ANTIBODIES AGAINST THE ECTODOMAIN OF ERBB3 AND USES THEREOF

Background of the Invention

The ErbB/HER subfamily of polypeptide growth factor receptors include the epidermal growth factor (EGF) receptor (EGFR/ErbB1/HER1), the *neu* oncogene product (ErbB2/HER2), and the more recently identified ErbB3/HER3 and ErbB4/HER4 receptor proteins (see, *e.g.*, Hynes *et. al.* (1994) *Biochim. Biophys. Acta Rev. Cancer* 1198, 165–184). Each of these receptors is predicted to consist of an ectodomain (extracellular ligand-binding domain), a membrane-spanning domain, a cytosolic, protein tyrosine kinase (PTK) domain and a C-terminal phosphorylation domain (see, *e.g.*, Kim *et al.*, (1998) *Biochem. J.* 334, 189-195). The ectodomains of the ErbB receptors are further characterized as being divided into four domains (I-IV). Domains I and III of the ErbB ectodomain are involved in ligand binding (see, *e.g.*, Hynes *et. al.* (2005) *Nature Rev. Cancer* 5, 341-354). Ligands for these receptors include heregulin (HRG) and betacellulin (BTC).

Experiments *in vitro* have indicated that the protein tyrosine kinase activity of the ErbB3 receptor (ErbB3) protein is attenuated significantly relative to that of other ErbB/HER family members and this attenuation has been attributed, in part, to the occurrence of non-conservative amino acid substitutions in the predicted intracellular catalytic domain of ErbB3 (see, *e.g.*, Guy *et al.* (1994) *Proc. Natl. Acad. Sci. USA*. 91, 8132–8136; Sierke *et al.* (1997) Biochem. J. 322, 757–763). However, the ErbB3 protein has been shown to be phosphorylated in a variety of cellular contexts. For example, ErbB3 is constitutively phosphorylated on tyrosine residues in a subset of human breast cancer cell lines overexpressing this protein (see, *e.g.*, Kraus *et al.* (1993) *Proc. Natl. Acad. Sci. USA*. 90, 2900–2904; and Kim *et al.* Supra; see, also, Schaefer et al. (2006) Neoplasia 8(7):613-22 and Schaefer et al. Cancer Res (2004) 64(10):3395-405).

Although, the role of ErbB3 in cancer has been explored (see, *e.g.*, Horst *et al.* (2005) 115, 519-527; Xue *et al.* (2006) *Cancer Res.* 66, 1418-1426), ErbB3 remains largely unappreciated as a target for clinical intervention. Current immunotherapies primarily focus on inhibiting the action of ErbB2 and, in particular, heterodimerization of ErbB2/ErbB3 complexes (see, *e.g.*, Sliwkowski *et al.* (1994) J. Biol. Chem. 269(20):14661-14665 (1994)). Accordingly, it is an object of the present invention to provide improved immunotherapies that effectively inhibit ErbB3 signaling, and can be used to treat and diagnose a variety of cancers.

Summary of the Invention

In certain of its aspects, the present invention provides a novel class of antibodies (e.g., monoclonal antibodies) that bind to the ErbB3 receptor and inhibit various ErbB3 functions. For example, the antibodies described herein are capable of binding to ErbB3 and inhibiting EGF-like ligand mediated phosphorylation of the receptor. As described herein, EGF-like ligands include EGF, TGF-α, betacellulin, heparin-binding epidermal growth factor, biregulin and amphiregulin, which bind to EGFR and induce dimerization of EGFR with ErbB3. This dimerization, in turn, causes phosphorylation of ErbB3, and activates signaling through the receptor. Antibodies of the present invention are thus useful for treating and diagnosing a variety of cancers associated with ErbB3-mediated cellular signaling. Accordingly, in one embodiment, the present invention provides antibodies (including antigen binding portions thereof) which bind to ErbB3 and inhibit EGF-like ligand mediated phosphorylation of ErbB3.

In another embodiment, the antibodies and fragments thereof are further characterized by one or more of the following properties: (i) inhibition of ErbB3 ligand-mediated signaling, including signaling mediated by binding of ErbB3 ligands, such as heregulin, epiregulin, epigen and biregulin, to ErbB3; (ii) inhibition of proliferation of cells expressing ErbB3; (iii) the ability to decrease levels of ErbB3 on cell surfaces (*e.g.*, by inducing internalization of ErbB3); (iv) inhibition of secretion of VEGF (vascular endothelial growth factor) by cells expressing ErbB3; (v) inhibition of the migration of cells expressing ErbB3; (vi) inhibition of spheroid growth of cells expressing ErbB3; and (vii) binding to an epitope located on ectodomain (extracellular domain) Domain I, which corresponds to amino acid residues 1 to about 190 of mature ErbB3 (SEQ ID NO: 73), for example, an epitope involving or spanning any portion of residues 1-183 of SEQ ID NO: 73, more preferably involving or spanning residues 93-104 or 92-129 of SEQ ID NO: 73, even more preferably involving residues 92, 93, 99, 101, 102, 104 and 129 of SEQ ID NO: 73 or residues 93, 101, 102, and 104 of SEQ ID NO: 73.

In a preferred embodiment, the antibody binds to an epitope involving or spanning residues 93-104 or 92-129 of SEQ ID NO: 73, even more preferably involving residues 92, 93, 99, 101, 102, 104 and 129 of SEQ ID NO: 73 or residues 93, 101, 102, and 104 of SEQ ID NO: 73, with the proviso that the antibody is not: (i) Ab #6 as disclosed herein; (ii) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 1 and 2, respectively; or (iii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 7, 8 and 9, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 10, 11 and 12, respectively.

In another preferred embodiment, the antibody binds to an epitope involving or spanning residues 93-104 or 92-129 of SEQ ID NO: 73, even more preferably involving residues 92, 93, 99, 101, 102, 104 and 129 of SEQ ID NO: 73 or residues 93, 101, 102,

and 104 of SEQ ID NO: 73, with the proviso that the antibody is not: (i) Ab #6 as disclosed herein; (ii) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 1 and 2, respectively; (iii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 7, 8 and 9, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 10, 11 and 12, respectively; (iv) Ab #3 as disclosed herein; (v) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 3 and 4, respectively; (vi) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 13, 14 and 15, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 16, 17 and 18, respectively; (vii) Ab #17 as disclosed herein; (viii) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 35 and 36, respectively; (ix) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 39, 40 and 41, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 42, 43 and 44, respectively; (x) Ab #19 as disclosed herein; (xi) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 37 and 38, respectively; or (xii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 45, 46 and 47, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 48, 49 and 50, respectively.

