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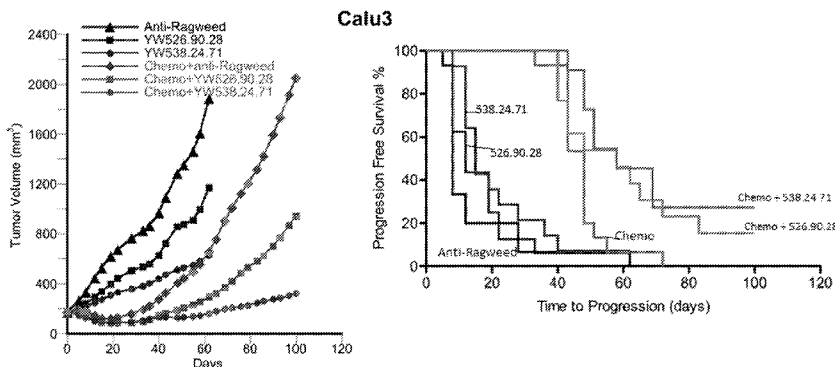
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(54) **Title:** NEUREGULIN ANTIBODIES AND USES THEREOF



(57) **Abstract:** The invention provides anti-neuregulin1 antibodies and methods of using the antibodies in treating diseases or disorders, such as cancer. In a particular embodiment, the anti-neuregulin1 antibodies bind to both neuregulin1 $\alpha$  and neuregulin1 $\beta$  isoforms.

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## NEUREGULIN ANTIBODIES AND USES THEREOF

### CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. provisional patent application 61/524,421, filed August  
5 17, 2011, the disclosure of which is incorporated herein by reference in its entirety.

### SEQUENCE LISTING

The present application contains a Sequence Listing which has been submitted in ASCII format  
via EFS-Web and is hereby incorporated by reference in its entirety. Said ASCII copy, created on  
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### FIELD OF THE INVENTION

The invention provides neuregulin antibodies and methods for using the antibodies in treating  
diseases or disorders, such as cancer.

### BACKGROUND

For most cancers, poor response to or disease relapse after chemotherapy is a major cause of  
15 mortality. This is particularly relevant for non-small cell lung cancer (NSCLC) because chemotherapy  
is used to treat patients with all stages of disease. More than two-thirds of patients present with  
unresectable advanced disease and are treated with frontline chemotherapy, radiation or a combination  
of the two. However, despite the aggressive use of chemotherapy in the treatment of NSCLC the 5-  
year survival rate remains at 8% and 3.5% for locally advanced and advanced disease respectively  
20 (Doebele et al).

Partial responses to chemotherapy and relapse after chemotherapy suggest that tumor cells are  
heterogeneous in their drug sensitivities. Some tumor cells are effectively killed by a given agent while  
others are spared. Cancer stem cells (CSCs) have been an area of intense study in recent years as they  
provide a possible explanation for the failure of existing therapies. Several groups have reported that  
25 CSCs show enhanced resistance to conventional chemotherapeutic agents and radiation treatment (Bao  
et al., 2006; Costello et al., 2000; Dean et al., 2005; Dylla et al., 2008; Matsui et al., 2004; Phillips et  
al., 2006). However, the role of CSCs in maintaining the growth of an established tumor or in re-  
initiating a tumor after chemotherapy either at a primary or distant site, remains to be determined. The  
cells responsible for tumor re-growth after chemotherapy may not be stem cells at all, but rather cells  
30 that achieve resistance through other properties that may reflect stage of the cell cycle, stroma-niche

interactions, or levels of prosurvival signals. These cells are referred to as “tumor reinitiating cells”, or TRICs. US Patent Publication 20110229493.

Epidermal growth factor receptor (EGFR) inhibitors are frequently used to treat NSCLC patients and have been shown to be effective in treating the majority of patients whose tumors harbor an EGFR-activating mutations. Deregulation of EGFR signaling via overexpression or activating mutations is a relatively frequent event in lung adenocarcinoma (reviewed in ((Dahabreh et al., 2010))). EGFR is the prototypical member of the ErbB or HER-family of tyrosine kinases, which includes EGFR (HER1), HER2, HER3 and HER4. Recent evidence shows that other HER family members may also play a role in NSCLC. However their contributions to the disease are less well characterized and most studies have focused on their ability to activate EGFR signalling (Ding et al., 2008; Johnson and Janne, 2006; Kuyama et al., 2008; Zhou et al., 2006). Neuregulin 1 (NRG1), also referred to as Heregulin1, is a ligand for the HER3 and HER4 receptors

There are four known members of the neuregulin family, NRG1, NRG2, NRG3, and NRG4 (Falls 2003; Hirsch and Wu 2007). The NRG1 transcript undergoes extensive alternative splicing resulting in at least 15 different isoforms. All active isoforms share an EGF-like domain that is necessary and sufficient for activity (Holmes 1992, Yarden 1991).

NRG1 autocrine signaling has been shown to regulate lung epithelial cell proliferation and to play a role in human lung development (Patel et al., 2000), and has been implicated in insensitivity of NSCLC to EGFR inhibitors (Zhou et al., 2006).

## SUMMARY

The invention provides anti-neuregulin1 (anti-NRG1) antibodies and methods of using the same.

One aspect of the invention provides for an isolated anti-NRG1 antibody that binds to neuregulin1 $\alpha$  and neuregulin1 $\beta$ . In one embodiment, the anti-NRG1 antibody binds to the EGF domain of neuregulin1 $\beta$  and the EGF domain of neuregulin1 $\alpha$ . In one embodiment, the anti-NRG1 antibody binds to the EGF domain of neuregulin1 $\beta$  with an affinity that is greater than the affinity to which it binds to EGF domain of neuregulin1 $\alpha$ . In specific embodiments, the anti-NRG1 antibody binds to the EGF domain neuregulin1 $\beta$  with an affinity that is greater than 20-fold, 50-fold, 100-fold, 200-fold, 500-fold, 1000-fold the affinity to which it binds to EGF domain of neuregulin1 $\alpha$ .

In one embodiment, the anti-NRG1 antibody binds to the EGF domain of neuregulin1 $\beta$  with a kD of 10 nM or less and binds to the EGF domain of neuregulin1 $\alpha$  with a kD of 10 nM or less. In specific embodiments, the anti-NRG1 antibody binds to the EGF domain of neuregulin1 $\beta$  with a kD of 10 nM or less, 1 nM or less,  $1 \times 10^{-1}$  nM or less,  $1 \times 10^{-2}$  nM or less, or  $1 \times 10^{-3}$  nM or less. The affinity of the anti-NRG1 antibody in one embodiment is measured by a surface plasmon resonance assay.

One aspect of the invention provides for an isolated anti-NGR1 antibody that binds to an epitope of neuregulin1 $\beta$ , wherein the epitope of neuregulin1 $\beta$  comprises the amino acid sequence of amino acids 1-37 of SEQ ID NO: 4 or the amino acid sequence of amino acids 38-64 of SEQ ID NO: 4. In one embodiment, the epitope of neuregulin1 $\beta$  comprises the amino acid sequence of SEQ ID NO: 4.

5 In one embodiment, the anti-NGR1 antibody further binds to an epitope of neuregulin1 $\alpha$ , wherein the epitope of neuregulin1 $\alpha$  comprises the amino acid sequence of amino acids 1-36 of SEQ ID NO: 3 or the amino acid sequence of amino acids 37-58 of SEQ ID NO: 3. In one embodiment, the epitope of neuregulin1 $\alpha$  comprises the amino acid sequence of SEQ ID NO: 3.

In certain embodiments, the anti-NGR1 antibody is a monoclonal antibody. In certain

10 embodiments, the anti-NGR1 antibody is a human, humanized, or chimeric antibody. In certain embodiments, the anti-NGR1 antibody is an antibody fragment that binds to neuregulin1 $\alpha$  and neuregulin1 $\beta$ .

Another aspect of the invention provides for an isolated anti-NGR1 antibody which comprises

(a) HVR-H1 comprising the amino acid sequence of SEQ ID NO: 5, (b) HVR-H2 comprising the

15 amino acid sequence of SEQ ID NO: 6, and (c) HVR-H3 comprising the amino acid sequence of SEQ ID NO: 7.

Another aspect of the invention provides for an isolated anti-NGR1 antibody which comprises

(a) HVR-L1 comprising the amino acid sequence of SEQ ID NO: 16, (b) HVR-L2 comprising the

amino acid sequence of SEQ ID NO: 17, and (c) HVR-L3 comprising the amino acid sequence of SEQ

20 ID NO: 18. In one embodiment, the anti-NGR1 further comprises (a) HVR-L1 comprising the amino acid sequence of SEQ ID NO: 16, (b) HVR-L2 comprising the amino acid sequence of SEQ ID NO: 17, and (c) HVR-L3 comprising the amino acid sequence of SEQ ID NO: 18.

Another aspect of the invention provides for an isolated anti-NGR1 antibody which comprises

(a) HVR-H1 comprising the amino acid sequence of SEQ ID NO: 76, (b) HVR-H2 comprising the

25 amino acid sequence of SEQ ID NO: 29, and (c) HVR-H3 comprising the amino acid sequence of SEQ ID NO: 43.

Another aspect of the invention provides for an isolated anti-NGR1 antibody which comprises

(a) HVR-L1 comprising the amino acid sequence of SEQ ID NO: 31, (b) HVR-L2 comprising the

amino acid sequence of SEQ ID NO: 32, and (c) HVR-L3 comprising the amino acid sequence of SEQ

30 ID NO: 33. In one embodiment, the anti-NGR1 antibody further comprises (a) HVR-L1 comprising the amino acid sequence of SEQ ID NO: 31, (b) HVR-L2 comprising the amino acid sequence of SEQ ID NO: 32, and (c) HVR-L3 comprising the amino acid sequence of SEQ ID NO: 33.

Another aspect of the invention provides for an isolated anti-NGR1 antibody which comprises

(a) a VH sequence having at least 95% sequence identity to the amino acid sequence of SEQ ID NO:

21; (b) a VL sequence having at least 95% sequence identity to the amino acid sequence of SEQ ID NO: 26; or (c) a VH sequence as in (a) and a VL sequence as in (b). In one embodiment, the anti-NRG1 antibody comprises a VH sequence of SEQ ID NO: 21. In one embodiment, the anti-NRG1 antibody comprises a VL sequence of SEQ ID NO: 26. In one embodiment, the anti-NRG1 antibody  
5 comprises a VH sequence of SEQ ID NO: 21 and a VL sequence of SEQ ID NO: 26.

One aspect of the invention provides for an isolated anti-NRG1 antibody comprising a VH sequence of SEQ ID NO: 53 and a VL sequence of SEQ ID NO: 63.

Another aspect of the invention provides for an isolated nucleic acid encoding an anti-NRG1 antibody. Another aspect of the invention provides for a host cell comprising a nucleic acid encoding  
10 an anti-NRG1 antibody.

Another aspect of the invention provides for a method of producing an anti-NRG1 antibody comprising culturing such a host cell so that the antibody is produced.

Another aspect of the invention provides for an immunoconjugate comprising an anti-NRG1 antibody and a cytotoxic agent.

Another aspect of the invention provides for a pharmaceutical formulation comprising an anti-NRG1 antibody and a pharmaceutically acceptable carrier. In one embodiment, the pharmaceutical formulation further comprises an additional therapeutic agent, such as, gemcitabine, paclitaxel, or cisplatin, or a combination of paclitaxel and cisplatin.  
15

Another aspect of the invention provides for an anti-NRG1 antibody for use as a medicament.

Another aspect of the invention provides for an anti-NRG1 antibody for use in treating cancer.  
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Another aspect of the invention provides for an anti-NRG1 antibody in the manufacture of a medicament. In one embodiment, the medicament is for treatment of cancer, such as non-small cell lung cancer, breast cancer, ovarian cancer, head and neck cancer, cervical cancer, bladder cancer, oesophageal cancer, prostate cancer, and colorectal cancer .

Another aspect of the invention provides for a method of treating an individual having cancer comprising administering to the individual an effective amount of an anti-NRG1 antibody. The cancer to be treated is, for example, non-small cell lung cancer, breast cancer, ovarian cancer, head and neck cancer, cervical cancer, bladder cancer, oesophageal cancer, prostate cancer, and colorectal cancer. In one embodiment, the method further comprises an additional therapeutic agent to the individual, such  
25 as gemcitabine, paclitaxel, carboplatin, and cisplatin or a combination or two or all three of paclitaxel, carboplatin, and cisplatin.  
30

Another aspect of the invention provides for a method of increasing time to tumor recurrence in a cancer patient comprising administering to the patient an effective amount an anti-NRG1 antibody. In one embodiment, the method further comprises administering a therapeutic agent to the patient. In  
35 one embodiment, the therapeutic agent is a chemotherapeutic agent or a second antibody. The chemotherapeutic agent is, for example, gemcitabine, paclitaxel, carboplatin, and cisplatin or a

combination or two or all three of paclitaxal, carboplatin, and cisplatin. In certain embodiments, the second antibody binds to EGFR, HER2, HER3, or HER4, or binds to two or more of these targets. In certain embodiments, the cancer to be treated is non-small cell lung cancer, breast cancer, ovarian cancer, head and neck cancer, cervical cancer, bladder cancer, oesophageal cancer, prostate cancer, and/or colorectal cancer. In one embodiment, the increase in time to tumor recurrence is at least 1.25 fold greater than the time to recurrence in the absence of the antibody. In one embodiment, the increase in time to tumor recurrence is at least 1.50 fold greater than the time to recurrence in the absence of the antibody.

### BRIEF DESCRIPTION OF THE DRAWINGS

10 Figure 1A. Graph showing tumor growth curves for mice with established Calu3-shNRG1 xenograft tumors administered vehicle (sucrose) or dox (2gm/L) in their drinking water ad libitum. Tumor volume was measured twice a week for the duration of the study. Data presented as Linear Mixed Effect (LME) model generated fit of tumor volume graphed as cubic splines with auto-determined knots.

15 Figure 1B. Graph showing tumor growth curves for mice with established Calu3-shNRG1 xenograft tumors treated with chemo+sucrose or chemo+dox. Data presented as LME model generated fit of tumor volume graphed as cubic splines with auto-determined knots.

20 Figure 2A. Graph showing tumor growth curves for mice with established H441-shNRG1 xenograft tumors treated with sucrose or dox (n=12 /group). Data is presented as LME fit analysis of tumor volume graphed as cubic splines with auto-determined knots.

Figure 2B. Graph showing tumor growth curves for mice with established H441-shNRG1 xenograft tumors treated with chemo + sucrose or chemo + dox (n=12/group). Data presented as LME fit analysis of tumor volume graphed as cubic splines with auto-determined knots.

25 Figure 3A. Graph showing average tumor volume +/- SEM for LSL-K-ras<sup>G12D</sup>; p53<sup>Fl/+</sup> mice treated with vehicle + control IgG (n=6), cisplatin + control IgG (n=6), or cisplatin + HER4ECD-Fc (n=8). Ragweed, control murine IgG2a antibody.

Figure 3B. Graph showing the daily fold change in tumor burden by treatment regimen with 95% confidence intervals.

30 Figure 3C. Graph showing average percent change in tumor burden from baseline  $\pm$  SEM for LSL-K-ras<sup>G12D</sup>; p53<sup>Fl/Fl</sup> mice treated with vehicle + control IgG (n=10), cisplatin + control IgG (n=11), cisplatin + HER4-ECD (n=8) or Vehicle + HER4-ECD (n=7).

Figure 4 A. Graph showing NRG1 mRNA enrichment in residual tumor cells from the Kras-LSL-G12D mouse NSCLC model, data is shown from one microarray probe and as validated by qPCR on independent samples.

Figure 4B. Graph showing expression of NRG1 in vehicle treated and residual chemo-treated Calu3 tumor cells as assessed by qPCR.

Figure 4C. Graph showing expression of NRG1 in vehicle treated and residual chemo-treated H441 tumor cells as assessed by qPCR.

Figure 4D. Graph showing expression of NRG1 in vehicle treated and residual gemcitabine- and vinorelbine-treated Calu3 and H441 tumor cells as assessed by qPCR.

Figure 5. Alignment of the EGF domain of NRG1 $\alpha$  (SEQ ID NO: 3) or NRG2 $\beta$  (SEQ ID NO: 4).

Figure 6. Graph showing the inhibition of 125I-NRG $\beta$ 1 binding to HER3-Fc by anti-NRG1 antibodies.

Figure 7. Graph showing the inhibition of 125I-NRG $\beta$ 1 binding to HER3-Fc by affinity matured anti-NRG1 antibody variants.

Figure 8. Binding affinities of 538.24 affinity matured variant anti-NRG1 IgGs for NRG1 $\beta$  as measured in a BIAcore™ assay.

Figure 9. Binding affinities of 538.24 affinity matured variant anti-NRG1 IgGs for NRG1 $\alpha$  as measured in a BIAcore™ assay.

Figure 10. Binding affinities of 538.24.71 anti-NRG1 antibody for NRG1 $\beta$  and NRG1 $\alpha$  as measured in a BIAcore™ assay.

Figure 11. Binding affinities of 538.24.71 anti-NRG1 antibody for NRG1 $\beta$  and NRG1 $\alpha$  as measured in a BIAcore™ assay.

Figure 12. Graph showing that the 526.09 antibody competes with the 538.24.71 antibody for binding to both HRG1 $\alpha$  and HRG1 $\beta$ .

Figure 13. Table showing the the ability of affinity matured variants of the 526.09 anti-NRG1 antibody to block NRG1 $\alpha$  and NRG1 $\beta$  binding to an anti-HER3 antibody in a KIRA assay.

Figure 14. Graph showing results of BV test of 526.90 affinity matured variants.

Figure 15. Binding affinities of 538.90.28 anti-NRG1 antibody for NRG1 $\beta$  and NRG1 $\alpha$  as measured in a BIAcore™ assay.

Figure 16. Graph showing the ability of anti-NRG1 antibodies 526.90.28 and 538.24.71 to block NRG1 $\alpha$  induced HER3 activation as determined using KIRA.

Figure 17. Graph showing the ability of anti-NRG1 antibodies 526.90.28 and 538.24.71 to block NRG1 $\beta$  induced HER3 activation as determined using KIRA.

5 Figure 18. Western Blot showing ability of anti-NRG1 antibodies to inhibit NRG1 autocrine signaling in both human and mouse cells.

Figure 19. Graph showing the effect of anti-NRG1 antibodies +/- chemotherapy on HNSCC tumor growth in a mouse model system.

10 Figure 20. Tumor Growth curves showing the effect of anti-NRG1 antibodies +/- chemotherapy on lung cancer tumor growth in a mouse model system and a Kaplan-Meier curve showing progression free survival in the model system.

Figure 21. Tumor Growth curves showing the effect of anti-NRG1 antibodies +/- chemotherapy on NSCLC LKPH2 tumor growth in a mouse model system and a Kaplan-Meier curve showing progression free survival in the model system.

15 Figure 22. Tumor Growth curves showing the effect of anti-NRG1 antibodies +/- chemotherapy on NSCLC H596 tumor growth in a mouse model system .

Figure 23. Tumor Growth curves showing the effect of anti-NRG1 antibodies +/- chemotherapy on NSCLC LKPH2 tumor growth in a mouse model system and a Kaplan-Meier curve showing progression free survival in the model system.

20 Figure 24. Tumor Growth curves howing the effect of anti-NRG1 antibodies on tumor growth driven by NRG1-HER3 signaling (A) and on growth of tumors driven by NRG1-HER4 signaling (B).

Figure 25. Heavy chain variable region amino acid sequences of anti-NRG antibodies (SEQ ID NO: 20).

25 Figure 26. Light chain variable region amino acid sequences of anti-NRG antibodies (SEQ ID NOs: 22-27, respectively).

Figure 27. Heavy chain variable region amino acid sequences of anti-NRG antibodies (SEQ ID NOs: 52, 54, 56, 58, 60, 62, 63, 64, 66, 68, 70, respectively).

Figure 28. Light chain variable region amino acid sequences of anti-NRG antibodies (SEQ ID NOs: 53, 55, 57, 59, 61, 53, 53, 65, 67, 69, 71, respectively).



**DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION****I. DEFINITIONS**

An “acceptor human framework” for the purposes herein is a framework comprising the amino acid sequence of a light chain variable domain (VL) framework or a heavy chain variable domain (VH) framework derived from a human immunoglobulin framework or a human consensus framework, as defined below. An acceptor human framework “derived from” a human immunoglobulin framework or a human consensus framework may comprise the same amino acid sequence thereof, or it may contain amino acid sequence changes. In some embodiments, the number of amino acid changes are 10 or less, 9 or less, 8 or less, 7 or less, 6 or less, 5 or less, 4 or less, 3 or less, or 2 or less. In some embodiments, the VL acceptor human framework is identical in sequence to the VL human immunoglobulin framework sequence or human consensus framework sequence.

“Affinity” refers to the strength of the sum total of noncovalent interactions between a single binding site of a molecule (e.g., an antibody) and its binding partner (e.g., an antigen). Unless indicated otherwise, as used herein, “binding affinity” refers to intrinsic binding affinity which reflects a 1:1 interaction between members of a binding pair (e.g., antibody and antigen). The affinity of a molecule X for its partner Y can generally be represented by the dissociation constant (K<sub>d</sub>). Affinity can be measured by common methods known in the art, including those described herein. Specific illustrative and exemplary embodiments for measuring binding affinity are described in the following.

An “affinity matured” antibody refers to an antibody with one or more alterations in one or more hypervariable regions (HVRs), compared to a parent antibody which does not possess such alterations, such alterations resulting in an improvement in the affinity of the antibody for antigen.

The terms “anti-NGR1 antibody” and “an antibody that binds to NRG1” refer to an antibody that is capable of binding a neuregulin1 (NRG1) with sufficient affinity such that the antibody is useful as a diagnostic and/or therapeutic agent in targeting a NRG1. In one embodiment, the extent of binding of an anti-NGR1 antibody to an unrelated, non-NRG1 protein is less than about 10% of the binding of the antibody to NRG1 as measured, e.g., by a radioimmunoassay (RIA). In certain embodiments, an antibody that binds to NRG1 has a dissociation constant (K<sub>d</sub>) of  $\leq 1\mu\text{M}$ ,  $\leq 100\text{ nM}$ ,  $\leq 10\text{ nM}$ ,  $\leq 1\text{ nM}$ ,  $\leq 0.1\text{ nM}$ ,  $\leq 0.01\text{ nM}$ , or  $\leq 0.001\text{ nM}$  (e.g.  $10^{-8}\text{ M}$  or less, e.g. from  $10^{-8}\text{ M}$  to  $10^{-13}\text{ M}$ , e.g., from  $10^{-9}\text{ M}$  to  $10^{-13}\text{ M}$ ). In certain embodiments, an anti-NGR1 antibody binds to an epitope of NRG1 that is conserved among NRG1s from different species.

The term “antibody” herein is used in the broadest sense and encompasses various antibody structures, including but not limited to monoclonal antibodies, polyclonal antibodies, multispecific antibodies (e.g., bispecific antibodies), and antibody fragments so long as they exhibit the desired antigen-binding activity.

An "antibody fragment" refers to a molecule other than an intact antibody that comprises a portion of an intact antibody that binds the antigen to which the intact antibody binds. Examples of antibody fragments include but are not limited to Fv, Fab, Fab', Fab'-SH, F(ab')<sub>2</sub>; diabodies; linear antibodies; single-chain antibody molecules (e.g. scFv); and multispecific antibodies formed from antibody fragments.

An "antibody that binds to the same epitope" as a reference antibody refers to an antibody that blocks binding of the reference antibody to its antigen in a competition assay by 50% or more, and conversely, the reference antibody blocks binding of the antibody to its antigen in a competition assay by 50% or more. An exemplary competition assay is provided herein.

The term "chimeric" antibody refers to an antibody in which a portion of the heavy and/or light chain is derived from a particular source or species, while the remainder of the heavy and/or light chain is derived from a different source or species.

The terms "cancer" and "cancerous" refer to or describe the physiological condition in mammals that is typically characterized by unregulated cell growth/proliferation. Examples of cancer include, but are not limited to, carcinoma, lymphoma (e.g., Hodgkin's and non-Hodgkin's lymphoma), blastoma, sarcoma, and leukemia. More particular examples of such cancers include squamous cell cancer, small-cell lung cancer, non-small cell lung cancer, adenocarcinoma of the lung, squamous carcinoma of the lung, cancer of the peritoneum, hepatocellular cancer, gastrointestinal cancer, pancreatic cancer, glioma, cervical cancer, ovarian cancer, liver cancer, bladder cancer, hepatoma, breast cancer, colon cancer, colorectal cancer, endometrial or uterine carcinoma, salivary gland carcinoma, kidney cancer, liver cancer, prostate cancer, vulval cancer, thyroid cancer, hepatic carcinoma, leukemia and other lymphoproliferative disorders, and various types of head and neck cancer.

The "class" of an antibody refers to the type of constant domain or constant region possessed by its heavy chain. There are five major classes of antibodies: IgA, IgD, IgE, IgG, and IgM, and several of these may be further divided into subclasses (isotypes), e.g., IgG<sub>1</sub>, IgG<sub>2</sub>, IgG<sub>3</sub>, IgG<sub>4</sub>, IgA<sub>1</sub>, and IgA<sub>2</sub>. The heavy chain constant domains that correspond to the different classes of immunoglobulins are called  $\alpha$ ,  $\delta$ ,  $\epsilon$ ,  $\gamma$ , and  $\mu$ , respectively.

The term "cytotoxic agent" as used herein refers to a substance that inhibits or prevents a cellular function and/or causes cell death or destruction. Cytotoxic agents include, but are not limited to, radioactive isotopes (e.g., At<sup>211</sup>, I<sup>131</sup>, I<sup>125</sup>, Y<sup>90</sup>, Re<sup>186</sup>, Re<sup>188</sup>, Sm<sup>153</sup>, Bi<sup>212</sup>, P<sup>32</sup>, Pb<sup>212</sup> and radioactive isotopes of Lu); chemotherapeutic agents or drugs (e.g., methotrexate, adriamycin, vinca alkaloids (vincristine, vinblastine, etoposide), doxorubicin, melphalan, mitomycin C, chlorambucil, daunorubicin or other intercalating agents); growth inhibitory agents; enzymes and fragments thereof such as nucleolytic enzymes; antibiotics; toxins such as small molecule toxins or enzymatically active toxins of

bacterial, fungal, plant or animal origin, including fragments and/or variants thereof; and the various antitumor or anticancer agents disclosed below.

“Effector functions” refer to those biological activities attributable to the Fc region of an antibody, which vary with the antibody isotype. Examples of antibody effector functions include: C1q binding and complement dependent cytotoxicity (CDC); Fc receptor binding; antibody-dependent cell-mediated cytotoxicity (ADCC); phagocytosis; down regulation of cell surface receptors (e.g. B cell receptor); and B cell activation.

An "effective amount" of an agent, e.g., a pharmaceutical formulation, refers to an amount effective, at dosages and for periods of time necessary, to achieve the desired therapeutic or prophylactic result.

The term “Fc region” herein is used to define a C-terminal region of an immunoglobulin heavy chain that contains at least a portion of the constant region. The term includes native sequence Fc regions and variant Fc regions. In one embodiment, a human IgG heavy chain Fc region extends from Cys226, or from Pro230, to the carboxyl-terminus of the heavy chain. However, the C-terminal lysine (Lys447) of the Fc region may or may not be present. Unless otherwise specified herein, numbering of amino acid residues in the Fc region or constant region is according to the EU numbering system, also called the EU index, as described in Kabat et al., *Sequences of Proteins of Immunological Interest*, 5th Ed. Public Health Service, National Institutes of Health, Bethesda, MD, 1991.

"Framework" or "FR" refers to variable domain residues other than hypervariable region (HVR) residues. The FR of a variable domain generally consists of four FR domains: FR1, FR2, FR3, and FR4. Accordingly, the HVR and FR sequences generally appear in the following sequence in VH (or VL): FR1-H1(L1)-FR2-H2(L2)-FR3-H3(L3)-FR4.

The terms “full length antibody,” “intact antibody,” and “whole antibody” are used herein interchangeably to refer to an antibody having a structure substantially similar to a native antibody structure or having heavy chains that contain an Fc region as defined herein.

The terms "host cell," "host cell line," and "host cell culture" are used interchangeably and refer to cells into which exogenous nucleic acid has been introduced, including the progeny of such cells. Host cells include "transformants" and "transformed cells," which include the primary transformed cell and progeny derived therefrom without regard to the number of passages. Progeny may not be completely identical in nucleic acid content to a parent cell, but may contain mutations. Mutant progeny that have the same function or biological activity as screened or selected for in the originally transformed cell are included herein.

A “human antibody” is one which possesses an amino acid sequence which corresponds to that of an antibody produced by a human or a human cell or derived from a non-human source that utilizes human antibody repertoires or other human antibody-encoding sequences. This definition of a human antibody specifically excludes a humanized antibody comprising non-human antigen-binding residues.

A “human consensus framework” is a framework which represents the most commonly occurring amino acid residues in a selection of human immunoglobulin VL or VH framework sequences. Generally, the selection of human immunoglobulin VL or VH sequences is from a subgroup of variable domain sequences. Generally, the subgroup of sequences is a subgroup as in  
5 Kabat et al., *Sequences of Proteins of Immunological Interest*, Fifth Edition, NIH Publication 91-3242, Bethesda MD (1991), vols. 1-3. In one embodiment, for the VL, the subgroup is subgroup kappa I as in Kabat et al., *supra*. In one embodiment, for the VH, the subgroup is subgroup III as in Kabat et al., *supra*.

A “humanized” antibody refers to a chimeric antibody comprising amino acid residues from  
10 non-human HVRs and amino acid residues from human FRs. In certain embodiments, a humanized antibody will comprise substantially all of at least one, and typically two, variable domains, in which all or substantially all of the HVRs (e.g., CDRs) correspond to those of a non-human antibody, and all or substantially all of the FRs correspond to those of a human antibody. A humanized antibody optionally may comprise at least a portion of an antibody constant region derived from a human  
15 antibody. A “humanized form” of an antibody, e.g., a non-human antibody, refers to an antibody that has undergone humanization.

The term “hypervariable region” or “HVR,” as used herein, refers to each of the regions of an antibody variable domain which are hypervariable in sequence and/or form structurally defined loops (“hypervariable loops”). Generally, native four-chain antibodies comprise six HVRs; three in the VH  
20 (H1, H2, H3), and three in the VL (L1, L2, L3). HVRs generally comprise amino acid residues from the hypervariable loops and/or from the “complementarity determining regions” (CDRs), the latter being of highest sequence variability and/or involved in antigen recognition. Exemplary hypervariable loops occur at amino acid residues 26-32 (L1), 50-52 (L2), 91-96 (L3), 26-32 (H1), 53-55 (H2), and 96-101 (H3). (Chothia and Lesk, *J. Mol. Biol.* 196:901-917 (1987).) Exemplary CDRs (CDR-L1,  
25 CDR-L2, CDR-L3, CDR-H1, CDR-H2, and CDR-H3) occur at amino acid residues 24-34 of L1, 50-56 of L2, 89-97 of L3, 31-35B of H1, 50-65 of H2, and 95-102 of H3. (Kabat et al., *Sequences of Proteins of Immunological Interest*, 5th Ed. Public Health Service, National Institutes of Health, Bethesda, MD (1991).) With the exception of CDR1 in VH, CDRs generally comprise the amino acid residues that form the hypervariable loops. CDRs also comprise “specificity determining residues,” or “SDRs,”  
30 which are residues that contact antigen. SDRs are contained within regions of the CDRs called abbreviated-CDRs, or a-CDRs. Exemplary a-CDRs (a-CDR-L1, a-CDR-L2, a-CDR-L3, a-CDR-H1, a-CDR-H2, and a-CDR-H3) occur at amino acid residues 31-34 of L1, 50-55 of L2, 89-96 of L3, 31-35B of H1, 50-58 of H2, and 95-102 of H3. (See Almagro and Fransson, *Front. Biosci.* 13:1619-1633 (2008).) Unless otherwise indicated, HVR residues and other residues in the variable domain (e.g., FR  
35 residues) are numbered herein according to Kabat et al., *supra*.

An “immunoconjugate” is an antibody conjugated to one or more heterologous molecule(s), including but not limited to a cytotoxic agent.

An “individual” or “subject” or “patient” is a mammal. Mammals include, but are not limited to, domesticated animals (e.g., cows, sheep, cats, dogs, and horses), primates (e.g., humans and non-  
5 human primates such as monkeys), rabbits, and rodents (e.g., mice and rats). In certain embodiments, the individual, subject, or patient is a human.

An "isolated" antibody is one which has been separated from a component of its natural environment. In some embodiments, an antibody is purified to greater than 95% or 99% purity as determined by, for example, electrophoretic (e.g., SDS-PAGE, isoelectric focusing (IEF), capillary  
10 electrophoresis) or chromatographic (e.g., ion exchange or reverse phase HPLC). For review of methods for assessment of antibody purity, see, e.g., Flatman et al., *J. Chromatogr. B* 848:79-87 (2007).

An "isolated" nucleic acid refers to a nucleic acid molecule that has been separated from a component of its natural environment. An isolated nucleic acid includes a nucleic acid molecule  
15 contained in cells that ordinarily contain the nucleic acid molecule, but the nucleic acid molecule is present extrachromosomally or at a chromosomal location that is different from its natural chromosomal location.

“Isolated nucleic acid encoding an anti-NRG1 antibody” refers to one or more nucleic acid molecules encoding antibody heavy and light chains (or fragments thereof), including such nucleic acid  
20 molecule(s) in a single vector or separate vectors, and such nucleic acid molecule(s) present at one or more locations in a host cell.

The term "monoclonal antibody" as used herein refers to an antibody obtained from a population of substantially homogeneous antibodies, i.e., the individual antibodies comprising the population are identical and/or bind the same epitope, except for possible variant antibodies, e.g.,  
25 containing naturally occurring mutations or arising during production of a monoclonal antibody preparation, such variants generally being present in minor amounts. In contrast to polyclonal antibody preparations, which typically include different antibodies directed against different determinants (epitopes), each monoclonal antibody of a monoclonal antibody preparation is directed against a single determinant on an antigen. Thus, the modifier “monoclonal” indicates the character of the antibody as  
30 being obtained from a substantially homogeneous population of antibodies, and is not to be construed as requiring production of the antibody by any particular method. For example, the monoclonal antibodies to be used in accordance with the present invention may be made by a variety of techniques, including but not limited to the hybridoma method, recombinant DNA methods, phage-display methods, and methods utilizing transgenic animals containing all or part of the human immunoglobulin  
35 loci, such methods and other exemplary methods for making monoclonal antibodies being described herein.

A “naked antibody” refers to an antibody that is not conjugated to a heterologous moiety (e.g., a cytotoxic moiety) or radiolabel. The naked antibody may be present in a pharmaceutical formulation.

“Native antibodies” refer to naturally occurring immunoglobulin molecules with varying structures. For example, native IgG antibodies are heterotetrameric glycoproteins of about 150,000 daltons, composed of two identical light chains and two identical heavy chains that are disulfide-bonded. From N- to C-terminus, each heavy chain has a variable region (VH), also called a variable heavy domain or a heavy chain variable domain, followed by three constant domains (CH1, CH2, and CH3). Similarly, from N- to C-terminus, each light chain has a variable region (VL), also called a variable light domain or a light chain variable domain, followed by a constant light (CL) domain. The light chain of an antibody may be assigned to one of two types, called kappa ( $\kappa$ ) and lambda ( $\lambda$ ), based on the amino acid sequence of its constant domain.

The term “package insert” is used to refer to instructions customarily included in commercial packages of therapeutic products, that contain information about the indications, usage, dosage, administration, combination therapy, contraindications and/or warnings concerning the use of such therapeutic products.

“Percent (%) amino acid sequence identity” with respect to a reference polypeptide sequence is defined as the percentage of amino acid residues in a candidate sequence that are identical with the amino acid residues in the reference polypeptide sequence, after aligning the sequences and introducing gaps, if necessary, to achieve the maximum percent sequence identity, and not considering any conservative substitutions as part of the sequence identity. Alignment for purposes of determining percent amino acid sequence identity can be achieved in various ways that are within the skill in the art, for instance, using publicly available computer software such as BLAST, BLAST-2, ALIGN or Megalign (DNASTAR) software. Those skilled in the art can determine appropriate parameters for aligning sequences, including any algorithms needed to achieve maximal alignment over the full length of the sequences being compared. For purposes herein, however, % amino acid sequence identity values are generated using the sequence comparison computer program ALIGN-2. The ALIGN-2 sequence comparison computer program was authored by Genentech, Inc., and the source code has been filed with user documentation in the U.S. Copyright Office, Washington D.C., 20559, where it is registered under U.S. Copyright Registration No. TXU510087. The ALIGN-2 program is publicly available from Genentech, Inc., South San Francisco, California, or may be compiled from the source code. The ALIGN-2 program should be compiled for use on a UNIX operating system, including digital UNIX V4.0D. All sequence comparison parameters are set by the ALIGN-2 program and do not vary.

In situations where ALIGN-2 is employed for amino acid sequence comparisons, the % amino acid sequence identity of a given amino acid sequence A to, with, or against a given amino acid sequence B (which can alternatively be phrased as a given amino acid sequence A that has or

comprises a certain % amino acid sequence identity to, with, or against a given amino acid sequence B) is calculated as follows:

$$100 \text{ times the fraction } X/Y$$

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where X is the number of amino acid residues scored as identical matches by the sequence alignment program ALIGN-2 in that program's alignment of A and B, and where Y is the total number of amino acid residues in B. It will be appreciated that where the length of amino acid sequence A is not equal to the length of amino acid sequence B, the % amino acid sequence identity of A to B will not equal the % amino acid sequence identity of B to A. Unless specifically stated otherwise, all % amino acid sequence identity values used herein are obtained as described in the immediately preceding paragraph using the ALIGN-2 computer program.

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The term "pharmaceutical formulation" refers to a preparation which is in such form as to permit the biological activity of an active ingredient contained therein to be effective, and which contains no additional components which are unacceptably toxic to a subject to which the formulation would be administered.

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A "pharmaceutically acceptable carrier" refers to an ingredient in a pharmaceutical formulation, other than an active ingredient, which is nontoxic to a subject. A pharmaceutically acceptable carrier includes, but is not limited to, a buffer, excipient, stabilizer, or preservative.

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The term "NRG" as used herein, refers to any native neuregulin (also known as heregulin) from any vertebrate source, including mammals such as primates (e.g. humans) and rodents (e.g., mice and rats), unless otherwise indicated. The term encompasses "full-length," unprocessed NRG as well as any form of NRG that results from processing in the cell. The term also encompasses naturally occurring variants of NRG, e.g., splice variants or allelic variants. There are four known forms of NRG: NRG1 (Holmes, W.E. et al., Science 256:1205-1210 (1992)); NRG2 (Caraway, K.L. et al., Nature 387:512-516 (1997)); NRG3 (Zhang, E. et al., Proc Natl Acad Sci USA 94:9562-9567)); and NRG4 (Harari, D. et al., Oncogene 18:2681-2689)). Due to alternative splicing there are two active isoforms of the NRG1 EGF-like domain that are required for receptor binding, referred to as NRG1alpha (NRG1 $\alpha$ ) and NRG1beta (NRG1 $\beta$ ). Sequences of exemplary human NRG1s are shown in Genbank Accession No. BK000383 (Falls, D. L., Ex Cell Res, 284:14-30 (2003) and in US Patent No. 5,367,060. In one embodiment, NRG1 $\alpha$  comprises the amino acid sequence of Swiss Prot accession number Q7RTV8 (SEQ ID NO: 1). In one embodiment, the EGF domain of NRG1 $\alpha$  comprises the amino acid sequence of amino acids S177-K241 of SEQ ID NO: 1 (SEQ ID NO: 3). In one embodiment, NRG1 $\beta$  comprises the amino acid sequence of NCBI accession number NP\_039250 (SEQ ID NO:2). In embodiment, the EGF domain of NRG1 $\beta$  comprises the amino acid sequence of amino acids T176-K246 of SEQ ID NO: 2 (SEQ ID NO: 4).

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As used herein, "treatment" (and grammatical variations thereof such as "treat" or "treating") refers to clinical intervention in an attempt to alter the natural course of the individual being treated, and can be performed either for prophylaxis or during the course of clinical pathology. Desirable effects of treatment include, but are not limited to, preventing occurrence or recurrence of disease, alleviation of symptoms, diminishment of any direct or indirect pathological consequences of the disease, preventing metastasis, decreasing the rate of disease progression, amelioration or palliation of the disease state, and remission or improved prognosis. In some embodiments, the anti-*NRG1* antibodies of the invention are used to delay development of a disease, slow the progression of a disease, prevent relapse, or to increase time to tumor recurrence. In certain embodiments, treatment results in a reduction in the number of or complete absence of tumor reinitating cells; a decrease in number of tumor reinitating cells in a solid tumor relative to cells in the tumor that are not tumor reinitating cells; and/or inhibition of the proliferation of tumor reinitating cells. In certain embodiments, treatment with an anti-*NRG1* antibody results in an increase in time to tumor recurrence of at least 1.25, 1.50, 1.75, 2.0 fold greater than the time to tumor recurrence in the absence of treatment with an anti-*NRG1* antibody.

