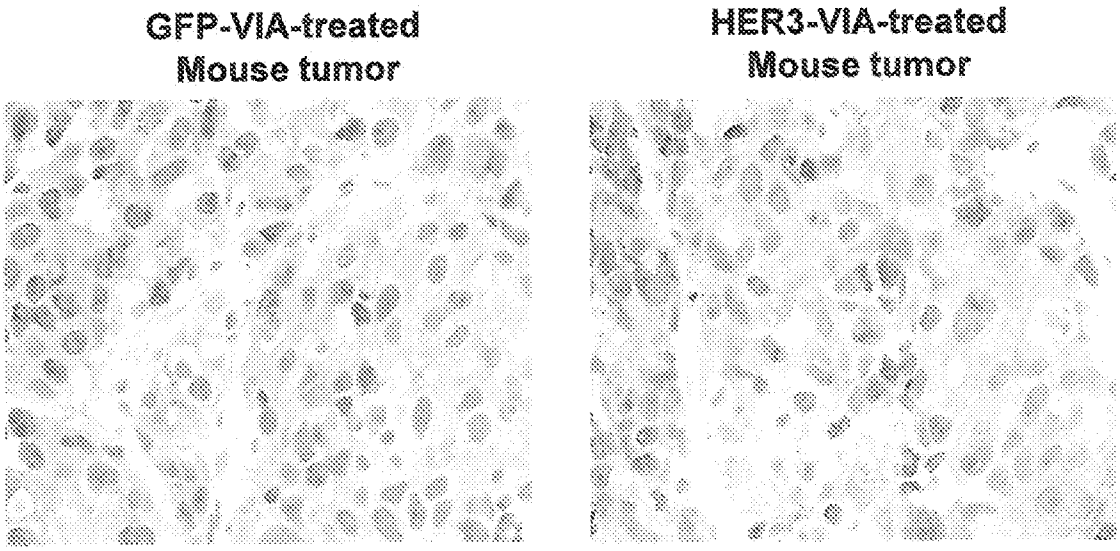

GFP-VIA-treated
Mouse tumor
HER3-VIA-treated
Mouse tumor

Fig. 4B

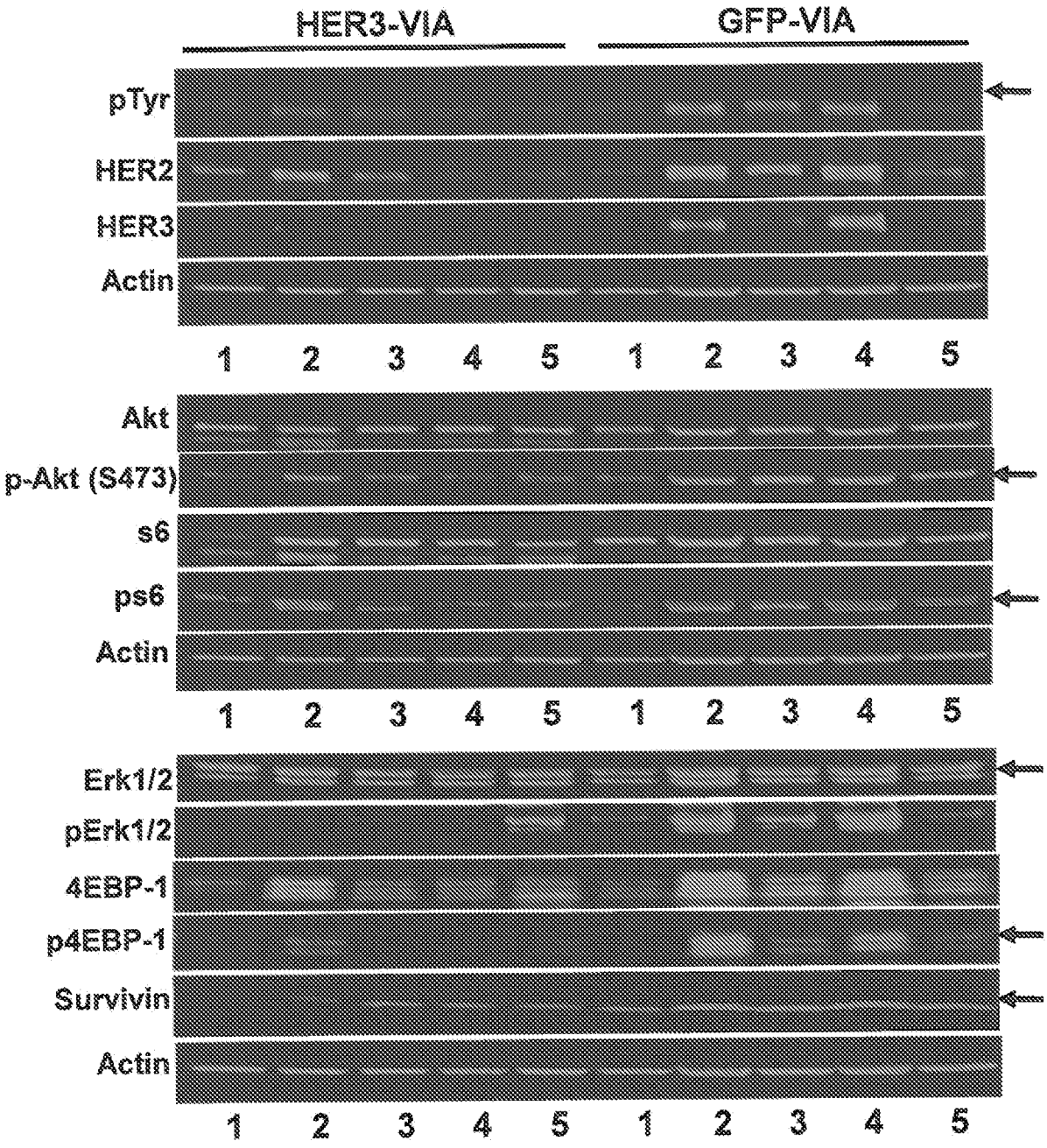

HER3-VIA
GFP-VIA
pTyr
HER2
HER3
Actin
1 2 3 4 5 1 2 3 4 5
Akt
p-Akt (S473)
s6
ps6
Actin
1 2 3 4 5 1 2 3 4 5
Erk1/2
pErk1/2
4EBP-1
p4EBP-1
Survivin
Actin