Preferred antibodies and antigen binding portions thereof disclosed herein exhibit a K_D of 50 nM or less, as measured by a surface plasmon resonance assay or a cell binding assay

In further embodiments, particular antibodies and antigen binding portions thereof of the present invention include a heavy chain variable region (V_H) comprising an amino acid sequence which is at least 80% (*e.g.*, 85%, 90%, 95%, 96%, 97%, 98% or 99%) identical to the heavy chain variable region amino acid sequence set forth in SEQ ID NO:1, SEQ ID NO:3, SEQ ID NO:5, SEQ ID NO:35, or SEQ ID NO: 37. Other particular antibodies and antigen binding portions thereof of the invention include a light chain variable region (V_L) comprising an amino acid sequence which is at least 80% (*e.g.*, 85%, 90%, 95%, 96%, 97%, 98% or 99%) identical to the light chain variable region amino acid sequence set forth in SEQ ID NO:2, SEQ ID NO:4, SEQ ID NO:6, SEQ ID NO:36, or SEQ ID NO:38. The antibodies may also include both of the aforementioned heavy chain and light chain variable regions.

The variable heavy and light chain regions of the antibodies or antigen binding portions thereof typically include one or more complementarity determining regions (CDRs). These include one or more CDR1, CDR2, and CDR3 regions. Accordingly, other particular antibodies and antigen binding portions thereof of the present disclosure include one or more CDR sequences selected from a heavy chain variable region CDR1 comprising SEQ ID NO:7; a heavy chain variable region CDR2 comprising SEQ ID

NO:8; a heavy chain variable region CDR3 comprising SEQ ID NO:9; a light chain variable region CDR1 comprising SEQ ID NO:10; a light chain variable region CDR2 comprising SEQ ID NO:11; a light chain variable region CDR3 comprising SEQ ID NO:12; and combinations thereof.

Still other particular antibodies and antigen binding portions thereof of the present disclosure include one or more CDR sequences selected from a heavy chain variable region CDR1 comprising SEQ ID NO:13; a heavy chain variable region CDR2 comprising SEQ ID NO:14; a heavy chain variable region CDR3 comprising SEQ ID NO:15; a light chain variable region CDR1 comprising SEQ ID NO:16; a light chain variable region CDR2 comprising SEQ ID NO:17; a light chain variable region CDR3 comprising SEQ ID NO:18; and combinations thereof.

Still other particular antibodies and antigen binding portions thereof of the present disclosure include; or one or more CDR sequences selected from a heavy chain variable region CDR1 comprising SEQ ID NO:19; a heavy chain variable region CDR2 comprising SEQ ID NO:20; a heavy chain variable region CDR3 comprising SEQ ID NO:21; a light chain variable region CDR1 comprising SEQ ID NO:22; a light chain variable region CDR2 comprising SEQ ID NO:23; a light chain variable region CDR3 comprising SEQ ID NO:24; and combinations thereof.

Still other particular antibodies and antigen binding portions thereof of the present disclosure include; or one or more CDR sequences selected from a heavy chain variable region CDR1 comprising SEQ ID NO:39; a heavy chain variable region CDR2 comprising SEQ ID NO:40; a heavy chain variable region CDR3 comprising SEQ ID NO:41; a light chain variable region CDR1 comprising SEQ ID NO:42; a light chain variable region CDR2 comprising SEQ ID NO:43; a light chain variable region CDR3 comprising SEQ ID NO:44; and combinations thereof.

Still other particular antibodies and antigen binding portions thereof of the present disclosure include; or one or more CDR sequences selected from a heavy chain variable region CDR1 comprising SEQ ID NO:45; a heavy chain variable region CDR2 comprising SEQ ID NO:46; a heavy chain variable region CDR3 comprising SEQ ID NO:47; a light chain variable region CDR1 comprising SEQ ID NO:48; a light chain variable region CDR2 comprising SEQ ID NO:49; a light chain variable region CDR3 comprising SEQ ID NO:50; and combinations thereof.

The antibodies and antigen binding portions thereof may also comprise one or more CDRs which are at least 80% (*e.g.*, 85%, 90%, 95%, 96%, 97%, 98% or 99%) identical to any of the aforementioned CDRs, or combinations of CDRs.

In one embodiment, the antibodies and antibody portions thereof are fully human (*i.e.*, contains human CDR and framework sequences). Particular human antibodies of the present disclosure include those having a heavy chain variable region that is from a

human VH3 germ line gene, and/or a light chain variable region from human VL2 germ line gene.

Also encompassed by the present invention are antibodies and antigen binding portions thereof that bind to the same or overlapping epitopes bound by any of the antibodies or portions thereof described herein (*e.g.*, an epitope located on Domain I of the ectodomain of ErbB3), such as an epitope involving or spanning any of residues 1-183 of the amino acid sequence of mature ErbB3 (SEQ ID NO: 73), more preferably involving or spanning residues 93-104 or 92-129 of SEQ ID NO: 73, even more preferably involving residues 92, 93, 99,101, 102, 104 and 129 of SEQ ID NO: 73 or residues 93, 101, 102, and 104 of SEQ ID NO: 73. Antibodies which have the same epitope binding activity as the antibodies described herein, *e.g.*, antibodies having the same sequence as Ab #6 or binding epitopes involving residues 93-104 of SEQ ID NO: 73, are also encompassed by the present invention.

Also encompassed by the present invention are antibodies and antigen binding portions thereof that bind to the ectodomain of human ErbB3 and comprise:

a heavy chain variable region comprising CDR1, CDR2, and CDR3 sequences; and a light chain variable region comprising CDR1, CDR2, and CDR3 sequences, wherein:

the heavy chain variable region CDR1, CDR2 and CDR3 sequences comprise consensus heavy chain CDR1, CDR2 and CDR3 sequences shown in SEQ ID NOs: 60 or 75 (CDR1), 61 (CDR2) and 62 (CDR3), respectively, and

the light chain variable region CDR1, CDR2 and CDR3 sequences comprise consensus light chain CDR1, CDR2 and CDR3 sequences shown in SEQ ID NOs: 66 or 77 (CDR1), 67 (CDR2) and 68 or 79 (CDR3), respectively, with the proviso that the antibody is not: (i) Ab #6 as disclosed herein; (ii) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 1 and 2, respectively; or (iii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 7, 8 and 9, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 10, 11 and 12, respectively.