The term "variable region" or "variable domain" refers to the domain of an antibody heavy or light chain that is involved in binding the antibody to antigen. The variable domains of the heavy chain and light chain (VH and VL, respectively) of a native antibody generally have similar structures, with each domain comprising four conserved framework regions (FRs) and three hypervariable regions (HVRs). (See, e.g., Kindt et al. *Kuby Immunology*, 6<sup>th</sup> ed., W.H. Freeman and Co., page 91 (2007).) A single VH or VL domain may be sufficient to confer antigen-binding specificity. Furthermore, antibodies that bind a particular antigen may be isolated using a VH or VL domain from an antibody that binds the antigen to screen a library of complementary VL or VH domains, respectively. See, e.g., Portolano et al., *J. Immunol.* 150:880-887 (1993); Clarkson et al., *Nature* 352:624-628 (1991).

The term "vector," as used herein, refers to a nucleic acid molecule capable of propagating another nucleic acid to which it is linked. The term includes the vector as a self-replicating nucleic acid structure as well as the vector incorporated into the genome of a host cell into which it has been introduced. Certain vectors are capable of directing the expression of nucleic acids to which they are operatively linked. Such vectors are referred to herein as "expression vectors."

## II. COMPOSITIONS AND METHODS

Neuregulin (*NRG1*) signaling, which can occur through either the *HER3* (*ErbB3*) or *HER4* (*ErbB4*) receptor, can trigger multiple signaling cascades including the *PI3K/Akt*, *PKC*, *MAPK* and the *Ras* signaling pathways. Junttila, T. T., *et al.* (2009); Lee-Hoeflich et al., (2008); WO2011103242; US Patent Publication No. 20110229493. Furthermore, inhibition of *NRG1* signaling results in the delay or prevention of tumor relapse or recurrence after treatment with a therapeutic agent. Examples 2 – 4



and WO2011103242; US Patent Publication No. 20110229493. Anti-NRG1 antibodies that inhibit NRG1 induced signaling are useful in the treatment of cancers associated with NRG1 signaling, including autocrine NRG1 signaling.

Accordingly, one aspect of the invention provides for antibodies that bind to NRG1 (anti-  
5 NRG1 antibodies). These antibodies find use in treating cancer and in preventing resistance and/or recurrence of cancer after treatment with a therapeutic agent.

In one embodiment, the anti-NRG1 antibody binds to both neuregulin1 $\alpha$  and to neuregulin1 $\beta$  isoforms. In one embodiment, the anti-NRG1 antibody binds to the EGF domain of neuregulin1 $\beta$  and the EGF domain of neuregulin1 $\alpha$ .

10 In some embodiments, the anti-NRG1 antibody binds to neuregulin1 $\beta$  with a kD of 10 nM, 1 nM,  $1 \times 10^{-1}$  nM,  $1 \times 10^{-2}$  nM,  $1 \times 10^{-3}$  nM or less and binds to neuregulin1 $\alpha$  with a kD of 10 nM, 1 nM,  $1 \times 10^{-1}$  nM,  $1 \times 10^{-2}$  nM,  $1 \times 10^{-3}$  nM or less.

In some embodiments, the anti-NRG1 antibody binds to the EGF domain of neuregulin1 $\beta$  with a kD of 10 nM, 1 nM,  $1 \times 10^{-1}$  nM,  $1 \times 10^{-2}$  nM,  $1 \times 10^{-3}$  nM or less and binds to the EGF domain of  
15 neuregulin1 $\alpha$  with a kD of 10 nM, 1 nM,  $1 \times 10^{-1}$  nM,  $1 \times 10^{-2}$  nM,  $1 \times 10^{-3}$  nM or less.

In some embodiments, the anti-NRG1 antibody binds to neuregulin1 $\beta$  with a kD of 10 nM, 1 nM,  $1 \times 10^{-1}$  nM,  $1 \times 10^{-2}$  nM,  $1 \times 10^{-3}$  nM or less.

In some embodiments, the anti-NRG1 antibody binds to the EGF domain of neuregulin1 $\beta$  with a kD of 10 nM, 1 nM,  $1 \times 10^{-1}$  nM,  $1 \times 10^{-2}$  nM,  $1 \times 10^{-3}$  nM or less.

20 In some embodiments, the anti-NRG1 antibody binds to neuregulin1 $\beta$  with equal or greater affinity than it binds to neuregulin1 $\alpha$ . In some embodiments, the anti-NRG1 antibody binds neuregulin1 $\beta$  with an affinity that is greater than 10-, 20-, 30-, 40-, 50-, 60-, 70- 80- 90- 100-, 125-, 150-, 200-, 250-, 300-, 350-, 400-, 450-, 500-, 550-, 600-, 650-, 700-, 750-, 800-, 850-, 900-, 950-, 1000-, 1500-, 2000-fold or greater affinity to which it binds neuregulin1 $\alpha$ .

25 In some embodiments, the anti-NRG1 antibody binds to the EGF domain of neuregulin1 $\beta$  with equal or greater affinity than it binds to the EGF domain of neuregulin1 $\alpha$ . In some embodiments, the anti-NRG1 antibody binds to the EGF domain of neuregulin1 $\beta$  with an affinity that is greater than 10-, 20-, 30-, 40-, 50-, 60-, 70- 80- 90- 100-, 125-, 150-, 200-, 250-, 300-, 350-, 400-, 450-, 500-, 550-, 600-, 650-, 700-, 750-, 800-, 850-, 900-, 950-, 1000-, 1500-, 2000-fold or greater affinity to which it binds to  
30 the EGF domain of neuregulin1 $\alpha$ .

In some embodiments, the anti-NRG1 antibody binds to neuregulin1 $\alpha$  with equal or greater affinity than it binds to neuregulin1 $\beta$ . In some embodiments, the anti-NRG1 antibody binds to neuregulin1 $\alpha$  with an affinity that is greater than 10-, 20-, 30-, 40-, 50-, 60-, 70- 80- 90- 100-, 125-

150-, 200-, 250-, 300-, 350-, 400-, 450-, 500-, 550-, 600-, 650-, 700-, 750-, 800-, 850-, 900-, 950-, 1000-, 1500-, 2000-fold or greater affinity to which it binds to neuregulin1 $\beta$ .

In some embodiments, the anti-NRG1 antibody binds to the EGF domain of neuregulin1 $\alpha$  with equal or greater affinity than it binds to the EGF domain of neuregulin1 $\beta$ . In some embodiments, the anti-NRG1 antibody binds to the EGF domain of neuregulin1 $\alpha$  with an affinity that is greater than 10-, 20-, 30-, 40-, 50-, 60-, 70-, 80-, 90-, 100-, 125-, 150-, 200-, 250-, 300-, 350-, 400-, 450-, 500-, 550-, 600-, 650-, 700-, 750-, 800-, 850-, 900-, 950-, 1000-, 1500-, 2000-fold or greater affinity to which it binds to the EGF domain of neuregulin1 $\beta$ .

In one embodiment, the anti-NRG1 antibody binds to an epitope of neuregulin1 $\beta$  and to an epitope of neuregulin1 $\alpha$ . In one embodiment, the epitopes are present in the EGF domain of neuregulin1 $\beta$  and neuregulin1 $\alpha$ . In one embodiment, anti-NRG1 antibody binds to an epitope of neuregulin1 $\beta$  that is from, within, or overlapping the amino acid sequence of SEQ ID NO: 4. In one embodiment, the epitope of neuregulin1 $\beta$  that is bound by the anti-NRG1 antibody is from, within, or overlapping a segment the amino acid sequence of SEQ ID NO: 4, such as, for example, amino 1-37 of SEQ ID NO: 4 or amino acids 38-64 of SEQ ID NO: 4.

In one embodiment, the anti-NRG1 antibody binds to an epitope of neuregulin1 $\alpha$  that is from, within, or overlapping the amino acid sequence of SEQ ID NO: 3. In one embodiment, the epitope of neuregulin1 $\alpha$  that is bound by the anti-NRG1 antibody is from, within, or overlapping a segment the amino acid sequence of SEQ ID NO: 3, such as, for example, amino 1-36 of SEQ ID NO: 3 or the amino acid sequence of amino acids 37-58 of SEQ ID NO: 3.

In another aspect, the invention provides for an anti-NRG1 antibody that binds to the same epitope as an anti-NRG1 antibody provided herein. In another aspect, the invention provides for an anti-NRG1 antibody that competes for binding to the same epitope as an anti-NRG1 antibody provided herein.

#### **A. Exemplary NRG Antibodies**

In one aspect, the invention provides an anti-NRG1 antibody comprising an HVR-H1 comprising an amino acid sequence selected from SEQ ID NOs: 5, 28, 34, 37, 39, 41, and 76, an HVR-H2, comprising an amino acid sequence selected from SEQ ID NOs: 6 and 29, and an HVR-H3 comprising an amino acid sequence selected from SEQ ID NOs: 7, 30, 42, 43, 44, 48, and 50. In one aspect, the invention provides an anti-NRG1 antibody comprising an HVR-L1 comprising an amino acid sequence selected from SEQ ID NOs: 8, 12, 16, 19, and 31, an HVR-L2, comprising an amino acid sequence selected from SEQ ID NOs: 9, 13, 17, 32, 46, and 49, and an HVR-L3 comprising an amino acid sequence selected from SEQ ID NOs: 10, 11, 14, 15, 18, 20, 33, 35, 36, 38, 40, 45, 47, and

51. In one aspect, the invention provides an anti-NRG1 antibody comprising an HVR-H1 comprising an amino acid sequence selected from SEQ ID NOs: 5, 28, 34, 37, 39, 41, and 76, an HVR-H2, comprising an amino acid sequence selected from SEQ ID NOs: 6 and 29, and an HVR-H3 comprising an amino acid sequence selected from SEQ ID NOs: 7, 30, 42, 43, 44, 48, and 50, an HVR-L1  
5 comprising an amino acid sequence selected from SEQ ID NOs: 8, 12, 16, 19, and 31, an HVR-L2, comprising an amino acid sequence selected from SEQ ID NOs: 9, 13, 17, 32, 46, and 49, and an HVR-L3 comprising an amino acid sequence selected from SEQ ID NOs: 10, 11, 14, 15, 18, 20, 33, 35, 36, 38, 40, 45, 47, and 51.

In one aspect, the invention provides an anti-NRG1 antibody comprising an HVR-H1  
10 comprising the amino acid sequence of SEQ ID NO: 5, an HVR-H2, comprising the amino acid sequence of SEQ ID NO: 6, and an HVR-H3 comprising the amino acid sequence of SEQ ID NO: 7. In one aspect, the invention provides an anti-NRG1 antibody comprising an HVR-L1 comprising an amino acid sequence selected from SEQ ID NOs: 8, 12, 16, and 19, an HVR-L2, comprising an amino acid sequence selected from SEQ ID NOs: 9, 13, and 17, and an HVR-L3 comprising an amino acid  
15 sequence selected from SEQ ID NOs: 10, 11, 14, 15, 18, and 20. In one aspect, the invention provides an anti-NRG1 antibody comprising an HVR-H1 comprising the amino acid sequence of SEQ ID NO: 5, an HVR-H2, comprising the amino acid sequence of SEQ ID NO: 6, and an HVR-H3 comprising the amino acid sequence of SEQ ID NO: 7, an HVR-L1 comprising an amino acid sequence selected from SEQ ID NOs: 8, 12, 16, and 19, an HVR-L2, comprising an amino acid  
20 sequence selected from SEQ ID NOs: 9, 13, and 17, and an HVR-L3 comprising an amino acid sequence selected from SEQ ID NOs: 10, 11, 14, 15, 18, and 20.

In one aspect, the invention provides an anti-NRG1 antibody comprising an HVR-H1 comprising an amino acid sequence selected from SEQ ID NOs: 28, 34, 37, 39, 41, and 76, an HVR-H2, comprising the amino acid sequence of SEQ ID NO: 6, and an HVR-H3 comprising an amino acid  
25 sequence selected from SEQ ID NOs: 30, 42, 43, 44, 48, and 50. In one aspect, the invention provides an anti-NRG1 antibody comprising an HVR-L1 comprising an amino acid sequence selected from SEQ ID NOs: 19 and 31, an HVR-L2, comprising an amino acid sequence selected from SEQ ID NOs: 32, 46, and 49, and an HVR-L3 comprising an amino acid sequence selected from SEQ ID NOs: 33, 35, 36, 38, 40, 45, 47, and 51. In one aspect, the invention provides an anti-NRG1 antibody comprising  
30 an HVR-H1 comprising an amino acid sequence selected from SEQ ID NOs: 28, 34, 37, 39, 41, and 76, an HVR-H2, comprising the amino acid sequence of SEQ ID NO: 6, and an HVR-H3 comprising an amino acid sequence selected from SEQ ID NOs: 30, 42, 43, 44, 48, and 50, an HVR-L1 comprising an amino acid sequence selected from SEQ ID NOs: 19 and 31, an HVR-L2, comprising an amino acid sequence selected from SEQ ID NOs: 32, 46, and 49, and an HVR-L3 comprising an amino acid  
35 sequence selected from SEQ ID NOs: 33, 35, 36, 38, 40, 45, 47, and 51.

In one aspect, the invention provides an anti-NRG1 antibody comprising at least one, two, three, four, five, or six HVRs selected from (a) HVR-H1 comprising the amino acid sequence of SEQ ID NO: 5; (b) HVR-H2 comprising the amino acid sequence of SEQ ID NO: 6; (c) HVR-H3 comprising the amino acid sequence of SEQ ID NO: 7; (d) HVR-L1 comprising the amino acid sequence of SEQ ID NO: 16; (e) HVR-L2 comprising the amino acid sequence of SEQ ID NO: 17; and (f) HVR-L3 comprising the amino acid sequence of SEQ ID NO: 18.

In one aspect, the invention provides an antibody comprising at least one, at least two, or all three VH HVR sequences selected from (a) HVR-H1 comprising the amino acid sequence of SEQ ID NO: 5; (b) HVR-H2 comprising the amino acid sequence of SEQ ID NO: 6; and (c) HVR-H3 comprising the amino acid sequence of SEQ ID NO: 7. In a further embodiment, the antibody comprises (a) HVR-H1 comprising the amino acid sequence of SEQ ID NO: 5; (b) HVR-H2 comprising the amino acid sequence of SEQ ID NO: 6; and (c) HVR-H3 comprising the amino acid sequence of SEQ ID NO: 7.

In one aspect, the invention provides an antibody comprising at least one, at least two, or all three VL HVR sequences selected from (a) HVR-L1 comprising the amino acid sequence of SEQ ID NO: 16; (b) HVR-L2 comprising the amino acid sequence of SEQ ID NO: 17 and (c) HVR-L3 comprising the amino acid sequence of SEQ ID NO: 18. In one embodiment, the antibody comprises (a) HVR-L1 comprising the amino acid sequence of SEQ ID NO: 16; (b) HVR-L2 comprising the amino acid sequence of SEQ ID NO: 17; and (c) HVR-L3 comprising the amino acid sequence of SEQ ID NO: 18.

In another aspect, an antibody of the invention comprises (a) a VH domain comprising at least one, at least two, or all three VH HVR sequences selected from (i) HVR-H1 comprising the amino acid sequence of SEQ ID NO: 5, (ii) HVR-H2 comprising the amino acid sequence of SEQ ID NO: 6, and (iii) HVR-H3 comprising an amino acid sequence selected from SEQ ID NO: 7; and (b) a VL domain comprising at least one, at least two, or all three VL HVR sequences selected from (i) HVR-L1 comprising the amino acid sequence of SEQ ID NO: 16, (ii) HVR-L2 comprising the amino acid sequence of SEQ ID NO: 17, and (c) HVR-L3 comprising the amino acid sequence of SEQ ID NO: 18.

In another aspect, the invention provides an antibody comprising (a) HVR-H1 comprising the amino acid sequence of SEQ ID NO: 5; (b) HVR-H2 comprising the amino acid sequence of SEQ ID NO: 6; (c) HVR-H3 comprising the amino acid sequence of SEQ ID NO: 7; (d) HVR-L1 comprising the amino acid sequence of SEQ ID NO: 16; (e) HVR-L2 comprising the amino acid sequence of SEQ ID NO: 17; and (f) HVR-L3 comprising an amino acid sequence selected from SEQ ID NO: 18.

In one aspect, the invention provides an anti-NRG1 antibody comprising at least one, two, three, four, five, or six HVRs selected from (a) HVR-H1 comprising the amino acid sequence of SEQ ID NO: 76; (b) HVR-H2 comprising the amino acid sequence of SEQ ID NO: 29; (c) HVR-H3 comprising the amino acid sequence of SEQ ID NO: 43; (d) HVR-L1 comprising the amino acid

sequence of SEQ ID NO: 31; (e) HVR-L2 comprising the amino acid sequence of SEQ ID NO: 32; and (f) HVR-L3 comprising the amino acid sequence of SEQ ID NO: 33.

In one aspect, the invention provides an antibody comprising at least one, at least two, or all three VH HVR sequences selected from (a) HVR-H1 comprising the amino acid sequence of SEQ ID NO: 76; (b) HVR-H2 comprising the amino acid sequence of SEQ ID NO: 29; and (c) HVR-H3 comprising the amino acid sequence of SEQ ID NO: 43. In a further embodiment, the antibody comprises (a) HVR-H1 comprising the amino acid sequence of SEQ ID NO: 76; (b) HVR-H2 comprising the amino acid sequence of SEQ ID NO: 29; and (c) HVR-H3 comprising the amino acid sequence of SEQ ID NO: 43.

In one aspect, the invention provides an antibody comprising at least one, at least two, or all three VL HVR sequences selected from (a) HVR-L1 comprising the amino acid sequence of SEQ ID NO: 31; (b) HVR-L2 comprising the amino acid sequence of SEQ ID NO: 32 and (c) HVR-L3 comprising the amino acid sequence of SEQ ID NO: 33. In one embodiment, the antibody comprises (a) HVR-L1 comprising the amino acid sequence of SEQ ID NO: 31; (b) HVR-L2 comprising the amino acid sequence of SEQ ID NO: 32; and (c) HVR-L3 comprising the amino acid sequence of SEQ ID NO: 33.

In another aspect, an antibody of the invention comprises (a) a VH domain comprising at least one, at least two, or all three VH HVR sequences selected from (i) HVR-H1 comprising the amino acid sequence of SEQ ID NO: 76, (ii) HVR-H2 comprising the amino acid sequence of SEQ ID NO: 29, and (iii) HVR-H3 comprising an amino acid sequence selected from SEQ ID NO: 43; and (b) a VL domain comprising at least one, at least two, or all three VL HVR sequences selected from (i) HVR-L1 comprising the amino acid sequence of SEQ ID NO: 31, (ii) HVR-L2 comprising the amino acid sequence of SEQ ID NO: 32, and (c) HVR-L3 comprising the amino acid sequence of SEQ ID NO: 33.

In another aspect, the invention provides an antibody comprising (a) HVR-H1 comprising the amino acid sequence of SEQ ID NO: 76; (b) HVR-H2 comprising the amino acid sequence of SEQ ID NO: 29; (c) HVR-H3 comprising the amino acid sequence of SEQ ID NO: 43; (d) HVR-L1 comprising the amino acid sequence of SEQ ID NO: 31; (e) HVR-L2 comprising the amino acid sequence of SEQ ID NO: 32; and (f) HVR-L3 comprising an amino acid sequence selected from SEQ ID NO: 33.

In one aspect, the invention provides an anti-NRG1 antibody comprising a heavy chain variable region (VH) comprising the amino acid sequence of SEQ ID NO: 21. In one aspect, the invention provides an anti-NRG1 antibody comprising a light chain variable region (VL) comprising an amino acid sequence selected from SEQ ID NOs: 22, 23, 24, 25, 26, and 27. In one aspect, the invention provides an anti-NRG1 antibody comprising a VH comprising the amino acid sequence of SEQ ID NO: 21 and a VL comprising an amino acid sequence selected from SEQ ID NOs: 22, 23, 24, 25, 26, and 27.

In one aspect, the invention provides an anti-NRG1 antibody comprising a heavy chain variable region (VH) comprising an amino acid sequence selected from SEQ ID NOs: 52, 54, 56, 58, 60, 62, 63, 64, 66, 68, 70, and 72. In one aspect, the invention provides an anti-NRG1 antibody comprising a light chain variable region (VL) comprising an amino acid sequence selected from SEQ ID NOs: 53, 55, 57, 59, 61, 63, 65, 67, 69, 71, 73, and 75. In one aspect, the invention provides an anti-NRG1 antibody comprising a VH comprising an amino acid sequence selected from SEQ ID NOs: 52, 54, 56, 58, 60, 62, 63, 64, 66, 68, 70, and 72 and a VL comprising an amino acid sequence selected from SEQ ID NOs: 53, 55, 57, 59, 61, 63, 65, 67, 69, 71, 73, and 75.

In another aspect, an anti-NRG1 antibody comprises a VH sequence having at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% sequence identity to the amino acid sequence of SEQ ID NO: 21. In another aspect, an anti-NRG1 antibody comprises a VL sequence having at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% sequence identity to an amino acid selected from SEQ ID NOs: 22, 23, 24, 25, 26, and 27. In another aspect, an anti-NRG1 antibody comprises a VH sequence having at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% sequence identity to the amino acid sequence of SEQ ID NO: 21 and a VL sequence having at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% sequence identity to an amino acid selected from SEQ ID NOs: 22, 23, 24, 25, 26, and 27.

In another aspect, an anti-NRG1 antibody comprises a VH sequence having at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% sequence identity to an amino acid sequence selected from SEQ ID NOs: 52, 54, 56, 58, 60, 62, 63, 64, 66, 68, 70, and 72. In another aspect, an anti-NRG1 antibody comprises a VL sequence having at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% sequence identity to an amino acid sequence selected from SEQ ID NOs: 53, 55, 57, 59, 61, 63, 65, 67, 69, 71, 73, and 75. In another aspect, an anti-NRG1 antibody comprises a VH sequence having at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% sequence identity to an amino acid sequence selected from SEQ ID NOs: 52, 54, 56, 58, 60, 62, 63, 64, 66, 68, 70, and 72 and a VL sequence having at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% sequence identity to an amino acid selected from SEQ ID NOs: 53, 55, 57, 59, 61, 63, 65, 67, 69, 71, 73, and 75.

In another aspect, an anti-NRG1 antibody comprises a VH sequence having at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% sequence identity to the amino acid sequence of SEQ ID NO: 21. In certain embodiments, a VH sequence having at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identity contains substitutions (e.g., conservative substitutions), insertions, or deletions relative to the reference sequence, but an anti-NRG1 antibody comprising that sequence retains the ability to bind to NRG1 $\alpha$  and NRG1 $\beta$ . In certain embodiments, a total of 1 to 10 amino acids have been substituted, inserted and/or deleted in SEQ ID NO: 21. In certain embodiments,

substitutions, insertions, or deletions occur in regions outside the HVRs (i.e., in the FRs). Optionally, the anti-NRG1 antibody comprises the VH sequence in SEQ ID NO: 21, including post-translational modifications of that sequence. In a particular embodiment, the VH comprises one, two or three HVRs selected from: (a) HVR-H1 comprising the amino acid sequence of SEQ ID NO: 5, (b) HVR-H2  
5 comprising the amino acid sequence of SEQ ID NO: 6, and (c) HVR-H3 comprising the amino acid sequence of SEQ ID NO: 7.

In another aspect, an anti-NRG1 antibody is provided, wherein the antibody comprises a light chain variable domain (VL) having at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% sequence identity to the amino acid sequence of SEQ ID NO: 26. In certain embodiments, a  
10 VL sequence having at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identity contains substitutions (e.g., conservative substitutions), insertions, or deletions relative to the reference sequence, but an anti-NRG1 antibody comprising that sequence retains the ability to bind to NRG1 $\alpha$  and NRG1 $\beta$ . In certain embodiments, a total of 1 to 10 amino acids have been substituted, inserted and/or deleted in SEQ ID NO: 26. In certain embodiments, the substitutions, insertions, or deletions  
15 occur in regions outside the HVRs (i.e., in the FRs). Optionally, the anti-NRG1 antibody comprises the VL sequence in SEQ ID NO: 26, including post-translational modifications of that sequence. In a particular embodiment, the VL comprises one, two or three HVRs selected from (a) HVR-L1 comprising the amino acid sequence of SEQ ID NO: 16; (b) HVR-L2 comprising the amino acid sequence of SEQ ID NO: 17; and (c) HVR-L3 comprising the amino acid sequence of SEQ ID NO: 18.

20 In another aspect, an anti-NRG1 antibody is provided, wherein the antibody comprises a VH as in any of the embodiments provided above, and a VL as in any of the embodiments provided above. In one embodiment, the antibody comprises the VH and VL sequences in SEQ ID NO: 21 and SEQ ID NO: 26, respectively, including post-translational modifications of those sequences.

In another aspect, an anti-NRG1 antibody comprises a VH sequence having at least 90%, 91%,  
25 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% sequence identity to the amino acid sequence of SEQ ID NO: 63. In certain embodiments, a VH sequence having at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identity contains substitutions (e.g., conservative substitutions), insertions, or deletions relative to the reference sequence, but an anti-NRG1 antibody comprising that sequence retains the ability to bind to NRG1 $\alpha$  and NRG1 $\beta$ . In certain embodiments, a total of 1 to 10  
30 amino acids have been substituted, inserted and/or deleted in SEQ ID NO: 63. In certain embodiments, substitutions, insertions, or deletions occur in regions outside the HVRs (i.e., in the FRs). Optionally, the anti-NRG1 antibody comprises the VH sequence in SEQ ID NO: 63, including post-translational modifications of that sequence. In a particular embodiment, the VH comprises one, two or three HVRs selected from: (a) HVR-H1 comprising the amino acid sequence of SEQ ID NO: 76, (b) HVR-H2  
35 comprising the amino acid sequence of SEQ ID NO: 29, and (c) HVR-H3 comprising the amino acid sequence of SEQ ID NO: 43.

In another aspect, an anti-NRG1 antibody is provided, wherein the antibody comprises a light chain variable domain (VL) having at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% sequence identity to the amino acid sequence of SEQ ID NO: 53. In certain embodiments, a VL sequence having at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identity contains substitutions (e.g., conservative substitutions), insertions, or deletions relative to the reference sequence, but an anti-NRG1 antibody comprising that sequence retains the ability to bind to NRG1 $\alpha$  and NRG1 $\beta$ . In certain embodiments, a total of 1 to 10 amino acids have been substituted, inserted and/or deleted in SEQ ID NO: 53. In certain embodiments, the substitutions, insertions, or deletions occur in regions outside the HVRs (i.e., in the FRs). Optionally, the anti-NRG1 antibody comprises the VL sequence in SEQ ID NO: 53, including post-translational modifications of that sequence. In a particular embodiment, the VL comprises one, two or three HVRs selected from (a) HVR-L1 comprising the amino acid sequence of SEQ ID NO: 31; (b) HVR-L2 comprising the amino acid sequence of SEQ ID NO: 32 and (c) HVR-L3 comprising the amino acid sequence of SEQ ID NO: 33.

In another aspect, an anti-NRG1 antibody is provided, wherein the antibody comprises a VH as in any of the embodiments provided above, and a VL as in any of the embodiments provided above. In one embodiment, the antibody comprises the VH and VL sequences in SEQ ID NO: 63 and SEQ ID NO: 53, respectively, including post-translational modifications of those sequences.

In another aspect, an anti-NRG1 antibody comprises a heavy chain sequence having at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% sequence identity to the amino acid sequence of SEQ ID NO: 72. In certain embodiments, a heavy chain sequence having at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identity contains substitutions (e.g., conservative substitutions), insertions, or deletions relative to the reference sequence, but an anti-NRG1 antibody comprising that sequence retains the ability to bind to NRG1 $\alpha$  and NRG1 $\beta$ . In certain embodiments, a total of 1 to 10 amino acids have been substituted, inserted and/or deleted in SEQ ID NO: 72. In certain embodiments, substitutions, insertions, or deletions occur in regions outside the HVRs (i.e., in the FRs). Optionally, the anti-NRG1 antibody comprises the heavy chain sequence in SEQ ID NO: 72, including post-translational modifications of that sequence.

In another aspect, an anti-NRG1 antibody is provided, wherein the antibody comprises a light chain having at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% sequence identity to the amino acid sequence of SEQ ID NO: 73. In certain embodiments, a light chain sequence having at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identity contains substitutions (e.g., conservative substitutions), insertions, or deletions relative to the reference sequence, but an anti-NRG1 antibody comprising that sequence retains the ability to bind to NRG1 $\alpha$  and NRG1 $\beta$ . In certain embodiments, a total of 1 to 10 amino acids have been substituted, inserted and/or deleted in SEQ ID NO: 73. In certain embodiments, the substitutions, insertions, or deletions



occur in regions outside the HVRs (i.e., in the FRs). Optionally, the anti-NRG1 antibody comprises the light chain sequence in SEQ ID NO: 73, including post-translational modifications of that sequence.

In another aspect, an anti-NRG1 antibody is provided, wherein the antibody comprises a heavy chain as in any of the embodiments provided above, and a light chain in any of the embodiments provided above. In one embodiment, the antibody comprises the heavy chain and light chain sequences in SEQ ID NO: 72 and SEQ ID NO: 73, respectively, including post-translational modifications of those sequences.

In another aspect, an anti-NRG1 antibody comprises a heavy chain sequence having at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% sequence identity to the amino acid sequence of SEQ ID NO: 74. In certain embodiments, a heavy chain sequence having at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identity contains substitutions (e.g., conservative substitutions), insertions, or deletions relative to the reference sequence, but an anti-NRG1 antibody comprising that sequence retains the ability to bind to NRG1 $\alpha$  and NRG1 $\beta$ . In certain embodiments, a total of 1 to 10 amino acids have been substituted, inserted and/or deleted in SEQ ID NO: 74. In certain embodiments, substitutions, insertions, or deletions occur in regions outside the HVRs (i.e., in the FRs). Optionally, the anti-NRG1 antibody comprises the heavy chain sequence in SEQ ID NO: 74, including post-translational modifications of that sequence.

In another aspect, an anti-NRG1 antibody is provided, wherein the antibody comprises a light chain having at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, or 100% sequence identity to the amino acid sequence of SEQ ID NO: 75. In certain embodiments, a light chain sequence having at least 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, or 99% identity contains substitutions (e.g., conservative substitutions), insertions, or deletions relative to the reference sequence, but an anti-NRG1 antibody comprising that sequence retains the ability to bind to NRG1 $\alpha$  and NRG1 $\beta$ . In certain embodiments, a total of 1 to 10 amino acids have been substituted, inserted and/or deleted in SEQ ID NO: 75. In certain embodiments, the substitutions, insertions, or deletions occur in regions outside the HVRs (i.e., in the FRs). Optionally, the anti-NRG1 antibody comprises the light chain sequence in SEQ ID NO: 75, including post-translational modifications of that sequence.

In another aspect, an anti-NRG1 antibody is provided, wherein the antibody comprises a heavy chain as in any of the embodiments provided above, and a light chain in any of the embodiments provided above. In one embodiment, the antibody comprises the heavy chain and light chain sequences in SEQ ID NO: 74 and SEQ ID NO: 75, respectively, including post-translational modifications of those sequences.

In a further aspect, the invention provides an antibody that binds to the same epitope or epitopes as an anti-NRG1 antibody provided herein. In one embodiment, an antibody is provided that binds to the same epitope as an anti-NRG1 antibody comprising (a) HVR-H1 comprising the amino acid sequence of SEQ ID NO: 5; (b) HVR-H2 comprising the amino acid sequence of SEQ ID NO: 6;

(c) HVR-H3 comprising the amino acid sequence of SEQ ID NO: 7; (d) HVR-L1 comprising the amino acid sequence of SEQ ID NO: 16; (e) HVR-L2 comprising the amino acid sequence of SEQ ID NO: 17; and (f) HVR-L3 comprising an amino acid sequence selected from SEQ ID NO: 18.

In one embodiment, an antibody is provided that binds to the same epitope or epitopes as an anti-NRG1 antibody comprising (a) HVR-H1 comprising the amino acid sequence of SEQ ID NO: 76; (b) HVR-H2 comprising the amino acid sequence of SEQ ID NO: 29; (c) HVR-H3 comprising the amino acid sequence of SEQ ID NO: 43; (d) HVR-L1 comprising the amino acid sequence of SEQ ID NO: 31; (e) HVR-L2 comprising the amino acid sequence of SEQ ID NO: 32; and (f) HVR-L3 comprising an amino acid sequence selected from SEQ ID NO: 33.

In one embodiment, an antibody is provided that binds to the same epitope or epitopes as an anti-NRG1 antibody comprising the VH sequence of SEQ ID NO: 21 and the VL sequence of SEQ ID NO: 26. In one embodiment, an antibody is provided that binds to the same epitope or epitopes as an anti-NRG1 antibody comprising the VH sequence of SEQ ID NO: 63 and the VL sequence of SEQ ID NO: 53.

In other embodiments, an antibody is provided that competes for binding to the same epitope or epitopes as an anti-NRG1 antibody as described herein.

In one embodiment, the anti-NRG1 antibody binds to an epitope of neuregulin1 $\beta$  and to an epitope of neuregulin1 $\alpha$ . In one embodiment, the epitopes are present in the EGF domain of neuregulin1 $\beta$  and neuregulin1 $\alpha$ . In one embodiment, anti-NRG1 antibody binds to an epitope of neuregulin1 $\beta$  that is from, within, or overlapping the amino acid sequence of SEQ ID NO: 4. In one embodiment, the epitope of neuregulin1 $\beta$  that is bound by the anti-NRG1 antibody is from, within, or overlapping a segment the amino acid sequence of SEQ ID NO: 4, such as, for example, amino 1-37 of SEQ ID NO: 4 or amino acids 38-64 of SEQ ID NO: 4.

In one embodiment, the anti-NRG1 antibody binds to an epitope of neuregulin1 $\alpha$  that is from, within, or overlapping the amino acid sequence of SEQ ID NO: 3. In one embodiment, the epitope of neuregulin1 $\alpha$  that is bound by the anti-NRG1 antibody is from, within, or overlapping a segment the amino acid sequence of SEQ ID NO: 3, such as, for example, amino 1-36 of SEQ ID NO: 3 or the amino acid sequence of amino acids 37-58 of SEQ ID NO: 3.

In a further aspect of the invention, an anti-NRG1 antibody according to any of the above embodiments is a monoclonal antibody, including a chimeric, humanized or human antibody. In one embodiment, an anti-NRG1 antibody is an antibody fragment, e.g., a Fv, Fab, Fab', scFv, diabody, or F(ab')<sub>2</sub> fragment. In another embodiment, the antibody is a full length antibody, e.g., an intact IgG1 antibody or other antibody class or isotype as defined herein.

In a further aspect, an anti-NRG1 antibody according to any of the above embodiments may incorporate any of the features, singly or in combination, as described in Sections 1-7 below:

### 1) Antibody Affinity

In certain embodiments, an antibody provided herein has a dissociation constant (Kd) of  $\leq 1\mu\text{M}$ ,  $\leq 100\text{ nM}$ ,  $\leq 10\text{ nM}$ ,  $\leq 1\text{ nM}$ ,  $\leq 0.1\text{ nM}$ ,  $\leq 0.01\text{ nM}$ , or  $\leq 0.001\text{ nM}$  (e.g.  $10^{-8}\text{ M}$  or less, e.g. from  $10^{-8}\text{ M}$  to  $10^{-13}\text{ M}$ , e.g., from  $10^{-9}\text{ M}$  to  $10^{-13}\text{ M}$ ).

5 In one embodiment, Kd is measured by a radiolabeled antigen binding assay (RIA) performed with the Fab version of an antibody of interest and its antigen as described by the following assay. Solution binding affinity of Fabs for antigen is measured by equilibrating Fab with a minimal concentration of ( $^{125}\text{I}$ )-labeled antigen in the presence of a titration series of unlabeled antigen, then capturing bound antigen with an anti-Fab antibody-coated plate (see, e.g., Chen et al., *J. Mol. Biol.* 10 293:865-881(1999)). To establish conditions for the assay, MICROTITER<sup>®</sup> multi-well plates (Thermo Scientific) are coated overnight with 5  $\mu\text{g/ml}$  of a capturing anti-Fab antibody (Cappel Labs) in 50 mM sodium carbonate (pH 9.6), and subsequently blocked with 2% (w/v) bovine serum albumin in PBS for two to five hours at room temperature (approximately 23°C). In a non-adsorbent plate (Nunc #269620), 100 pM or 26 pM [ $^{125}\text{I}$ ]-antigen are mixed with serial dilutions of a Fab of interest (e.g., 15 consistent with assessment of the anti-VEGF antibody, Fab-12, in Presta et al., *Cancer Res.* 57:4593-4599 (1997)). The Fab of interest is then incubated overnight; however, the incubation may continue for a longer period (e.g., about 65 hours) to ensure that equilibrium is reached. Thereafter, the mixtures are transferred to the capture plate for incubation at room temperature (e.g., for one hour). The solution is then removed and the plate washed eight times with 0.1% polysorbate 20 (TWEEN-20<sup>®</sup>) in PBS. When the plates have dried, 150  $\mu\text{l/well}$  of scintillant (MICROSCINT-20<sup>™</sup>; Packard) is added, and the plates are counted on a TOPCOUNT<sup>™</sup> gamma counter (Packard) for ten minutes. Concentrations of each Fab that give less than or equal to 20% of maximal binding are chosen for use in competitive binding assays.

According to another embodiment, Kd is measured using surface plasmon resonance assays 25 using a BIACORE<sup>®</sup>-2000 or a BIACORE<sup>®</sup>-3000 (BIAcore, Inc., Piscataway, NJ) at 25°C with immobilized antigen CM5 chips at  $\sim 10$  response units (RU). Briefly, carboxymethylated dextran biosensor chips (CM5, BIACORE, Inc.) are activated with *N*-ethyl-*N'*-(3-dimethylaminopropyl)-carbodiimide hydrochloride (EDC) and *N*-hydroxysuccinimide (NHS) according to the supplier's instructions. Antigen is diluted with 10 mM sodium acetate, pH 4.8, to 5  $\mu\text{g/ml}$  ( $\sim 0.2\text{ }\mu\text{M}$ ) before 30 injection at a flow rate of 5  $\mu\text{l/minute}$  to achieve approximately 10 response units (RU) of coupled protein. Following the injection of antigen, 1 M ethanolamine is injected to block unreacted groups. For kinetics measurements, two-fold serial dilutions of Fab (0.78 nM to 500 nM) are injected in PBS with 0.05% polysorbate 20 (TWEEN-20<sup>™</sup>) surfactant (PBST) at 25°C at a flow rate of approximately 25  $\mu\text{l/min}$ . Association rates ( $k_{\text{on}}$ ) and dissociation rates ( $k_{\text{off}}$ ) are calculated using a simple one-to- 35 one Langmuir binding model (BIACORE<sup>®</sup> Evaluation Software version 3.2) by simultaneously fitting the association and dissociation sensorgrams. The equilibrium dissociation constant (Kd) is calculated

as the ratio  $k_{\text{off}}/k_{\text{on}}$ . See, e.g., Chen et al., *J. Mol. Biol.* 293:865-881 (1999). If the on-rate exceeds  $10^6 \text{ M}^{-1} \text{ s}^{-1}$  by the surface plasmon resonance assay above, then the on-rate can be determined by using a fluorescent quenching technique that measures the increase or decrease in fluorescence emission intensity (excitation = 295 nm; emission = 340 nm, 16 nm band-pass) at 25°C of a 20 nM anti-antigen antibody (Fab form) in PBS, pH 7.2, in the presence of increasing concentrations of antigen as measured in a spectrometer, such as a stop-flow equipped spectrophotometer (Aviv Instruments) or a 8000-series SLM-AMINCO™ spectrophotometer (ThermoSpectronic) with a stirred cuvette.

## 2) Antibody Fragments

In certain embodiments, an antibody provided herein is an antibody fragment. Antibody fragments include, but are not limited to, Fab, Fab', Fab'-SH, F(ab')<sub>2</sub>, Fv, and scFv fragments, and other fragments described below. For a review of certain antibody fragments, see Hudson et al. *Nat. Med.* 9:129-134 (2003). For a review of scFv fragments, see, e.g., Pluckthün, in *The Pharmacology of Monoclonal Antibodies*, vol. 113, Rosenberg and Moore eds., (Springer-Verlag, New York), pp. 269-315 (1994); see also WO 93/16185; and U.S. Patent Nos. 5,571,894 and 5,587,458. For discussion of Fab and F(ab')<sub>2</sub> fragments comprising salvage receptor binding epitope residues and having increased in vivo half-life, see U.S. Patent No. 5,869,046.