1 2 3 4 5 1 2 3 4 5

Fig. 5

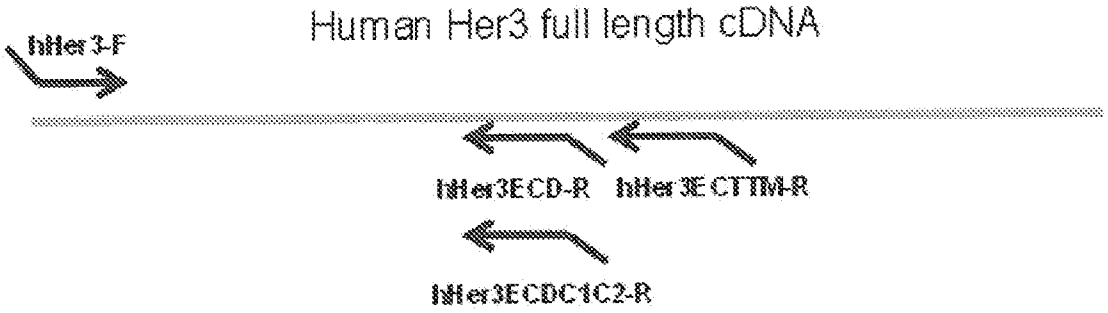

Human Her3 full length cDNA
hHer3-F
hHer3ECD-R
hHer3ECTTM-R
hHer3ECDC1C2-R

Fig. 6

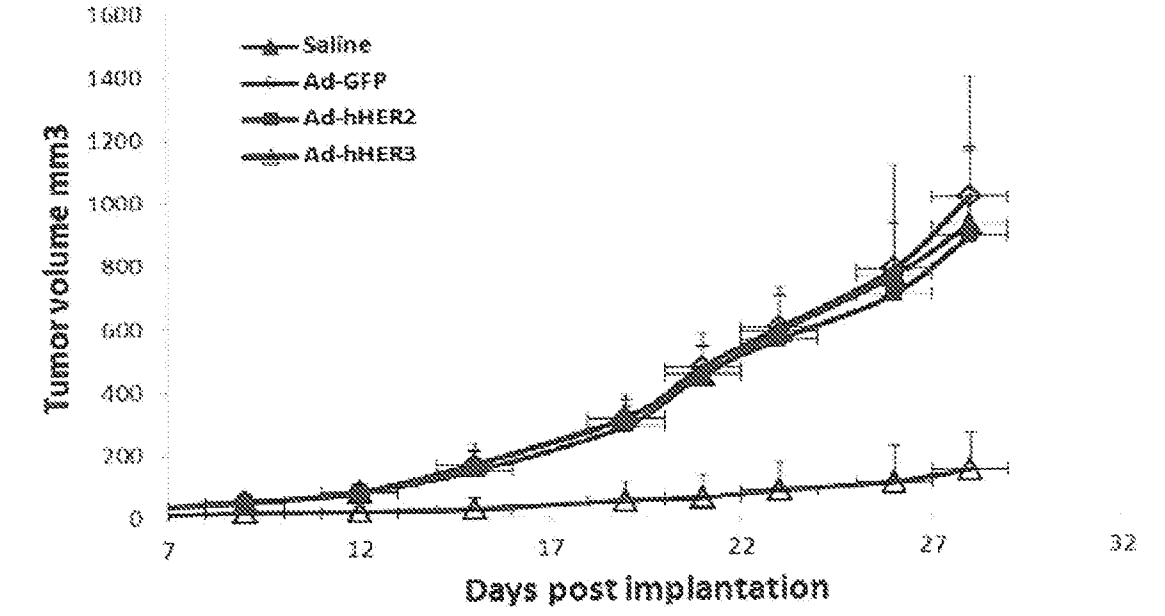

Saline
Ad-GFP
Ad-hHER2
Ad-hHER3
Tumor volume mm3
1600
1400
1200
1000
800
600
400
200
0
7
12
17
22
27
32
Days post implantation