In a preferred embodiment, the isolated antibody, or antigen binding portion thereof, binds to an epitope within Domain I of the ectodomain of human ErbB3 comprising residues 92-129 or 93-104 of SEQ ID NO: 73. Even more preferably, the isolated antibody, or antigen binding portion thereof, binds to an epitope within Domain I of the ectodomain of human ErbB3 comprising residues 92-129 or 93-104 of SEQ ID NO: 73 and inhibits proliferation of a cancer cell expressing ErbB3. Preferably, the cancer cell is a MALME-3M melanoma cell, an AdrR (ADRr) ovarian adenocarcinoma cell or an ACHN renal carcinoma cell and the proliferation is reduced by at least 10% relative to a control (i.e., matched untreated cells).

In another embodiment of the isolated antibody, or antigen binding portion thereof, that binds to Domain I of the ectodomain of human ErbB3, when any one of amino acid residues of Domain I of the ectodomain of human ErbB3 selected from residue 93 (asparagine), residue 99 (phenylalanine), residue 101 (methionine), residue 102 (leucine) and residue 104 (tyrosine) of SEQ ID NO: 73 is replaced by an alanine, or residue 92 (tyrosine) or 129 (tyrosine) of SEQ ID NO: 73 is replaced by phenylalanine, to generate a mutant ErbB3 with a single amino acid substitution, there is a substantial reduction in binding of the antibody or antigen binding portion thereof to the mutant ErbB3 (or fragment thereof) as compared to binding of the antibody or antigen binding portion thereof to human ErbB3 comprising the unaltered amino acid sequence of SEQ ID NO: 73 (or a corresponding fragment thereof). Preferably, the substantial reduction in binding is at least a ten-fold change in K_D value of binding.

Also encompassed by the present invention are antibodies and antigen binding portions thereof that bind to the Domain I of the ectodomain of human ErbB3 and comprise:

a heavy chain variable region comprising CDR1, CDR2, and CDR3 sequences; and a light chain variable region comprising CDR1, CDR2, and CDR3 sequences, wherein:

the heavy chain variable region paratope comprises CDR1, CDR2 and CDR3 sequences shown in SEQ ID NOs: 63 or 76 (CDR1), 64 (CDR2) and 65 (CDR3), respectively, and

the light chain variable region paratope comprises CDR1, CDR2 and CDR3 sequences shown in SEQ ID NOs: 69 or 78 (CDR1), 70 (CDR2) and 71 or 80 (CDR3), respectively, with the proviso that the antibody is not: (i) Ab #6 as disclosed herein; (ii) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 1 and 2, respectively; or (iii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 7, 8 and 9, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 10, 11 and 12, respectively. .

Also encompassed by the present invention are antibodies and antigen binding portions thereof, that bind specifically to Domain I of the ectodomain of human ErbB3, wherein the antibody or antigen binding portion thereof comprises:

a heavy chain variable region CDR1 comprising SEQ ID NO:7 or conservative amino acid substitutions thereof;

a heavy chain variable region CDR2 comprising SEQ ID NO:8 or conservative amino acid substitutions thereof;

a heavy chain variable region CDR3 comprising SEQ ID NO:9 or conservative amino acid substitutions thereof;

a light chain variable region CDR1 comprising SEQ ID NO:10 or conservative amino acid substitutions thereof;

a light chain variable region CDR2 comprising SEQ ID NO:11 or conservative amino acid substitutions thereof; and

a light chain variable region CDR3 comprising SEQ ID NO:12 or conservative amino acid substitutions thereof,

wherein the binding of the antibody or antigen binding portion thereof to ErbB3 exhibits a K_D of 50 nM or better as measured by a surface plasmon resonance assay or a cell binding assay.

Antibodies of the present invention include all known forms of antibodies and other protein scaffolds with antibody-like properties. For example, the antibody can be a human antibody, a humanized antibody, a bispecific antibody, a chimeric antibody or a protein scaffold with antibody-like properties, such as fibronectin or ankyrin repeats. The antibody also can be a Fab, Fab'2, ScFv, SMIP, affibody, nanobody, or a domain antibody. The antibody also can have any of the following isotypes: IgG1, IgG2, IgG3, IgG4, IgM, IgA1, IgA2, IgAsec, IgD, and IgE.

In yet another embodiment, the present invention further provides compositions comprising combinations of antibodies or antigen binding portions described herein, formulated with an acceptable carrier and/or adjuvant. In a particular embodiment, the composition comprises two or more antibodies that bind different epitopes on ErbB3 or antibodies described herein combined with anti-cancer antibodies which do not bind ErbB3.

In still another embodiment, the present invention provides isolated nucleic acids encoding the antibodies and antigen binding portions thereof described herein. In particular embodiments, the nucleic acid encodes a heavy chain variable region comprising a nucleotide sequence which is at least 80% (*e.g.*, 85%, 90%, 95%, 96%, 97%, 98% or 99%) identical to, or which hybridizes under high stringency conditions to, SEQ ID NO:25, SEQ ID NO:27, SEQ ID NO:29, SEQ ID NO:35, or SEQ ID NO:37; or a light chain variable region comprising a nucleotide sequence which is at least 80% (*e.g.*, 85%, 90%, 95%, 96%, 97%, 98% or 99%) identical to, or which hybridizes under high stringency conditions to, SEQ ID NO:26, SEQ ID NO:28, SEQ ID NO:30, SEQ ID NO:36, or SEQ ID NO:38; or combinations of such heavy and light variable regions.

The present invention further provides transgenic non-human mammals, hybridomas, and transgenic plants that express and/or produce the antibodies and antigen binding portions described herein.

Also provided by the invention are kits comprising one or more isolated antibodies or antigen binding portions thereof described herein and, optionally,

instructions for use in treating or diagnosing a disease associated with ErbB3 dependent signaling, such as cancers.