Diabodies are antibody fragments with two antigen-binding sites that may be bivalent or bispecific. See, for example, EP 404,097; WO 1993/01161; Hudson et al., *Nat. Med.* 9:129-134 (2003); and Hollinger et al., *Proc. Natl. Acad. Sci. USA* 90: 6444-6448 (1993). Triabodies and tetrabodies are also described in Hudson et al., *Nat. Med.* 9:129-134 (2003).

Single-domain antibodies are antibody fragments comprising all or a portion of the heavy chain variable domain or all or a portion of the light chain variable domain of an antibody. In certain embodiments, a single-domain antibody is a human single-domain antibody (Domantis, Inc., Waltham, MA; see, e.g., U.S. Patent No. 6,248,516 B1).

Antibody fragments can be made by various techniques, including but not limited to proteolytic digestion of an intact antibody as well as production by recombinant host cells (e.g. *E. coli* or phage), as described herein.

## 3) Chimeric and Humanized Antibodies

In certain embodiments, an antibody provided herein is a chimeric antibody. Certain chimeric antibodies are described, e.g., in U.S. Patent No. 4,816,567; and Morrison et al., *Proc. Natl. Acad. Sci. USA*, 81:6851-6855 (1984)). In one example, a chimeric antibody comprises a non-human variable region (e.g., a variable region derived from a mouse, rat, hamster, rabbit, or non-human primate, such as a monkey) and a human constant region. In a further example, a chimeric antibody is a "class

switched” antibody in which the class or subclass has been changed from that of the parent antibody. Chimeric antibodies include antigen-binding fragments thereof.

In certain embodiments, a chimeric antibody is a humanized antibody. Typically, a non-human antibody is humanized to reduce immunogenicity to humans, while retaining the specificity and affinity of the parental non-human antibody. Generally, a humanized antibody comprises one or more variable domains in which HVRs, e.g., CDRs, (or portions thereof) are derived from a non-human antibody, and FRs (or portions thereof) are derived from human antibody sequences. A humanized antibody optionally will also comprise at least a portion of a human constant region. In some embodiments, some FR residues in a humanized antibody are substituted with corresponding residues from a non-human antibody (e.g., the antibody from which the HVR residues are derived), e.g., to restore or improve antibody specificity or affinity.

Humanized antibodies and methods of making them are reviewed, e.g., in Almagro and Fransson, *Front. Biosci.* 13:1619-1633 (2008), and are further described, e.g., in Riechmann et al., *Nature* 332:323-329 (1988); Queen et al., *Proc. Nat’l Acad. Sci. USA* 86:10029-10033 (1989); US Patent Nos. 5, 821,337, 7,527,791, 6,982,321, and 7,087,409; Kashmiri et al., *Methods* 36:25-34 (2005) (describing SDR (a-CDR) grafting); Padlan, *Mol. Immunol.* 28:489-498 (1991) (describing “resurfacing”); Dall’Acqua et al., *Methods* 36:43-60 (2005) (describing “FR shuffling”); and Osbourn et al., *Methods* 36:61-68 (2005) and Klimka et al., *Br. J. Cancer*, 83:252-260 (2000) (describing the “guided selection” approach to FR shuffling).

Human framework regions that may be used for humanization include but are not limited to: framework regions selected using the “best-fit” method (see, e.g., Sims et al. *J. Immunol.* 151:2296 (1993)); framework regions derived from the consensus sequence of human antibodies of a particular subgroup of light or heavy chain variable regions (see, e.g., Carter et al. *Proc. Natl. Acad. Sci. USA*, 89:4285 (1992); and Presta et al. *J. Immunol.*, 151:2623 (1993)); human mature (somatically mutated) framework regions or human germline framework regions (see, e.g., Almagro and Fransson, *Front. Biosci.* 13:1619-1633 (2008)); and framework regions derived from screening FR libraries (see, e.g., Baca et al., *J. Biol. Chem.* 272:10678-10684 (1997) and Rosok et al., *J. Biol. Chem.* 271:22611-22618 (1996)).

#### 4) Human Antibodies

In certain embodiments, an antibody provided herein is a human antibody. Human antibodies can be produced using various techniques known in the art. Human antibodies are described generally in van Dijk and van de Winkel, *Curr. Opin. Pharmacol.* 5: 368-74 (2001) and Lonberg, *Curr. Opin. Immunol.* 20:450-459 (2008).

Human antibodies may be prepared by administering an immunogen to a transgenic animal that has been modified to produce intact human antibodies or intact antibodies with human variable regions in response to antigenic challenge. Such animals typically contain all or a portion of the human

immunoglobulin loci, which replace the endogenous immunoglobulin loci, or which are present extrachromosomally or integrated randomly into the animal's chromosomes. In such transgenic mice, the endogenous immunoglobulin loci have generally been inactivated. For review of methods for obtaining human antibodies from transgenic animals, see Lonberg, *Nat. Biotech.* 23:1117-1125 (2005).  
5 See also, e.g., U.S. Patent Nos. 6,075,181 and 6,150,584 describing XENOMOUSE™ technology; U.S. Patent No. 5,770,429 describing HUMAB® technology; U.S. Patent No. 7,041,870 describing K-M MOUSE® technology, and U.S. Patent Application Publication No. US 2007/0061900, describing VELOCIMOUSE® technology). Human variable regions from intact antibodies generated by such animals may be further modified, e.g., by combining with a different human constant region.

10 Human antibodies can also be made by hybridoma-based methods. Human myeloma and mouse-human heteromyeloma cell lines for the production of human monoclonal antibodies have been described. (See, e.g., Kozbor *J. Immunol.*, 133: 3001 (1984); Brodeur et al., *Monoclonal Antibody Production Techniques and Applications*, pp. 51-63 (Marcel Dekker, Inc., New York, 1987); and Boerner et al., *J. Immunol.*, 147: 86 (1991).) Human antibodies generated via human B-cell hybridoma  
15 technology are also described in Li et al., *Proc. Natl. Acad. Sci. USA*, 103:3557-3562 (2006). Additional methods include those described, for example, in U.S. Patent No. 7,189,826 (describing production of monoclonal human IgM antibodies from hybridoma cell lines) and Ni, *Xiandai Mianyixue*, 26(4):265-268 (2006) (describing human-human hybridomas). Human hybridoma technology (Trioma technology) is also described in Vollmers and Brandlein, *Histology and*  
20 *Histopathology*, 20(3):927-937 (2005) and Vollmers and Brandlein, *Methods and Findings in Experimental and Clinical Pharmacology*, 27(3):185-91 (2005).

Human antibodies may also be generated by isolating Fv clone variable domain sequences selected from human-derived phage display libraries. Such variable domain sequences may then be combined with a desired human constant domain. Techniques for selecting human antibodies from  
25 antibody libraries are described below.

### 5) Library-Derived Antibodies

Antibodies of the invention may be isolated by screening combinatorial libraries for antibodies with the desired activity or activities. For example, a variety of methods are known in the art for generating phage display libraries and screening such libraries for antibodies possessing the desired  
30 binding characteristics. Such methods are reviewed, e.g., in Hoogenboom et al. in *Methods in Molecular Biology* 178:1-37 (O'Brien et al., ed., Human Press, Totowa, NJ, 2001) and further described, e.g., in the McCafferty et al., *Nature* 348:552-554; Clackson et al., *Nature* 352: 624-628 (1991); Marks et al., *J. Mol. Biol.* 222: 581-597 (1992); Marks and Bradbury, in *Methods in Molecular Biology* 248:161-175 (Lo, ed., Human Press, Totowa, NJ, 2003); Sidhu et al., *J. Mol. Biol.* 338(2): 299-  
35 310 (2004); Lee et al., *J. Mol. Biol.* 340(5): 1073-1093 (2004); Fellouse, *Proc. Natl. Acad. Sci. USA* 101(34): 12467-12472 (2004); and Lee et al., *J. Immunol. Methods* 284(1-2): 119-132(2004).

In certain phage display methods, repertoires of VH and VL genes are separately cloned by polymerase chain reaction (PCR) and recombined randomly in phage libraries, which can then be screened for antigen-binding phage as described in Winter et al., *Ann. Rev. Immunol.*, 12: 433-455 (1994). Phage typically display antibody fragments, either as single-chain Fv (scFv) fragments or as Fab fragments. Libraries from immunized sources provide high-affinity antibodies to the immunogen without the requirement of constructing hybridomas. Alternatively, the naive repertoire can be cloned (e.g., from human) to provide a single source of antibodies to a wide range of non-self and also self antigens without any immunization as described by Griffiths et al., *EMBO J.*, 12: 725-734 (1993). Finally, naive libraries can also be made synthetically by cloning unrearranged V-gene segments from stem cells, and using PCR primers containing random sequence to encode the highly variable CDR3 regions and to accomplish rearrangement *in vitro*, as described by Hoogenboom and Winter, *J. Mol. Biol.*, 227: 381-388 (1992). Patent publications describing human antibody phage libraries include, for example: US Patent No. 5,750,373, and US Patent Publication Nos. 2005/0079574, 2005/0119455, 2005/0266000, 2007/0117126, 2007/0160598, 2007/0237764, 2007/0292936, and 2009/0002360.

Antibodies or antibody fragments isolated from human antibody libraries are considered human antibodies or human antibody fragments herein.

#### 6) Multispecific Antibodies

In certain embodiments, an antibody provided herein is a multispecific antibody, e.g. a bispecific antibody. Multispecific antibodies are monoclonal antibodies that have binding specificities for at least two different sites. In certain embodiments, one of the binding specificities is for NRG1 and the other is for any other antigen. In certain embodiments, bispecific antibodies may bind to two different epitopes of NRG1. Bispecific antibodies may also be used to localize cytotoxic agents to cells which express NRG1. Bispecific antibodies can be prepared as full length antibodies or antibody fragments.

Techniques for making multispecific antibodies include, but are not limited to, recombinant co-expression of two immunoglobulin heavy chain-light chain pairs having different specificities (see Milstein and Cuello, *Nature* 305: 537 (1983)), WO 93/08829, and Traunecker et al., *EMBO J.* 10: 3655 (1991)), and "knob-in-hole" engineering (see, e.g., U.S. Patent No. 5,731,168). Multi-specific antibodies may also be made by engineering electrostatic steering effects for making antibody Fc-heterodimeric molecules (WO 2009/089004A1); cross-linking two or more antibodies or fragments (see, e.g., US Patent No. 4,676,980, and Brennan et al., *Science*, 229: 81 (1985)); using leucine zippers to produce bi-specific antibodies (see, e.g., Kostelny et al., *J. Immunol.*, 148(5):1547-1553 (1992)); using "diabody" technology for making bispecific antibody fragments (see, e.g., Hollinger et al., *Proc. Natl. Acad. Sci. USA*, 90:6444-6448 (1993)); and using single-chain Fv (sFv) dimers (see, e.g. Gruber et al., *J. Immunol.*, 152:5368 (1994)); and preparing trispecific antibodies as described, e.g., in Tutt et al. *J. Immunol.* 147: 60 (1991).

Engineered antibodies with three or more functional antigen binding sites, including “Octopus antibodies,” are also included herein (see, e.g. US 2006/0025576A1).

The antibody or fragment herein also includes a “Dual Acting FAb” or “DAF” comprising an antigen binding site that binds to NRG1 as well as another, different antigen (see, US 2008/0069820, for example).

## 7) Antibody Variants

In certain embodiments, amino acid sequence variants of the antibodies provided herein are contemplated. For example, it may be desirable to improve the binding affinity and/or other biological properties of the antibody. Amino acid sequence variants of an antibody may be prepared by introducing appropriate modifications into the nucleotide sequence encoding the antibody, or by peptide synthesis. Such modifications include, for example, deletions from, and/or insertions into and/or substitutions of residues within the amino acid sequences of the antibody. Any combination of deletion, insertion, and substitution can be made to arrive at the final construct, provided that the final construct possesses the desired characteristics, e.g., antigen-binding.

### a. Substitution, Insertion, and Deletion Variants

In certain embodiments, antibody variants having one or more amino acid substitutions are provided. Sites of interest for substitutional mutagenesis include the HVRs and FRs. Conservative substitutions are shown in Table 1 under the heading of "conservative substitutions." More substantial changes are provided in Table 1 under the heading of "exemplary substitutions," and as further described below in reference to amino acid side chain classes. Amino acid substitutions may be introduced into an antibody of interest and the products screened for a desired activity, e.g., retained/improved antigen binding, decreased immunogenicity, or improved ADCC or CDC.

**TABLE 1**

<b>Original Residue</b>	<b>Exemplary Substitutions</b>	<b>Preferred Substitutions</b>
Ala (A)	Val; Leu; Ile	Val
Arg (R)	Lys; Gln; Asn	Lys
Asn (N)	Gln; His; Asp, Lys; Arg	Gln
Asp (D)	Glu; Asn	Glu
Cys (C)	Ser; Ala	Ser
Gln (Q)	Asn; Glu	Asn
Glu (E)	Asp; Gln	Asp
Gly (G)	Ala	Ala
His (H)	Asn; Gln; Lys; Arg	Arg
Ile (I)	Leu; Val; Met; Ala; Phe; Norleucine	Leu



Original Residue	Exemplary Substitutions	Preferred Substitutions
Leu (L)	Norleucine; Ile; Val; Met; Ala; Phe	Ile
Lys (K)	Arg; Gln; Asn	Arg
Met (M)	Leu; Phe; Ile	Leu
Phe (F)	Trp; Leu; Val; Ile; Ala; Tyr	Tyr
Pro (P)	Ala	Ala
Ser (S)	Thr	Thr
Thr (T)	Val; Ser	Ser
Trp (W)	Tyr; Phe	Tyr
Tyr (Y)	Trp; Phe; Thr; Ser	Phe
Val (V)	Ile; Leu; Met; Phe; Ala; Norleucine	Leu

Amino acids may be grouped according to common side-chain properties:

- (1) hydrophobic: Norleucine, Met, Ala, Val, Leu, Ile;
- (2) neutral hydrophilic: Cys, Ser, Thr, Asn, Gln;
- (3) acidic: Asp, Glu;
- (4) basic: His, Lys, Arg;
- (5) residues that influence chain orientation: Gly, Pro;
- (6) aromatic: Trp, Tyr, Phe.

Non-conservative substitutions will entail exchanging a member of one of these classes for another class.

One type of substitutional variant involves substituting one or more hypervariable region residues of a parent antibody (e.g. a humanized or human antibody). Generally, the resulting variant(s) selected for further study will have modifications (e.g., improvements) in certain biological properties (e.g., increased affinity, reduced immunogenicity) relative to the parent antibody and/or will have substantially retained certain biological properties of the parent antibody. An exemplary substitutional variant is an affinity matured antibody, which may be conveniently generated, e.g., using phage display-based affinity maturation techniques such as those described herein. Briefly, one or more HVR residues are mutated and the variant antibodies displayed on phage and screened for a particular biological activity (e.g. binding affinity).

Alterations (e.g., substitutions) may be made in HVRs, e.g., to improve antibody affinity. Such alterations may be made in HVR "hotspots," i.e., residues encoded by codons that undergo mutation at high frequency during the somatic maturation process (see, e.g., Chowdhury, *Methods Mol. Biol.* 207:179-196 (2008)), and/or SDRs (a-CDRs), with the resulting variant VH or VL being tested for binding affinity. Affinity maturation by constructing and reselecting from secondary libraries has been

described, e.g., in Hoogenboom et al. in *Methods in Molecular Biology* 178:1-37 (O'Brien et al., ed., Human Press, Totowa, NJ, (2001).) In some embodiments of affinity maturation, diversity is introduced into the variable genes chosen for maturation by any of a variety of methods (e.g., error-prone PCR, chain shuffling, or oligonucleotide-directed mutagenesis). A secondary library is then created. The library is then screened to identify any antibody variants with the desired affinity. Another method to introduce diversity involves HVR-directed approaches, in which several HVR residues (e.g., 4-6 residues at a time) are randomized. HVR residues involved in antigen binding may be specifically identified, e.g., using alanine scanning mutagenesis or modeling. CDR-H3 and CDR-L3 in particular are often targeted.

In certain embodiments, substitutions, insertions, or deletions may occur within one or more HVRs so long as such alterations do not substantially reduce the ability of the antibody to bind antigen. For example, conservative alterations (e.g., conservative substitutions as provided herein) that do not substantially reduce binding affinity may be made in HVRs. Such alterations may be outside of HVR "hotspots" or SDRs. In certain embodiments of the variant VH and VL sequences provided above, each HVR either is unaltered, or contains no more than one, two or three amino acid substitutions.

A useful method for identification of residues or regions of an antibody that may be targeted for mutagenesis is called "alanine scanning mutagenesis" as described by Cunningham and Wells (1989) *Science*, 244:1081-1085. In this method, a residue or group of target residues (e.g., charged residues such as arg, asp, his, lys, and glu) are identified and replaced by a neutral or negatively charged amino acid (e.g., alanine or polyalanine) to determine whether the interaction of the antibody with antigen is affected. Further substitutions may be introduced at the amino acid locations demonstrating functional sensitivity to the initial substitutions. Alternatively, or additionally, a crystal structure of an antigen-antibody complex to identify contact points between the antibody and antigen. Such contact residues and neighboring residues may be targeted or eliminated as candidates for substitution. Variants may be screened to determine whether they contain the desired properties.

Amino acid sequence insertions include amino- and/or carboxyl-terminal fusions ranging in length from one residue to polypeptides containing a hundred or more residues, as well as intrasequence insertions of single or multiple amino acid residues. Examples of terminal insertions include an antibody with an N-terminal methionyl residue. Other insertional variants of the antibody molecule include the fusion to the N- or C-terminus of the antibody to an enzyme (e.g. for ADEPT) or a polypeptide which increases the serum half-life of the antibody.

#### **b. Glycosylation variants**

In certain embodiments, an antibody provided herein is altered to increase or decrease the extent to which the antibody is glycosylated. Addition or deletion of glycosylation sites to an antibody may be conveniently accomplished by altering the amino acid sequence such that one or more glycosylation sites is created or removed.

Where the antibody comprises an Fc region, the carbohydrate attached thereto may be altered. Native antibodies produced by mammalian cells typically comprise a branched, biantennary oligosaccharide that is generally attached by an N-linkage to Asn297 of the CH2 domain of the Fc region. See, e.g., Wright et al. *TIBTECH* 15:26-32 (1997). The oligosaccharide may include various carbohydrates, e.g., mannose, N-acetyl glucosamine (GlcNAc), galactose, and sialic acid, as well as a fucose attached to a GlcNAc in the “stem” of the biantennary oligosaccharide structure. In some embodiments, modifications of the oligosaccharide in an antibody of the invention may be made in order to create antibody variants with certain improved properties.

In one embodiment, antibody variants are provided having a carbohydrate structure that lacks fucose attached (directly or indirectly) to an Fc region. For example, the amount of fucose in such antibody may be from 1% to 80%, from 1% to 65%, from 5% to 65% or from 20% to 40%. The amount of fucose is determined by calculating the average amount of fucose within the sugar chain at Asn297, relative to the sum of all glycostructures attached to Asn 297 (e. g. complex, hybrid and high mannose structures) as measured by MALDI-TOF mass spectrometry, as described in WO 2008/077546, for example. Asn297 refers to the asparagine residue located at about position 297 in the Fc region (Eu numbering of Fc region residues); however, Asn297 may also be located about  $\pm 3$  amino acids upstream or downstream of position 297, i.e., between positions 294 and 300, due to minor sequence variations in antibodies. Such fucosylation variants may have improved ADCC function. See, e.g., US Patent Publication Nos. US 2003/0157108 (Presta, L.); US 2004/0093621 (Kyowa Hakko Kogyo Co., Ltd). Examples of publications related to “defucosylated” or “fucose-deficient” antibody variants include: US 2003/0157108; WO 2000/61739; WO 2001/29246; US 2003/0115614; US 2002/0164328; US 2004/0093621; US 2004/0132140; US 2004/0110704; US 2004/0110282; US 2004/0109865; WO 2003/085119; WO 2003/084570; WO 2005/035586; WO 2005/035778; WO2005/053742; WO2002/031140; Okazaki et al. *J. Mol. Biol.* 336:1239-1249 (2004); Yamane-Ohnuki et al. *Biotech. Bioeng.* 87: 614 (2004). Examples of cell lines capable of producing defucosylated antibodies include Lec13 CHO cells deficient in protein fucosylation (Ripka et al. *Arch. Biochem. Biophys.* 249:533-545 (1986); US Pat Appl No US 2003/0157108 A1, Presta, L; and WO 2004/056312 A1, Adams *et al.*, especially at Example 11), and knockout cell lines, such as alpha-1,6-fucosyltransferase gene, *FUT8*, knockout CHO cells (see, e.g., Yamane-Ohnuki et al. *Biotech. Bioeng.* 87: 614 (2004); Kanda, Y. et al., *Biotechnol. Bioeng.*, 94(4):680-688 (2006); and WO2003/085107).

Antibodies variants are further provided with bisected oligosaccharides, e.g., in which a biantennary oligosaccharide attached to the Fc region of the antibody is bisected by GlcNAc. Such antibody variants may have reduced fucosylation and/or improved ADCC function. Examples of such antibody variants are described, e.g., in WO 2003/011878 (Jean-Mairet et al.); US Patent No. 6,602,684 (Umana et al.); and US 2005/0123546 (Umana *et al.*). Antibody variants with at least one

galactose residue in the oligosaccharide attached to the Fc region are also provided. Such antibody variants may have improved CDC function. Such antibody variants are described, e.g., in WO 1997/30087 (Patel et al.); WO 1998/58964 (Raju, S.); and WO 1999/22764 (Raju, S.).

**c. Fc region variants**

5 In certain embodiments, one or more amino acid modifications may be introduced into the Fc region of an antibody provided herein, thereby generating an Fc region variant. The Fc region variant may comprise a human Fc region sequence (e.g., a human IgG1, IgG2, IgG3 or IgG4 Fc region) comprising an amino acid modification (e.g. a substitution) at one or more amino acid positions.

10 In certain embodiments, the invention contemplates an antibody variant that possesses some but not all effector functions, which make it a desirable candidate for applications in which the half life of the antibody *in vivo* is important yet certain effector functions (such as complement and ADCC) are unnecessary or deleterious. *In vitro* and/or *in vivo* cytotoxicity assays can be conducted to confirm the reduction/depletion of CDC and/or ADCC activities. For example, Fc receptor (FcR) binding assays can be conducted to ensure that the antibody lacks FcγR binding (hence likely lacking ADCC activity),  
15 but retains FcRn binding ability. The primary cells for mediating ADCC, NK cells, express FcγRIII only, whereas monocytes express FcγRI, FcγRII and FcγRIII. FcR expression on hematopoietic cells is summarized in Table 3 on page 464 of Ravetch and Kinet, *Annu. Rev. Immunol.* 9:457-492 (1991). Non-limiting examples of *in vitro* assays to assess ADCC activity of a molecule of interest is described in U.S. Patent No. 5,500,362 (see, e.g. Hellstrom, I. et al. *Proc. Nat'l Acad. Sci. USA* 83:7059-7063  
20 (1986)) and Hellstrom, I et al., *Proc. Nat'l Acad. Sci. USA* 82:1499-1502 (1985); 5,821,337 (see Bruggemann, M. et al., *J. Exp. Med.* 166:1351-1361 (1987)). Alternatively, non-radioactive assays methods may be employed (see, for example, ACTI™ non-radioactive cytotoxicity assay for flow cytometry (CellTechnology, Inc. Mountain View, CA; and CytoTox 96® non-radioactive cytotoxicity assay (Promega, Madison, WI). Useful effector cells for such assays include peripheral blood  
25 mononuclear cells (PBMC) and Natural Killer (NK) cells. Alternatively, or additionally, ADCC activity of the molecule of interest may be assessed *in vivo*, e.g., in a animal model such as that disclosed in Clynes et al. *Proc. Nat'l Acad. Sci. USA* 95:652-656 (1998). C1q binding assays may also be carried out to confirm that the antibody is unable to bind C1q and hence lacks CDC activity. See, e.g., C1q and C3c binding ELISA in WO 2006/029879 and WO 2005/100402. To assess complement  
30 activation, a CDC assay may be performed (see, for example, Gazzano-Santoro *et al.*, *J. Immunol. Methods* 202:163 (1996); Cragg, M.S. et al., *Blood* 101:1045-1052 (2003); and Cragg, M.S. and M.J. Glennie, *Blood* 103:2738-2743 (2004)). FcRn binding and *in vivo* clearance/half life determinations can also be performed using methods known in the art (see, e.g., Petkova, S.B. et al., *Int'l. Immunol.* 18(12):1759-1769 (2006)).

Antibodies with reduced effector function include those with substitution of one or more of Fc region residues 238, 265, 269, 270, 297, 327 and 329 (U.S. Patent No. 6,737,056). Such Fc mutants include Fc mutants with substitutions at two or more of amino acid positions 265, 269, 270, 297 and 327, including the so-called "DANA" Fc mutant with substitution of residues 265 and 297 to alanine (US Patent No. 7,332,581).

Certain antibody variants with improved or diminished binding to FcRs are described. (See, e.g., U.S. Patent No. 6,737,056; WO 2004/056312, and Shields et al., *J. Biol. Chem.* 9(2): 6591-6604 (2001).)

In certain embodiments, an antibody variant comprises an Fc region with one or more amino acid substitutions which improve ADCC, e.g., substitutions at positions 298, 333, and/or 334 of the Fc region (EU numbering of residues).

In some embodiments, alterations are made in the Fc region that result in altered (*i.e.*, either improved or diminished) C1q binding and/or Complement Dependent Cytotoxicity (CDC), e.g., as described in US Patent No. 6,194,551, WO 99/51642, and Idusogie et al. *J. Immunol.* 164: 4178-4184 (2000).

Antibodies with increased half lives and improved binding to the neonatal Fc receptor (FcRn), which is responsible for the transfer of maternal IgGs to the fetus (Guyer et al., *J. Immunol.* 117:587 (1976) and Kim et al., *J. Immunol.* 24:249 (1994)), are described in US2005/0014934A1 (Hinton et al.). Those antibodies comprise an Fc region with one or more substitutions therein which improve binding of the Fc region to FcRn. Such Fc variants include those with substitutions at one or more of Fc region residues: 238, 256, 265, 272, 286, 303, 305, 307, 311, 312, 317, 340, 356, 360, 362, 376, 378, 380, 382, 413, 424 or 434, e.g., substitution of Fc region residue 434 (US Patent No. 7,371,826).

See also Duncan & Winter, *Nature* 322:738-40 (1988); U.S. Patent No. 5,648,260; U.S. Patent No. 5,624,821; and WO 94/29351 concerning other examples of Fc region variants.

#### **d. Cysteine engineered antibody variants**

In certain embodiments, it may be desirable to create cysteine engineered antibodies, e.g., "thioMAbs," in which one or more residues of an antibody are substituted with cysteine residues. In particular embodiments, the substituted residues occur at accessible sites of the antibody. By substituting those residues with cysteine, reactive thiol groups are thereby positioned at accessible sites of the antibody and may be used to conjugate the antibody to other moieties, such as drug moieties or linker-drug moieties, to create an immunoconjugate, as described further herein. In certain embodiments, any one or more of the following residues may be substituted with cysteine: V205 (Kabat numbering) of the light chain; A118 (EU numbering) of the heavy chain; and S400 (EU numbering) of the heavy chain Fc region. Cysteine engineered antibodies may be generated as described, e.g., in U.S. Patent No. 7,521,541.

### e. Antibody Derivatives

In certain embodiments, an antibody provided herein may be further modified to contain additional nonproteinaceous moieties that are known in the art and readily available. The moieties suitable for derivatization of the antibody include but are not limited to water soluble polymers. Non-limiting examples of water soluble polymers include, but are not limited to, polyethylene glycol (PEG), copolymers of ethylene glycol/propylene glycol, carboxymethylcellulose, dextran, polyvinyl alcohol, polyvinyl pyrrolidone, poly-1, 3-dioxolane, poly-1,3,6-trioxane, ethylene/maleic anhydride copolymer, polyaminoacids (either homopolymers or random copolymers), and dextran or poly(n-vinyl pyrrolidone)polyethylene glycol, propylene glycol homopolymers, polypropylene oxide/ethylene oxide co-polymers, polyoxyethylated polyols (e.g., glycerol), polyvinyl alcohol, and mixtures thereof. Polyethylene glycol propionaldehyde may have advantages in manufacturing due to its stability in water. The polymer may be of any molecular weight, and may be branched or unbranched. The number of polymers attached to the antibody may vary, and if more than one polymer are attached, they can be the same or different molecules. In general, the number and/or type of polymers used for derivatization can be determined based on considerations including, but not limited to, the particular properties or functions of the antibody to be improved, whether the antibody derivative will be used in a therapy under defined conditions, etc.

In another embodiment, conjugates of an antibody and nonproteinaceous moiety that may be selectively heated by exposure to radiation are provided. In one embodiment, the nonproteinaceous moiety is a carbon nanotube (Kam et al., *Proc. Natl. Acad. Sci. USA* 102: 11600-11605 (2005)). The radiation may be of any wavelength, and includes, but is not limited to, wavelengths that do not harm ordinary cells, but which heat the nonproteinaceous moiety to a temperature at which cells proximal to the antibody-nonproteinaceous moiety are killed.

### B. Recombinant Methods and Compositions

Antibodies may be produced using recombinant methods and compositions, e.g., as described in U.S. Patent No. 4,816,567. In one embodiment, isolated nucleic acid encoding an anti-NRG1 antibody described herein is provided. Such nucleic acid may encode an amino acid sequence comprising the VL and/or an amino acid sequence comprising the VH of the antibody (e.g., the light and/or heavy chains of the antibody). In a further embodiment, one or more vectors (e.g., expression vectors) comprising such nucleic acid are provided. In a further embodiment, a host cell comprising such nucleic acid is provided. In one such embodiment, a host cell comprises (e.g., has been transformed with): (1) a vector comprising a nucleic acid that encodes an amino acid sequence comprising the VL of the antibody and an amino acid sequence comprising the VH of the antibody, or (2) a first vector comprising a nucleic acid that encodes an amino acid sequence comprising the VL of the antibody and a second vector comprising a nucleic acid that encodes an amino acid sequence

comprising the VH of the antibody. In one embodiment, the host cell is eukaryotic, e.g. a Chinese Hamster Ovary (CHO) cell or lymphoid cell (e.g., Y0, NS0, Sp20 cell). In one embodiment, a method of making an anti-NRG1 antibody is provided, wherein the method comprises culturing a host cell comprising a nucleic acid encoding the antibody, as provided above, under conditions suitable for expression of the antibody, and optionally recovering the antibody from the host cell (or host cell culture medium).

For recombinant production of an anti-NRG1 antibody, nucleic acid encoding an antibody, e.g., as described above, is isolated and inserted into one or more vectors for further cloning and/or expression in a host cell. Such nucleic acid may be readily isolated and sequenced using conventional procedures (e.g., by using oligonucleotide probes that are capable of binding specifically to genes encoding the heavy and light chains of the antibody).

Suitable host cells for cloning or expression of antibody-encoding vectors include prokaryotic or eukaryotic cells described herein. For example, antibodies may be produced in bacteria, in particular when glycosylation and Fc effector function are not needed. For expression of antibody fragments and polypeptides in bacteria, see, e.g., U.S. Patent Nos. 5,648,237, 5,789,199, and 5,840,523. (See also Charlton, *Methods in Molecular Biology, Vol. 248* (B.K.C. Lo, ed., Humana Press, Totowa, NJ, 2003), pp. 245-254, describing expression of antibody fragments in *E. coli*.) After expression, the antibody may be isolated from the bacterial cell paste in a soluble fraction and can be further purified.

In addition to prokaryotes, eukaryotic microbes such as filamentous fungi or yeast are suitable cloning or expression hosts for antibody-encoding vectors, including fungi and yeast strains whose glycosylation pathways have been "humanized," resulting in the production of an antibody with a partially or fully human glycosylation pattern. See Gerngross, *Nat. Biotech.* 22:1409-1414 (2004), and Li et al., *Nat. Biotech.* 24:210-215 (2006).

Suitable host cells for the expression of glycosylated antibody are also derived from multicellular organisms (invertebrates and vertebrates). Examples of invertebrate cells include plant and insect cells. Numerous baculoviral strains have been identified which may be used in conjunction with insect cells, particularly for transfection of *Spodoptera frugiperda* cells.

Plant cell cultures can also be utilized as hosts. See, e.g., US Patent Nos. 5,959,177, 6,040,498, 6,420,548, 7,125,978, and 6,417,429 (describing PLANTIBODIES™ technology for producing antibodies in transgenic plants).

Vertebrate cells may also be used as hosts. For example, mammalian cell lines that are adapted to grow in suspension may be useful. Other examples of useful mammalian host cell lines are monkey kidney CV1 line transformed by SV40 (COS-7); human embryonic kidney line (293 or 293 cells as described, e.g., in Graham et al., *J. Gen Virol.* 36:59 (1977)); baby hamster kidney cells (BHK); mouse sertoli cells (TM4 cells as described, e.g., in Mather, *Biol. Reprod.* 23:243-251 (1980)); monkey kidney

cells (CV1); African green monkey kidney cells (VERO-76); human cervical carcinoma cells (HELA); canine kidney cells (MDCK; buffalo rat liver cells (BRL 3A); human lung cells (W138); human liver cells (Hep G2); mouse mammary tumor (MMT 060562); TRI cells, as described, e.g., in Mather et al., *Annals N.Y. Acad. Sci.* 383:44-68 (1982); MRC 5 cells; and FS4 cells. Other useful mammalian host cell lines include Chinese hamster ovary (CHO) cells, including DHFR<sup>-</sup> CHO cells (Urlaub et al., *Proc. Natl. Acad. Sci. USA* 77:4216 (1980)); and myeloma cell lines such as Y0, NS0 and Sp2/0. For a review of certain mammalian host cell lines suitable for antibody production, see, e.g., Yazaki and Wu, *Methods in Molecular Biology, Vol. 248* (B.K.C. Lo, ed., Humana Press, Totowa, NJ), pp. 255-268 (2003).

### 10 C. Assays

NRG1 antibodies provided herein may be identified, screened for, or characterized for their physical/chemical properties and/or biological activities by various assays known in the art.

In one aspect, an antibody of the invention is tested for its antigen binding activity, e.g., by known methods such as ELISA, Western blot, etc.

15 In another aspect, assays are provided for identifying anti-NRG antibodies having biological activity. Biological activity may include, e.g., inhibition of NRG1 induced receptor tyrosine kinase signaling, inhibition of tumor growth, inhibition of cellular proliferation, etc. Anti-NRG1 antibodies having such biological activity in vivo and/or in vitro are also provided.

In certain embodiments, an anti-NRG1 antibody of the invention is tested for such biological activity. In one embodiment, the ability of an anti-NRG1 antibody to inhibit NRG1 induced receptor tyrosine kinase signaling can be measured by determining the level of NRG1 induced phosphorylation of the tyrosine residues of receptor tyrosine kinases in the presence and absence of a potential anti-NRG1 antibody. Holmes, et al. 1992. The following is an exemplary assay to determine the phosphorylation state of receptor tyrosine kinases. Cells expressing Her2 and Her3 (such as Caov3 cells, or cells engineered to express Her2 and Her3) are stimulated with 10 nM NRG following a 60 minute pre-incubation with either the potential anti-NRG1 antibody or buffer (control). Whole cell lysates are analyzed on a Western blot probed with an anti-phosphotyrosine antibody to determine level of tyrosine phosphorylation. The blots may be scanned to quantitate the anti-phosphotyrosine signal. Anti-NRG1 antibodies would reduce the level of tyrosine phosphorylation as compared to the buffer control. In one embodiment, the anti-NRG1 antibodies inhibits NRG1 induced tyrosine kinase signaling by at least 30%, 40%, 50%, 60% 70%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, or 99% as compared to an untreated control.

In certain embodiments, an antibody of the invention is tested for its ability to inhibit cell growth or proliferation in vitro. Assays for inhibition of cell growth or proliferation are well known in the art. Certain assays for cell proliferation, exemplified by the "cell killing" assays described herein,



measure cell viability. One such assay is the CellTiter-Glo™ Luminescent Cell Viability Assay, which is commercially available from Promega (Madison, WI). That assay determines the number of viable cells in culture based on quantitation of ATP present, which is an indication of metabolically active cells. See Crouch et al (1993) *J. Immunol. Meth.* 160:81-88, US Pat. No. 6602677. The assay may be conducted in 96- or 384-well format, making it amenable to automated high-throughput screening (HTS). See Cree et al (1995) *AntiCancer Drugs* 6:398-404. The assay procedure involves adding a single reagent (CellTiter-Glo® Reagent) directly to cultured cells. This results in cell lysis and generation of a luminescent signal produced by a luciferase reaction. The luminescent signal is proportional to the amount of ATP present, which is directly proportional to the number of viable cells present in culture. Data can be recorded by luminometer or CCD camera imaging device. The luminescence output is expressed as relative light units (RLU).

Another assay for cell proliferation is the “MTT” assay, a colorimetric assay that measures the oxidation of 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide to formazan by mitochondrial reductase. Like the CellTiter-Glo™ assay, this assay indicates the number of metabolically active cells present in a cell culture. See, e.g., Mosmann (1983) *J. Immunol. Meth.* 65:55-63, and Zhang et al. (2005) *Cancer Res.* 65:3877-3882.

In one aspect, an anti-NRG1 antibody is tested for its ability to induce cell death in vitro. Assays for induction of cell death are well known in the art. In some embodiments, such assays measure, e.g., loss of membrane integrity as indicated by uptake of propidium iodide (PI), trypan blue (see Moore et al. (1995) *Cytotechnology*, 17:1-11), or 7AAD. In an exemplary PI uptake assay, cells are cultured in Dulbecco's Modified Eagle Medium (D-MEM):Ham's F-12 (50:50) supplemented with 10% heat-inactivated FBS (Hyclone) and 2 mM L-glutamine. Thus, the assay is performed in the absence of complement and immune effector cells. Cells are seeded at a density of  $3 \times 10^6$  per dish in 100 x 20 mm dishes and allowed to attach overnight. The medium is removed and replaced with fresh medium alone or medium containing various concentrations of the antibody or immunoconjugate. The cells are incubated for a 3-day time period. Following treatment, monolayers are washed with PBS and detached by trypsinization. Cells are then centrifuged at 1200 rpm for 5 minutes at 4 °C, the pellet resuspended in 3 ml cold  $\text{Ca}^{2+}$  binding buffer (10 mM Hepes, pH 7.4, 140 mM NaCl, 2.5 mM  $\text{CaCl}_2$ ) and aliquoted into 35 mm strainer-capped 12 x 75 mm tubes (1 ml per tube, 3 tubes per treatment group) for removal of cell clumps. Tubes then receive PI (10 µg/ml). Samples are analyzed using a FACSCAN™ flow cytometer and FACSCONVERT™ CellQuest software (Becton Dickinson). Antibodies which induce statistically significant levels of cell death as determined by PI uptake are thus identified.

In one aspect, an anti-NRG1 is tested for its ability to induce apoptosis (programmed cell death) in vitro. An exemplary assay for antibodies or immunconjugates that induce apoptosis is an annexin binding assay. In an exemplary annexin binding assay, cells are cultured and seeded in dishes

as discussed in the preceding paragraph. The medium is removed and replaced with fresh medium alone or medium containing 0.001 to 10 µg/ml of the antibody or immunoconjugate. Following a three-day incubation period, monolayers are washed with PBS and detached by trypsinization. Cells are then centrifuged, resuspended in Ca<sup>2+</sup> binding buffer, and aliquoted into tubes as discussed in the preceding paragraph. Tubes then receive labeled annexin (e.g. annexin V-FITC) (1 µg/ml). Samples are analyzed using a FACSCAN™ flow cytometer and FACSCONVERT™ CellQuest software (BD Biosciences). Antibodies that induce statistically significant levels of annexin binding relative to control are thus identified. Another exemplary assay for antibodies or immunconjugates that induce apoptosis is a histone DNA ELISA colorimetric assay for detecting internucleosomal degradation of genomic DNA. Such an assay can be performed using, e.g., the Cell Death Detection ELISA kit (Roche, Palo Alto, CA).

Cells for use in any of the above in vitro assays include cells or cell lines that naturally express NRG1 or that have been engineered to express NRG1. Such cells include tumor cells that overexpress NRG1 relative to normal cells of the same tissue origin. Such cells also include cell lines (including tumor cell lines) that express NRG1 and cell lines that do not normally express NRG1 but have been transfected with nucleic acid encoding NRG1.