Fig 7

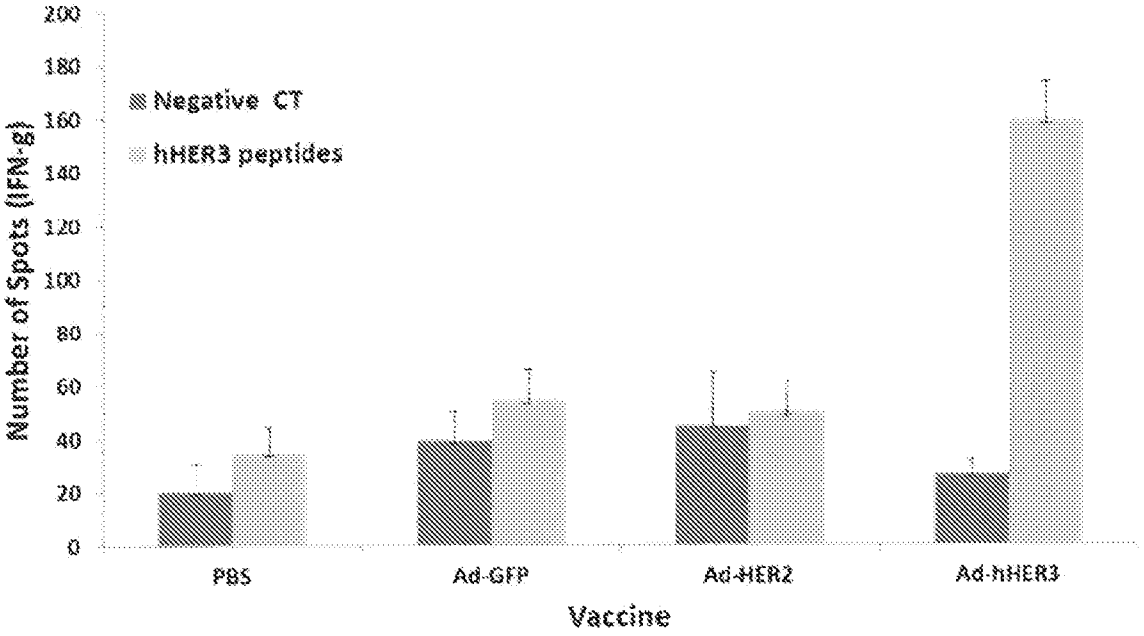

200
180
160
140
120
100
80
60
40
20
0
Number of Spots (IFN-g)
Negative CT
hHER3 peptides
PBS
Ad-GFP
Ad-HER2
Ad-hHER3
Vaccine

Fig. 8

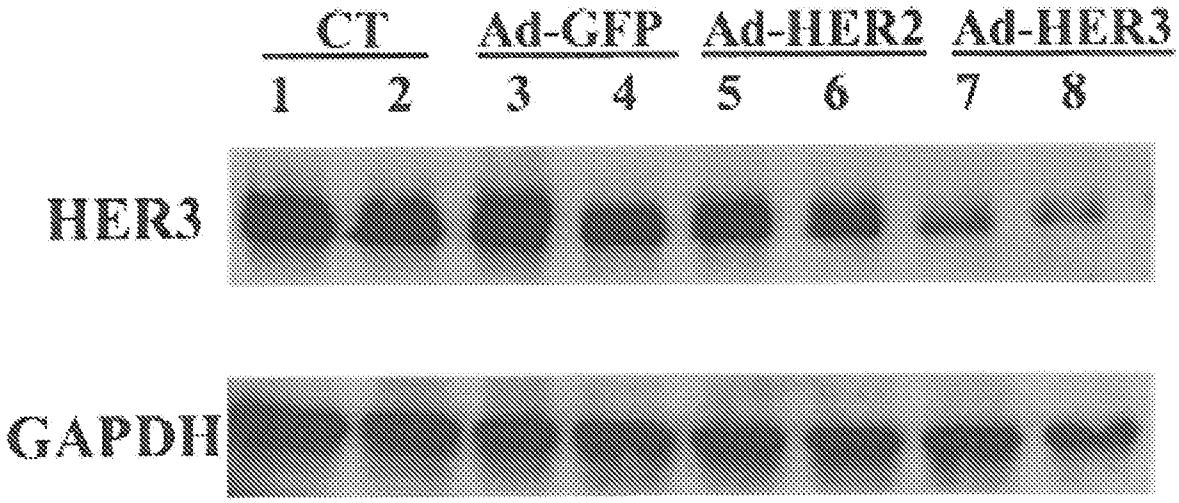

CT
Ad-GFP
Ad-HER2
Ad-HER3
1 2 3 4 5 6 7 8
HER3
GAPDH

Fig. 9