Antibodies and antigen binding portions thereof disclosed herein can be used in a broad variety of therapeutic and diagnostic applications, particularly oncological applications. Accordingly, in another aspect, the present invention provides method for inhibiting EGF-like ligand mediated phosphorylation of ErbB3 in a subject by administering one or more antibodies or antigen binding portions thereof described herein in an amount sufficient to inhibit EGF-like mediated phosphorylation of ErbB3. The invention further provides methods for treating a variety of cancers in a subject, including, but not limited to, melanoma, breast cancer, ovarian cancer, renal carcinoma, gastrointestinal/colon cancer, lung cancer, clear cell sarcoma, and prostate cancer, by administering one or more antibodies or antigen binding portions thereof described herein in an amount sufficient to treat the cancer. In one embodiment, the cancer comprises cells comprising a KRAS mutation. Exemplary KRAS mutations are in either or both of codon 12 and codon 13 of the human KRAS gene. Mutations in codon 12 or codon 13, each of which normally codes for a glycine (including any of those changing the wild-type glycine 12 or glycine 13 to serine, arginine, cysteine, aspartate, or valine) are activating KRAS mutations that promote oncogenesis, as are mutations in codons 15, 20, 61 and 146 of the human KRAS gene. In another embodiment, the cancer comprises cells comprising a PI3K (phosphatidylinositol 3-kinase) mutation. Exemplary PI3K mutations are activating mutations in the human PIK3CA gene in either or both of exon 9 or exon 20. The antibodies or antigen binding portions thereof can be administered alone or in combination with other therapeutic agents, such as anti-cancer agents, *e.g.*, other antibodies, chemotherapeutic agents and/or radiation.

In one embodiment, an antibody or antigen binding portion thereof is administered in combination with a second agent, which second agent is selected from the group consisting of a protein synthesis inhibitor, a somatostatin analogue, an immunotherapeutic agent, and an enzyme inhibitor. In other embodiments, the second agent is selected from: a small molecule targeting IGF1R, a small molecule targeting EGFR, a small molecule targeting ErbB2, a small molecule targeting cMET, an antimetabolite, an alkylating agent, a topoisomerase inhibitor, a microtubule targeting agent, a kinase inhibitor, a hormonal therapy, a glucocorticoid, an aromatase inhibitor, an mTOR inhibitor, a chemotherapeutic agent, a protein kinase B inhibitor, a phosphatidylinositol 3-kinase inhibitor, a cyclin dependent kinase inhibitor, and an MEK inhibitor. Exemplary antibodies for use as second agents in combination therapy include anti-Her2 antibodies, e.g., trastuzumab and anti-EGFR antibodies, e.g., panitumumab or cetuximab. Certain preferred anti-cancer agents for use as second agents in combination therapy include erlotinib, lapatinib, paclitaxel and cisplatin.

In yet other embodiments, the present invention provides methods for diagnosing and prognosing diseases (*e.g.*, cancers) associated with ErbB3. In one embodiment, this is achieved by contacting antibodies or antigen binding portions of the present disclosure(*e.g.*, *ex vivo* or *in vivo*) with cells from the subject, and measuring the level of binding to ErbB3 on the cells, wherein abnormally high levels of binding to ErbB3 indicate that the subject has a cancer associated with ErbB3.

Other features and advantages of the invention will be apparent from the following detailed description, and from the claims.

Brief Description of the Drawings

Figures 1A and 1B are bar graphs depicting the binding of various anti-ErbB3 antibody candidates to ErbB3 expressed on MALME-3M melanoma cells using a goat anti-human Alexa 647 secondary antibody (GAHu-Alexa 674). In these experiments the antibodies indicated as "Ab#" are used in the form of Fab fragments and "GAHu-Alexa 674" indicates the fluorescent dye-conjugated secondary antibody used alone as a control, while "unstained" indicates a control in the absence of the secondary antibody .

Figures 2A-2D are graphs depicting binding of antibodies to ErbB3 set forth as K_D values of various anti-ErbB3 antibody candidates. Figures 2A and 2B are graphs depicting the K_D value of Ab #6 and Ab # 3, respectively, as measured using surface plasmon resonance (SPR) technology and the formula $K_D = k_d/k_a$. Figures 2C and 2D are graphs depicting the K_D values of Ab #6 and Ab #3, respectively, as measured using a cell binding assay using MALME-3M melanoma cells and the formula $Y=Bmax*X/K_D+X$.

Figure 3 is a graph depicting the binding specificity of an anti-ErbB3 antibody (Ab #6) to ErbB3 using ELISA. EGFR extracellular domain, bovine serum albumin (BSA) and TGFα were used as controls.

Figure 4 is a graph depicting the ability of an anti-ErbB3 antibody (Ab #6) to decrease total ErbB3 levels in MALME-3M melanoma cells *in vitro*, as measured using ELISA.

Figures 5A and 5B are graphs depicting the ability of an anti-ErbB3 antibody (Ab #6) to downregulate ErbB3 receptors on MALME-3M cells, measured using FACS analysis, as described in Example 5 below. Figure 5A shows the results using an IgG1 isotype of the antibody. Figure 5B shows the results using an IgG2 isotype of the antibody.

Figures 6A-6D are graphs depicting the timecourse of antibody-mediated ErbB3 downregulation (Ab #6), as measured using FACS analysis.

Figure 7 shows the results of a pharmacodynamic study. The a bar graph depicts 24hrs post-injection results of indicated anti-ErbB3 antibodies on total ErbB3 levels in

MALME3M melanoma cells in xenografts *in vivo*. As can be seen, the data demonstrate the ability of Ab #6 to downregulate ErbB3.

Figure 8 is a bar graph depicting the ability of an anti-ErbB3 antibody (Ab #6) to downregulate ErbB3 in AdrR xenografts *in vivo*. Total ErbB3 levels in AdrR xenografts are shown.

Figure 9 is a graph depicting the ability of an anti-ErbB3 antibody (Ab #6) to inhibit proliferation of MALME-3M cells in a CellTiter-Glo® assay.

Figure 10 is a graph depicting the ability of an anti-ErbB3 antibody (Ab #6) to inhibit cell proliferation of AdrR cells.

Figure 11 is a graph depicting the ability of an anti-ErbB3 antibody (Ab #6) to inhibit proliferation of ACHN cells.

Figure 12 is a bar graph depicting the ability of an anti-ErbB3 antibody (Ab #6) to inhibit ErbB3 phosphorylation in AdrR xenografts *in vivo*.

Figures 13A-13C are graphs depicting the ability of an anti-ErbB3 antibody (Ab #6) to inhibit betacellulin, heregulin, and TGFα-mediated phosphorylation of ErbB3 in AdrR cells.