In one aspect, an anti-NRG1 antibody is tested for its ability to inhibit cell growth or proliferation in vivo. In certain embodiments, an anti-NRG1 antibody is tested for its ability to inhibit tumor growth in vivo. In vivo model systems, such as xenograft models, can be used for such testing. In an exemplary xenograft system, human tumor cells are introduced into a suitably immunocompromised non-human animal, e.g., an athymic “nude” mouse. An antibody of the invention is administered to the animal. The ability of the antibody to inhibit or decrease tumor growth is measured. In certain embodiments of the above xenograft system, the human tumor cells are tumor cells from a human patient. Such xenograft models are commercially available from Oncotest GmbH (Friedberg, Germany). In certain embodiments, the human tumor cells are cells from a human tumor cell line. In certain embodiments, the human tumor cells are introduced into a suitably immunocompromised non-human animal by subcutaneous injection or by transplantation into a suitable site, such as a mammary fat pad.

In certain embodiments, the anti-NRG1 antibody inhibits cellular proliferation by at least 30%, 40%, 50%, 60% 70%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, or 99% as compared to an untreated control. In other embodiments, the anti-NRG1 antibody inhibits tumor growth by at least 30%, 40%, 50%, 60% 70%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, or 99% as compared to an untreated control.

#### **D. Immunoconjugates**

The invention also provides immunoconjugates comprising an anti-NRG1 antibody herein conjugated to one or more cytotoxic agents, such as chemotherapeutic agents or drugs, growth

inhibitory agents, toxins (e.g., protein toxins, enzymatically active toxins of bacterial, fungal, plant, or animal origin, or fragments thereof), or radioactive isotopes.

In one embodiment, an immunoconjugate is an antibody-drug conjugate (ADC) in which an antibody is conjugated to one or more drugs, including but not limited to a maytansinoid (see U.S. Patent Nos. 5,208,020, 5,416,064 and European Patent EP 0 425 235 B1); an auristatin such as monomethylauristatin drug moieties DE and DF (MMAE and MMAF) (see U.S. Patent Nos. 5,635,483 and 5,780,588, and 7,498,298); a dolastatin; a calicheamicin or derivative thereof (see U.S. Patent Nos. 5,712,374, 5,714,586, 5,739,116, 5,767,285, 5,770,701, 5,770,710, 5,773,001, and 5,877,296; Hinman et al., *Cancer Res.* 53:3336-3342 (1993); and Lode et al., *Cancer Res.* 58:2925-2928 (1998)); an anthracycline such as daunomycin or doxorubicin (see Kratz et al., *Current Med. Chem.* 13:477-523 (2006); Jeffrey et al., *Bioorganic & Med. Chem. Letters* 16:358-362 (2006); Torgov et al., *Bioconj. Chem.* 16:717-721 (2005); Nagy et al., *Proc. Natl. Acad. Sci. USA* 97:829-834 (2000); Dubowchik et al., *Bioorg. & Med. Chem. Letters* 12:1529-1532 (2002); King et al., *J. Med. Chem.* 45:4336-4343 (2002); and U.S. Patent No. 6,630,579); methotrexate; vindesine; a taxane such as docetaxel, paclitaxel, larotaxel, tesetaxel, and ortataxel; a trichothecene; and CC1065.

In another embodiment, an immunoconjugate comprises an antibody as described herein conjugated to an enzymatically active toxin or fragment thereof, including but not limited to diphtheria A chain, nonbinding active fragments of diphtheria toxin, exotoxin A chain (from *Pseudomonas aeruginosa*), ricin A chain, abrin A chain, modeccin A chain, alpha-sarcin, Aleurites fordii proteins, dianthin proteins, *Phytolaca americana* proteins (PAPI, PAPII, and PAP-S), momordica charantia inhibitor, curcin, crotin, sapaonaria officinalis inhibitor, gelonin, mitogellin, restrictocin, phenomycin, enomycin, and the tricothecenes.

In another embodiment, an immunoconjugate comprises an antibody as described herein conjugated to a radioactive atom to form a radioconjugate. A variety of radioactive isotopes are available for the production of radioconjugates. Examples include At<sup>211</sup>, I<sup>131</sup>, I<sup>125</sup>, Y<sup>90</sup>, Re<sup>186</sup>, Re<sup>188</sup>, Sm<sup>153</sup>, Bi<sup>212</sup>, P<sup>32</sup>, Pb<sup>212</sup> and radioactive isotopes of Lu. When the radioconjugate is used for detection, it may comprise a radioactive atom for scintigraphic studies, for example tc99m or I123, or a spin label for nuclear magnetic resonance (NMR) imaging (also known as magnetic resonance imaging, mri), such as iodine-123 again, iodine-131, indium-111, fluorine-19, carbon-13, nitrogen-15, oxygen-17, gadolinium, manganese or iron.

Conjugates of an antibody and cytotoxic agent may be made using a variety of bifunctional protein coupling agents such as N-succinimidyl-3-(2-pyridyldithio) propionate (SPDP), succinimidyl-4-(N-maleimidomethyl) cyclohexane-1-carboxylate (SMCC), iminothiolane (IT), bifunctional derivatives of imidoesters (such as dimethyl adipimidate HCl), active esters (such as disuccinimidyl suberate), aldehydes (such as glutaraldehyde), bis-azido compounds (such as bis (p-azidobenzoyl) hexanediamine), bis-diazonium derivatives (such as bis-(p-diazoniumbenzoyl)-ethylenediamine),

diisocyanates (such as toluene 2,6-diisocyanate), and bis-active fluorine compounds (such as 1,5-difluoro-2,4-dinitrobenzene). For example, a ricin immunotoxin can be prepared as described in Vitetta et al., *Science* 238:1098 (1987). Carbon-14-labeled 1-isothiocyanatobenzyl-3-methyl-diethylene triamine-pentaacetic acid (MX-DTPA) is an exemplary chelating agent for conjugation of  
5 radionucleotide to the antibody. See WO94/11026. The linker may be a “cleavable linker” facilitating release of a cytotoxic drug in the cell. For example, an acid-labile linker, peptidase-sensitive linker, photolabile linker, dimethyl linker or disulfide-containing linker (Chari et al., *Cancer Res.* 52:127-131 (1992); U.S. Patent No. 5,208,020) may be used.

The immunoconjugates or ADCs herein expressly contemplate, but are not limited to such  
10 conjugates prepared with cross-linker reagents including, but not limited to, BMPS, EMCS, GMBS, HBVS, LC-SMCC, MBS, MPBH, SBAP, SIA, SIAB, SMCC, SMPB, SMPH, sulfo-EMCS, sulfo-GMBS, sulfo-KMUS, sulfo-MBS, sulfo-SIAB, sulfo-SMCC, and sulfo-SMPB, and SVSB (succinimidyl-(4-vinylsulfone)benzoate) which are commercially available (e.g., from Pierce Biotechnology, Inc., Rockford, IL., U.S.A).

#### 15 E. Methods and Compositions for Diagnostics and Detection

In certain embodiments, anti-*NRG1* antibodies provided herein are useful for detecting the presence of *NRG1* in a biological sample. The term “detecting” as used herein encompasses quantitative or qualitative detection. In certain embodiments, a biological sample comprises a cell or  
tissue, such as lung tissue or breast tissue.

20 In one embodiment, an anti-*NRG1* antibody for use in a method of diagnosis or detection is provided. In a further aspect, a method of detecting the presence of *NRG1* in a biological sample is provided. In certain embodiments, the method comprises contacting the biological sample with an anti-*NRG1* antibody as described herein under conditions permissive for binding of the anti-*NRG1* antibody to *NRG1*, and detecting whether a complex is formed between the anti-*NRG1* antibody and  
25 *NRG1*. Such method may be an *in vitro* or *in vivo* method. In one embodiment, an anti-*NRG1* antibody is used to select subjects eligible for therapy with an anti *NRG1* antibody, e.g. where *NRG1* is a biomarker for selection of patients.

In one embodiment, a patient is selected for treatment with an anti-*NRG1* antibody if the patient has a cancer which is or is likely to become resistant to therapy. One aspect of the invention  
30 provides for an assay which determines if a patient has a cancer which is or is likely to become resistant to therapy. In one embodiment, the assay comprises assaying tumor cells taken from the patient for *NRG1* expression, wherein expression of *NRG1* is indicative that the patient has a cancer which is or is likely to become resistant to therapy. In one embodiment, the patient is selected as one who has a cancer which or is likely to become resistant to therapy if the level of *NRG1* expression in  
35 the tumor is less than the level of *NRG1* expression in the TRICs of the tumor.

In one embodiment, a patient is selected for treatment with an anti-*NRG1* antibody if the patient has a cancer which is likely to relapse after treatment with a therapeutic agent. One aspect of the invention provides for an assay which determines if a patient has a cancer which is likely to relapse after treatment with a therapeutic agent. In one embodiment, the assay comprises assaying tumor cells taken from the patient for *NRG1* expression, wherein expression of *NRG1* is indicative that the patient has a cancer which is likely to relapse after treatment with a therapeutic agent. In one embodiment, the patient is selected as one who has a cancer which is likely to relapse after treatment with a therapeutic agent if the level of *NRG1* expression in the tumor is less than the level of *NRG1* expression in the TRICs of the tumor.

In certain embodiments, a diagnostic assay comprises determining the expression of neuregulin in a tumor cell, using, for example, immunohistochemistry, in situ hybridization, or RT-PCR. In other embodiments, a diagnostic assay comprises determining expression levels of neuregulin in a tumor cell using, for example, quantitative RT-PCR. In some embodiments, a diagnostic assay further comprises determining expression levels of neuregulin compared to a control tissue such as, for example, non-cancerous adjacent tissue.

In certain embodiments, labeled anti-*NRG1* antibodies are provided. Labels include, but are not limited to, labels or moieties that are detected directly (such as fluorescent, chromophoric, electron-dense, chemiluminescent, and radioactive labels), as well as moieties, such as enzymes or ligands, that are detected indirectly, e.g., through an enzymatic reaction or molecular interaction. Exemplary labels include, but are not limited to, the radioisotopes  $^{32}\text{P}$ ,  $^{14}\text{C}$ ,  $^{125}\text{I}$ ,  $^3\text{H}$ , and  $^{131}\text{I}$ , fluorophores such as rare earth chelates or fluorescein and its derivatives, rhodamine and its derivatives, dansyl, umbelliferone, luciferases, e.g., firefly luciferase and bacterial luciferase (U.S. Patent No. 4,737,456), luciferin, 2,3-dihydrophthalazinediones, horseradish peroxidase (HRP), alkaline phosphatase,  $\beta$ -galactosidase, glucoamylase, lysozyme, saccharide oxidases, e.g., glucose oxidase, galactose oxidase, and glucose-6-phosphate dehydrogenase, heterocyclic oxidases such as uricase and xanthine oxidase, coupled with an enzyme that employs hydrogen peroxide to oxidize a dye precursor such as HRP, lactoperoxidase, or microperoxidase, biotin/avidin, spin labels, bacteriophage labels, stable free radicals, and the like.

#### **F. Pharmaceutical Formulations**

Pharmaceutical formulations of an anti-*NRG1* antibody as described herein are prepared by mixing such antibody having the desired degree of purity with one or more optional pharmaceutically acceptable carriers (Remington's Pharmaceutical Sciences 16th edition, Osol, A. Ed. (1980)), in the form of lyophilized formulations or aqueous solutions. Pharmaceutically acceptable carriers are generally nontoxic to recipients at the dosages and concentrations employed, and include, but are not limited to: buffers such as phosphate, citrate, and other organic acids; antioxidants including ascorbic

acid and methionine; preservatives (such as octadecyldimethylbenzyl ammonium chloride; hexamethonium chloride; benzalkonium chloride; benzethonium chloride; phenol, butyl or benzyl alcohol; alkyl parabens such as methyl or propyl paraben; catechol; resorcinol; cyclohexanol; 3-pentanol; and m-cresol); low molecular weight (less than about 10 residues) polypeptides; proteins, such as serum albumin, gelatin, or immunoglobulins; hydrophilic polymers such as polyvinylpyrrolidone; amino acids such as glycine, glutamine, asparagine, histidine, arginine, or lysine; monosaccharides, disaccharides, and other carbohydrates including glucose, mannose, or dextrans; chelating agents such as EDTA; sugars such as sucrose, mannitol, trehalose or sorbitol; salt-forming counter-ions such as sodium; metal complexes (e.g. Zn-protein complexes); and/or non-ionic surfactants such as polyethylene glycol (PEG). Exemplary pharmaceutically acceptable carriers herein further include interstitial drug dispersion agents such as soluble neutral-active hyaluronidase glycoproteins (sHASEGP), for example, human soluble PH-20 hyaluronidase glycoproteins, such as rHuPH20 (HYLENEX®, Baxter International, Inc.). Certain exemplary sHASEGPs and methods of use, including rHuPH20, are described in US Patent Publication Nos. 2005/0260186 and 2006/0104968. In one aspect, a sHASEGP is combined with one or more additional glycosaminoglycanases such as chondroitinases.

Exemplary lyophilized antibody formulations are described in US Patent No. 6,267,958. Aqueous antibody formulations include those described in US Patent No. 6,171,586 and WO2006/044908, the latter formulations including a histidine-acetate buffer.

The formulation herein may also contain more than one active ingredient as necessary for the particular indication being treated, preferably those with complementary activities that do not adversely affect each other. For example, it may be desirable to further provide paclitaxal, carboplatin, and cisplatin or a combination of two or all three of paclitaxal, carboplatin, and cisplatin. In another example, it may be desirable to further provide an anti-HER antibody. Such active ingredients are suitably present in combination in amounts that are effective for the purpose intended.

Active ingredients may be entrapped in microcapsules prepared, for example, by coacervation techniques or by interfacial polymerization, for example, hydroxymethylcellulose or gelatin-microcapsules and poly-(methylmethacrylate) microcapsules, respectively, in colloidal drug delivery systems (for example, liposomes, albumin microspheres, microemulsions, nano-particles and nanocapsules) or in macroemulsions. Such techniques are disclosed in Remington's Pharmaceutical Sciences 16th edition, Osol, A. Ed. (1980).

Sustained-release preparations may be prepared. Suitable examples of sustained-release preparations include semipermeable matrices of solid hydrophobic polymers containing the antibody or immunoconjugate, which matrices are in the form of shaped articles, e.g. films, or microcapsules.

The formulations to be used for in vivo administration are generally sterile. Sterility may be readily accomplished, e.g., by filtration through sterile filtration membranes.

### G. Therapeutic Methods and Compositions

The anti-NRG1 antibodies provided herein may be used in therapeutic methods.

One aspect of the invention provides for a method of treating cancer. One aspect of the invention provides for a method of preventing resistance to treatment with a therapeutic agent in a patient by administering to the patient an anti-NRG1 antibody. Another aspect of the invention provides for preventing recurrence of cancer after treatment with a therapeutic agent by administering to the patient an anti-NRG1 antibody.

Specific aspects include a method of preventing tumor recurrence or increasing time to tumor recurrence comprising administering to the patient an effective amount of an anti-NRG1 antibody. In one embodiment, the patient has been treated with a therapeutic agent, such as a chemotherapeutic agent or an antigen binding agent, such as an antibody. In one embodiment, the cancer comprises tumor re-initiating cells. In one embodiment, the cancer is non-small cell lung cancer. In one embodiment, the cancer is breast cancer. In one embodiment, the patient was treated with a chemotherapeutic agent. In one embodiment, the chemotherapeutic agent is an agent used as a standard of care treatment for cancer. In one embodiment, the chemotherapeutic agent is gemcitabine, paclitaxal or cisplatin or a combination of paclitaxal and cisplatin. In one embodiment, the chemotherapeutic agent is not a tyrosine kinase inhibitor. In another embodiment, the chemotherapeutic agent is a tyrosine kinase inhibitor. In one embodiment, the chemotherapeutic agent is an inhibitor EGFR, HER2, HER3 and/or HER4. Another embodiment comprises additionally administering a chemotherapeutic agent to the patient in combination with an anti-NRG1 antibody.

In another embodiment, the patient was treated with an antibody. In one embodiment, the antibody is an anti-tyrosine kinase antibody. In one embodiment, the antibody is an EGFR, HER2, HER3 and/or HER4 antibody. Another embodiment comprises additionally administering an antibody to the patient in combination with an anti-NRG1 antibody.

In certain embodiments, the time to tumor recurrence is at least 1.25, 1.50, 1.75, 2.0, 2.5, 5.0, 10, 20, or 50 times greater than the time to tumor recurrence in the absence of the anti-NRG1 antibody.

Another aspect provides for a method of treating a patient with a resistant cancer comprising administering to a patient an effective amount of an anti-NRG1 antibody. In one embodiment, the cancer comprises tumor re-initiating cells. In one embodiment, the cancer is non-small cell lung cancer. In one embodiment, the cancer is breast cancer. In one embodiment, the cancer is resistant to treatment with chemotherapeutic agents. In one embodiment, the cancer is resistant to treatment with gemcitabine, paclitaxal, carboplatin, and cisplatin or a combination of two or all three of paclitaxal, carboplatin, and cisplatin. In one embodiment, the cancer is resistant to treatment with a tyrosine kinase inhibitor. In one embodiment, the cancer is resistant to treatment with an EGFR, HER2, HER3 and/or HER4 inhibitor. Another embodiment comprises additionally administering a chemotherapeutic

agent to the patient. In one embodiment, the chemotherapeutic agent is gemcitabine, paclitaxal, carboplatin, and cisplatin or a combination of two or all three of paclitaxal, carboplatin, and cisplatin. In one embodiment, the chemotherapeutic agent is an EGFR, HER2, HER3 and/or HER4 inhibitor.

In one embodiment, the cancer is resistant to treatment with a therapeutic antibody. In one  
5 embodiment, the cancer is resistant to treatment with an EGFR, HER2, HER3, or HER4 antibody. Another embodiment comprises additionally administering an antibody to the patient. In one embodiment, the antibody is trastuzumab or pertuzumab.

Another aspect provides for a method of preventing resistance in a cancer comprising  
10 administering to a patient who has cancer an effective amount of an anti-NRG1 antibody and a therapeutic agent. In one embodiment, the cancer comprises tumor re-initiating cells. In one embodiment, the cancer is non-small cell lung cancer. In one embodiment, the cancer is breast cancer. In one embodiment, the cancer is resistant to treatment with chemotherapeutic agents. In one embodiment, the cancer resistant to treatment with gemcitabine, paclitaxal, carboplatin, and cisplatin or a combination of two or all three of paclitaxal, carboplatin, and cisplatin. In one embodiment, the  
15 chemotherapeutic agent is not a tyrosine kinase inhibitor. In another embodiment, the chemotherapeutic agent is a tyrosine kinase inhibitor. In one embodiment, the chemotherapeutic agent is an inhibitor EGFR, HER2, HER3 and/or HER4. Another embodiment comprises additionally administering a chemotherapeutic agent to the patient. In one embodiment, the chemotherapeutic agent is gemcitabine, paclitaxal, carboplatin, and cisplatin or a combination of two or all three of paclitaxal,  
20 carboplatin, and cisplatin.

In one embodiment, the cancer is resistant to treatment with a therapeutic antibody. In one  
embodiment, the cancer is resistant to treatment with an EGFR, HER2, HER3, or HER4 antibody. Another embodiment comprises additionally administering an antibody to the patient. In one  
embodiment, the antibody is trastuzumab or pertuzumab.

25 In certain embodiments, an anti-NRG1 antibody for use in a method of treatment is provided. In certain embodiments, the invention provides an anti-NRG1 antibody for use in a method of treating an individual having cancer comprising administering to the individual an effective amount of an anti-NRG1 antibody. In one such embodiment, the method further comprises administering to the individual an effective amount of at least one additional therapeutic agent, e.g., as described below. In  
30 further embodiments, the invention provides an anti-NRG1 antibody for use in treating a patient who has experienced a recurrence of cancer. In certain embodiments, the invention provides an anti-NRG1 antibody for use in a method of preventing resistance to treatment with a therapeutic agent in an individual comprising administering to the individual an effective of the anti-NRG1 antibody to prevent resistance to the therapeutic agent.

35 In a further aspect, the invention provides for the use of an anti-NRG1 antibody in the manufacture or preparation of a medicament. In one embodiment, the medicament is for treatment of



cancer. In a further embodiment, the medicament is for use in a method of treating cancer comprising administering to an individual having cancer an effective amount of the medicament. In one such embodiment, the method further comprises administering to the individual an effective amount of at least one additional therapeutic agent, e.g., as described below. In a further embodiment, the medicament is for preventing resistance to treatment with a therapeutic agent in patient. In a further embodiment, the medicament is for preventing recurrence of cancer in a patient.

In a further aspect, the invention provides pharmaceutical formulations comprising any anti-NRG1 antibody provided herein, e.g., for use in any of the above therapeutic methods. In one embodiment, a pharmaceutical formulation comprises any of the anti-NRG1 antibody provided herein and a pharmaceutically acceptable carrier. In another embodiment, a pharmaceutical formulation comprises an anti-NRG1 antibody provided herein and at least one additional therapeutic agent, e.g., as described below.

Antibodies of the invention can be used either alone or in combination with other agents in a therapy. For instance, an antibody of the invention may be co-administered with at least one additional therapeutic agent. Examples of additional therapeutic agents are described below.

Such combination therapies noted above encompass combined administration (where two or more therapeutic agents are included in the same or separate formulations), and separate administration, in which case, administration of the antibody of the invention can occur prior to, simultaneously, and/or following, administration of the additional therapeutic agent and/or adjuvant.

Antibodies of the invention can also be used in combination with radiation therapy.

An antibody of the invention (and any additional therapeutic agent) can be administered by any suitable means, including parenteral, intrapulmonary, and intranasal, and, if desired for local treatment, intralesional administration. Parenteral infusions include intramuscular, intravenous, intraarterial, intraperitoneal, or subcutaneous administration. Dosing can be by any suitable route, e.g. by injections, such as intravenous or subcutaneous injections, depending in part on whether the administration is brief or chronic. Various dosing schedules including but not limited to single or multiple administrations over various time-points, bolus administration, and pulse infusion are contemplated herein.

Antibodies of the invention would be formulated, dosed, and administered in a fashion consistent with good medical practice. Factors for consideration in this context include the particular disorder being treated, the particular mammal being treated, the clinical condition of the individual patient, the cause of the disorder, the site of delivery of the agent, the method of administration, the scheduling of administration, and other factors known to medical practitioners. The antibody need not be, but is optionally formulated with one or more agents currently used to prevent or treat the disorder in question. The effective amount of such other agents depends on the amount of antibody present in the formulation, the type of disorder or treatment, and other factors discussed above. These are

generally used in the same dosages and with administration routes as described herein, or about from 1 to 99% of the dosages described herein, or in any dosage and by any route that is empirically/clinically determined to be appropriate.

For the prevention or treatment of disease, the appropriate dosage of an antibody of the invention (when used alone or in combination with one or more other additional therapeutic agents) will depend on the type of disease to be treated, the type of antibody, the severity and course of the disease, whether the antibody is administered for preventive or therapeutic purposes, previous therapy, the patient's clinical history and response to the antibody, and the discretion of the attending physician. The antibody is suitably administered to the patient at one time or over a series of treatments.

Depending on the type and severity of the disease, about 1  $\mu\text{g}/\text{kg}$  to 15  $\text{mg}/\text{kg}$  (e.g. 0.1  $\text{mg}/\text{kg}$ -10  $\text{mg}/\text{kg}$ ) of antibody can be an initial candidate dosage for administration to the patient, whether, for example, by one or more separate administrations, or by continuous infusion. One typical daily dosage might range from about 1  $\mu\text{g}/\text{kg}$  to 100  $\text{mg}/\text{kg}$  or more, depending on the factors mentioned above. For repeated administrations over several days or longer, depending on the condition, the treatment would generally be sustained until a desired suppression of disease symptoms occurs. One exemplary dosage of the antibody would be in the range from about 0.05  $\text{mg}/\text{kg}$  to about 10  $\text{mg}/\text{kg}$ . Thus, one or more doses of about 0.5  $\text{mg}/\text{kg}$ , 2.0  $\text{mg}/\text{kg}$ , 4.0  $\text{mg}/\text{kg}$  or 10  $\text{mg}/\text{kg}$  (or any combination thereof) may be administered to the patient. Such doses may be administered intermittently, e.g. every week or every three weeks (e.g. such that the patient receives from about two to about twenty, or e.g. about six doses of the antibody). An initial higher loading dose, followed by one or more lower doses may be administered. The progress of this therapy is easily monitored by conventional techniques and assays.

It is understood that any of the above formulations or therapeutic methods may be carried out using an immunoconjugate of the invention in place of or in addition to an anti-NRG1 antibody.

#### Additional Therapeutic Agents

In certain embodiments, an additional therapeutic agent is an agent that inhibits a tyrosine kinase receptor pathway. In one embodiment, the additional therapeutic agent inhibits a HER pathway. In one embodiment the additional therapeutic agent is an inhibitor of EGFR, HER2, HER3, and/or HER4.

As used herein, the term "EGFR inhibitor" refers to compounds that bind to or otherwise interact directly with EGFR and prevent or reduce its signaling activity, and is alternatively referred to as an "EGFR antagonist." Examples of such agents include antibodies and small molecules that bind to EGFR. Examples of antibodies which bind to EGFR include MAb 579 (ATCC CRL HB 8506), MAb 455 (ATCC CRL HB8507), MAb 225 (ATCC CRL 8508), MAb 528 (ATCC CRL 8509) (see, US Patent No. 4,943, 533, Mendelsohn *et al.*) and variants thereof, such as chimerized 225 (C225 or Cetuximab; ERBUTIX<sup>®</sup>) and reshaped human 225 (H225) (see, WO 96/40210, Imclone Systems Inc.);

IMC-11F8, a fully human, EGFR-targeted antibody (Imclone); antibodies that bind type II mutant EGFR (US Patent No. 5,212,290); humanized and chimeric antibodies that bind EGFR as described in US Patent No. 5,891,996; and human antibodies that bind EGFR, such as ABX-EGF or Panitumumab (see WO98/50433, Abgenix/Amgen); EMD 55900 (Stragliotto *et al. Eur. J. Cancer* 32A:636-640 (1996)); EMD7200 (matuzumab) a humanized EGFR antibody directed against EGFR that competes with both EGF and TGF-alpha for EGFR binding (EMD/Merck); human EGFR antibody, HuMax-EGFR (GenMab); fully human antibodies known as E1.1, E2.4, E2.5, E6.2, E6.4, E2.11, E6.3 and E7.6.3 and described in US 6,235,883; MDX-447 (Medarex Inc); and mAb 806 or humanized mAb 806 (Johns *et al., J. Biol. Chem.* 279(29):30375-30384 (2004)). The anti-EGFR antibody may be conjugated with a cytotoxic agent, thus generating an immunoconjugate (see, *e.g.*, EP659,439A2, Merck Patent GmbH). EGFR antagonists include small molecules such as compounds described in US Patent Nos: 5,616,582, 5,457,105, 5,475,001, 5,654,307, 5,679,683, 6,084,095, 6,265,410, 6,455,534, 6,521,620, 6,596,726, 6,713,484, 5,770,599, 6,140,332, 5,866,572, 6,399,602, 6,344,459, 6,602,863, 6,391,874, 6,344,455, 5,760,041, 6,002,008, and 5,747,498, as well as the following PCT publications: WO98/14451, WO98/50038, WO99/09016, and WO99/24037. Particular small molecule EGFR antagonists include OSI-774 (CP-358774, erlotinib, TARCEVA<sup>®</sup> Genentech/OSI Pharmaceuticals); PD 183805 (CI 1033, 2-propenamide, N-[4-[(3-chloro-4-fluorophenyl)amino]-7-[3-(4-morpholinyl)propoxy]-6-quinazoliny]-, dihydrochloride, Pfizer Inc.); ZD1839, gefitinib (IRESSA<sup>™</sup>) 4-(3'-Chloro-4'-fluoroanilino)-7-methoxy-6-(3-morpholinopropoxy)quinazoline, AstraZeneca); ZM 105180 ((6-amino-4-(3-methylphenyl-amino)-quinazoline, Zeneca); BIBX-1382 (N8-(3-chloro-4-fluoro-phenyl)-N2-(1-methyl-piperidin-4-yl)-pyrimido[5,4-d]pyrimidine-2,8-diamine, Boehringer Ingelheim); PKI-166 ((R)-4-[4-[(1-phenylethyl)amino]-1H-pyrrolo[2,3-d]pyrimidin-6-yl]-phenol); (R)-6-(4-hydroxyphenyl)-4-[(1-phenylethyl)amino]-7H-pyrrolo[2,3-d]pyrimidine); CL-387785 (N-[4-[(3-bromophenyl)amino]-6-quinazoliny]-2-butyramide); EKB-569 (N-[4-[(3-chloro-4-fluorophenyl)amino]-3-cyano-7-ethoxy-6-quinoliny]-4-(dimethylamino)-2-butenamide) (Wyeth); AG1478 (Pfizer); AG1571 (SU 5271; Pfizer); dual EGFR/HER2 tyrosine kinase inhibitors such as lapatinib (TYKERB<sup>®</sup>, GSK572016 or N-[3-chloro-4-[(3 fluorophenyl) methoxy]phenyl] 6[5[[[2methylsulfonyl] ethyl] amino]methyl]-2-furanyl]-4-quinazolinamine; Glaxo-SmithKline).

As used herein, the term "HER2 inhibitor" refers to compounds that bind to or otherwise interact directly with HER2 and prevent or reduce its signaling activity, and is alternatively referred to as an "HER2 antagonist." Examples of such agents include antibodies and small molecules that bind to HER2. Particular HER2 antibodies include pertuzumab and trastuzumab. As used herein, the term "HER3 inhibitor" refers to compounds that bind to or otherwise interact directly with HER3 and prevent or reduce its signaling activity, and is alternatively referred to as an "HER3 antagonist." Examples of such agents include antibodies and small molecules that bind to HER3. As used herein, the term "HER4 inhibitor" refers to compounds that bind to or otherwise interact directly with HER4

and prevent or reduce its signaling activity, and is alternatively referred to as an “HER4 antagonist.” Examples of such agents include antibodies and small molecules that bind to HER4.

Patent publications related to HER antibodies include: U.S. Pat. No. 5,677,171, U.S. Pat. No. 5,720,937, U.S. Pat. No. 5,720,954, U.S. Pat. No. 5,725,856, U.S. Pat. No. 5,770,195, U.S. Pat. No. 5,772,997, U.S. Pat. No. 6,165,464, U.S. Pat. No. 6,387,371, U.S. Pat. No. 6,399,063, US2002/0192211A1, U.S. Pat. No. 6,015,567, U.S. Pat. No. 6,333,169, U.S. Pat. No. 4,968,603, U.S. Pat. No. 5,821,337, U.S. Pat. No. 6,054,297, U.S. Pat. No. 6,407,213, U.S. Pat. No. 6,719,971, U.S. Pat. No. 6,800,738, US2004/0236078A1, U.S. Pat. No. 5,648,237, U.S. Pat. No. 6,267,958, U.S. Pat. No. 6,685,940, U.S. Pat. NO. 6,821,515, WO98/17797, U.S. Pat. No. 6,333,398, U.S. Pat. No. 6,797,814, U.S. Pat. No. 6,339,142, U.S. Pat. No. 6,417,335, U.S. Pat. No. 6,489,447, WO99/31140, US2003/0147884A1, US2003/0170234A1, US2005/0002928A1, U.S. Pat. No. 6,573,043, US2003/0152987A1, WO99/48527, US2002/0141993A1, WO01/00245, US2003/0086924, US2004/0013667A1, WO00/69460, WO01/00238, WO01/15730, U.S. Pat. No. 6,627,19681, U.S. Pat. No. 6,632,979B1, WO01/00244, US2002/0090662A1, WO01/89566, US2002/0064785, US2003/0134344, WO 04/24866, US2004/0082047, US2003/0175845A1, WO03/087131, US2003/0228663, WO2004/008099A2, US2004/0106161, WO2004/048525, US2004/0258685A1, U.S. Pat. No. 5,985,553, U.S. Pat. No. 5,747,261, U.S. Pat. No. 4,935,341, U.S. Pat. No. 5,401,638, U.S. Pat. No. 5,604,107, WO 87/07646, WO 89/10412, WO 91/05264, EP 412,116 B1, EP 494,135 B1, U.S. Pat. No. 5,824,311, EP 444,181 B1, EP 1,006,194 A2, US 2002/0155527A1, WO 91/02062, U.S. Pat. No. 5,571,894, U.S. Pat. No. 5,939,531, EP 502,812 B1, WO 93/03741, EP 554,441 B1, EP 656,367 A1, U.S. Pat. No. 5,288,477, U.S. Pat. No. 5,514,554, U.S. Pat. No. 5,587,458, WO 93/12220, WO 93/16185, U.S. Pat. No. 5,877,305, WO 93/21319, WO 93/21232, U.S. Pat. No. 5,856,089, WO 94/22478, U.S. Pat. No. 5,910,486, U.S. Pat. No. 6,028,059, WO 96/07321, U.S. Pat. No. 5,804,396, U.S. Pat. No. 5,846,749, EP 711,565, WO 96/16673, U.S. Pat. No. 5,783,404, U.S. Pat. No. 5,977,322, U.S. Pat. No. 6,512,097, WO 97/00271, U.S. Pat. No. 6,270,765, U.S. Pat. No. 6,395,272, U.S. Pat. No. 5,837,243, WO 96/40789, U.S. Pat. No. 5,783,186, U.S. Pat. No. 6,458,356, WO 97/20858, WO 97/38731, U.S. Pat. No. 6,214,388, U.S. Pat. No. 5,925,519, WO 98/02463, U.S. Pat. No. 5,922,845, WO 98/18489, WO 98/33914, U.S. Pat. No. 5,994,071, WO 98/45479, U.S. Pat. No. 6,358,682 B1, US 2003/0059790, WO 99/55367, WO 01/20033, US 2002/0076695 A1, WO 00/78347, WO 01/09187, WO 01/21192, WO 01/32155, WO 01/53354, WO 01/56604, WO 01/76630, WO02/05791, WO 02/11677, U.S. Pat. No. 6,582,919, US2002/0192652A1, US 2003/0211530A1, WO 02/44413, US 2002/0142328, U.S. Pat. No. 6,602,670 B2, WO 02/45653, WO 02/055106, US 2003/0152572, US 2003/0165840, WO 02/087619, WO 03/006509, WO03/012072, WO 03/028638, US 2003/0068318, WO 03/041736, EP 1,357,132, US 2003/0202973, US 2004/0138160, U.S. Pat. No. 5,705,157, U.S. Pat. No. 6,123,939, EP 616,812 B1, US 2003/0103973, US 2003/0108545, U.S. Pat. No. 6,403,630 B1, WO 00/61145, WO 00/61185, U.S. Pat. No. 6,333,348 B1, WO 01/05425, WO 01/64246, US

2003/0022918, US 2002/0051785 A1, U.S. Pat. No. 6,767,541, WO 01/76586, US 2003/0144252, WO 01/87336, US 2002/0031515 A1, WO 01/87334, WO 02/05791, WO 02/09754, US 2003/0157097, US 2002/0076408, WO 02/055106, WO 02/070008, WO 02/089842, WO 03/86467, and US 2010/0255010.

5           In certain embodiments, an additional therapeutic agent is a chemotherapeutic agent. A "chemotherapeutic agent" refers to a chemical compound useful in the treatment of cancer. Examples of chemotherapeutic agents include alkylating agents such as thiotepa and cyclophosphamide (CYTOXAN®); alkyl sulfonates such as busulfan, improsulfan and piposulfan; aziridines such as benzodopa, carboquone, meturedopa, and uredopa; ethylenimines and methylamelamines including  
10   altretamine, triethylenemelamine, triethylenephosphoramidate, triethylenethiophosphoramidate and trimethylomelamine; acetogenins (especially bullatacin and bullatacinone); delta-9-tetrahydrocannabinol (dronabinol, MARINOL®); beta-lapachone; lapachol; colchicines; betulinic acid; a camptothecin (including the synthetic analogue topotecan (HYCAMTIN®), CPT-11 (irinotecan, CAMPTOSAR®), acetylcamptothecin, scopolectin, and 9-aminocamptothecin); bryostatin;  
15   callystatin; CC-1065 (including its adozelesin, carzelesin and bizelesin synthetic analogues); podophyllotoxin; podophyllinic acid; teniposide; cryptophycins (particularly cryptophycin 1 and cryptophycin 8); dolastatin; duocarmycin (including the synthetic analogues, KW-2189 and CB1-TM1); eleutherobin; pancratistatin; a sarcodictyin; spongistatin; nitrogen mustards such as chlorambucil, chlornaphazine, chlorophosphamide, estramustine, ifosfamide, mechlorethamine, mechlorethamine oxide hydrochloride, melphalan, novembichin, phenesterine, prednimustine, trofosfamide, uracil mustard; nitrosoureas such as carmustine, chlorozotocin, fotemustine, lomustine, nimustine, and ranimustine; antibiotics such as the enediyne antibiotics (e. g., calicheamicin, especially calicheamicin gammaII and calicheamicin omegaII (see, e.g., Nicolaou *et al.*, *Angew. Chem Intl. Ed. Engl.*, 33: 183-186 (1994)); CDP323, an oral alpha-4 integrin inhibitor; dynemicin, including  
25   dynemicin A; an esperamicin; as well as neocarzinostatin chromophore and related chromoprotein enediyne antibiotic chromophores), aclacinomysins, actinomycin, authramycin, azaserine, bleomycins, cactinomycin, carabycin, carminomycin, carzinophilin, chromomycins, dactinomycin, daunorubicin, detorubicin, 6-diazo-5-oxo-L-norleucine, doxorubicin (including ADRIAMYCIN®, morpholino-doxorubicin, cyanomorpholino-doxorubicin, 2-pyrrolino-doxorubicin, doxorubicin HCl liposome  
30   injection (DOXIL®), liposomal doxorubicin TLC D-99 (MYOCET®), pegylated liposomal doxorubicin (CAELYX®), and deoxydoxorubicin), epirubicin, esorubicin, idarubicin, marcellomycin, mitomycins such as mitomycin C, mycophenolic acid, nogalamycin, olivomycins, peplomycin, porfiromycin, puromycin, quelamycin, rodorubicin, streptonigrin, streptozocin, tubercidin, ubenimex, zinostatin, zorubicin; anti-metabolites such as methotrexate, gemcitabine (GEMZAR®), tegafur  
35   (UFTORAL®), capecitabine (XELODA®), an epothilone, and 5-fluorouracil (5-FU); folic acid analogues such as denopterin, methotrexate, pteropterin, trimetrexate; purine analogs such as

fludarabine, 6-mercaptopurine, thiamiprine, thioguanine; pyrimidine analogs such as ancitabine, azacitidine, 6-azauridine, carmofur, cytarabine, dideoxyuridine, doxifluridine, enocitabine, floxuridine; androgens such as calusterone, dromostanolone propionate, epitio stanol, mepitio stanane, testolactone; anti-adrenals such as aminoglutethimide, mitotane, trilostane; folic acid replenisher such as froinic acid; aceglatone; aldophosphamide glycoside; aminolevulinic acid; eniluracil; amsacrine; bestrabucil; bisantrene; edatraxate; defofamine; demecolcine; diaziquone; elfornithine; elliptinium acetate; an epothilone; etoglucid; gallium nitrate; hydroxyurea; lentinan; lonidainine; maytansinoids such as maytansine and ansamitocins; mitoguazone; mitoxantrone; mopidanmol; nitraerine; pentostatin; phenamet; pirarubicin; losoxantrone; 2-ethylhydrazide; procarbazine; PSK® polysaccharide complex (JHS Natural Products, Eugene, OR); razoxane; rhizoxin; sizofiran; spirogermanium; tenuazonic acid; triaziquone; 2,2',2'-trichlorotriethylamine; trichothecenes (especially T-2 toxin, verracurin A, roridin A and anguidine); urethan; vindesine (ELDISINE®, FILDESIN®); dacarbazine; mannomustine; mitobronitol; mitolactol; pipobroman; gacytosine; arabinoside ("Ara-C"); thiotepa; taxoid, *e.g.*, paclitaxel (TAXOL®), albumin-engineered nanoparticle formulation of paclitaxel (ABRAXANE™), and docetaxel (TAXOTERE®); chloranbucil; 6-thioguanine; mercaptopurine; methotrexate; platinum agents such as cisplatin, oxaliplatin (*e.g.*, ELOXATIN®), and carboplatin; vincas, which prevent tubulin polymerization from forming microtubules, including vinblastine (VELBAN®), vincristine (ONCOVIN®), vindesine (ELDISINE®, FILDESIN®), and vinorelbine (NAVELBINE®); etoposide (VP-16); ifosfamide; mitoxantrone; leucovorin; novantrone; edatrexate; daunomycin; aminopterin; ibandronate; topoisomerase inhibitor RFS 2000; difluoromethylornithine (DMFO); retinoids such as retinoic acid, including bexarotene (TARGRETIN®); bisphosphonates such as clodronate (for example, BONEFOS® or OSTAC®), etidronate (DIDROCAL®), NE-58095, zoledronic acid/zoledronate (ZOMETA®), alendronate (FOSAMAX®), pamidronate (AREDIA®), tiludronate (SKELID®), or risedronate (ACTONEL®); troxacitabine (a 1,3-dioxolane nucleoside cytosine analog); antisense oligonucleotides, particularly those that inhibit expression of genes in signaling pathways implicated in aberrant cell proliferation, such as, for example, PKC-alpha, Raf, H-Ras, and epidermal growth factor receptor (EGF-R); vaccines such as THERATOPE® vaccine and gene therapy vaccines, for example, ALLOVECTIN® vaccine, LEUVECTIN® vaccine, and VAXID® vaccine; topoisomerase 1 inhibitor (*e.g.*, LURTOTECAN®); rmRH (*e.g.*, ABARELIX®); BAY439006 (sorafenib; Bayer); SU-11248 (sunitinib, SUTENT®, Pfizer); perifosine, COX-2 inhibitor (*e.g.* celecoxib or etoricoxib), proteasome inhibitor (*e.g.* PS341); bortezomib (VELCADE®); CCI-779; tipifarnib (R11577); orafenib, ABT510; Bcl-2 inhibitor such as oblimersen sodium (GENASENSE®); pixantrone; EGFR inhibitors (see definition below); tyrosine kinase inhibitors (see definition below); serine-threonine kinase inhibitors such as rapamycin (sirolimus, RAPAMUNE®); farnesyltransferase inhibitors such as lonafarnib (SCH 6636, SARASAR™); and pharmaceutically acceptable salts, acids or derivatives of any of the above; as well as combinations of two or more of the above such as CHOP,

an abbreviation for a combined therapy of cyclophosphamide, doxorubicin, vincristine, and prednisolone; and FOLFOX, an abbreviation for a treatment regimen with oxaliplatin (ELOXATIN™) combined with 5-FU and leucovorin.

Chemotherapeutic agents as defined herein include “anti-hormonal agents” or “endocrine therapeutics” which act to regulate, reduce, block, or inhibit the effects of hormones that can promote the growth of cancer. They may be hormones themselves, including, but not limited to: anti-estrogens with mixed agonist/antagonist profile, including, tamoxifen (NOLVADEX®), 4-hydroxytamoxifen, toremifene (FARESTON®), idoxifene, droloxifene, raloxifene (EVISTA®), trioxifene, keoxifene, and selective estrogen receptor modulators (SERMs) such as SERM3; pure anti-estrogens without agonist properties, such as fulvestrant (FASLODEX®), and EM800 (such agents may block estrogen receptor (ER) dimerization, inhibit DNA binding, increase ER turnover, and/or suppress ER levels); aromatase inhibitors, including steroidal aromatase inhibitors such as formestane and exemestane (AROMASIN®), and nonsteroidal aromatase inhibitors such as anastrozole (ARIMIDEX®), letrozole (FEMARA®) and aminoglutethimide, and other aromatase inhibitors include vorozole (RIVISOR®), megestrol acetate (MEGASE®), fadrozole, and 4(5)-imidazoles; lutenizing hormone-releasing hormone agonists, including leuprolide (LUPRON® and ELIGARD®), goserelin, busarelin, and triptorelin; sex steroids, including progestines such as megestrol acetate and medroxyprogesterone acetate, estrogens such as diethylstilbestrol and premarin, and androgens/retinoids such as fluoxymesterone, all transretinoic acid and fenretinide; onapristone; anti-progesterones; estrogen receptor down-regulators (ERDs); anti-androgens such as flutamide, nilutamide and bicalutamide; and pharmaceutically acceptable salts, acids or derivatives of any of the above; as well as combinations of two or more of the above.

Such combination therapy also includes: (i) lipid kinase inhibitors; (ii) antisense oligonucleotides, particularly those which inhibit expression of genes in signaling pathways implicated in aberrant cell proliferation, such as, for example, PKC-alpha, Ralf and H-Ras; (iii) ribozymes such as a VEGF expression inhibitor (e.g., ANGIOZYME® ribozyme) and a HER2 expression inhibitor; (iv) vaccines such as gene therapy vaccines, for example, ALLOVECTIN® vaccine, LEUVECTIN® vaccine, and VAXID® vaccine; PROLEUKIN® rIL-2; LURTOTECAN® topoisomerase 1 inhibitor; ABARELIX® rmRH; (v) anti-angiogenic agents such as bevacizumab (AVASTIN®, Genentech); and pharmaceutically acceptable salts, acids or derivatives of any of the above.

Such combination therapies noted above encompass combined administration (where two or more therapeutic agents are included in the same or separate formulations), and separate administration, in which case, administration of the anti-NRG1 antibody of the invention can occur prior to, simultaneously, and/or following, administration of the additional therapeutic agent and/or adjuvant.

## H. Articles of Manufacture

In another aspect of the invention, an article of manufacture containing materials useful for the treatment, prevention and/or diagnosis of the disorders described above is provided. The article of manufacture comprises a container and a label or package insert on or associated with the container.

5 Suitable containers include, for example, bottles, vials, syringes, IV solution bags, etc. The containers may be formed from a variety of materials such as glass or plastic. The container holds a composition which is by itself or combined with another composition effective for treating, preventing and/or diagnosing the condition and may have a sterile access port (for example the container may be an intravenous solution bag or a vial having a stopper pierceable by a hypodermic injection needle). At  
10 least one active agent in the composition is an antibody of the invention. The label or package insert indicates that the composition is used for treating the condition of choice. Moreover, the article of manufacture may comprise (a) a first container with a composition contained therein, wherein the composition comprises an antibody of the invention; and (b) a second container with a composition contained therein, wherein the composition comprises a further cytotoxic or otherwise therapeutic  
15 agent. The article of manufacture in this embodiment of the invention may further comprise a package insert indicating that the compositions can be used to treat a particular condition. Alternatively, or additionally, the article of manufacture may further comprise a second (or third) container comprising a pharmaceutically-acceptable buffer, such as bacteriostatic water for injection (BWI), phosphate-buffered saline, Ringer's solution and dextrose solution. It may further include other materials  
20 desirable from a commercial and user standpoint, including other buffers, diluents, filters, needles, and syringes.

## III. EXAMPLES

The following are examples of methods and compositions of the invention. It is understood that various other embodiments may be practiced, given the general description provided above.

### 25 Example 1 : Methods

#### Cell Lines

NSCLC cell lines Calu3, H441, H1299, H1993, A549 and H596, and KPL4 breast cancer cell line were obtained from American Type Culture Collection (ATCC), Manassas, VA. These cell lines were maintained in RPMI containing 10% FBS, Pen/Strep and L-Glutamine. Calu3 was cultured in  
30 ATCC media instead of RPMI. Calu3, H441 and KPL4 cell lines were transduced with TZV-b-actin-eGFP lentivirus. After multiple passages, high GFP expressing cells were sorted and amplified to get ~95% GFP positive cells, and these sub-lines were described as Calu3-GFP and H441-GFP and KPL4-GFP. Mouse NSCLC cell lines LKPH1 and LKPH2 were derived from two independent tumors from a  $Kras^{LSL-G12D/+}$ ;  $p53^{FL/+}$ ; Z/EG lung tumor-bearing mouse. Cell lines were initially established in



DMEM/F12 media containing 5% FBS, Bovine Pituitary Extract, N2 supplement, EGF, FGF, Pen/Strep and L-Glutamine. LKPH1 and LKPH2 were cultured in DMEM high-glucose media containing 10% FBS, Pen/Strep and L-Glutamine.

5 **Inducible shRNA lentivirus:** Hairpin oligonucleotides used in this study are as follows:

shNRG1: 5'- GATCCCCCATGGTGAACATAGCGAATTTCAAGAGAA  
TTCGCTATGTTACCATGTTTTTTGGAAA-3' (sense) (SEQ ID NO: 77)

and

5'- AGCTTTTCC AAAAAACATGGTGAACAT AGC GAATTCTCTTGAAATTCGCTATGTTTAC  
10 CATGGGG-3' (antisense) (SEQ ID NO: 78).

shNRG1.2: 5'GATCCCCGAGTATATGTGCAAAGTGAT TCAAGAGATCAC TTTG  
CACATATACTCTTTTTTTGGAAA-3' (sense) (SEQ ID NO: 79) and

5'-AGCTTTTCCAAAAAAGAGTATATGTGCAAAGTGATCTCTTGAATCACTTTGCA  
CATATACTCGGG-3' (antisense) (SEQ ID NO: 80).

15 shErbB4: 5'- GATCCCCGATCACAACCTGCTGCTTAATTCAAGAGATTAAGCAGCAGTTGT  
GATCTTTTTTTGGAAA-3' (sense) (SEQ ID NO: 81) and

5' AGCTTTTCCAAAAAAGATCACAACCTGCTGCTTAATCTCTTGA ATTAAGCAGCAGTT  
GTGATCGGG-3' (antisense) (SEQ ID NO: 82).

shErbB3: 5'-

20 GATCCCCAAGAGGATGTCAACGGTTATTCAAGAGATAACCGTTGACATCCTCTTTTTTTTTG  
GAAA-3' (sense) (SEQ ID NO: 83) and

5'-AGCTTTTCCAAAAAAGAGGATGTCAACGGTTATCTCTTGAATAACCGTT  
GACATCCTCTTGGG-3' (antisense) (SEQ ID NO: 84).

Mouse shNRG1: 5'- GATCCCCCATGGTGAACATAGCGAATTTCA AGAGAA

25 TTCGCTATGTTACCATGTTTTTTGGAAA-3' (sense) (SEQ ID NO: 85) and

5'- AGCTTTTCC AAAAAACATGGTGAACATAGC GAATTCTCTTGAAATTCG CTATGTTTAC  
CATGGGG-3' (antisense) (SEQ ID NO: 86).

The complementary double-stranded shRNA oligonucleotides were inserted into a Tet-  
inducible viral gene transfer vector as described (Hoeflich et al. Cancer Res. 2006). The vector system  
30 is composed of a shuttle vector and a dsRed expressing viral vector backbone that contains a codon-  
optimized Tet repressor-internal ribosomal entry site–dsRed cassette to enable Tet-regulated shRNA  
expression. The luciferase shRNA construct was previously described (Hoeflich et al.).

**Viral packaging and cell line generation:** Inducible-shRNA bearing lentivirus constructs were made based on previously described methods by co-transfecting pHUSH-Lenti-dsRed constructs containing a desired shRNA with plasmids expressing the vesicular stomatitis virus (VSV-G) envelope glycoprotein and HIV-1 packaging proteins (GAG-POL) in HEK293T cells using Lipofectamine (Invitrogen, Carlsbad, CA). Target cells were transduced with these viruses. After >3 passages, FACS sorting was used to select the top ~20% dsRed expressing tumor cells which were collected, pooled and expanded.

**In vitro studies:** To induce shRNA expression, stable cell lines harboring doxycycline-inducible shNRG1 or shLuciferase were grown in 1µg/ml doxycycline for a total of 6 days. The first day of induction cells were grown in 10% FBS, followed by a titration of FBS over the course of 4 more days. The cells were then completely serum starved during the last 6 hours of growth. Cells were then processed for RNA extraction or western blotting. For HER4ECD studies in mouse lung tumor cell lines, LKPH cells were grown in serum starved conditions for 24 hours prior to addition of HER4ECD at a concentration of 2mg/ml. LKPH cells were then incubated for another 48 hours prior to processing for Western blotting. Addition of exogenous NRG1 on H441 cells were performed as follows: H441 cells were serum starved for 18 hours prior to addition of 1µM recombinant human NRG1 beta-1 extracellular domain (R&D systems) or 1µM anti-ragweed IgG2A as the control. Ten minutes after addition of NRG1 or ragweed, cells were processed for Western blotting.

**RNA Isolation, cDNA preparation and qPCR:** RNA was isolated using the Qiagen RNeasy Micro Kit. Complementary DNA was prepared from total RNA using ABI high fidelity kit according to manufacturer's instructions. NRG1alpha, NRG1beta, HER3, HER4 expression was determined using ABI gene specific primers/probe by quantitative real time PCR (ABI 7500). Gene expression was normalized using GAPDH or RAB14 house keeping genes.

**In vivo xenograft tumor studies:** Tumor cells (10-20 million) were transplanted into right flank of athymic nude mice. When tumor size reached ~200 mm<sup>3</sup>, the mice were divided into different treatment groups. Mice were then treated with either vehicle or chemotherapy (paclitaxel, i.v. + cisplatin, i.p.) for the initial studies. The chemotherapy dosing regimen was paclitaxel 20 mg/kg i.v. every other day for 5 doses and cisplatin 5 mg/kg i.p. on days 1 and 7 for the Calu3 model and days 1 and 14 for the H441 model. Regressed tumors and time matched vehicle controls were collected at least 1 week after the last dose of chemo. Tumors were dissociated using dispase/collagenase and samples were FACS sorted to collect the GFP positive tumor cells. For the NRG1 knockdown studies, the treatment groups were: sucrose, doxycycline (dox), chemotherapy + sucrose, and chemotherapy+ doxycycline. Treatment with sucrose or doxycycline was started at the same time as the first dose of chemotherapy and continued for the duration of the study. 5% sucrose water was provided ad libitum for the vehicle groups and 1 mg/ml doxycycline in 5% sucrose was provided for the doxycycline groups.

**Xenograft Tumor Growth Analysis:** To appropriately analyze the repeated measurement of tumor volumes from the same animals over time, a mixed-modeling approach was used (Pinheiro et al. 2009). This approach can address both repeated measurements and modest drop-out rate due to nontreatment-related termination of animals prior to study end. Cubic regression splines were used to fit a nonlinear profile to the time courses of log<sub>2</sub> tumor volume for each treatment group.

**In vivo *LSL-K-ras<sup>G12D</sup>;p53<sup>FU/+</sup>* and *LSL-K-ras<sup>G12D</sup>;p53<sup>FU/FI</sup>* Her4ECD study:** *LSL-K-ras<sup>G12D</sup>;p53<sup>FU/+</sup>* were infected with Adeno-Cre virus and allowed to age for 16 weeks post-tumor induction. Baseline CT scans were performed at 16 weeks post-tumor induction (day 0 of study) and mice were grouped such that average starting tumor volume per group were equal. Mice were dosed once a week for three weeks with cisplatin (7mg/kg) or phosphate-buffered saline, and bi-weekly with HER4ECD-Fc (25mg/kg) or anti-ragweed IgG2A (25mg/kg) for the duration of the study. Serial CT scans were performed at days 14, 45, and 66.

**X-ray micro-computed tomography (micro-CT):** Two micro-CT systems (vivaCT 40 and vivaCT 75, Scanco Medical, Switzerland) were utilized for longitudinal lung imaging. Animals were randomized between micro-CT systems and rescanned on the same system used for baseline imaging. Data was acquired at 38 μm (vivaCT 40) or 50 μm (vivaCT 75) isotropic voxel size, 1000 projections, 250 ms (vivaCT 40) or 200 ms (vivaCT 75) integration time, 45 keV photon energy, and 177 mA current. For the duration of the *in-vivo* imaging, the animals were anesthetized with 2% isoflurane in medical air and maintained at constant 37°C temperature by regulated warm airflow. The imaging time for each session was approximately 15 minutes (vivaCT 75) or 25 minutes (vivaCT 40) per animal and the estimated radiation dose was approximately 0.2 Gy (vivaCT 75) or 0.1 Gy (vivaCT 40). The imaging data were evaluated in the coronal plane using the image analysis software package Analyze (AnalyzeDirect, Inc., Lenexa, KS, USA). Once the largest cross-sectional plane of each tumor was identified, estimates of maximal tumor diameter ( $d_1$ ) and the largest perpendicular diameter ( $d_2$ ) were determined. The total tumor burden was calculated as the sum of the cross-product of the directional estimates ( $d_1 \times d_2$ ) of all the tumors. *In-vivo* micro-CT tumor analysis was previously validated and was found to be well correlated with the total tumor volume as determined by *ex-vivo* microCT analysis (Singh et al., 2010).

**siRNA:** Small interfering RNA oligo (siRNA) pools for HER3 (M-003127-03), HER1 (M-003114-01), HER2, HER4 and non targeting control (D-001206-14-20) were purchased from Dharmacon Lafayette, CO. siRNAs were introduced into H522 cells by reverse transfection. cells/well were seeded in 96 well microtiter plates containing a pre-incubated mix of pooled RNAi oligos at 50 mmol/L and DharmaFECT# (T-2001-02, Dharmacon) transfection reagent diluted in OPTI-MEM (Invitrogen) as per manufacturer's recommendation. 96h post transfection the effect on cell proliferation was measured by AlamarBlue staining.

**Western Blotting:** For Western blots of in vitro cell culture, adherent cells were washed three times with ice cold 1x phosphate-buffered saline (PBS) and lysed in RIPA buffer (Pierce Biotechnology), Halt protease inhibitor, and Halt phosphatase inhibitor cocktail (Thermo Scientific). The lysate was collected, homogenized, and clarified by centrifuging for 10 minutes. Primary mouse tumor lysates were prepared as stated above, without the PBS washes. Supernatant proteins were fractionated in a 4-12% NuPAGE Novex bis-tris gel (Invitrogen). Blotting was carried out using the iBlot dry blotting system (Invitrogen) according to manufacturer's specifications. Nitrocellulose membrane blocking and antibody staining was performed using the Odyssey Western blot analysis and infrared imaging system (Li-Cor Biosciences) according to manufacturer's instructions. Blots were visualized on the Odyssey scanner (Li-Cor Biosciences).

**Antibodies:** The following primary antibodies were used in Western blotting experiments: anti-actin (612656, BD Biosciences), anti-GAPDH (sc-25778, Santa Cruz Biotechnology), anti-EGF receptor (2232, Cell Signaling Technology), anti-Neu (sc-284, Santa Cruz Biotechnology), anti-ErbB3 (sc-285, Santa Cruz Biotechnology), anti-phospho-HER3 (4791, Cell Signaling Technology), anti-ErbB4 (sc-283, Santa Cruz Biotechnology), anti-phospho-HER4 (4757, Cell Signaling Technology), anti-Akt (4691, Cell Signaling Technology), anti-phospho-Akt (4058, Cell Signaling Technology), Stat/phospho-Stat antibody sampler kit (9939/9914, Cell Signaling Technology), anti-MEK 1/2 (9126, Cell Signaling Technology), anti-phospho-MEK 1/2 (2338, Cell Signaling Technology). The following secondary antibodies from Li-Cor Biosciences were used: IRDye 680 conjugated goat anti-mouse IgG, IRDye 800 CW conjugated goat anti-rabbit IgG.

### **BIAcore**

Binding affinities of anti-NGR1 IgGs were measured by Surface Plasmon Resonance (SRP) using a BIAcore™-T100 instrument. Anti-NGR1 human IgGs were captured by mouse anti-human Fc antibody (GE Healthcare, cat# BR-1008-39) coated on CM5 biosensor chips to achieve approximately 1000 response units (RU). For kinetics measurements, two-fold serial dilutions (500nM to 0.245nM) of human NRG1- $\alpha$  and NRG1- $\beta$  were injected in HBS-T buffer (GE Healthcare, cat#BR-1003-68) at 25°C with a flow rate of 30 $\mu$ l/min. Association rates ( $k_{on}$ ) and dissociation rates ( $k_{off}$ ) were calculated using a simple one-to-one Langmuir binding model (BIAcore Evaluation Software version 3.2). The equilibrium dissociation constant ( $K_D$ ) was calculated as the ratio  $k_{off}/k_{on}$ .

### **KIRA**

#### Culture MCF 7 cells

MCF 7 cells were added to a 96 well culture plate (No. 1270, BD Falcon; Franklin Lakes, NJ) at 5,000 cells/well seeding density in RPMI media with 10% fetal bovine serum (FBS) (Sigma Aldrich Corporation; St. Louis, MO). The plate was cultured at 37°C in 5% CO<sub>2</sub> for 3 days. On day 3

MCF 7 cells were switched to serum free media and cells were continuously incubated at 37°C for > 6 hrs prior to the addition of Neuregulin and test materials.

*Inhibition of Her3 hetero-dimer Phosphorylation Induced by NRG1 a and NRG1 b*

The test materials (538.24.71 and 526.90.28 antibodies) were serially diluted with non- serum  
5 containing RPMI media with 0.5 % BSA , penicillin (100 µ/mL, Gibco Invitrogen; Carlsbad, CA),  
streptomycin (100 µg/mL, Gibco Invitrogen), and L glutamine (10 mM, Genentech) to generate a total  
of ten concentrations. Recombinant human Neuregulin 1-alpha (rhNRG1a, R& D system Cat# 296-  
HR/CF, Minneapolis, MN) was prepared with non-serum containing media (as described above). Each  
diluted test material was mixed with an equal volume of rhNRG1a (0.5 nM final concentration).  
10 Recombinant human Neuregulin 1-beta (rhNRG1b, Genentech) was diluted with the non  
serum-containing media (as described above). Each diluted test material was mixed with an equal  
volume of rhNRG1b (0.2 nM final concentration).

The plate containing MCF 7 cells was removed from the incubator. A mixture containing the  
test material and rhNRG1a or rhNRG1b was then added to each well. The cells were incubated for 15  
15 minutes at 37°C with 5% CO<sub>2</sub>. The sample-containing media was decanted, and the plate was lightly  
tapped on a paper towel. To lyse the cells and solubilize the receptors, diluted cell lysis buffer (Cell  
Signaling Technologies, cat #9803) with Protease Inhibitor Cocktail Set I, No. 539131, Calbiochem)  
was added to each well. The plate was incubated at room temperature with agitation for 15 to 60  
minutes to complete the lysis. The lysate was either stored in -80°C freezer or used immediately for  
20 quantification of phosphorylation using an ELISA.

*ELISA for Kinase Receptor Activation*

A maxisorp immunoplate (4-64718, Nunc; Neptune, NJ) was coated overnight with anti erb3  
MAb (R+D Systems Duo Set IC Phospho-ErbB3 kit part# 841428, Minneapolis, MN) in PBS. On the  
following day, the capture MAb was removed and the plate was washed with wash buffer (PBS with  
25 0.05% Tween 20, pH 7.4) and blocked for 1 2 hours with block buffer (0.5% BSA in PBS). The plate  
was washed with wash buffer, and the cell lysates and controls (R+D Systems Duo Set IC Phospho-  
ErbB3 kit part# 841430, Minneapolis, MN) were added to the blocked plate and the plate was  
incubated with agitation at room temperature for 2 hours to allow sufficient binding. After incubation,  
the plate was washed six times with wash buffer, and anti phospho tyrosine MAb conjugated with  
30 horseradish peroxidase (HRP) (R+D Systems Duo Set IC Phospho-ErbB3 kit part# 841403,  
Minneapolis, MN) was added to each well. The plate was incubated at room temperature for 1 hour.  
The plate was washed again and a colorimetric substrate tetramethyl benzidine (Kirkegaard & Perry  
Laboratories; Gaithersburg, MD) was added. The color was allowed to develop for 20 minutes. Then  
the H<sub>3</sub>PO<sub>4</sub> was added to stop the reaction. The plates were read on a microplate reader (Thermo Lab

Systems; Waltham, MA) at 450 nm with a 620 nm reference. The absorbance was graphed and analyzed for inhibition. Data were transferred to KaleidaGraph 4.0 (Synergy Software; Reading, PA), and half maximal inhibitory concentration (IC50) values were calculated using a four parameter sigmoidal fit.

5

### **Example 2 - NRG1 Knockdown Inhibits Tumor Growth and Delays Tumor Relapse after Chemotherapy**

The effects of NRG1 knockdown on primary tumor growth and relapse after chemotherapy was determined by evaluating effects of NRG1 knockdown alone or in combination with chemotherapy.

10 Three human NSCLC models that exhibit varying expression patterns of the HER family receptors were used in this study. The Calu3 model has high protein levels of all the receptors, H441 shows strong expression of HER2 and HER3 and moderate HER1, and H1299 shows moderate levels HER1, 2 and 3.

To determine the efficacy of NRG1-targeting in the Calu3 model, Calu3-shNRG1 tumor bearing mice were assigned to four groups; 1) vehicle + sucrose, 2) vehicle + dox, 3) chemotherapy + sucrose, and 4) chemotherapy + dox. Chemotherapy consisted of paclitaxel (20mg/kg, i.v. every other day for 5 doses) and cisplatin (5mg/kg, i.p. every 7 days for 2 doses) and 5% sucrose or dox (2g/L) was administered orally in the drinking water ad libitum. Tumor volume was measured twice a week for the duration of the study. Tumor Growth curves were generated for the individual mice used in the study  
15 (n= 12 mice for vehicle+sucrose and n=13 mice for vehicle+dox) and are presented as Linear Mixed Effect (LME) model generated fit of tumor volume graphed as cubic splines with auto-determined knots in Fig. 1A and 1 B. There was a significant delay in tumor volume doubling time in the vehicle + dox group (time to doubling (TDT) = 44.5 days) vs. vehicle + sucrose (TDT = 17 days), suggesting that NRG1 knockdown partially inhibits tumor growth (Fig. 1A).

25 The effect of NRG1 on tumor relapse was assessed by comparing the growth of tumors in the chemotherapy + sucrose with those in the chemotherapy + dox group. There was significant delay in tumor relapse in the chemotherapy + dox group (TDT >181 days, not reached by end of study) vs. chemotherapy + sucrose (TDT = 124 days) (Fig. 1B). Furthermore, many of the relapsed tumors from the dox-treated mice, both with and without chemotherapy, were composed primarily of a  
30 brownish/black mucus-like liquid with only a small region of viable tumor tissue. Therefore, the measured volumes were considerably larger than the actual tumor volume in the dox-treated groups. No differences were observed between any of the groups in the Calu3-shLuc control study. In addition, immunohistochemistry (IHC) was performed for the proliferation marker Ki67 on the Calu3 tumors 3 days after the last dose of chemotherapy. There was a markedly lower proportion of Ki67 positive cells

in the chemotherapy + dox treated tumors compared to the chemotherapy + sucrose tumors, suggesting that NRG1 signaling stimulates proliferation in residual tumor cells after chemotherapy.

5 The mRNA levels of NRG1 $\alpha$  and NRG1 $\beta$  isoforms in tumor cells collected at early and late time points was determined. NRG1 transcripts increased at the late timepoint indicating that knockdown is not maintained in vivo.

10 The effect of NRG1 knockdown in the H441 xenograft model was also examined. Although there was a minimal effect on primary tumor growth (Fig. 2A (n=12 /group) tumor growth curves presented as LME fit analysis of tumor volume graphed as cubic splines with auto-determined knots), there was a significant delay in tumor relapse in the chemotherapy + dox group (TDT >150 days, not reached by end of study) vs. chemotherapy + sucrose (TDT = 94 days) (Fig. 2B((n=12/group)). There was no such difference in tumor volume in the H441-shLuc in vivo study. Similar to the Calu3 xenograft model, the H441 model also exhibited increased levels of NRG1 transcripts at the late time point.

15 To investigate the mechanism behind the restoration of NRG1 levels the tumor cells were analyzed for expression of the lentivirally transduced genes. Because the lentivirus used to transduce the cells with the shRNA also includes a dsRed marker gene, the proportion of dsRED positive tumor cells at early and late time points were compared by flow cytometry. In vivo loss of lentiviral gene expression was assessed for tumors at early (5 days) and late time points (>100 days) by FACS analysis examining the proportion of tumor cells (human specific-ESA positive) that express the  
20 lentiviral dsRed transgene. Mice in the early time point received sucrose or dox and mice in the late timepoint received chemo+sucrose or chemo+dox. A significant reduction in the proportion of dsRed positive cells at the late time point for both sucrose and dox treated tumors was observed, with the reduction being significantly greater for the dox treated tumors (1.8-fold vs. 4.1-fold, p=0.007). This suggests that loss of viral transgene expression correlates with a restoration of NRG1 levels.

25 Both Calu3 and H441 cells show increased levels of HER3 protein, raising the question of whether the role of NRG1 in tumor relapse is specific to tumors with receptor overexpression. To address this question the H1299 xenograft model that has much lower levels of HER3 was used. Knockdown of NRG1 alone had only a modest effect on primary tumor growth, similar to the H441 model. In contrast and despite the very aggressive growth of the H1299 tumors, NRG1 knockdown led  
30 to an enhanced response to chemotherapy resulting and a significant delay in tumor relapse in the chemotherapy + dox group (TDT = 30.45 days) vs. chemotherapy + sucrose (TDT = 11.5 days) (n=12/group) .

35 Furthermore, a stable subline of H1299 expressing a different shRNA to NRG1 (shNRG1.2) was generated that resulted in a more modest reduction in NRG1 mRNA levels. In vivo studies with H1299-shNRG1.2 also demonstrated an enhanced response to chemotherapy upon NRG1 knockdown.

However, the magnitude of the growth inhibition was smaller in this model, consistent with the lesser degree of NRG1 knockdown. There was no difference in tumor volumes between sucrose and dox treated groups with or without chemotherapy in H1299-shLuc in vivo studies.

Inhibition of NRG1 autocrine signaling by shRNA mediated knockdown had only modest to moderate effects on primary tumor growth but dramatically delayed tumor relapse after chemotherapy. Despite the inability to maintain long-term knockdown of NRG1 in the xenograft models, we observed a significant delay in tumor relapse upon NRG1 knockdown. These findings suggest there are differences in the key pathways regulating primary tumor growth, and chemoresistance and relapse.

### Example 3 - Inhibition of NRG1 Signaling Delays Tumor Relapse

To test the role of NRG1 signaling in promoting relapse after chemotherapy in the *LSL-K-ras<sup>G12D</sup>;p53<sup>F1/+</sup>* mouse model, a ligand-trap approach to sequester NRG1 and prevent its binding to receptors in vivo was employed. A fusion of the human HER4 extracellular domain (HER4-ECD) fused to murine IgG2A Fc was generated. HER4 shows high affinity binding for NRG1 (Tzahar et al., 1994). When HER4-ECD was added to serum starved LKPH1 and LKPH2 cells in vitro, inhibition of NRG1/HER3 signaling was observed as demonstrated by diminished p-HER3 levels. Thus, in vitro the molecule behaved as expected in interfering with autocrine-mediated NRG1 signaling.

Lung tumor bearing *LSL-K-ras<sup>G12D</sup>;p53<sup>F1/+</sup>* mice were imaged by X-ray micro-computed tomography (micro-CT) at the start of the study (day 0), segregated into three groups of equal starting tumor burdens and treated as follows: 1) PBS + control IgG2A; 2) cisplatin + control IgG2A; and 3) cisplatin + HER4-ECD. Mice underwent longitudinal micro-CT scans to measure changes in tumor burden. Analysis of average tumor burden (Fig. 3A (graph represents average tumor volume +/- SEM, ragweed, control murine IgG2a antibody)) and tumor growth rate ((Fig. 3B (graph showing daily fold change in tumor burden by treatment regimen with 95% confidence intervals)) revealed that only the combination of cisplatin + HER4-ECD but not cisplatin alone resulted in a significant inhibition of tumor growth. Although the cisplatin treated mice showed stasis of their tumor growth at the first micro-CT scan after chemotherapy, the average tumor burden at the conclusion of the study and overall tumor growth rate were not significantly different between the vehicle and cisplatin treated groups (Fig. 3A-B).

A second study was carried out in *LSL-K-ras<sup>G12D</sup>;p53<sup>F1/F1</sup>* mice as described above. However, this study included a HER4-ECD single agent arm in addition to the groups described above. Analysis of tumor burden by micro-CT on day 28 revealed a significant reduction in tumor burden in the cisplatin + HER4-ECD treated mice compared to cisplatin + vehicle treated mice and all other groups (Fig. 3C). In contrast, there was no effect of HER4-ECD treatment alone on tumor growth, further supporting a unique role for NRG1 autocrine signaling in chemoresistance and/or tumor regrowth. In this study, *LSL-K-ras<sup>G12D</sup>;p53<sup>F1/F1</sup>* mice were treated with vehicle + control IgG (n=10), cisplatin +



control IgG (n=11), cisplatin + HER4-ECD (n=8) or Vehicle + HER4-ECD (n=7). The graph in Fig. 3C represents average percent change in tumor burden from baseline  $\pm$  SEM. Dunnett's Multiple Comparison Test was utilized to compare all of the treatment groups against the vehicle control \*\* p = 0.0016. Combination activity was assessed using an unpaired t-test against its monotherapy \* p < 0.05, \*\* p < 0.01.

#### Example 4 – NRG1 is Enriched in Residual Tumor Cells that Survive Chemotherapy

A LSL-K-rasG12D genetically engineered mouse model (GEMM) of NSCLC (Jackson et al., 2001) crossed to the Z/EG Cre-reporter strain (Novak et al., 2000) was used to characterize TRIC populations. Cisplatin treatment of LSL-K-rasG12D mice results in a reduction in tumor burden but does not result in prolonged survival, indicating that tumors resume growing after therapy (Oliver et al., 2010). In addition, two human xenograph models in which tumors regress in response to cisplatin + paclitaxel doublet chemotherapy, but resume growth several weeks after the cessation of treatment were used. GFP-expressing sublines of the Calu3 and H441 human NSCLC xenograft models were generated to allow for isolation of tumor cells by fluorescent activated cell sorting (FACS). For each model, the GFP-positive cells that survived chemotherapy prior to the onset of tumor re-growth were isolated as they contained the TRIC population.

The TRICs in the LSL-K-rasG12D mouse model were analyzed. Lungs were collected 1 week after the final dose of cisplatin and GFP positive tumor cells were isolated by FACS. In order to characterize differences in the gene expression profiles of vehicle treated and residual tumor cells, RNA was isolated from the tumor cells (PI- & GFP+), and expression profiling was performed. Of all the genes on the array, NRG1 showed the most statistically significant enrichment in residual chemo-treated tumor cells – a 13.7 fold enrichment (p<0.001, q=1; n=6/group). Quantitative real time PCR (qPCR) on independently generated samples validated the microarray results (Fig. 4A).

The expression of NRG1 in TRICs isolated from the Calu3 and H441 xenograft models was analyzed. Due to alternative splicing there are two active isoforms of the NRG1 EGF-like domain that is required for receptor binding, referred to as NRG1 $\alpha$  and NRG1 $\beta$ . Expression of NRG1 $\alpha$  and NRG1 $\beta$  was significantly enriched in residual chemo-treated tumor cells from these models. The Calu3 tumor model showed a 4.7 fold enrichment for NRG1 $\alpha$  (p=0.02) and a 3.4 enrichment for NRG1 $\beta$  (p=0.04). (Fig. 4B). The H441 tumor model showed a 11.4 fold enrichment for NRG1 $\alpha$  (p=0.02) and a 12.1 enrichment for NRG1 $\beta$  (p=0.04). (Fig. 4C). Interestingly, neither HER3 nor HER4 receptor expression was consistently enriched in all models.

NRG1 expression in TRICS isolated from the Calu3 and H441 xenograft models after treatment with other chemotherapeutic agents commonly used to treat NSCLC. Treatment with

gemcitabine resulted in tumor regression in each of these models, and the residual tumor cells were highly enriched for NRG1. The Calu3 tumor model showed a 52.5 fold enrichment for NRG1 (p=0.011). The H441 tumor model showed a 11.7 fold enrichment for NRG1 (p=0.025) (Fig. 4D). However, Calu3 and H441 tumors continued to grow upon treatment with vinorelbine, and treatment did not result in enrichment of NRG1.

NRG1 protein levels and the activation of the NRG1 receptor, HER3, were also assessed via Western Blot. It was determined that NRG1 protein levels and phospho-Her3 levels were consistently higher in the residual tumor cells than in vehicle treated tumor cells. The activation of HER3 was examined by immunostaining tumors for phospho-HER3. The majority of tumor cells in the residual tumors were p-HER3 positive whereas the vehicle treated tumors showed only scattered clusters of p-HER3 positive cells. Thus, residual tumor cells express NRG1 and show enhanced receptor activation, demonstrating increased NRG1 autocrine signaling.

#### **Example 5- NRG1 Receptor Usage in NSCLC**

To understand which HER receptors are employed in NRG1 autocrine signaling in NSCLC, the effects of HER3 and HER4 knockdown on tumor cell proliferation were evaluated. The Calu3 NSCLC model expressed high levels of all the HER family receptors compared to other cell lines. Stable dox-inducible shHER3 (Calu3-shHER3) and shHER4 (Calu3-shHER4) Calu3 cell sub-lines were generated, as well as a control cell line carrying a dox-inducible shRNA to Luciferase. HER3 and HER4 transcript levels were decreased in Calu3-shHER3 and Calu3-shHER4 respectively in the presence of dox (2 ug/ml) as measured by qPCR, resulting in decreased protein levels, as measured by Western blot. Interestingly, the extent of p-AKT down-regulation observed in Calu3-shHER3 in the presence of dox was much greater than seen in Calu3-shHER4, suggesting that HER3 is the predominant receptor mediating NRG1 autocrine signaling in the Calu3 model.

To confirm this role in vivo, studies using Calu3-shHER3 and Calu3-shHER4 xenograft models treated with either sucrose or dox were performed. Mice with established Calu3-shHER3 or Calu3-shHer4 xenograft tumors were administered vehicle (sucrose) or dox (2gm/L) in their drinking water ad libitum (n=14/group). There was substantial inhibition of Calu3-shHER3 tumor growth in the mice receiving dox treatment (TDT = 19 days) compared to those receiving sucrose treatment (TDT = 11 days). However, there was not a notable inhibition of tumor growth in the Calu3-shHER4 in vivo study.

The in vitro receptor analysis and in vivo studies indicate that despite high HER4 levels, NRG1 autocrine signaling occurs mainly through HER3 in this model.

NRG1 autocrine signaling was assessed in the H522 human NSCLC cell line, which expresses high levels of HER4 but no detectable HER3. A H522-shNRG1 subline was generated. Administration

of dox to serum starved H522-shNRG1 cells results in decreased levels of phospho-HER4 and phospho-S6. No differences were observed in H522-shLuc control cells siRNA-mediated knockdown was used to test the requirement for each HER family member in cell proliferation. Only knockdown of HER4 and not the other HER family receptors resulted in decreased cell proliferation. These data suggest that NRG1 autocrine signaling occurs through HER4 in H522 cells. Thus, NRG1 autocrine signaling in NSCLC can be mediated by both HER3 and HER4.

### Example 6- Generation of anti-NGR1 Antibodies

#### Library Sorting and Screening to Identify Anti-NGR1 Antibodies

Recombinant human NRG1- $\alpha$  EGF domain (R&D Systems, cat# 296-HR/CF) (SEQ ID NO: 3) and NRG1- $\beta$  ECD domain (R&D Systems, cat# 377-HB/CF) (SEQ ID NO: 4) were used as antigens for library sorting. Fig. 5. Nunc 96 well Maxisorp immunoplates were coated overnight at 4°C with target antigen (10 $\mu$ g/ml) and were blocked for 1 hour at room temperature with phage blocking buffer PBST (phosphate-buffered saline (PBS) and 1% (w/v) bovine serum albumin (BSA) and 0.05% (v/v) tween-20). Antibody phage libraries (Lee et al., *J. Mol. Biol* 340, 1073-1093, 2004, Liang et al., *JMB*. 366: 815-829, 2007) were added to antigen plates separately and incubated overnight at room temperature. The following day antigen-coated plates were washed ten times with PBT (PBS with 0.05% Tween-20), and bound phage were eluted with 50mM HCl and 500mM NaCl for 30 minutes and neutralized with an equal volume of 1 M Tris base (pH7.5). Recovered phages were amplified in *E. coli* XL-1 Blue cells. During the subsequent selection rounds, incubation of antibody phage with the antigen-coated plates was reduced to 2-3 hours, and the stringency of plate washing was gradually increased.

After 5 rounds of panning, significant enrichment was observed. 1000 clones were picked from libraries sorting to determine whether they specifically bound to both human NRG1-alpha and NRG1-beta. The variable regions of these clones were sequenced to identify unique sequence clones.