Figures 14A-14B are graphs depicting the ability of an anti-ErbB3 antibody (Ab #6 IgG2 isotype) to inhibit ErbB3 phosphorylation in ovarian tumor cell lines OVCAR 5 and OVCAR 8.

Figures 15A-15C are graphs depicting the ability of betacellulin (BTC) to bind ErbB1 as shown by a lack of binding to ErbB1 negative MALME-3M cells (Fig.15A); binding to ErbB1 positive AdrR cells at concentrations of 10 nM (Figure 15B) and 200 nM (Fig. 15C), respectively, and the inhibition of such binding by cetuximab.

Figures 16A-16D are graphs depicting the ability of an anti-ErbB3 antibody (Ab #6, IgG2 isotype) to inhibit heregulin-mediated signaling in MALME-3M cells (Figures 16A and 16B) and OVCAR8 cells (16C and 16D). Figure 16A depicts the ability of the Ab #6 to inhibit heregulin-mediated phosphorylation of ErbB3 in MALME-3M cells (IC_{50} = 1.5 e-8). Figure 16B depicts the ability of Ab #6 to inhibit phosphorylation of AKT in MALME-3M cells (IC_{50} = 1.1e-8). Figure 16C depicts the ability of the Ab #6 to inhibit heregulin-mediated phosphorylation of ErbB3 in OVCAR8 cells (IC_{50} = 2.4 e-8). Figure 16B depicts the ability of Ab #6 to inhibit phosphorylation of AKT in OVCAR8 cells (IC_{50} = 6.7 e-8).

Figures 17A-D are graphs depicting the ability of an anti-ErbB3 antibody (Ab #6) to inhibit: (Fig.17A) ovarian (AdrR cells), (Fig. 17B) prostate (Du145 cells), (Fig. 17C) ovarian (OVCAR8 cells), and (Fig. 17D) pancreatic (Colo-357 cells) tumor growth via xenograft studies.

Figures 18A and 18B are graphs depicting the ability of Ab #6 (Figure 18A) and Fab for Ab #3 (Figure 18B) to inhibit heregulin binding to ErbB3 on MALME-3M cells, as measured using FACS analysis.

Figure 19A depicts the binding of epiregulin to AdrR cells, and Figure 19B depicts the ability of Ab #6, but not ERBITUX (cetuximab) to inhibit epiregulin binding to AdrR cells.

Figure 20 is a graph depicting the ability of heparin binding epidermal growth factor (HB-EGF) to bind to AdrR cells.

Figures 21A-21C show the amino acid sequences of the variable heavy and light chain regions of antibodies: Ab #6, Ab #3, Ab #14, Ab #17, and Ab #19.

Figures 22A-22B show the nucleotide sequences of the variable heavy and light chain regions of antibodies: Ab #6, Ab #3, and Ab #14.

Figure 23 shows the amino acid sequences of the variable light chain regions of antibodies: Ab #6, Ab #17, and Ab #19, which have been reverted to the corresponding germline amino acid sequence. Amino acid residue changes accomplishing this reversion (compare Figure 21) are underlined.

Figures 24A and B are graphs showing the ability of Ab #6 to inhibit VEGF secretion by tumor cells (see Example 11). Figure 24C shows the correlation between inhibition of VEGF secretion and inhibition of pErbB3 in cancer cells by Ab #6.

Figure 25 is a graph showing the effect of Ab #6 on cell migration (see Example 12). Control 0uM = RPMI medium alone, Control 8uM =RPMI medium + 8uM Ab #6, FBS 0mM = RPMI medium + 10% FBS, FBS 8uM = RPMI medium + 10% FBS + 8uM Ab #6.

Figures 26A-C are graphs showing (Fig. 26A) inhibition of spheroid growth in AdrR cells, (Fig. 26B) inhibition of HRG-induced spheroid growth in AdrR, and (Fig. 26C) inhibition of HRG-induced spheroid growth in Du145 cells.

Figures 27 A and B are graphs showing the effect of Ab #6 on HRG (Fig. 27A) and BTC (Fig. 27B) binding to AdrR cells.

Figure 28 is a graph showing the effect of Ab #6 on HGF (hepatocyte growth factor) induced ErbB3 phosphorylation in AdrR cells. The IC_{50} for HGF was determined to be 2.439e-10.

Figures 29 A and B show the effect of Ab #6 on phosphorylation of (Fig. 29A) pErbB1 and pErbB3 and (Fig. 29B) HRG induced ErbB2/3 complex formation.

Figure 30 is a graph showing the effect of Ab #6 alone, erlotinib alone or Ab #6 plus erlotinib on the growth of ACHN xenograft tumors in nude mice. The data show that after 27 days the combination a dose of 300 ug of Ab #6 (a suboptimal dose when administered alone) plus erlotinib synergistically inhibits tumor growth to a statistically significant extent.

Figure 31 is a graph showing the effect of Ab #6 alone, taxol alone or Ab #6 plus taxol on the growth of DU145 xenograft tumors in nude mice. The data show that after 27 days the combination of a dose of 300 ug of Ab #6 (a suboptimal dose when administered alone) plus taxol inhibits tumor growth to a greater extent than does treatment with either drug alone to a statistically significant extent.

Figure 32A is a graph showing the effect of Ab #6 treatment alone on the growth of multicellular tumor spheroids of KRAS mutant A549 lung cancer cells. Cells were treated with 0, 0.001, 0.01, 0.1 or 1 μM Ab #6 for seven days. The "-4" on the x axis corresponds to the "0" dose. The results show the Ab #6 dose response effect on KRAS mutant tumor spheroid growth.

Figure 32B is a set of photographs of representative A549 spheroids, either untreated or treated with 1 μM Ab #6, on day 1 and day 7 of treatment.

Figure 32C is a graph showing the effect of Ab #6 treatment alone on the growth of KRAS mutant A549 subcutaneous xenograft tumors in nude mice. Dosing of Ab #6 (600 μg every three days) was stopped on day 22.

Figure 33A is a graph showing the effect of Ab #6 treatment alone, erlotinib treatment alone or combined treatment with Ab #6 and erlotinib on the growth of KRAS mutant A549 subcutaneous xenograft tumors in nude mice.