The affinities of phage antibodies were ranked using spot competition ELISA. The phage supernatant was diluted 1:5 in ELISA (enzyme linked immunosorbent assay) buffer (PBS with 0.5% BSA, 0.05% Tween20) with or without 75nM NRG1-alpha in 100 $\mu$ l total volume and incubated at least 1 hour at room temperature in an F plate (NUNC). 95 $\mu$ l of mixture with or without target protein was transferred side-by-side to the target protein coated plates (1 $\mu$ g/ml NRG1-alpha coated overnight). The plate was gently shaken for 15 min to allow the capture of unbound phage to the target protein-coated plate. The plate was washed ten times with PBS-0.05% Tween 20. The binding was quantified by adding horseradish peroxidase (HRP)-conjugated anti-M13 antibody in ELISA buffer (1:5000) and incubated for 30 minutes at room temperature. The plates were washed ten times with PBS-0.05% Tween 20. Next, 100 $\mu$ l/well of a 1:1 ratio of 3,3',5,5'-tetramethylbenzidine (TMB) Peroxidase

substrate and Peroxidase Solution B (H<sub>2</sub>O<sub>2</sub>) (Kirkegaard-Perry Laboratories (Gaithersburg, MD)) was added to the well and incubated for 5 minutes at room temperature. The reaction was stopped by adding 100µl 0.1M phosphoric Acid (H<sub>3</sub>PO<sub>4</sub>) to each well and allowed to incubate for 5 minutes at room temperature. The OD (optical density) of the yellow color in each well was determined using a standard ELISA plate reader at 450 nm. The OD reduction (%) was calculated by the following equation.

$$\text{OD}_{450\text{nm}} \text{ reduction (\%)} = [(\text{OD}_{450\text{nm}} \text{ of wells with competitor}) / (\text{OD}_{450\text{nm}} \text{ of well with no competitor})] * 100$$

Clones that had the OD<sub>450nm</sub> reduction (%) lower than 30% for NRG1-α target were picked and reformatted into full length human IgG1 by cloning V<sub>L</sub> and V<sub>H</sub> regions of individual clones into the LPG3 and LPG4 vector respectively. These clones were subsequently transiently expressed in mammalian CHO cells, and purified with a protein A column.

#### Selection of functional antibodies

The antibodies were tested for their ability to inhibit NRG1β binding to HER3-Fc. 125I-HRG was generated at Genentech as described previously (Sliwkowski et al JBC 1994). Binding assays were performed in Nunc break-apart strip wells (Thermo-Fisher Scientific, Rochester, NY). Plates were coated at 4°C overnight with 250 ng/well of HER3-ECD-Fc fusion protein in carbonate buffer (pH 9.6). Plates were rinsed twice with wash buffer (PBS/0.05% Tween 20) and blocked with 100 µL PBS including 1% bovine serum albumin (BSA) for 30 minutes. Increasing concentrations of anti-NRG1 antibodies in RPMI 1640 medium (Invitrogen; Carlsbad, CA) with 0.2% BSA were pre-bound to HER3-ECD-Fc. 125I-HRG (specific activity: 266 mCi/mg, 75,000 cpm/well) was added immediately after in a total assay volume of 130 µL. Plates were incubated for 2 hours at room temperature, rinsed twice, and individual wells were counted using a 100 Series Iso Data γ-counter. Samples were assayed in triplicates. Plotting was performed using KaleidaGraph 3.6 software. The data, shown in Fig. 6, show a dose-dependent inhibition of NRGβ by a subset of the parental anti-NRG1 antibodies tested, with 526.02, 538.24 and 526.90 representing the most potent blockers. (These clones and affinity matured variants thereof as in some places herein identified with a “YW” preceding the numerical identifiers.)

The amino acid sequences of the heavy and light chains of the antibodies were determined. Fig. 25, Fig. 26, Fig. 27, and Fig. 28.

**Example 7 – Affinity Maturation of anti-NGR1 antibodies**

Selected anti-NGR1 antibodies were affinity matured. Amino acid sequences of the parent and affinity matured variants are shown in Fig. 25, Fig. 26, Fig. 27, and Fig. 28.

Construct Libraries for Affinity Improvement of Clones Derived from the  $V_H$  or  $V_HV_L$  Libraries

5 Phagemid pW0703 (derived from phagemid pV0350-2b (Lee et al., *J. Mol. Biol* 340, 1073-1093 (2004)), containing stop codon (TAA) in all CDR-L3 positions and displaying monovalent Fab on the surface of M13 bacteriophage) served as the library templates for grafting heavy chain variable domains ( $V_H$ ) of clones of interest from the  $V_H$  library for affinity maturation. Both hard and soft randomization strategies were used for affinity maturation. For hard randomization, one light chain  
10 library with selected positions of the three light chain CDRs was randomized using amino acids designed to mimic natural human antibodies and the designed DNA degeneracy was as described in Lee et al. (*J. Mol. Biol* 340, 1073-1093 (2004)). To achieve the soft randomization conditions, which introduced the mutation rate of approximately 50% at the selected positions, the mutagenic DNA was synthesized with 70-10-10-10 mixtures of bases favoring the wild type nucleotides (Gallop et al.,  
15 *Journal of Medicinal Chemistry* 37:1233-1251 (1994)). For soft randomization, residues at positions 91-96 of CDR-L3, 30-33, 35 of CDR-H1, 50, 52, 53-54, and 56 of CDR-H2, 95-98 of CDR-H3 were targeted; and two different combinations of CDR loops, H1/H3/L3, H2/L3, and H3/L3, were selected for randomization.

For clones originated from  $V_HV_L$  library, phagemids containing 4 stop codons (TAA) in each  
20 CDR and displaying monovalent Fab on the surface of M13 bacteriophage were generated individually, and served as the templates for kunkel mutagenesis for the construction of affinity maturation libraries. Only soft randomization strategy was used for clones derived from  $V_HV_L$  library, as diversity of CDR-L3 was built into the naïve library. To achieve the soft randomization conditions, residues at positions 28-31 of CDR-L1, 50, 53-55 of CDR-L2, 91-96 of CDR-L3, 30-35 of CDR-H1, 50-56 of CDR-H2, 95-  
25 100 of CDR-H3 were targeted; and ten different combinations of CDR loops, H1\*/H3, H1\*/H2, H2\*/L3, H3\*, H3\*/L2, L1\*/L2, L1\*/L3, H3/L3\*, L2/L3\* and H1/L3\* (where \* denotes the position of stop codons on the template), were selected for randomization.

Phage Sorting Strategy to Generate Affinity Improvement

30 For affinity improvement selection, NRG1-beta or NRG1-alpha were first biotinylated under limiting reagent condition and reverse phase chromatography to obtain mono-biotinylated-species. Phage libraries were subjected to six rounds of solution sorting with increasing stringency. For the first round of solution sorting, 3 O.D./ml in 1% BSA and 0.05% Tween 20 of phage input were incubated to plates pre-coated with either NRG1-alpha or NRG1-beta for 3 hours. The wells were washed with  
35 PBS-0.05% Tween 20 ten times. Bound phage was eluted with 150ul/well 50mM HCl, 500mM KCl for

30 minutes, and subsequently neutralized by 50ul/well of 1M Tris pH8, titered, and propagated for the next round. For subsequent rounds, panning of the phage libraries was done in solution phase, where phage library was incubated with 100 nM biotinylated target protein (the concentration is based on parental clone phage IC<sub>50</sub> value) in 100ul buffer containing 1% Superblock (Pierce Biotechnology) and 0.05% Tween20 for 2 hours at room temperature. The mixture was further diluted 10X with 1% Superblock, and 100ul/well was applied to neutravidin-coated wells (10ug/ml) for 30 minutes at room temperature with gentle shaking. To determine background binding, control wells containing phage were captured on neutravidin-coated plates. Bound phage was then washed, eluted and propagated as described for first round. Five more rounds of solution sorting were carried out together with increasing selection stringency. The first couple rounds of which is for on-rate selection by decreasing biotinylated target protein concentration from 100nM to 0.1nM, and the last two rounds of which is for off-rate selection by adding excess amounts of non-biotinylated target protein (300 to 1000 fold more) to compete off weaker binders at room temperature.

#### High Throughput Affinity Screening ELISA (Single Spot Competition)

Colonies were picked from the sixth round of screening. Colonies were grown overnight at 37°C in 150ul/well of 2YT media with 50ug/ml carbenicillin and  $1 \times 10^{10}$ /ml M13KO7 in 96-well plate (Falcon). From the same plate, a colony of XL-1 infected parental phage was picked as control. 96-well Nunc Maxisorp plates were coated with 100ul/well of either NRG1-alpha or NRG1-beta (0.5ug/ml) in PBS at 4°C overnight. The plates were blocked with 150ul of 1% BSA and 0.05% Tween in PBS 20 for 1 hour.

35ul of the phage supernatant was diluted with to 75ul of in ELISA (enzyme linked immunosorbent assay) buffer (PBS with 0.5% BSA, 0.05% Tween20) with or without 5nM NRG1-alpha or NRG1-beta and let incubate for 1 hour at room temperature in an F plate (NUNC). 95ul of mixture was transferred side by side to the antigen coated plates. The plate was gently shaken for 15 min and was washed ten times with PBS-0.05% Tween 20. The binding was quantified by adding horseradish peroxidase (HRP)-conjugated anti-M13 antibody in ELISA buffer (1:2500) and incubated for 30 minutes at room temperature. The plates were washed with PBS-0.05% Tween 20 ten times. Next, 100ul/well of Peroxidase substrate was added to the well and incubated for 5 minutes at room temperature. The reaction was stopped by adding 100ul 0.1M Phosphoric Acid (H<sub>3</sub>PO<sub>4</sub>) to each well and allowed to incubate for 5 minutes at room temperature. The O.D. (optical density) of the yellow color in each well was determined using a standard ELISA plate reader at 450 nm. In comparison to the OD<sub>450nm</sub> reduction (%) of the well of parental phage (100%), clones that had the OD<sub>450nm</sub> reduction (%) lower than 50% were picked for sequence analysis. Unique clones were selected for phage preparation to determine binding affinity (phage IC<sub>50</sub>) against both NRG1-alpha and NRG1-beta by comparison to parental clone. Then the most affinity-improved clones were reformatted into human

IgG1 for antibody production and further BIAcore binding kinetic analysis and other *in vitro* or *in vivo* assay.

#### Example 8 – Characterization of Affinity Matured 538.24 anti-NRG1 Antibodies

The affinity matured variants were tested for their ability to block HRG $\beta$  binding to HER3-Fc. 125I-HRG was generated at Genentech as described previously (Sliwkowski et al JBC 1994). Binding assays were performed in Nunc break-apart strip wells (Thermo-Fisher Scientific, Rochester, NY). Plates were coated at 4°C overnight with 250 ng/well of HER3-ECD-Fc fusion protein in carbonate buffer (pH 9.6). Plates were rinsed twice with wash buffer (PBS/0.05% Tween 20) and blocked with 100  $\mu$ L PBS including 1% bovine serum albumin (BSA) for 30 minutes. Increasing concentrations of anti-NRG1 antibodies in RPMI 1640 medium (Invitrogen; Carlsbad, CA) with 0.2% BSA were pre-bound to HER3-ECD-Fc. 125I-HRG (specific activity: 266 mCi/mg, 75,000 cpm/well) was added immediately after in a total assay volume of 130  $\mu$ L. Plates were incubated for 2 hours at room temperature, rinsed twice, and individual wells were counted using a 100 Series Iso Data  $\gamma$ -counter. Samples were assayed in triplicates. Plotting was performed using KaleidaGraph 3.6 software.

The data, shown in Fig. 7, show the dose-dependent inhibition of 125I-NRG1 $\beta$  binding to Her3 by several affinity matured clones of the 538.24 antibody. All but 538.24.38 are highly effective in blocking binding, with IC<sub>50</sub> values in the subnanomolar range.

Binding affinities of 538.24 affinity matured variant anti-NRG1 IgGs for NRG1 $\alpha$  and NRG1 $\beta$  were measured by Surface Plasmon Resonance (SRP) using a BIAcore™-T100 instrument as described in Example 1. The data using 125 nM NRG1 $\beta$  is shown in Fig. 8 and the data using 250 nM NRG1 $\alpha$  is shown in Fig. 9.

Further affinity analysis was performed on antibody 538.24.71 using 6.25 nM NRG1 $\beta$  or 6.25 nM NRG1 $\beta$  and on antibody 538.24.94 using 7.8 nM NRG1 $\beta$  or 7.8 nM NRG1 $\beta$ . The results are shown in Fig. 10 (538.24.71) and Fig. 11 (538.24.94).

#### Example 9 – Characterization of 526.09 and 526.02 anti-NRG1 Antibodies and Affinity Matured Variants Thereof

A competition assay was performed to determine the binding specificity of the 526.09 and 526.02 antibodies. As shown in Fig. 12, 526.90 competes with 538.24.17 for both HRG1 $\alpha$  and HRG1 $\beta$ , indicating that 526.90 binds to both of these HRG1 isoforms.

Several affinity matured variants of the 526.09 antibody were generated as described in Example 7 and analyzed for their ability to block NRG1 $\alpha$  and NRG1 $\beta$  binding to an anti-HER3 antibody in KIRA assays as described in detail in Example 1. Briefly, Serum-starved MCF-7 cells were treated with fixed amounts of Neuregulin 1-alpha or Neuregulin -beta and increasing amounts of

test materials (YW538.24.71 and YW526.90.28) for 15min in a CO<sub>2</sub> incubator. After decanting media, cells were lysed and analyzed in an ELISA previously described (Sadick et al. 1999). Her3 phosphorylation was measured using an anti-HER3 as capture MAb (R+D Systems Duo Set IC Phospho-ErbB3 kit part# 841428, Minneapolis, MN) and anti-phosphotyrosine MAb conjugated with horseradish peroxidase (HRP) as detection (R+D Systems Duo Set IC Phospho-ErbB3 kit part# 841403, Minneapolis, MN). After addition of colorimetric substrate, the plates were read at 450 nm with a 620 nm reference on a microplate reader (Thermo Lab Systems; Waltham, MA). The absorbance was graphed and analyzed for inhibition. The combined results of these assays are shown in Fig. 13.

10 The affinity-matured variants were also tested using a BV test, with results shown in Fig. 14.

Binding affinities of the 526.90.28 anti-NRG1 antibody for NRG1 $\alpha$  and NRG1 $\beta$  was measured by Surface Plasmon Resonance (SRP) using a BIAcore™-T100 instrument as described in Example 1. The data using 6.25 nM NRG1 $\beta$  and 6.25 nM NRG1 $\alpha$  is shown in Fig. 15.

#### 15 **Example 10 – Anti-NRG1 Antibodies Inhibit Her3 Phosphorylation**

The ability of the anti-NRG1 antibodies to inhibit Her3 phosphorylation in response to stimulation with exogenous NRG1 ligand was tested using a KIRA assay as described in Examples 1 and 9. Both YW538.24.71 and YW526.90.28 inhibited Her3 activation in response to NRG1 $\alpha$  stimulation with a similar IC<sub>50</sub> (14 + 2.8 nM and 13.9 + 4.8 nM respectively) (Fig. 16). However,

20 YW538.24.71 was a more potent blocker of NRG1 $\beta$  induced Her3 activation than YW526.90.28 (IC<sub>50</sub> 0.12 + 0.017 and 1.44 + 0.5 nM respectively) (Fig. 17).

#### **Example 11 – Anti-NRG1 Antibodies Are Specific for Neuregulin**

To confirm antibody specificity, binding of the antibodies to the related EGF family ligands, EGF, HB-EGF, and Betacellulin (BTC) was assessed. There was no detectable binding of these ligands to YW538.24.71 and YW526.90.28 when assayed by ELISA.

NRG1, HB-EGF and BTC are also ligands for the HER4 receptor. Therefore, the ability of YW538.24.71 and YW526.90.28 to inhibit BTC and HB-EGF-induced HER4 phosphorylation was analyzed in a cell-based assay. While YW538.24.71 potentially inhibited NRG1-B induced phosphorylation, it had no effect on BTC or HB-EGF induced phosphorylation when measured by Western blot analysis.

#### **Example 12 - Anti-NRG1 Antibodies Inhibit NRG1 Autocrine Signaling**

The ability of the anti-NRG1 antibodies to inhibit NRG1 autocrine signaling was determined.



Cells were grown in media containing 0.1%FBS + antibodies as indicated for 48 hours. Cells were washed 3 times with 1x PBS and lysed with RIPA buffer containing protease and phosphatase inhibitors. Lysates were collected, and processed for western blotting.

The data show that anti-NRG1 antibody YW538.24.71 inhibits NRG1 autocrine signaling in both human and mouse cells as shown by dose-dependent decreases in phospho-Her3 and phospho-AKT levels. Fig. 18.

### **Example 13 - Anti-NRG1 Antibodies Inhibit HNSCC Tumor Growth**

The ability of anti-NRG1 antibodies to inhibit tumor growth in a mouse model system for head and neck squamous carcinoma (HNSCC) was determined. C.B-17 SCID mice were inoculated with 5 million tumor HNSCC FADU cells subcutaneously on the right flank. When tumors reached a mean of 150-250 mm<sup>3</sup> animals were grouped out into treatment groups with equivalent mean starting tumor volumes. Groups were treated with the indicated antibody and dose, administered IP, qwk x4. Tumors were measured at least once per week for the duration of the study. The results shown in Fig. 19 shown that both exemplary anti-NRG1 antibodies inhibit HNSCC tumor growth.

### **Example 14 - Anti-NRG1 Antibodies Inhibit Lung Cancer Tumor Growth**

The ability of anti-NRG1 antibodies to inhibit tumor growth in a mouse model system for lung cancer was determined. Athymic nude mice were inoculated subcutaneously in the right flank with 15 million human lung adenocarcinoma cell line Calu3 cells. When tumors reached a mean of 150-250 mm<sup>3</sup> animals were grouped out into treatment groups with equivalent mean starting tumor volumes. Animals were treated as follows:

Group 1: Vehicle (antibody buffer/carboplatin buffer), i.p. qwk X 2 + Paclitaxel buffer, IV q2d X 5

Group 2: 538.24.71, 25 mg/kg,IP, qwk for study duration + carboplatin buffer, IP qwk X 2 + Paclitaxel buffer, IV q2d X 5

Group 3: 526.90.28, 25 mg/kg, IP qwk for study duration + carboplatin buffer, IP qwk X 2 + Paclitaxel buffer, IV q2d X 5.

Group 4: Carboplatin, 60 mg/kg,IP qwk X 2 + Paclitaxel, 20mg/kg, IV q2d X 5 .

Group 5: 538.24.71, 25 mg/kg, IP qwk for study duration + Carboplatin, 60 mg/kg, IP qwk X 2 + Paclitaxel, 20mg/kg, IV q2d X 5.

Group 6: 526.90.28, 25 mg/kg, IP, qwk for study duration + Carboplatin, 60 mg/kg, IP qwk X 2 + Paclitaxel, 20mg/kg, IV q2d X 5.

Tumor Growth curves are presented as Linear Mixed Effect (LME) model generated fit of tumor volume graphed as cubic splines with auto-determined knots. A Kaplan-Meier curve showing progression free survival (progression defined as a tumor reaching twice its starting volume) is also presented. P values were calculated by Gehan-Breslow-Wilcoxon test. Fig. 20.

The data show that single agent anti-NRG1 treatment significantly inhibits tumor growth. Furthermore, anti-NRG1 treatment lengthens the duration of the response to standard of care chemotherapy, delaying tumor regrowth.

#### **Example 15 - Anti-NRG1 Antibodies Inhibit NSCLC Tumor Growth**

5 The ability of anti-NRG1 antibodies to inhibit tumor growth in a mouse model system for non-small cell lung cancer (NSCLC) was determined. Athymic nude mice were inoculated subcutaneously into the right flank with a) 20 million H596 cells or b) 2 million LKPH2 cells. When tumors reached a mean of 150-250mm<sup>3</sup> animals were grouped out into treatment groups with equivalent mean starting tumor volumes. Animals were treated as follows:

10 Group 1: Vehicle: Anti-ragweed, 20mg/kg, IP qwk for study duration + Carboplatin buffer, IP q4d X 5 + Paclitaxel buffer, IV q4d x 5.

Group 2: Y538.24.71: Y538.24.71, 20mg/kg, IP qwk for study duration + Carboplatin buffer, IP q4d X 5 + Paclitaxel buffer, IV q4d X 5.

15 Group 3: Chemo + Ragweed: Anti-ragweed, 20mg/kg, IP qwk for study duration + Carboplatin, 60 mg/kg IP q4d X 5 + Paclitaxel 20mg/kg, IV q4d x 5.

Group 4: Chemo+538.24.71: 538.24.71, 20mg/kg, IP qwk for study duration + Carboplatin, 60 mg/kg IP q4d X 5 + Paclitaxel 20mg/kg, IV q4d x 5.

Tumor Growth curves and a Kaplan-Meier curve were generated as described in Example 15. Fig. 21 and 22.

20 The data show that anti-NRG1 treatment enhances the magnitude of the response to chemotherapy in NSCLC models that do not regress in response to chemotherapy alone. This synergy with chemotherapy can occur even when there is no effect of single agent anti-NRG1 treatment on tumor growth as seen in the H596 study.

25 Additionally, YW538.24.71 also enhanced the response of LKPH2 tumors to gemcitabine treatment, another chemotherapeutic agent commonly used to treat NSCLC (Fig. 23). In this study, gemcitabine, at 100 mg/kg, was administered to the mice every four days for four doses. Tumor Growth curves and Kaplan-Meier curve were generated as in Example 15.

#### **Example 16 - Anti-NRG1 Antibodies Inhibit Breast Cancer Tumor Growth**

30 The ability of anti-NRG1 antibodies to inhibit tumor growth in a mouse model system for breast cancer was determined. MDA-MB-175T tumor fragments were implanted into the mammary fat pad of Beige Nude mice. A 0.36 mg estrogen pellet was implanted 1-3 days prior to tumor implantation. When tumors reached a mean of 150 and 250 mm<sup>3</sup> mice were grouped out and treat as follows:

Group 1: Vehicle (PBS), IP, 1x/week x 4, n=8-10

Group 2: anti-HER3 antibody, 50 mg/kg, IP, 1x/week x 4, n=8-10

Group 3: 538.24.71, 25 mg/kg, IP, qwk x 4, n=8-10

Total injection volume (per treatment day) will not exceed 300 $\mu$ l/mouse.

- 5 NCI-H522 cells in a 1:1 HBSS:Matrigel solution were injected subcutaneously on the right flank. When tumors reached a mean of 250-350 mm<sup>3</sup>, mice were grouped out and treated as follows:
- Group 1: Vehicle (PBS), IP, 1x/week x 4 weeks, n=8-10
- Group 2: Pertuzumab, 25 mg/kg, IP, 1x/week x 4 weeks, n=8-10
- Group 3: HER4:1462, 25 mg/kg, IP, 1x/week x 4 weeks, n=8-10
- 10 Group 4: 526.90.28, 25 mg/kg, IP, 1x/week x 4 weeks, n=8-10
- Group 5: 538.24.71, 25 mg/kg, IP, 1x/week x 4 weeks, n=8-10

Tumors were measured at least once a week and animals were monitored at least twice a week for the duration of the study. Tumor sites were shaved as necessary to facilitate tumor measurements.

- 15 Tumor Growth curves are presented as Linear Mixed Effect (LME) model generated fit of tumor volume graphed as cubic splines with auto-determined knots. Tumor Growth curves and Kaplan-Meier curve were generated as in Example 15. % TGI is the percentage AUC/Day (on the original mm<sup>3</sup> volume scale) reduction compared to control based on the fitted curves for only those days where all treatment groups still have some animals present. Fig. 24.

- 20 These data show that single agent treatment with anti-NRG1 Abs significantly inhibits the growth of tumors driven by NRG1 autocrine signaling. Tumor growth inhibition in the MDA-MB-175 model demonstrates the ability of anti-NRG1 to inhibit tumor growth driven by NRG1 signaling mediated by the HER3 receptor (Fig. 24A), while growth inhibition in the H522 model, which does not express Her3, demonstrates the ability of anti-NRG1 to inhibit the growth of tumors driven by NRG1-
- 25 HER4 signaling (Fig. 24B).

Table A –Sequence Listing Key

SEQ ID	Description
SEQ ID NO: 1	Neuregulin 1 alpha
SEQ ID NO: 2	Neuregulin 1 beta
SEQ ID NO: 3	Neuregulin 1 alpha –EGF domain
SEQ ID NO: 4	Neuregulin 1 beta –EGF domain
SEQ ID NO: 5	HVR H1 538.24 <i>Same for all affinity matured variants</i>
SEQ ID NO: 6	HVR H2 538.24 <i>Same for all affinity matured variants</i>
SEQ ID NO: 7	HVR H3 538.24 <i>Same for all affinity matured variants</i>
SEQ ID NO: 8	HVR L1 538.24; 538.24.17; 538.24.38
SEQ ID NO: 9	HVR L2 538.24; 538.24.17; 538.24.38
SEQ ID NO: 10	HVR L3 538.24
SEQ ID NO: 11	HVR L3 538.24.17
SEQ ID NO: 12	HVR L1 538.24.36
SEQ ID NO: 13	HVR L2 538.24.36
SEQ ID NO: 14	HVR L3 538.24.36
SEQ ID NO: 15	HVR L3 538.24.38
SEQ ID NO: 16	HVR L1 538.24.71
SEQ ID NO: 17	HVR L2 538.24.71; 538.24.94
SEQ ID NO: 18	HVR L3 538.24.71
SEQ ID NO: 19	HVR L1 538.24.94
SEQ ID NO: 20	HVR L3 538.24.94
SEQ ID NO: 21	Heavy chain variable region 538.24 <i>Same for all affinity matured variants</i>
SEQ ID NO: 22	Light chain variable region 538.24
SEQ ID NO: 23	Light chain variable region 538.24.17
SEQ ID NO: 24	Light chain variable region 538.24.36
SEQ ID NO: 25	Light chain variable region 538.24.38
SEQ ID NO: 26	Light chain variable region 538.24.71
SEQ ID NO: 27	Light chain variable region 538.24.94
SEQ ID NO: 28	HVR H1 526.90; 526.90.59; 526.90.75; 526.90.86 526.90.89
SEQ ID NO: 29	HVR H2 526.90 <i>Same for all affinity matured variants</i>
SEQ ID NO: 30	HVR H3 526.90; 526.90.07; 526.90.13; 526.90.15; 526.90.17; 526.90.75
SEQ ID NO: 31	HVR L1 526.90 <i>Same for all affinity matured variants</i>
SEQ ID NO: 32	HVR L2 526.90; 526.90.07; 526.90.13; 526.90.15; 526.90.17; 526.90.26; 526.90.28; 526.90.59; 526.90.89
SEQ ID NO: 33	HVR L3 526.90; 526.90.26; 526.90.28; 526.90.86
SEQ ID NO: 34	HVR H1 526.90.07; 526.90.13
SEQ ID NO: 35	HVR L3 526.90.07
SEQ ID NO: 36	HVR L3 526.90.13
SEQ ID NO: 37	HVR H1 526.90.15

SEQ ID	Description
SEQ ID NO: 38	HVR L3 526.90.15
SEQ ID NO: 39	HVR H1 526.90.17
SEQ ID NO: 40	HVR L3 526.90.17
SEQ ID NO: 41	HVR H1 526.90.26
SEQ ID NO: 42	HVR H3 526.90.26
SEQ ID NO: 43	HVR H3 526.90.28
SEQ ID NO: 44	HVR H3 526.90.59
SEQ ID NO: 45	HVR L3 526.90.59
SEQ ID NO: 46	HVR L2 526.90.75
SEQ ID NO: 47	HVR L3 526.90.75
SEQ ID NO: 48	HVR H3 526.90.86
SEQ ID NO: 49	HVR L2 526.90.86
SEQ ID NO: 50	HVR H3 526.90.89
SEQ ID NO: 51	HVR L3 526.90.89
SEQ ID NO: 52	Heavy chain variable region 526.90
SEQ ID NO: 53	Light chain variable region 526.90; 526.90.26; 526.90.28
SEQ ID NO: 54	Heavy chain variable region 526.90.07
SEQ ID NO: 55	Light chain variable region 526.90.07
SEQ ID NO: 56	Heavy chain variable region 526.90.13
SEQ ID NO: 57	Light chain variable region 526.90.13
SEQ ID NO: 58	Heavy chain variable region 526.90.15
SEQ ID NO: 59	Light chain variable region 526.90.15
SEQ ID NO: 60	Heavy chain variable region 526.90.17
SEQ ID NO: 61	Light chain variable region 526.90.17
SEQ ID NO: 62	Heavy chain variable region 526.90.26
SEQ ID NO: 63	Heavy chain variable region 526.90.28
SEQ ID NO: 64	Heavy chain variable region 526.90.59
SEQ ID NO: 65	Light chain variable region 526.90.59
SEQ ID NO: 66	Heavy chain variable region 526.90.75
SEQ ID NO: 67	Light chain variable region 526.90.75
SEQ ID NO: 68	Heavy chain variable region 526.90.86
SEQ ID NO: 69	Light chain variable region 526.90.86
SEQ ID NO: 70	Heavy chain variable region 526.90.89
SEQ ID NO: 71	Light chain variable region 526.90.89
SEQ ID NO: 72	Heavy chain 538.24.71
SEQ ID NO: 73	Light chain 538.24.71
SEQ ID NO: 74	Heavy chain 526.90.28
SEQ ID NO: 75	Light chain 526.90.28
SEQ ID NO: 76	HVR H1 526.90.28
SEQ ID NO: 77	shNRG1 sense oligonucleotide
SEQ ID NO: 78	shNRG1 antisense oligonucleotide
SEQ ID NO: 79	shNRG1.2 sense oligonucleotide
SEQ ID NO: 80	shNRG1.2 antisense oligonucleotide
SEQ ID NO: 81	shErbB4 sense oligonucleotide
SEQ ID NO: 82	shErbB4 antisense oligonucleotide
SEQ ID NO: 83	shErbB3 sense oligonucleotide
SEQ ID NO: 84	shErbB3 antisense oligonucleotide
SEQ ID NO: 85	Mouse shNRG1 sense oligonucleotide
SEQ ID NO: 86	Mouse shNRG1 antisense oligonucleotide

Although the foregoing invention has been described in some detail by way of illustration and example for purposes of clarity of understanding, the descriptions and examples should not be construed as limiting the scope of the invention. The disclosures of all patent and scientific literature cited herein are expressly incorporated in their entirety by reference.

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## WHAT IS CLAIMED IS:

1. An isolated anti-NRG1 antibody that binds to neuregulin1 $\alpha$  and neuregulin1 $\beta$ .
2. The antibody of claim 1, wherein the antibody binds to the EGF domain of  
5 neuregulin1 $\beta$  and the EGF domain of neuregulin1 $\alpha$ .
3. The antibody of claim 2, wherein the antibody binds to the EGF domain of neuregulin1 $\beta$  with an affinity that is greater than 20-fold, 50-fold, 100-fold, 200-fold, 500-fold, or 1000-fold the affinity to which it binds to EGF domain of neuregulin1 $\alpha$ .
4. The antibody of any one of claims 1-3, wherein the antibody binds to the EGF domain  
10 of neuregulin1 $\beta$  with a kD of 10 nM or less and binds to the EGF domain of neuregulin1 $\alpha$  with a kD of 10 nM or less.
5. The antibody of any one of claims 1-4, wherein the antibody binds to the EGF domain of neuregulin1 $\beta$  with a kD of 10 nM or less, 1 nM or less,  $1 \times 10^{-1}$  nM,  $1 \times 10^{-2}$  nM, or  $1 \times 10^{-3}$  nM.
6. The antibody of any one of claims 3-5, wherein the affinity is measured by a surface  
15 plasmon resonance assay.
7. The antibody of any one of claims 1-6, wherein the antibody binds to an epitope of neuregulin1 $\beta$ , wherein the epitope of neuregulin1 $\beta$  comprises the amino acid sequence of amino acids 1-37 of SEQ ID NO: 4 or the amino acid sequence of amino acids 38-64 of SEQ ID NO: 4.
8. The antibody of claim 7, wherein the epitope of neuregulin1 $\beta$  comprises the amino  
20 acid sequence of SEQ ID NO: 4.
9. The antibody of claim 7 or 8, wherein the antibody further binds to an epitope of neuregulin1 $\alpha$ , wherein the epitope of neuregulin1 $\alpha$  comprises the amino acid sequence of amino acids 1-36 of SEQ ID NO: 3 or the amino acid sequence of amino acids 37-58 of SEQ ID NO: 3.
10. The antibody of claim 9, wherein the epitope of neuregulin1 $\alpha$  comprises the amino  
25 acid sequence of SEQ ID NO: 3.
11. The antibody of any one of claims 1-10, which is a monoclonal antibody.
12. The antibody of any one of claims 1-11, which is a human, humanized, or chimeric antibody.
13. An isolated anti-NRG1 antibody which comprises (a) HVR-H1 comprising the amino  
30 acid sequence of SEQ ID NO: 5, (b) HVR-H2 comprising the amino acid sequence of SEQ ID NO: 6, and (c) HVR-H3 comprising the amino acid sequence of SEQ ID NO: 7.

14. An isolated anti-NRG1 antibody which comprises (a) HVR-L1 comprising the amino acid sequence of SEQ ID NO: 16, (b) HVR-L2 comprising the amino acid sequence of SEQ ID NO: 17, and (c) HVR-L3 comprising the amino acid sequence of SEQ ID NO: 18.

5 15. The antibody of claim 13, further comprising (a) HVR-L1 comprising the amino acid sequence of SEQ ID NO: 16, (b) HVR-L2 comprising the amino acid sequence of SEQ ID NO: 17, and (c) HVR-L3 comprising the amino acid sequence of SEQ ID NO: 18.

16. An isolated anti-NRG1 antibody which comprises (a) HVR-H1 comprising the amino acid sequence of SEQ ID NO: 76, (b) HVR-H2 comprising the amino acid sequence of SEQ ID NO: 29, and (c) HVR-H3 comprising the amino acid sequence of SEQ ID NO: 43.

10 17. An isolated anti-NRG1 antibody which comprises (a) HVR-L1 comprising the amino acid sequence of SEQ ID NO: 31, (b) HVR-L2 comprising the amino acid sequence of SEQ ID NO: 32, and (c) HVR-L3 comprising the amino acid sequence of SEQ ID NO: 33.

15 18. The antibody of claim 16, further comprising (a) HVR-L1 comprising the amino acid sequence of SEQ ID NO: 31, (b) HVR-L2 comprising the amino acid sequence of SEQ ID NO: 32, and (c) HVR-L3 comprising the amino acid sequence of SEQ ID NO: 33.

19. The antibody of any of claims 1-12, comprising (a) a VH sequence having at least 95% sequence identity to the amino acid sequence of SEQ ID NO: 21; (b) a VL sequence having at least 95% sequence identity to the amino acid sequence of SEQ ID NO: 26; or (c) a VH sequence as in (a) and a VL sequence as in (b).

20 20. An isolated anti-NRG1 antibody comprising a VH sequence of SEQ ID NO: 21 and a VL sequence of SEQ ID NO: 26.

21. An isolated anti-NRG1 antibody comprising a VH sequence of SEQ ID NO: 53 and a VL sequence of SEQ ID NO: 63.

22. Isolated nucleic acid encoding the antibody of any of claims 1-21.

25 23. A host cell comprising the nucleic acid of claim 22.

24. A method of producing an antibody comprising culturing the host cell of claim 23 so that the antibody is produced.

25. An immunoconjugate comprising the antibody of any of claims 1-21 and a cytotoxic agent.

30 26. A pharmaceutical formulation comprising the antibody of any of claims 1-21 and a pharmaceutically acceptable carrier.

27. The pharmaceutical formulation of claim 26, further comprising an additional therapeutic agent.

35 28. The pharmaceutical agent of claim 27, wherein the additional therapeutic agent is gemcitabine, paclitaxel, or cisplatin, or a combination of paclitaxal and cisplatin.

29. The antibody of any of claims 1-21 for use as a medicament.

30. The antibody of any of claims 1-21 for use in treating cancer.

31. Use of the antibody of any of claims 1-21 in the manufacture of a medicament.

32. The use of claim 31 wherein the medicament is for treatment of cancer.

5 33. The antibody of claim 30 or the use of claim 32, wherein the cancer is selected from the group consisting non-small cell lung cancer, breast cancer, ovarian cancer, head and neck cancer, cervical cancer, bladder cancer , oesophageal cancer, prostate cancer, and colorectal cancer .

34. A method of treating an individual having cancer comprising administering to the individual an effective amount of the antibody of any of claims 1-21.

10 35. The method of claim 34, wherein the cancer is selected from the group consisting non-small cell lung cancer, breast cancer, ovarian cancer, head and neck cancer, cervical cancer, bladder cancer, oesophageal cancer, prostate cancer, and colorectal cancer .

36. The method of claim 34 or 35 further comprising administering an additional therapeutic agent to the individual.

15 37. The method of claim 36, wherein the additional therapeutic agent is selected from the group consisting of gemcitabine, paclitaxal, carboplatin, and cisplatin or a combination or two or all three of paclitaxal, carboplatin, and cisplatin .

38. A method of increasing time to tumor recurrence in a cancer patient comprising administering to the patient an effective amount of the antibody of any of claims 1-21.

20 39. The method of claim 38, further comprising administering a therapeutic agent to the patient.

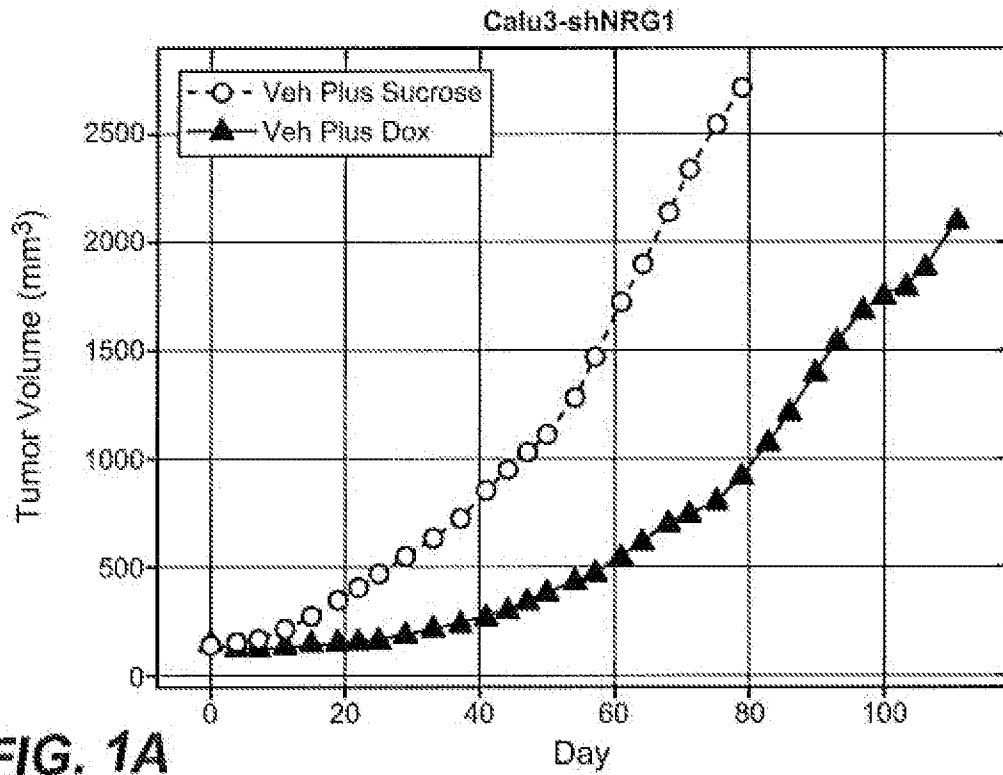
40. The method of claim 39, wherein the therapeutic agent is a chemotherapeutic agent or a second antibody.

25 41. The method of claim 40, wherein the chemotherapeutic agent is selected from the group consisting of gemcitabine, paclitaxal, carboplatin ,and cisplatin or a combination or two or all three of paclitaxal, carboplatin, and cisplatin.

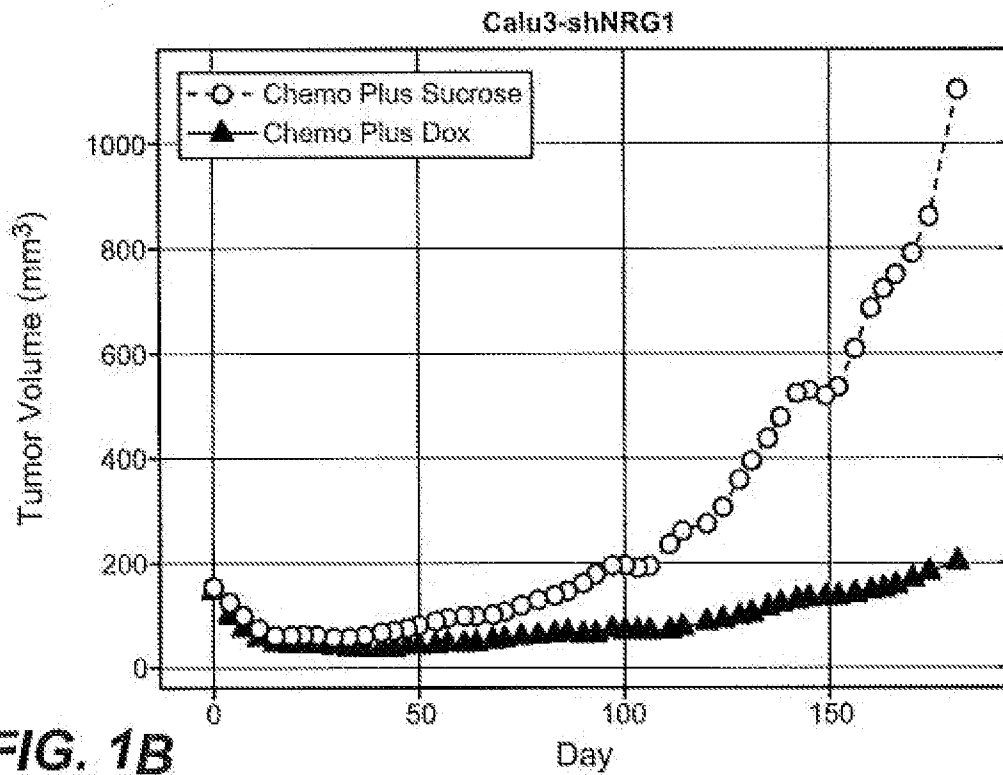
42. The method of claim 40, wherein the second antibody binds to a target selected from the group consisting of EGFR, HER2, HER3, or HER4, or binds to two or more of the targets selected from the group consisting of EGFR, HER2, HER3, or HER4.