Figure 33B is a graph showing the effect of Ab #6 treatment alone, taxol treatment alone or combined treatment with Ab #6 and taxol on the growth of KRAS mutant A549 subcutaneous xenograft tumors in nude mice.

Figures 34A-34E shows the results of a FACS analysis for the binding of Ab #6 and a control anti-ErbB3 antibody (SGP1) to CHO cells expressing either wild-type ErbB3 (Fig. 34A) or CHO cells expressing ErbB3 having one of the following point mutations: D93A (Fig. 34B), M101A (Fig. 34C), L102A (Fig. 34D) or Y104A (Fig. 34E).

Figure 35A is a graph showing the effect of Ab #6 treatment alone on the growth of PI3K mutant SKOV3 xenograft tumors in mice.

Figure 35B is a graph showing the showing the effect of Ab #6 treatment alone, or in combination with cisplatin (CDDP), on the growth of PI3K mutant SKOV3 xenograft tumors in mice.

Figure 36 presents data from paratope mapping experiments. Shown are the effects of single amino acid mutations (for identity of indicated mutations see example 20, Table 2) on the binding of Ab #6 mutants to ErbB3 as compared to the binding of the same mutants of Ab #6 to protein A. The diagonal bisecting the graph indicates a 1:1 correspondence of the effect on ErbB3 and protein A binding. The additional, parallel lines were located created by moving the diagonal down the y axis by 0.33 and 0.66 for convenient grouping of the mutations into three categories (large, small and no effect on

binding). The graph shows the effect on binding of the mutation normalized to the wild type Ab #6. Values on the Y axis are ratios of binding of wild type Ab #6 to binding of Ab #6 mutants to ErbB3. A ratio of < 1 means that the mutant has loss of binding to ErbB3 compared to wild type Ab #6, while a ratio of > 1 means that the mutant exhibits stronger binding to ErbB3 than wild type Ab #6.

Figures 37A and 37B are schematic diagrams of the Ab #6 wild type heavy chain variable region (V_H) CDR1, CDR2 and CDR3 sequences (SEQ ID NOs: 7, 8 and 9, respectively), the consensus V_H CDR1, CDR2 and CDR3 sequences (SEQ ID NOs: 60, 61 and 62, respectively, for Fig. 37A and SEQ ID NOs: 75, 61 and 62, respectively, for Fig. 37B), the V_H CDR1, CDR2 and CDR3 paratope sequences (SEQ ID NOs: 63, 64 and 65, respectively, for Fig. 37A and SEQ ID NOs: 76, 64, 65, respectively, for Fig. 37B), the Ab #6 wild type light chain variable region (V_L) CDR1, CDR2 and CDR3 sequences (SEQ ID NOs: 10, 11 and 12, respectively), the consensus V_L CDR1, CDR2 and CDR3 sequences (SEQ ID NOs: 66, 67 and 68, respectively, for Fig. 37A and SEQ ID NOs: 77, 67 and 79, respectively, for Fig. 37B) and the V_L CDR1, CDR2 and CDR3 paratope sequences (SEQ ID NOs: 69, 70 and 71, respectively, for Fig. 37A and SEQ ID NOs: 78, 70 and 80, respectively, for Fig. 37B). In these figures, the standard single letter amino acid abbreviations are used and the separation of single letters indicating amino acids by dashes indicates sequential residues in the sequence, while any group of two or more adjacent single letters indicating amino acids separated by one or more slashes indicates that any of the grouped adjacent amino acids so separated may be substituted for any of the others at that position in the sequence. For example, the notation "$(Xaa)_7$-W-T/A/G/S-L-$(Xaa)_7$" indicates a sequence running from amino to carboxy terminus as follows: seven unspecified amino acids followed by tryptophan, followed by (threonine or alanine or glycine or serine), followed by leucine, followed by seven unspecified amino acids. "Unspecified amino acid" is used here to indicate that any amino acid may appear independently at each position designated Xaa, even where several such positions appear together. The repetition of Xaa or of any group designated as $Xaa_{\#}$ -- e.g., "$(Xaa)_7$" -- does not indicate any correspondence between the designated group of unspecified amino acids at one position in these sequences and designated group of unspecified amino acids at any other position. Thus the repetition of $(Xaa)_7$ at the beginning and end of the sequence "$(Xaa)_7$-W-T/A/G/S-L-$(Xaa)_7$" does not indicate any correspondence between the sequence of each $(Xaa)_7$ other than that each contains seven unspecified amino acids.

Figures 38 A-D show the effects of Ab #6 (decreasing concentrations along the X axis, as indicated) on ligand-induced ErbB3 phosphorylation (pErbB3 levels; increasing concentrations along the Y axis as indicated) in AdrR cells. In Figure 38A,

the ligand is HRG, in Figure 38B, the ligand is BTC, in Figure 38C, the ligand is HGF, and in Figure 38D, the ligand is EGF.

Figure 39 is a FACS profile demonstrating that Ab #6 binds to Domain I of the ectodomain of ErbB3.

Detailed Description of the Invention

In order that the present invention may be more readily understood, certain terms are first defined. Additional definitions are set forth throughout the detailed description.

I. Definitions

The terms "ErbB3," "HER3," "ErbB3 receptor," and "HER3 receptor," as used interchangeably herein, refer to human ErbB3 protein, as described in U.S. Pat. No. 5,480,968 and Plowman *et al.*, *Proc. Natl. Acad. Sci. USA*, 87:4905-4909 (1990); see, also, Kani et al., Biochemistry 44:15842-857 (2005), Cho and Leahy, Science 297:1330-1333 (2002)). The full-length, mature human ErbB3 protein sequence (without leader sequence) is shown in SEQ ID NO: 73. This sequence corresponds to the sequence shown in Figure 4 and SEQ ID NO: 4 of U.S. Pat. No. 5,480,968, minus the 19 amino acid leader sequence that is cleaved from the mature protein.

The term "EGF-like ligand," as used herein, refers to ligands of epidermal growth factor receptor (EGFR), including epidermal growth factor (EGF) and closely related proteins, such as transforming growth factor-α (TGFα), betacellulin (BTC), heparin-binding epidermal growth factor (HB-EGF), biregulin (BIR) and amphiregulin (AR), which bind to EGFR on the surface of cells and stimulate the receptor's intrinsic protein-tyrosine kinase activity. Typically, EGF-like ligands induce formation of EGFR and ErbB3 protein complex (see *e.g.*, Kim *et al.*, (1998) *Biochem J.*, 334:189-195), which results in phosphorylation of tyrosine residues in the complex.

Preferred antibodies and antigen binding portions thereof disclosed herein inhibit EGF-like ligand mediated phosphorylation of ErbB3 and, in certain embodiments, exhibit one or more of the following additional properties: (i) inhibition of one or more of heregulin, epiregulin, epigen and biregulin-mediated signaling through ErbB3; (ii) inhibition of proliferation of cells expressing ErbB3; (iii) the ability to decrease levels of ErbB3 on cell surfaces; (iv) inhibition of VEGF secretion of cells expressing ErbB3; (v) inhibition of the migration of cells expressing ErbB3; (vi) inhibition of spheroid growth of cells expressing ErbB3; and/or (vii) specific binding to an epitope located on Domain I of the ectodomain of ErbB3, *e.g.*, an epitope which involves or spans residues 1-183 of the amino acid sequence of mature ErbB3 (SEQ ID NO: 73, more preferably involving or spanning or containing or comprising or including residues 92-129 or 93-104 or of SEQ ID NO: 73, even more preferably involving or containing or comprising or including residues 92, 93, 101, 102 and 104 and 129, or residues 93, 101, 102 and 104,

of SEQ ID NO: 73. One such antibody, Ab #6, is currently undergoing phase I clinical trails as MM-121.

The term "inhibition" as used herein, refers to any statistically significant decrease in biological activity, including full blocking of the activity. For example, "inhibition" can refer to a decrease of about 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, or 100% in biological activity.

Accordingly, the phrase "inhibition of EGF-like ligand mediated phosphorylation of ErbB3," as used herein, refers to the ability of an antibody or antigen binding portion to statistically significantly decrease the phosphorylation of ErbB3 induced by an EGF-like ligand, relative to the phosphorylation in an untreated (control) cell. The cell which expresses ErbB3 can be a naturally occurring cell or cell line or can be recombinantly produced by introducing nucleic acid encoding ErbB3 into a host cell. In one embodiment, the antibody or antigen binding portion thereof inhibits EGF-like ligand mediated phosphorylation of ErbB3 by at least 10%, or at least 20%, or at least 30%, or at least 40%, or at least 50%, or at least 60%, or at least 70%, or at least 80%, or at least 90%, or about 100%, as determined, for example, by Western blotting followed by probing with an anti-phosphotyrosine antibody as described in Kim *et al.*, (1998) *Biochem J.*, 334:189-195 and the Examples *infra*.

The phrase "inhibition of heregulin, epiregulin, epigen or biregulin-mediated signaling through ErbB3," as used herein, refers to the ability of an antibody or an antigen-binding portion thereof to statistically significantly decrease signaling mediated by an ErbB3 ligand (*e.g.*, heregulin, epiregullin, epigen and biregulin) through ErbB3, relative to the signaling in the absence of the antibody (control). ErbB3-ligands are also referred to herein as "heregulin-like ligands." This means that, in the presence of the antibody or antigen binding portion thereof, a signal mediated in a cell expressing ErbB3 by one or more of heregulin, epiregulin, epigen and biregulin, relative to a control (no antibody), is statistically significantly decreased. An ErbB3-ligand mediated signal can be measured by assaying for the level or activity of an ErbB3 substrate, and/or a protein which is present in a cellular cascade involving ErbB3. In one embodiment, the antibody or antigen binding portion thereof decreases the level or activity of an ErbB3 substrate and/or that of a protein in a cellular cascade involving ErbB3, by at least 10%, or at least 20%, or at least 30%, or at least 40%, or at least 50%, or at least 60%, or at least 70%, or at least 80%, or at least 90%, or 100% relative to the level or activity in the absence of such antibody or antigen binding portion thereof (control). Such ErbB3-ligand mediated signaling can be measured using art recognized techniques which measure the level or activity of a substrate of ErbB3 (*e.g.*, SHC or PI3K) or a protein in a cellular cascade involving ErbB3 (*e.g.*, the AKT pathway – AKT refers to a set of serine/threonine kinases also referred to as protein kinases B or PKB) using kinase

assays for such proteins (see, *e.g.*, Horst *et al. supra*, Sudo *et al.* (2000) *Methods Enzymol*, 322:388-92; and Morgan *et al.* (1990) *Eur. J. Biochem.*, 191:761-767).

In a particular embodiment, the antibody or antigen binding portion thereof inhibits ErbB3-ligand (*e.g.*, heregulin, epiregulin, epigen or biregulin) mediated signaling through ErbB3 by inhibiting the binding of the ErbB3-ligand (*e.g.*, one or more of heregulin, epiregulin, epigen or biregulin) to ErbB3. Some ligands (*e.g.*, biregulin, an artificial chimeric ligand: Barbacci, et al., J Biol Chem 1995 270(16) 9585-9) function both as EGF-like ligands (*i.e.*, bind to EGFR/ErbB1) as well as ErbB3-like ligands (*i.e.*, bind to ErbB3).

The phrase "inhibition of heregulin, epiregulin, epigen or biregulin binding to ErbB3," as used herein, refers to the ability of an antibody or an antigen-binding portion thereof to statistically significantly decrease the binding of an ErbB3 ligand (*e.g.*, one or more of heregulin, epiregulin, epigen or biregulin) to ErbB3, relative to the binding in the absence of the antibody (control). This means that, in the presence of the antibody or antigen binding portion thereof, the amount of the ErbB3-ligand (*e.g.*, heregulin, epiregulin, epigen or biregulin) which binds to ErbB3 relative to a control (no antibody), is statistically significantly decreased. The amount of an ErbB3 ligand which binds ErbB3 may be decreased in the presence of an antibody or antigen binding portion thereof of the present disclosure by at least 10%, or at least 20%, or at least 30%, or at least 40%, or at least 50%, or at least 60%, or at least 70%, or at least 80%, or at least 90%, or 100% relative to the amount in the absence of the antibody or antigen binding portion thereof (control). A decrease in ErbB3-ligand binding can be measured using art recognized techniques which measure the level of binding of labeled ErbB3-ligand (*e.g.*, radiolabeled heregulin, epiregulin, epigen or biregulin) to cells expressing ErbB3 in the presence or absence (control) of the antibody or antigen binding portion thereof.