30 43. The method of claim 42, wherein the cancer is selected from the group consisting of non-small cell lung cancer, breast cancer, ovarian cancer, head and neck cancer, cervical cancer, bladder cancer , oesophageal cancer, prostate cancer, and colorectal cancer .

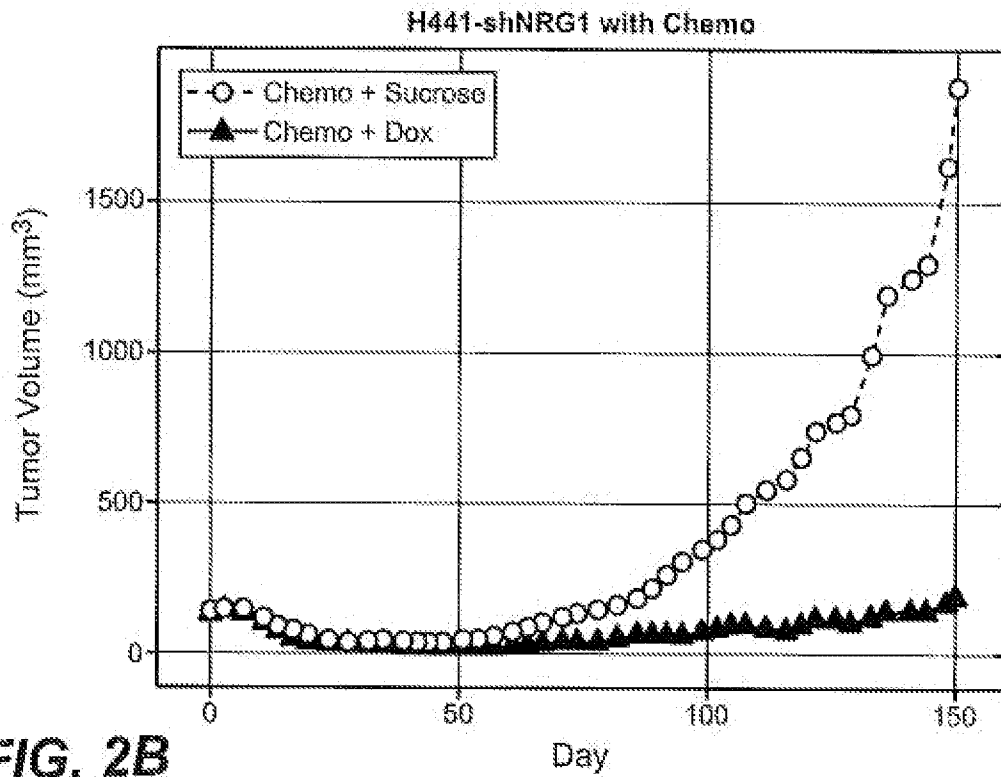
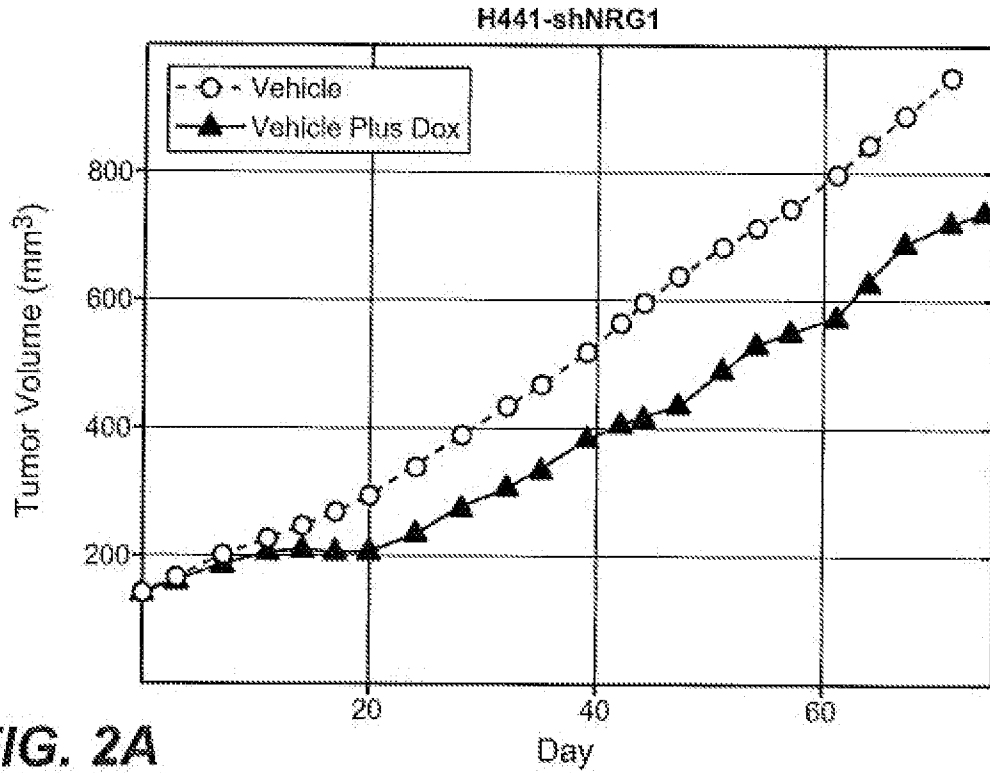
44. The method of claim 38, wherein the increase in time to tumor recurrence is at least 1.25 fold greater or at least 1.50 fold greater than the time to recurrence in the absence of the antibody.

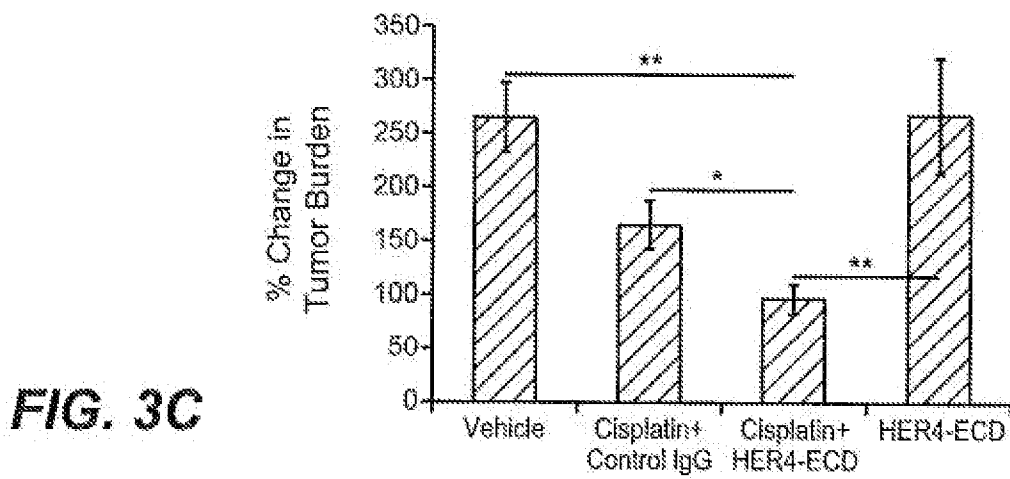
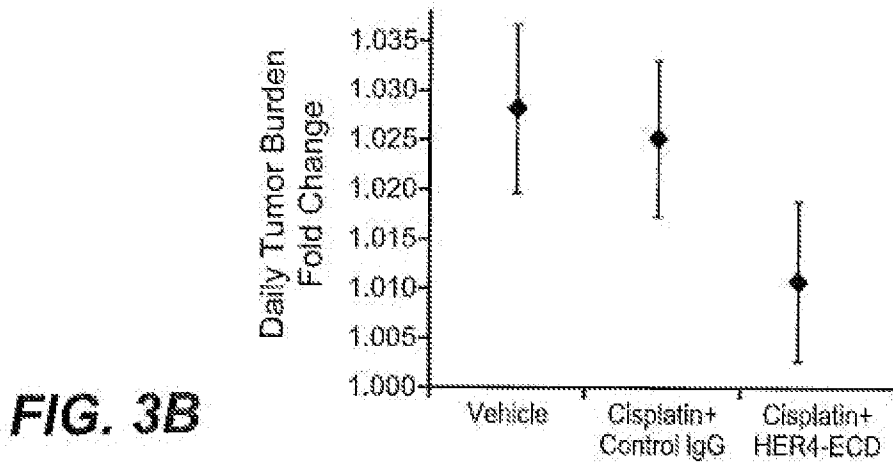
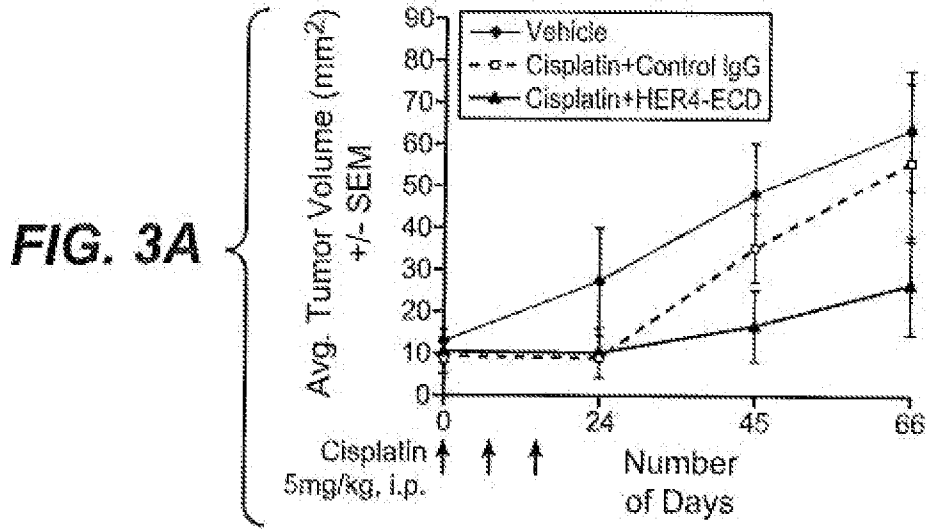


**FIG. 1A**

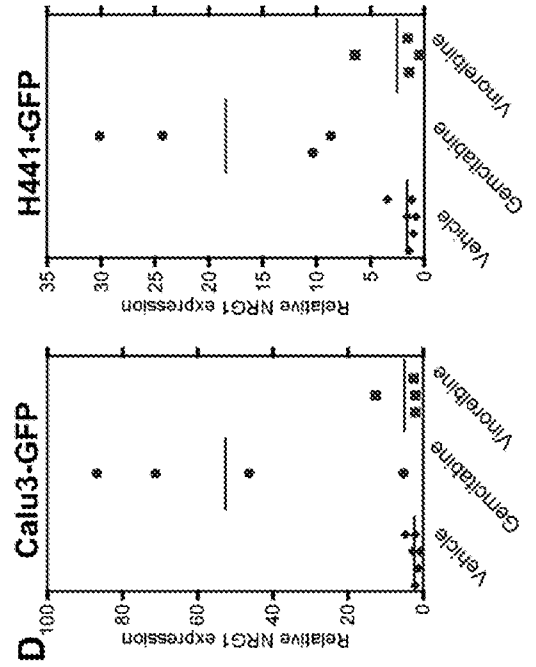
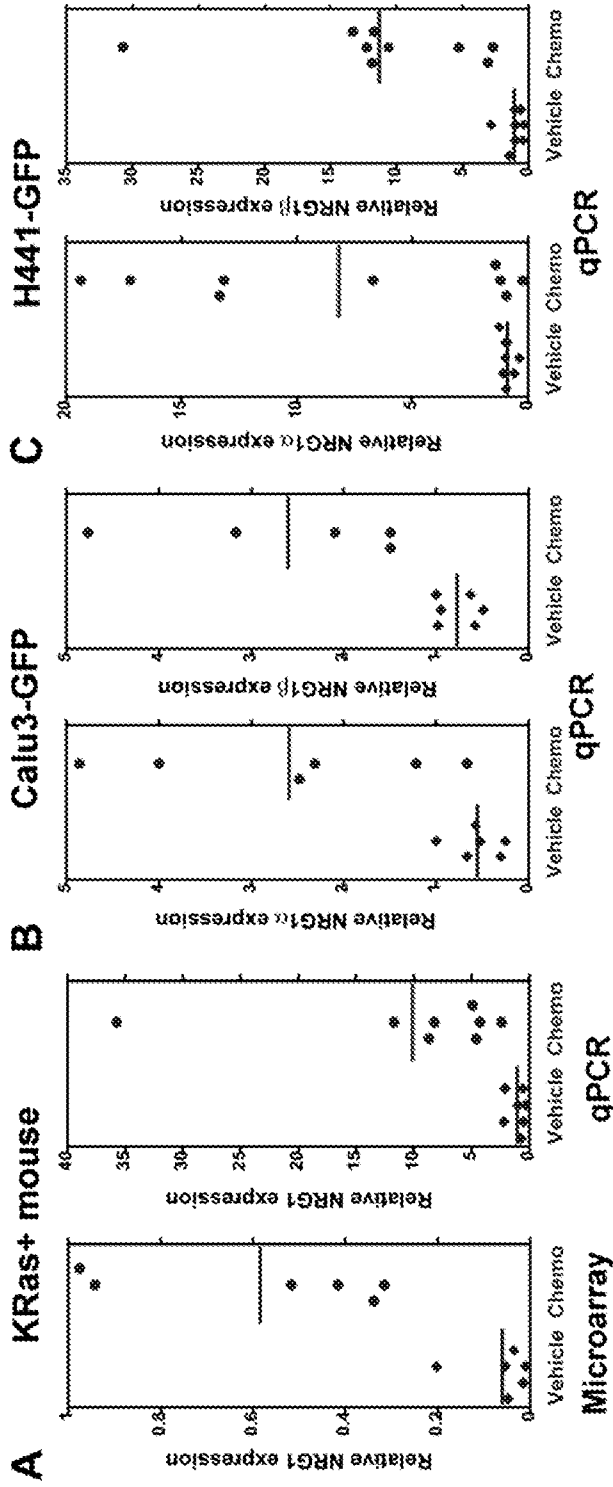


**FIG. 1B**









**FIG. 4**

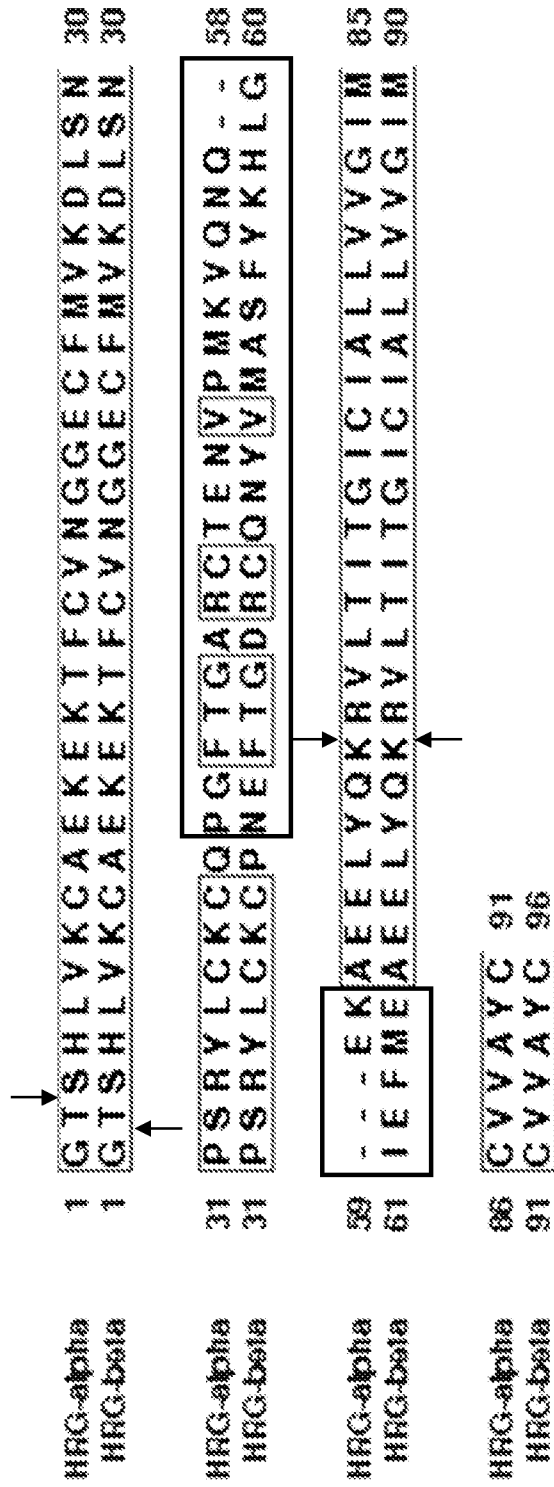


FIG. 5



FIG. 6

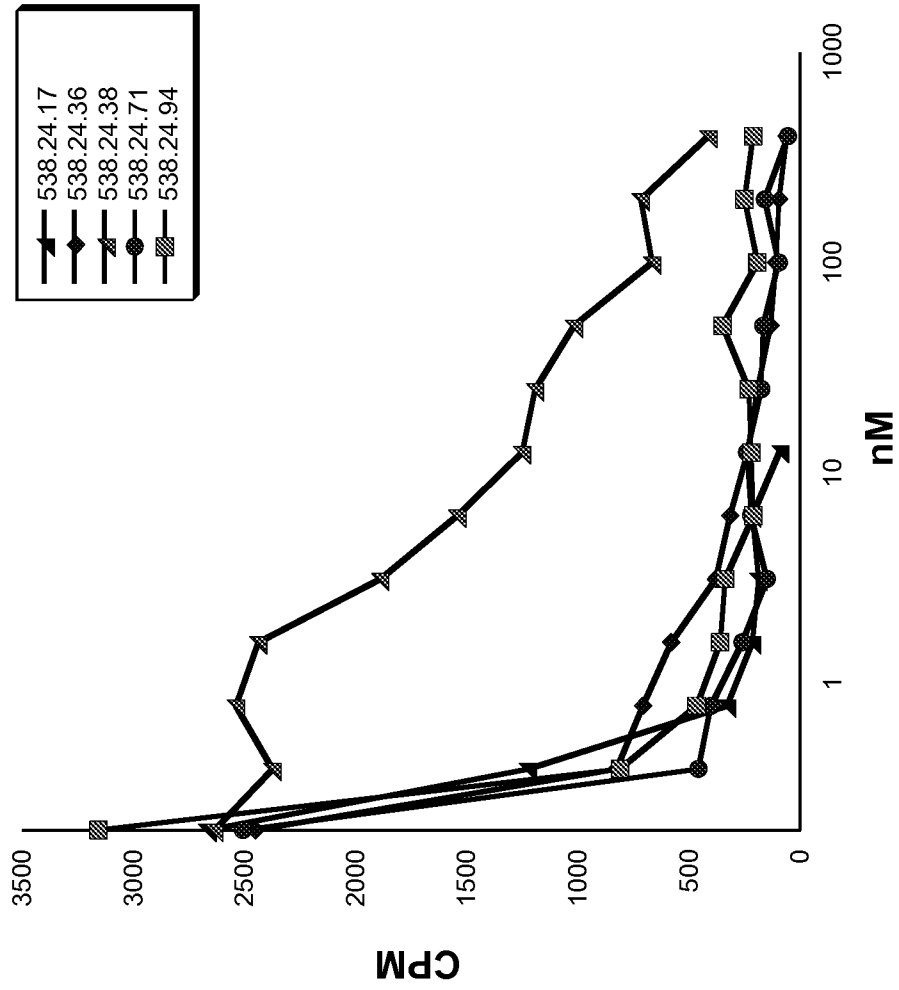
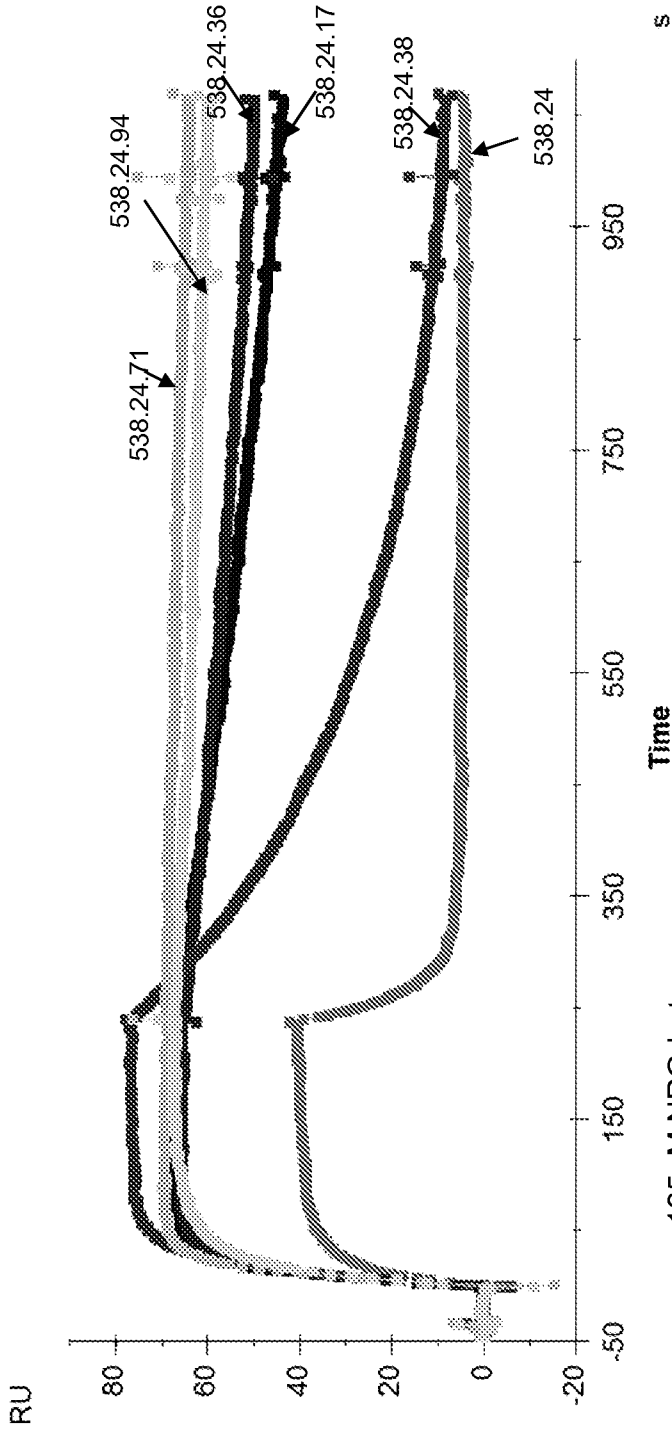
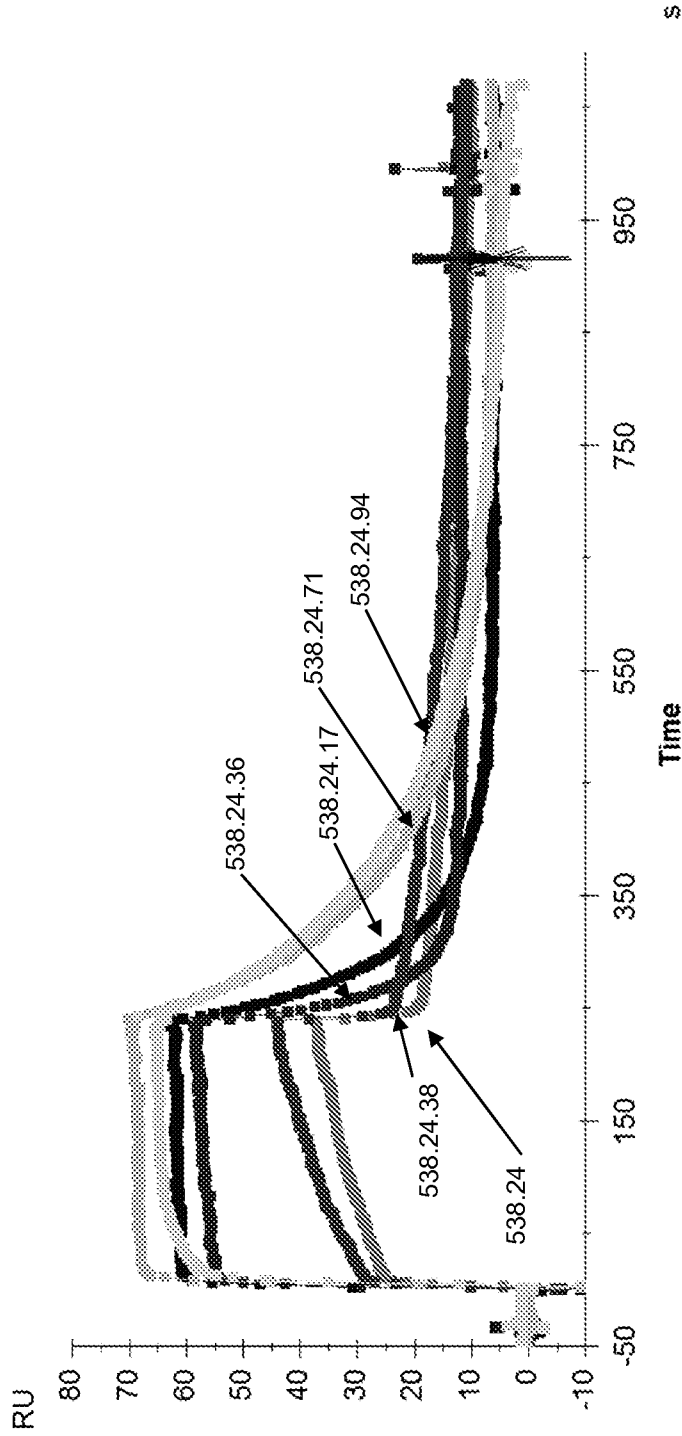


FIG. 7



	<b>ka (1/ Ms)</b>	<b>kd (1/s)</b>	<b>KD (nM)</b>
538.24			
538.24.17	1.56E+06	8.10E-03	5.18
538.24.36	1.91E+06	2.52E-02	13.2
538.24.38	n.d.	n.d.	n.d.
538.24.71	1.50E+07	3.00E-02	2.00
538.24.94	4.80E+05	1.27E-02	1.96

FIG. 8



250 nM NRG1-alpha

	<b>ka (1/MS)</b>	<b>kd (1/s)</b>	<b>KD (nM)</b>
538.24			>400
538.24.17	1.56E+06	8.10E-03	5.18
538.24.36	1.91E+06	2.52E-02	13.2
538.24.38	n.d.	n.d.	n.d.
538.24.71	1.50E+07	3.00E-02	2.00
538.24.94	4.80E+05	1.27E-02	1.96

FIG. 9

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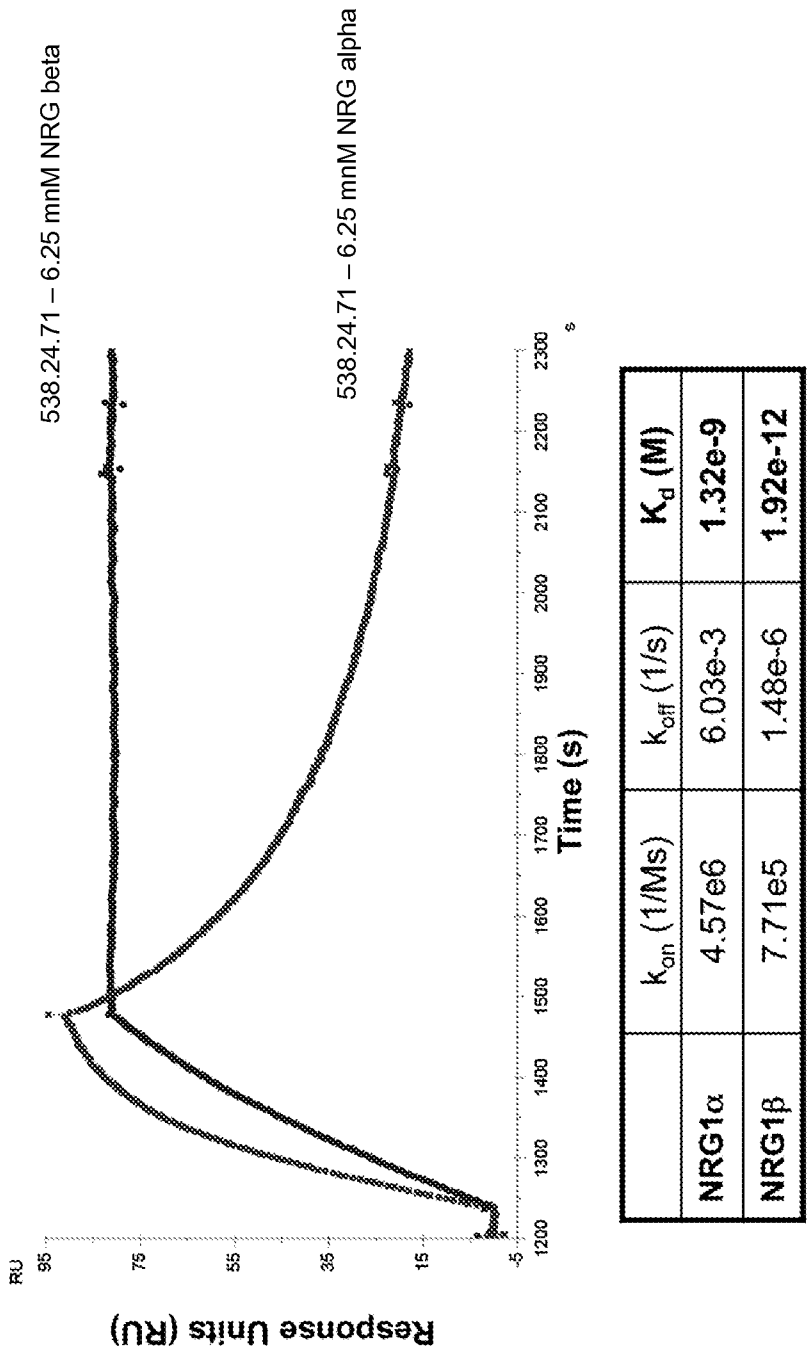
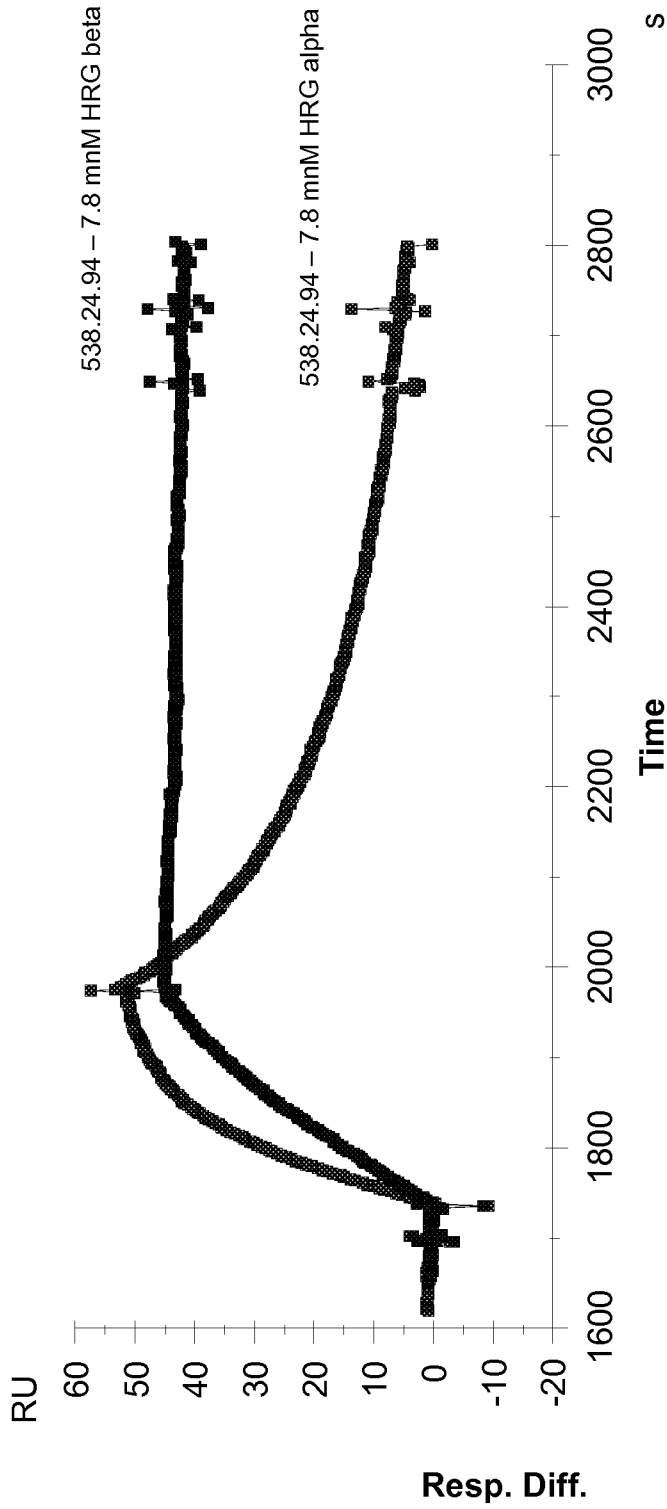


FIG. 10



	ka (1/Ms)	kd (1/s)	KD (M)
HRG-alpha	3.87e6	6.74e-3	1.74e-9
HRG-beta	6.74e5	7.34e-5	1.09e-10

FIG. 11



12/29

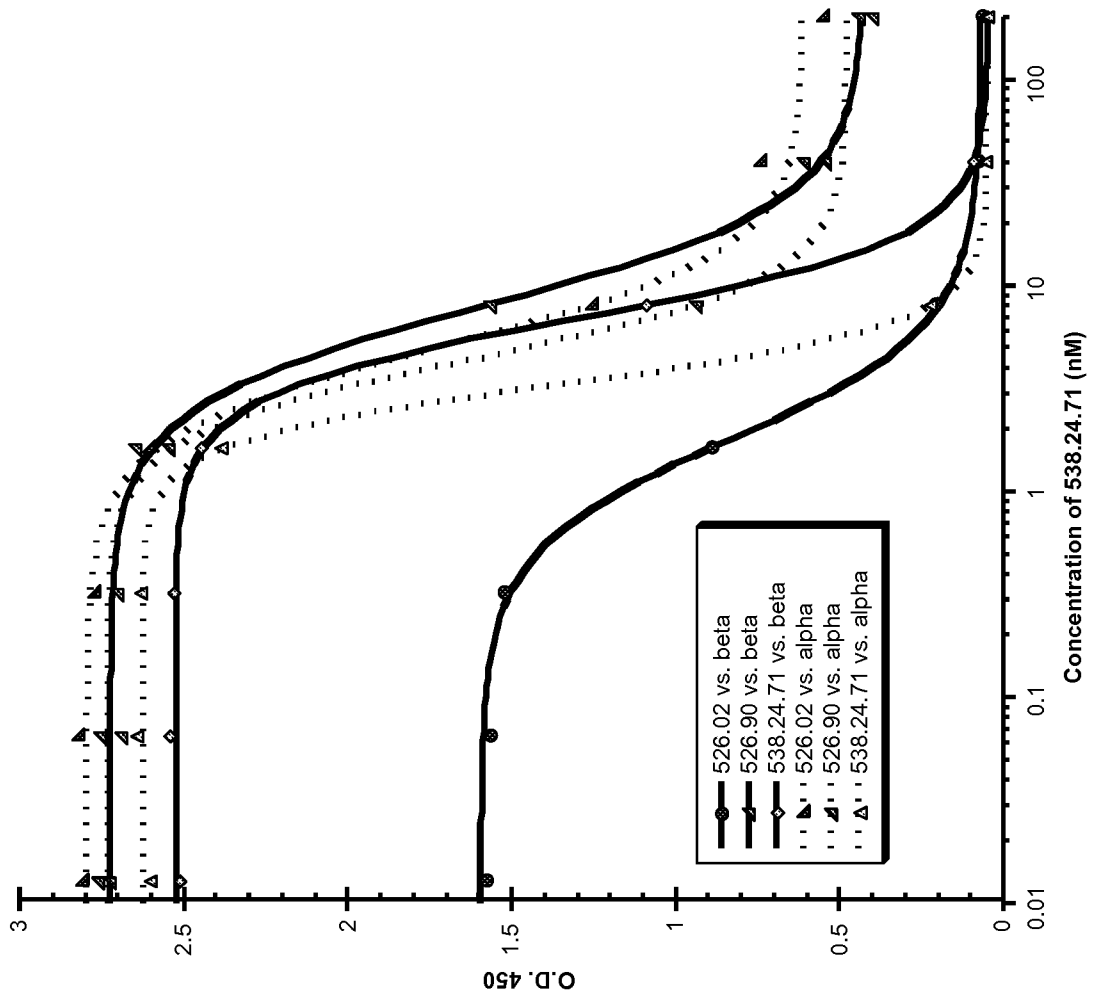
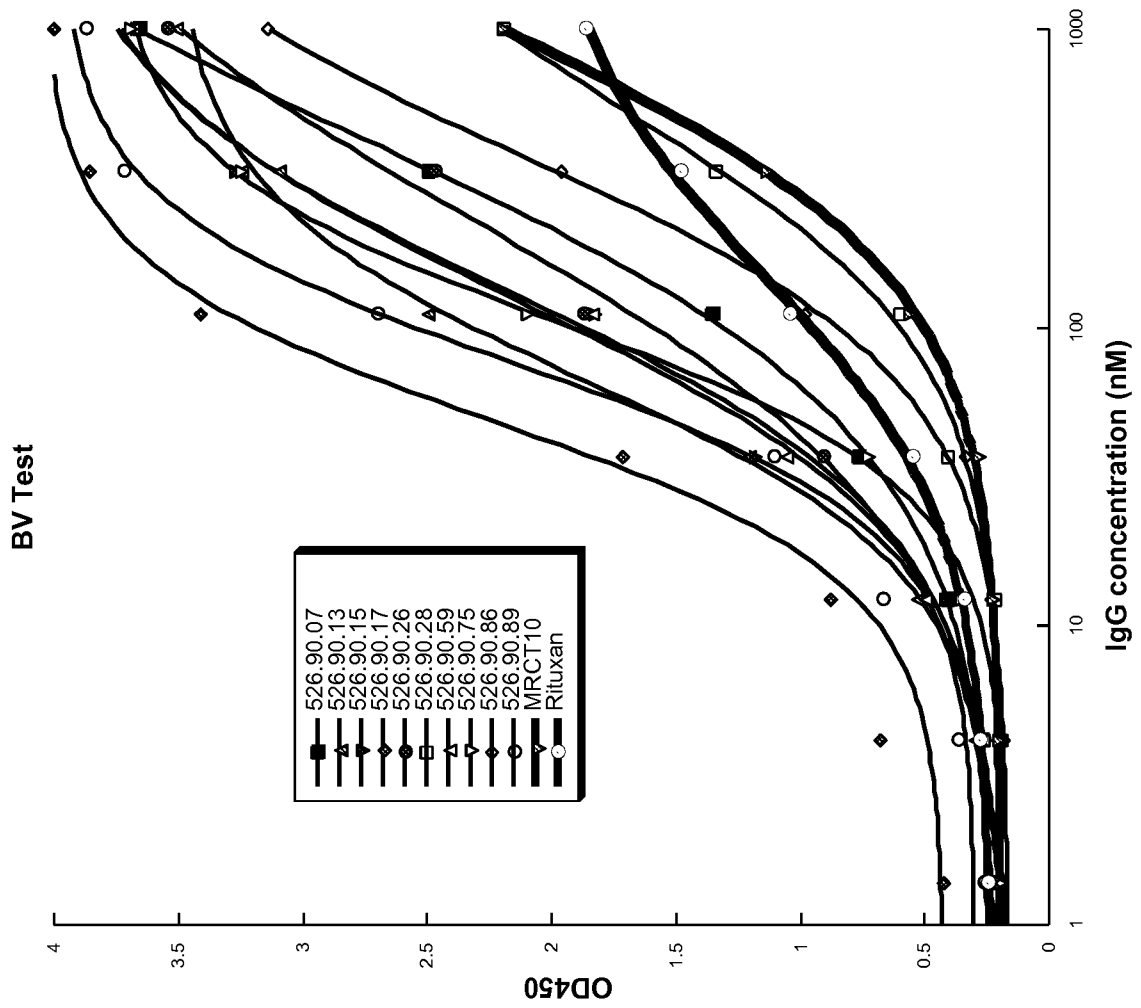


FIG. 12

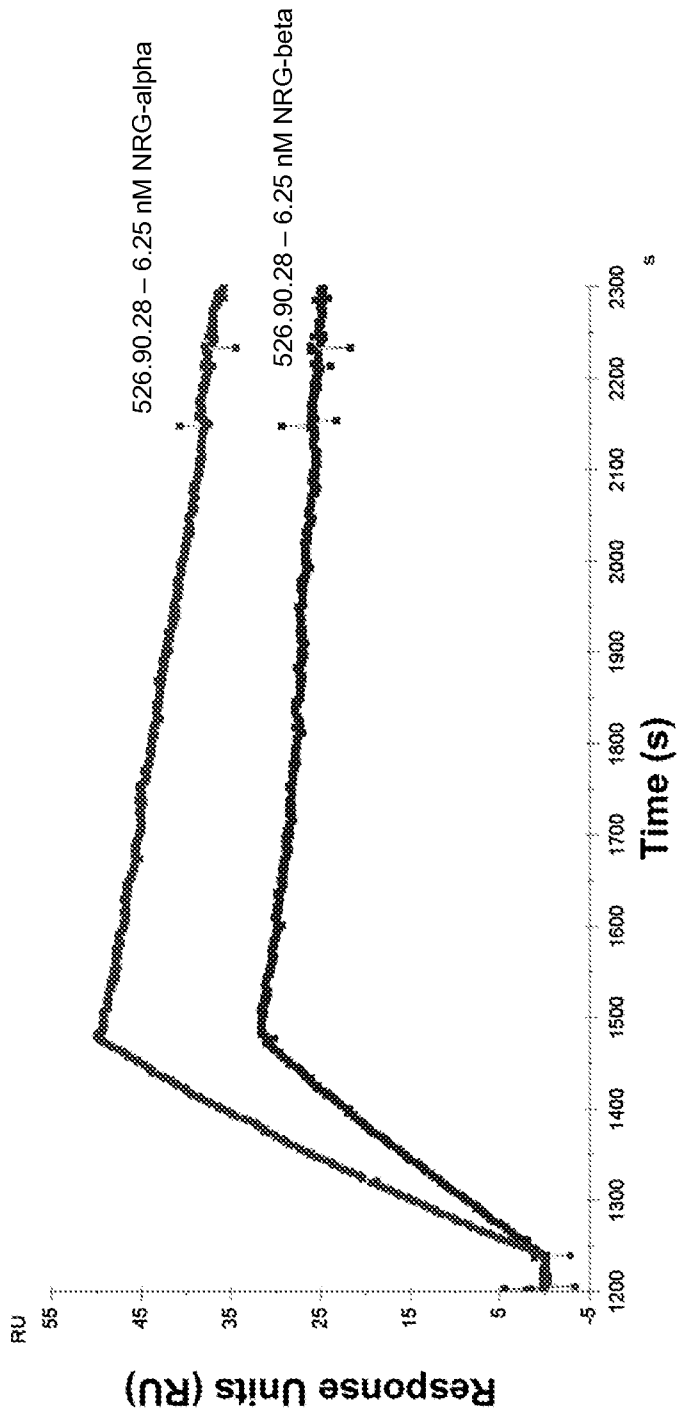
KIRA assay: MCF7 cells, with anti-HER3 Ab captured

xNRG Abs	Sample ID	Blocking NRG -a (@0.5 nM)			Blocking NRG -b (@0.2 nM)		
		IC50 (nM)			IC50 (nM)		
1	526.90.07	22.4	+ 10.8	+	3.7	+ 1.3	++
2	526.90.13	9.0	+ 1.3	+++	2.4	+ 0.5	+++
3	526.90.15	16.2	+ 5.0	++	13.6	+ 5.0	+
4	526.90.17	11.8	+ 2.1	++	8.5	+ 3.1	+
5	526.90.26	19.6	+ 4.2	++	1.8	+ 1.0	+++
6	526.90.28	13.9	+ 4.8	++	1.1	+ 0.5	+++
7	526.90.59	11.6	+ 3.2	++	0.1	+ 0.1	++++
8	526.90.75	23.9	+ 7.7	+	8.6	+ 2.3	+
9	526.90.86	13.0	+ 6.8	++	10.0	+ 4.6	+
10	526.90.89	9.6	+ 1.4	+++	0.6	+ 0.1	+++
11	538.24.71	14.0	+ 2.8	++	0.1	+ 0.0	++++
12	526.90 parental	n/a	+ n/a	+	n/a	+ n/a	+/-

FIG. 13

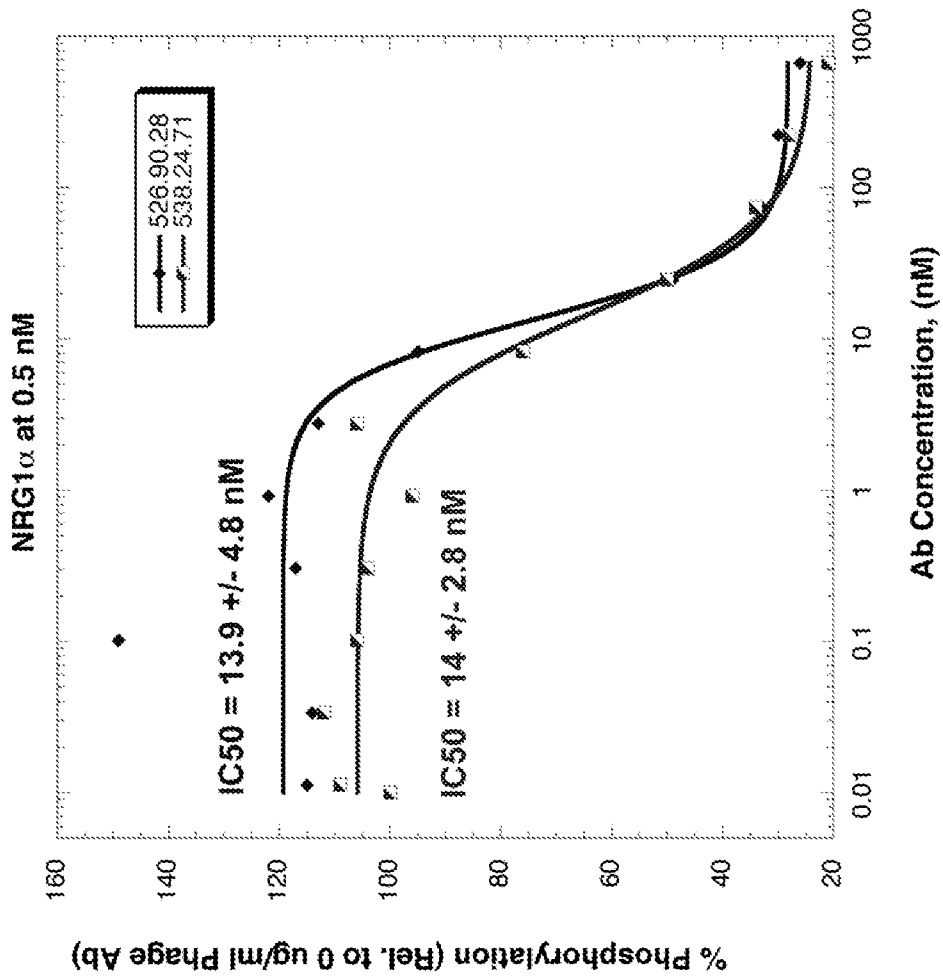


**FIG. 14**

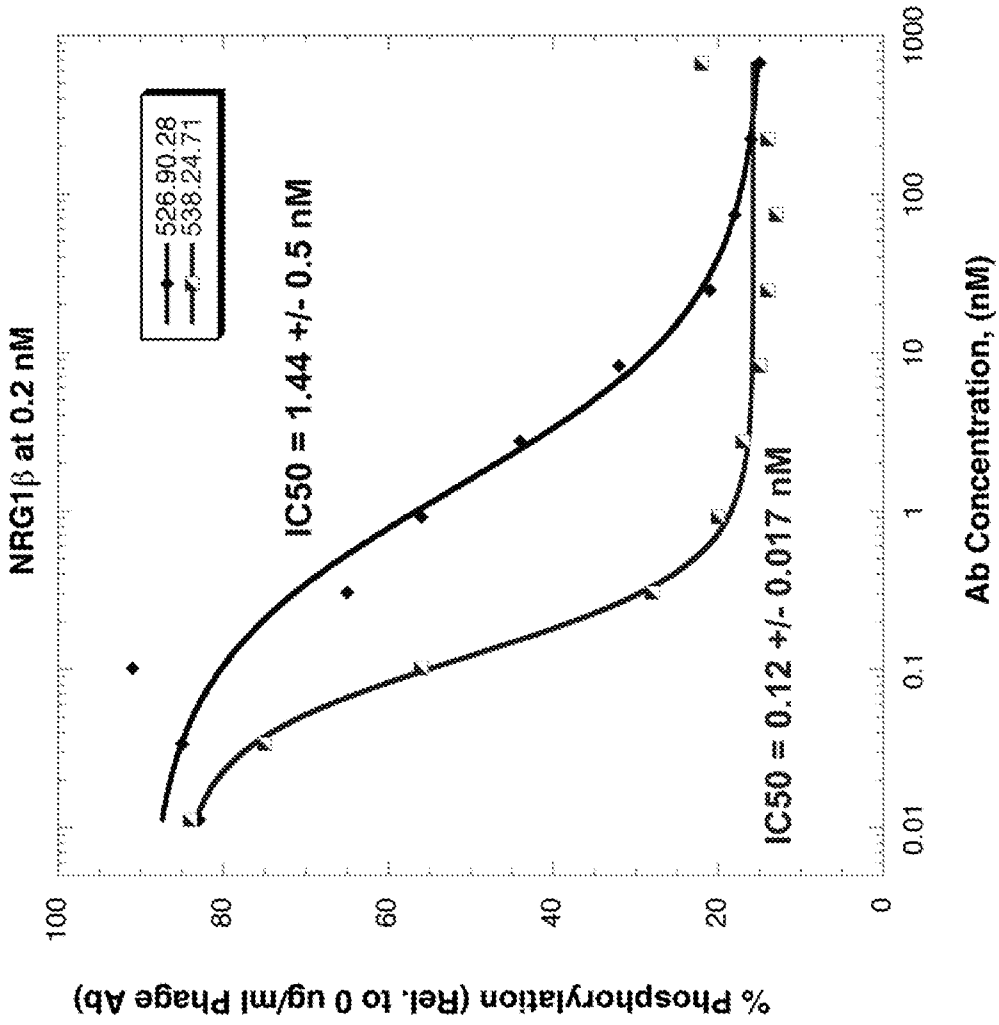


	$k_{on}$ (1/Ms)	$k_{off}$ (1/s)	$K_d$ (M)
<b>NRG1<math>\alpha</math></b>	1.01e6	5.95e-4	<b>5.87e-10</b>
<b>NRG1<math>\beta</math></b>	3.37e5	3.67e-4	<b>1.09e-9</b>

**FIG. 15**



**FIG. 16**



**FIG. 17**

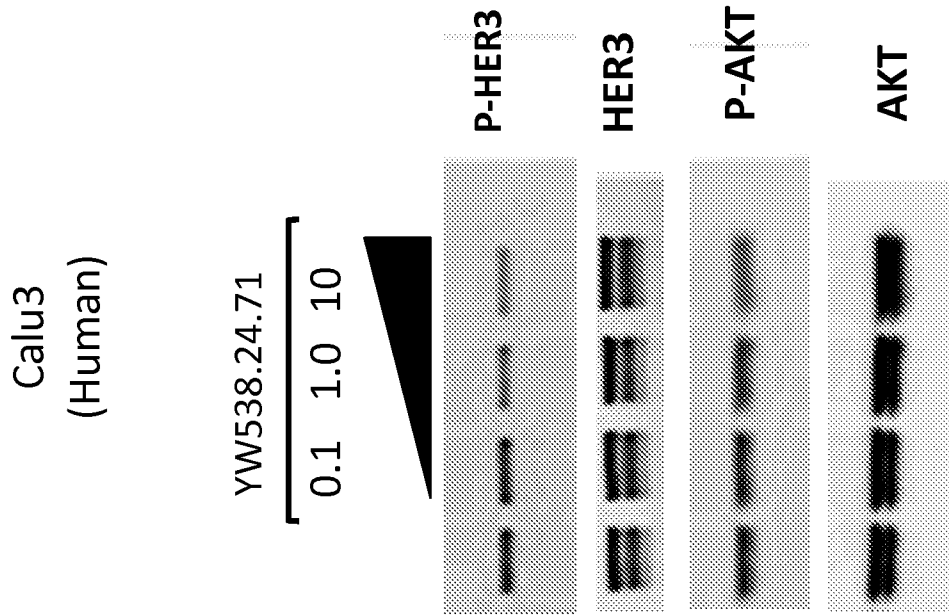
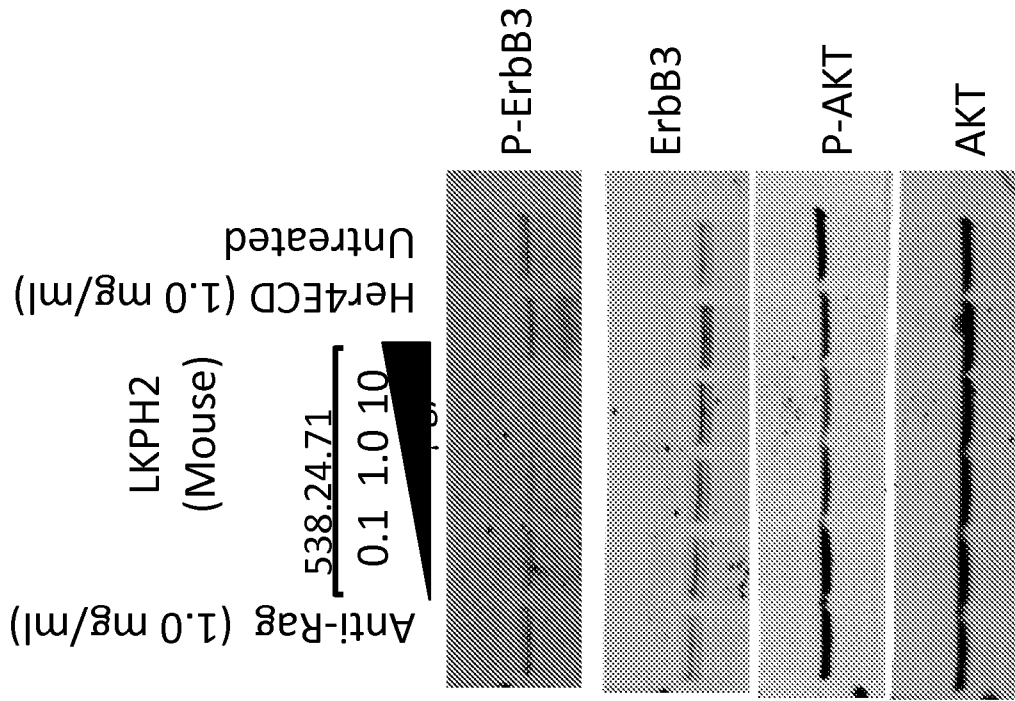


FIG. 18

# FaDu HNSCC Model

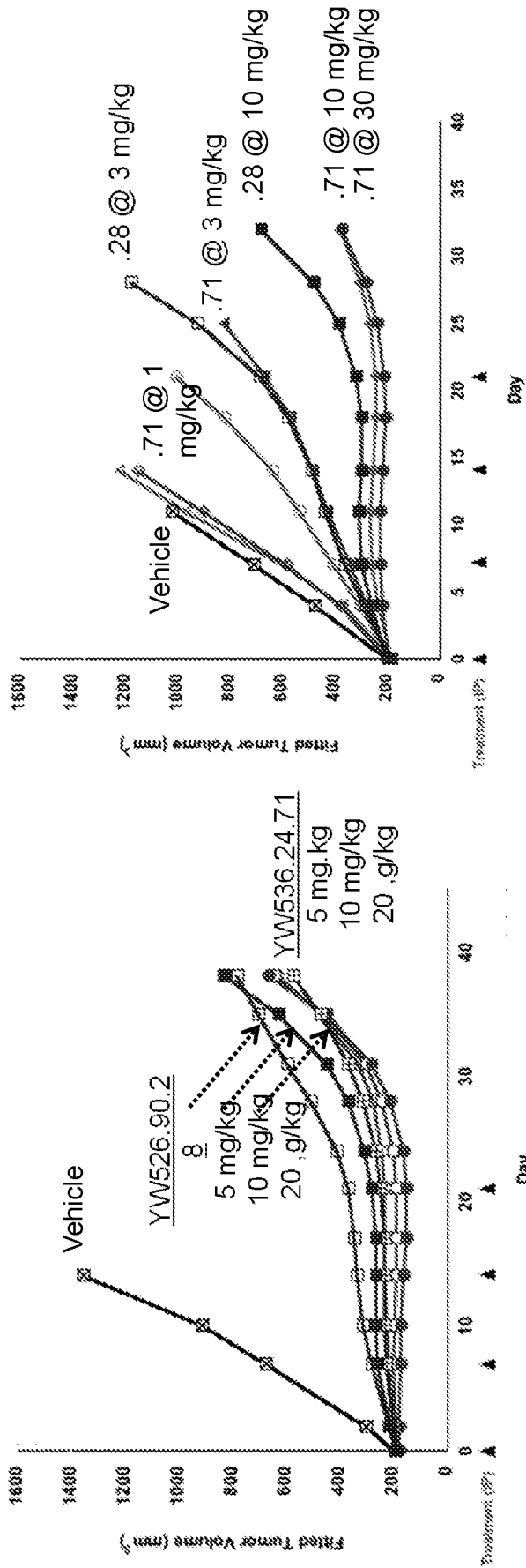
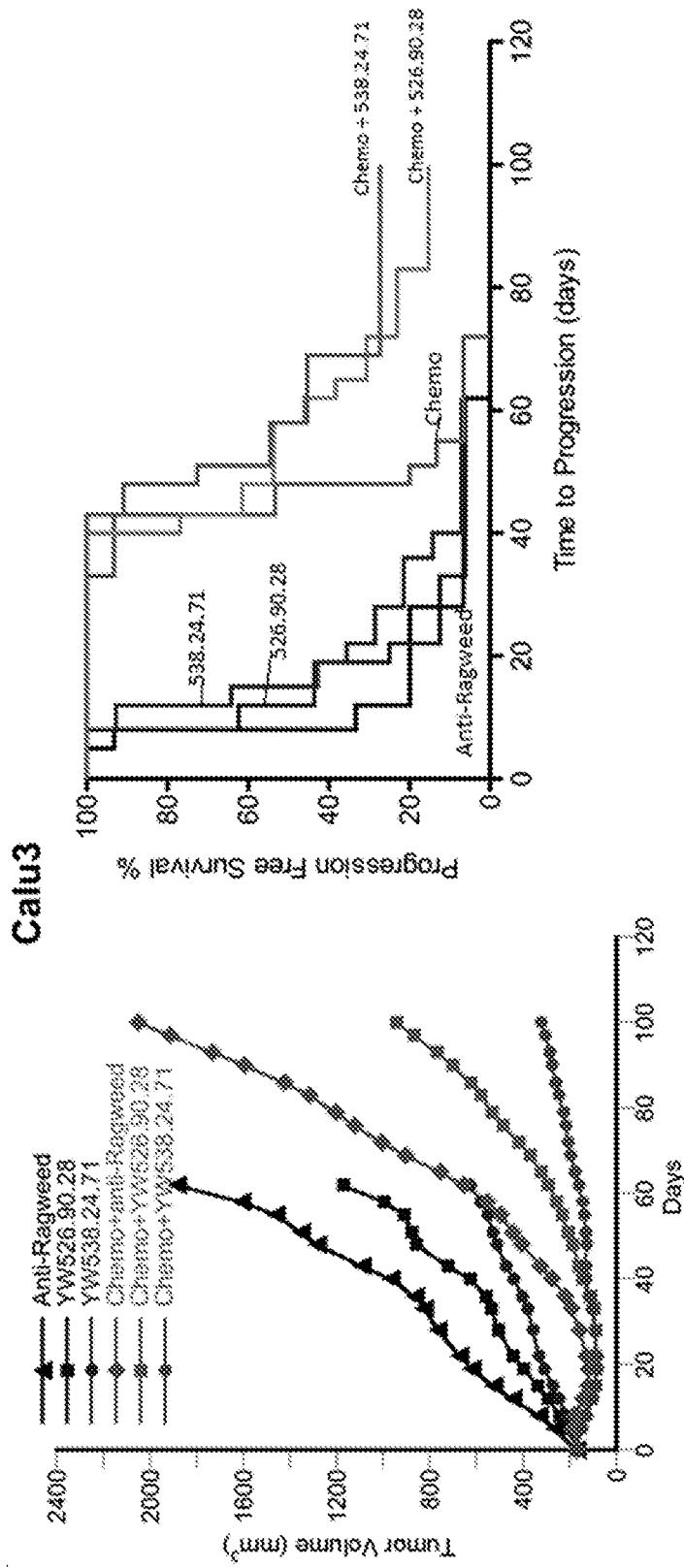


FIG. 19





**FIG. 20**

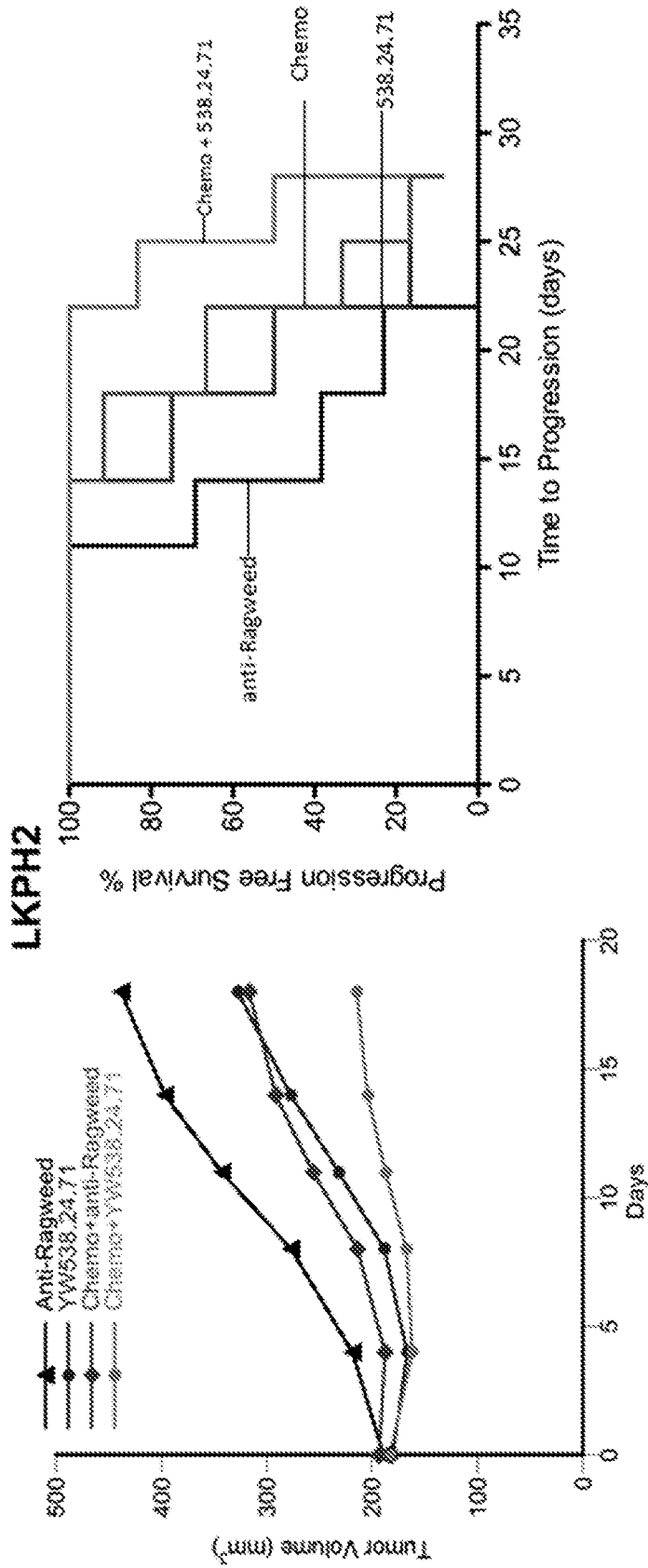
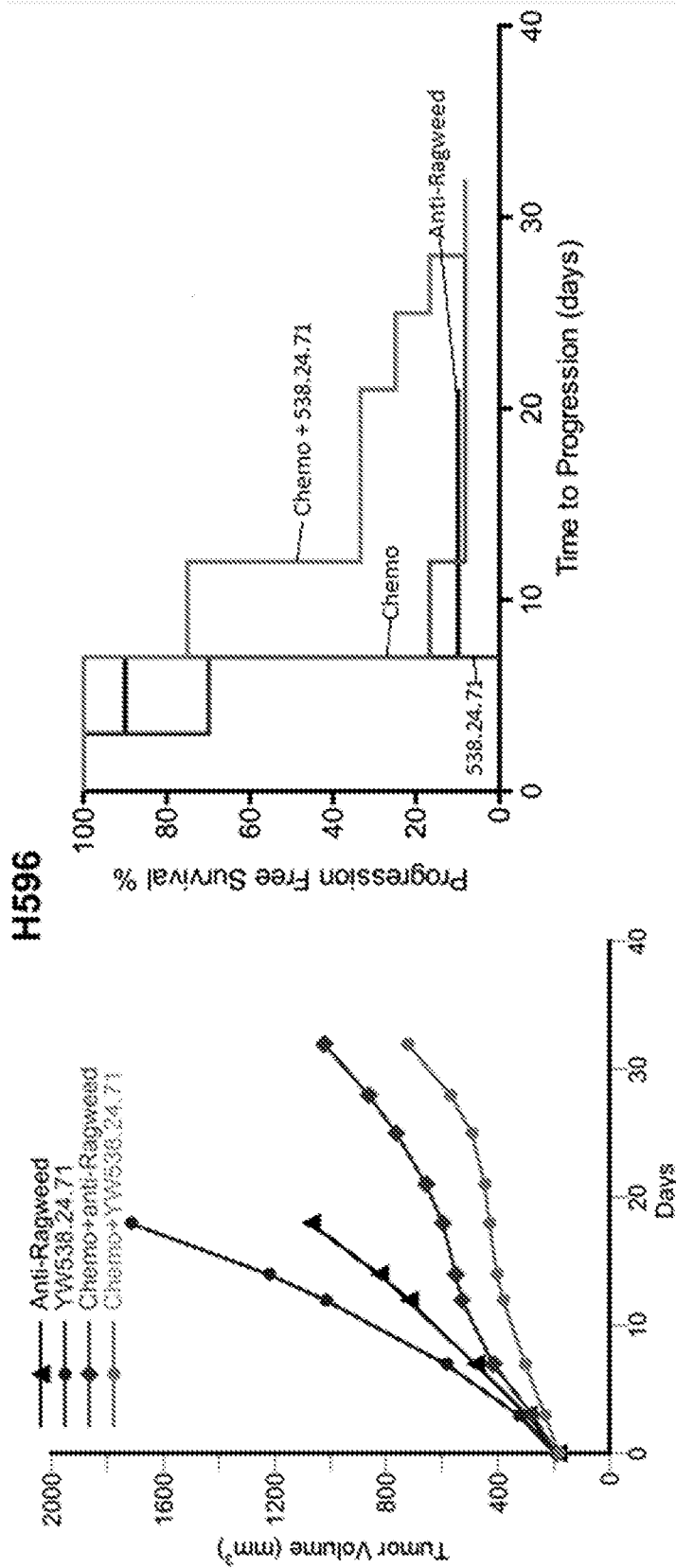
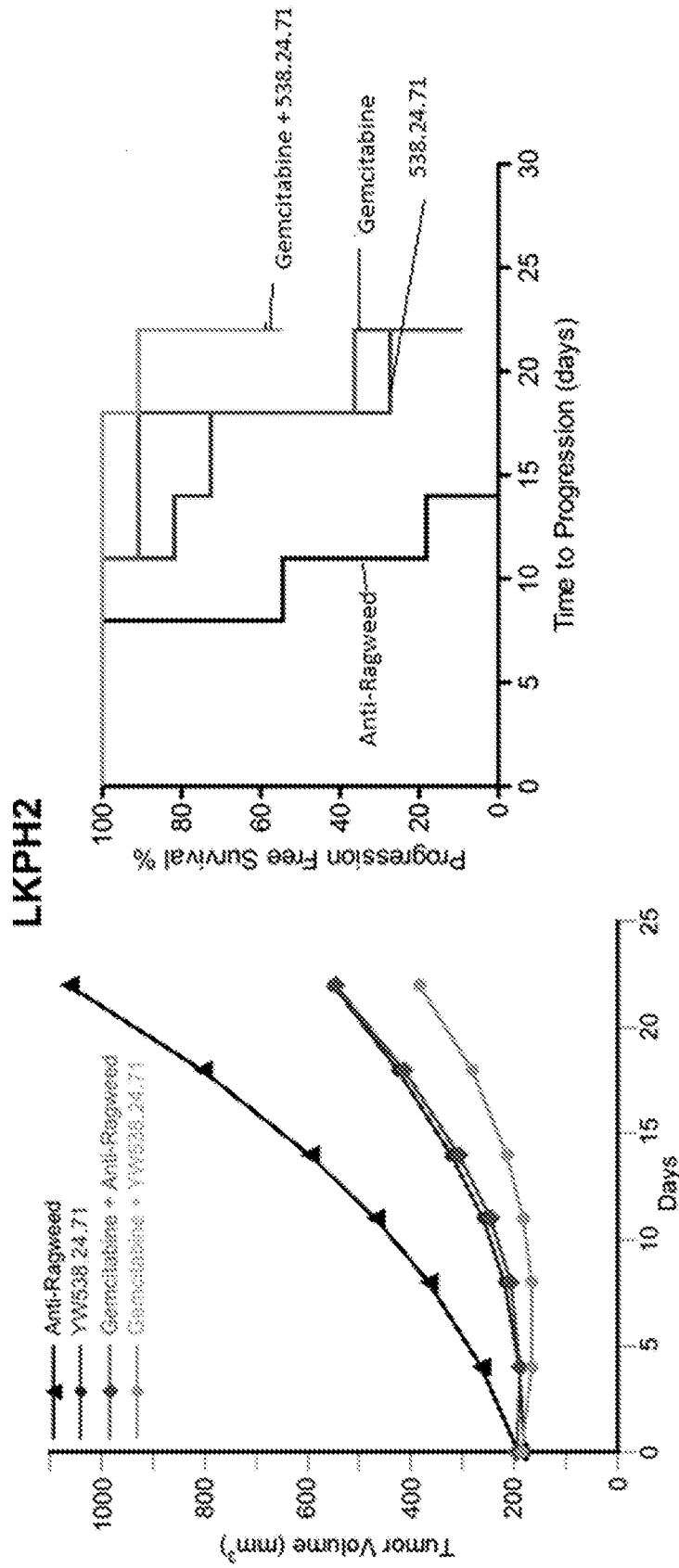


FIG. 21



**FIG. 22**



**FIG. 23**

MDA-MB Breast Cancer Model

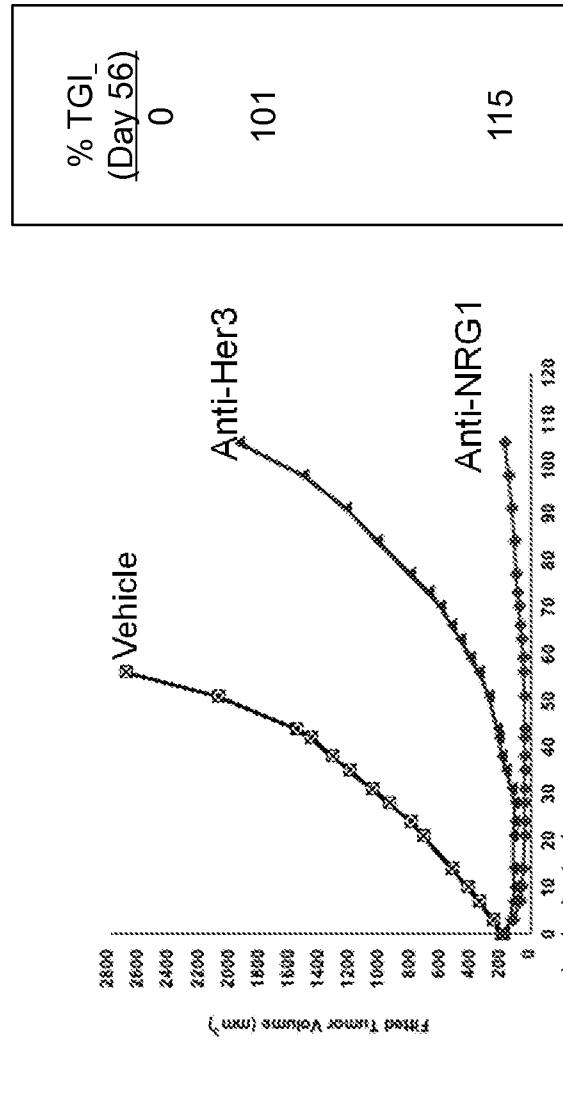
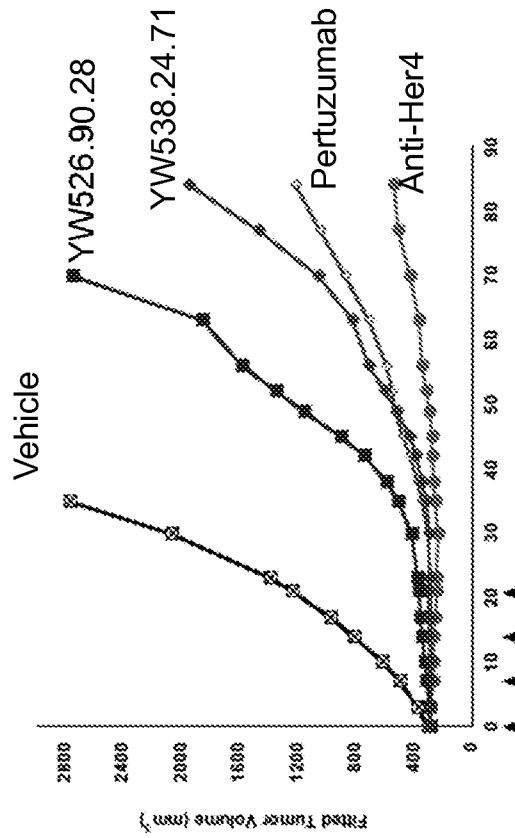


FIG. 24A

H522 NSCLC Model

Treatment IP	% TGI (Day 35)
Vehicle	0
YW526	91
YW538	100
Pertuzumab	100
Anti-Her4	105



Treatment IP

FIG. 24B







K:82418 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 4 8 36 37 38 39 40

526.9 E V Q L V E S G C G L Y Q P G G S L R L S C A A S G T F S G N A M S - - W V R Q A  
 526.90.07 E V Q L V E S G C G L Y Q P G G S L R L S C A A S G T F S G N A M S - - W V R Q A  
 526.90.10 E V Q L V E S G C G L Y Q P G G S L R L S C A A S G T F S G N A M S - - W V R Q A  
 526.90.15 E V Q L V E S G C G L Y Q P G G S L R L S C A A S G T F S G N A M S - - W V R Q A  
 526.90.17 E V Q L V E S G C G L Y Q P G G S L R L S C A A S G T F S G N A M S - - W V R Q A  
 526.90.26 E V Q L V E S G C G L Y Q P G G S L R L S C A A S G T F S G N A M S - - W V R Q A  
 526.90.28 E V Q L V E S G C G L Y Q P G G S L R L S C A A S G T F S G N A M S - - W V R Q A  
 526.90.59 E V Q L V E S G C G L Y Q P G G S L R L S C A A S G T F S G N A M S - - W V R Q A  
 526.90.75 E V Q L V E S G C G L Y Q P G G S L R L S C A A S G T F S G N A M S - - W V R Q A  
 526.90.86 E V Q L V E S G C G L Y Q P G G S L R L S C A A S G T F S G N A M S - - W V R Q A  
 526.90.89 E V Q L V E S G C G L Y Q P G G S L R L S C A A S G T F S G N A M S - - W V R Q A

K:82418 41 42 43 44 45 46 47 48 49 50 51 52 4 8 C 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79

526.9 F C K G L E W V S W I Y P - - S G C N T Y Y A D S V K G R F F T I S A D I S K N T A Y  
 526.90.07 F C K G L E W V S W I Y P - - S G C N T Y Y A D S V K G R F F T I S A D I S K N T A Y  
 526.90.13 F C K G L E W V S W I Y P - - S G C N T Y Y A D S V K G R F F T I S A D I S K N T A Y  
 526.90.15 F C K G L E W V S W I Y P - - S G C N T Y Y A D S V K G R F F T I S A D I S K N T A Y  
 526.90.17 F C K G L E W V S W I Y P - - S G C N T Y Y A D S V K G R F F T I S A D I S K N T A Y  
 526.90.26 F C K G L E W V S W I Y P - - S G C N T Y Y A D S V K G R F F T I S A D I S K N T A Y  
 526.90.28 F C K G L E W V S W I Y P - - S G C N T Y Y A D S V K G R F F T I S A D I S K N T A Y  
 526.90.59 F C K G L E W V S W I Y P - - S G C N T Y Y A D S V K G R F F T I S A D I S K N T A Y  
 526.90.75 F C K G L E W V S W I Y P - - S G C N T Y Y A D S V K G R F F T I S A D I S K N T A Y  
 526.90.86 F C K G L E W V S W I Y P - - S G C N T Y Y A D S V K G R F F T I S A D I S K N T A Y  
 526.90.89 F C K G L E W V S W I Y P - - S G C N T Y Y A D S V K G R F F T I S A D I S K N T A Y

K:82418 80 81 82 4 8 C 83 84 85 86 87 88 89 90 31 92 93 94 95 96 97 98 99 100 A B C D E F G 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115

526.9 L Q M N S L R A E E D T A V Y Y C A R S Y I L S Y P S I T W A F D Y W C Q G T L V I V S S  
 526.90.07 L Q M N S L R A E E D T A V Y Y C A R S Y I L S Y P S I T W A F D Y W C Q G T L V I V S S  
 526.90.10 L Q M N S L R A E E D T A V Y Y C A R S Y I L S Y P S I T W A F D Y W C Q G T L V I V S S  
 526.90.15 L Q M N S L R A E E D T A V Y Y C A R S Y I L S Y P S I T W A F D Y W C Q G T L V I V S S  
 526.90.17 L Q M N S L R A E E D T A V Y Y C A R S Y I L S Y P S I T W A F D Y W C Q G T L V I V S S  
 526.90.26 L Q M N S L R A E E D T A V Y Y C A R S Y I L S Y P S I T W A F D Y W C Q G T L V I V S S  
 526.90.28 L Q M N S L R A E E D T A V Y Y C A R S Y I L S Y P S I T W A F D Y W C Q G T L V I V S S  
 526.90.59 L Q M N S L R A E E D T A V Y Y C A R S Y I L S Y P S I T W A F D Y W C Q G T L V I V S S  
 526.90.75 L Q M N S L R A E E D T A V Y Y C A R S Y I L S Y P S I T W A F D Y W C Q G T L V I V S S  
 526.90.86 L Q M N S L R A E E D T A V Y Y C A R S Y I L S Y P S I T W A F D Y W C Q G T L V I V S S  
 526.90.89 L Q M N S L R A E E D T A V Y Y C A R S Y I L S Y P S I T W A F D Y W C Q G T L V I V S S

FIG. 27

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FIG. 28

## INTERNATIONAL SEARCH REPORT

International application No  
PCT/US2012/051033

A. CLASSIFICATION OF SUBJECT MATTER INV. C07K16/22 A61K39/395 A61P35/00 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols) C07K		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data, BIOSIS, EMBASE		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
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Y	the whole document in particular section 2.5.1 ----- -/--	3-6, 11-44
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.		
* Special categories of cited documents :		
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention	
"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone	
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art	
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family	
"P" document published prior to the international filing date but later than the priority date claimed		
Date of the actual completion of the international search  31 October 2012	Date of mailing of the international search report  19/11/2012	
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer  Pérez-Mato, Isabel	

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International application No  
PCT/US2012/051033

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