The phrase "inhibition of proliferation of a cell expressing ErbB3," as used herein, refers to the ability of an antibody or an antigen-binding portion thereof to statistically significantly decrease proliferation of a cell expressing ErbB3 relative to the proliferation in the absence of the antibody. In one embodiment, the proliferation of a cell expressing ErbB3 (*e.g.*, a cancer cell) may be decreased by at least 10%, or at least 20%, or at least 30%, or at least 40%, or at least 50%, or at least 60%, or at least 70%, or at least 80%, or at least 90%, or 100% when the cells are contacted with an antibody or antigen binding portion thereof of the present disclosure, relative to the proliferation measured in the absence of the antibody or antigen binding portion thereof (control). Cellular proliferation can be assayed using art recognized techniques which measure rate of cell division, the fraction of cells within a cell population undergoing cell division, and/or rate of cell loss from a cell population due to terminal differentiation or cell death (*e.g.*, using a CellTiter-Glo® assay or thymidine incorporation).

The phrase "the ability to decrease levels of ErbB3 on cell surfaces," as used herein, refers to the ability of an antibody or antigen binding portion thereof to statistically significantly reduce the amount of ErbB3 found on the surface of a cell which has been exposed to the antibody relative to an untreated (control) cell. For example, a decrease in levels of ErbB3 on cell surfaces may result from increased internalization of ErbB3 (or increased ErbB3 endocytosis). In one embodiment, the antibody or antigen binding portion thereof decreases cell surface expression of ErbB3 by at least 10%, or at least 20%, or at least 30%, or at least 40%, or at least 50%, or at least 60%, or at least 70%, or at least 80%, or at least 90%, or 100% and/or increases internalization of the ErbB3 receptor by at least 10%, or at least 20%, or at least 30%, or at least 40%, or at least 50%, or at least 60%, or at least 70%, or at least 80%, or at least 90%, or 100% relative to the cell surface expression or internalization in the absence of the antibody or antigen binding portion thereof (control). The levels of ErbB3 on surfaces of cells and/or internalization of the ErbB3 receptor in the absence and the presence of an antibody or antigen-binding portion thereof can be readily measured using art recognized techniques, such as those described in Horst *et al.*, *supra* and in the examples herein.

The phrase "inhibition of VEGF secretion of cells expressing ErbB3," as used herein, refers to the ability of an antibody or an antigen-binding portion thereof to statistically significantly decrease VEGF secretion of a cell expressing ErbB3 relative to the VEGF secretion in the absence of the antibody. In one embodiment, the VEGF secretion of a cell expressing ErbB3 (*e.g.*, a cancer cell) may be decreased by at least 10%, or at least 20%, or at least 30%, or at least 40%, or at least 50%, or at least 60%, or at least 70%, or at least 80%, or at least 90%, or 100% when the cells are contacted with an antibody or antigen binding portion thereof of the present disclosure, relative to the VEGF secretion measured in the absence of the antibody or antigen binding portion thereof (control). VEGF secretion can be assayed using art recognized techniques, such as those described herein.

The phrase "inhibition of the migration of cells expressing ErbB3," as used herein, refers to the ability of an antibody or an antigen-binding portion thereof to statistically significantly decrease the migration of a cell expressing ErbB3 relative to the migration of the cell in the absence of the antibody. In one embodiment, the migration of a cell expressing ErbB3 (*e.g.*, a cancer cell) may be decreased by at least 10%, or at least 20%, or at least 30%, or at least 40%, or at least 50%, or at least 60%, or at least 70%, or at least 80%, or at least 90%, or 100% when the cells are contacted with an antibody or antigen binding portion thereof of the present disclosure, relative to cell migration measured in the absence of the antibody or antigen binding portion thereof

(control). Cell migration can be assayed using art recognized techniques, such as those described herein.

The phrase "inhibition of spheroid growth of cells expressing ErbB3," as used herein, refers to the ability of an antibody or an antigen-binding portion thereof to statistically significantly decrease the migration of a cell expressing ErbB3 relative to the migration of the cell in the absence of the antibody. In one embodiment, the migration of a cell expressing ErbB3 (*e.g.*, a cancer cell) may be decreased by at least 10%, or at least 20%, or at least 30%, or at least 40%, or at least 50%, or at least 60%, or at least 70%, or at least 80%, or at least 90%, or 100% when the cells are contacted with an antibody or antigen binding portion thereof of the present disclosure, relative to cell migration measured in the absence of the antibody or antigen binding portion thereof (control). Cell migration can be assayed using art recognized techniques, such as those described herein.

The term "antibody" or "immunoglobulin," as used interchangeably herein, includes whole antibodies and any antigen binding fragment (*i.e.*, "antigen-binding portion") or single chains thereof. A typical antibody comprises at least two heavy (H) chains and two light (L) chains inter-connected by disulfide bonds. Each heavy chain is comprised of a heavy chain variable region (abbreviated herein as V_H) and a heavy chain constant region. The heavy chain constant region is comprised of three domains, CH1, CH2 and CH3. Each light chain is comprised of a light chain variable region (abbreviated herein as V_L) and a light chain constant region. The light chain constant region is comprised of one domain, CL. The V_H and V_L regions can be further subdivided into regions of hypervariability, termed complementarity determining regions (CDR), interspersed with regions that are more conserved, termed framework regions (FR). Each V_H and V_L is composed of three CDRs and four FRs, arranged from amino-terminus to carboxy-terminus in the following order: FR1, CDR1, FR2, CDR2, FR3, CDR3, FR4. The variable regions of the heavy and light chains contain a binding domain that interacts with an antigen. The constant regions of the antibodies may mediate the binding of the immunoglobulin to host tissues or factors, including various cells of the immune system (*e.g.*, effector cells) and the first component (Clq) of the classical complement system. Exemplary antibodies of the present disclosure include antibodies#1, 3, 6 and 14, and antigen-binding portions thereof.

The term "antigen-binding portion" of an antibody (or simply "antibody portion"), as used herein, refers to one or more fragments of an antibody that retain the ability to specifically bind to an antigen (*e.g.*, ErbB3). It has been shown that the antigen-binding function of an antibody can be performed by fragments of a full-length antibody. Examples of binding fragments encompassed within the term "antigen-binding portion" of an antibody include (i) a Fab fragment, a monovalent fragment

consisting of the V_L, V_H, CL and CH1 domains; (ii) a $F(ab')_2$ fragment, a bivalent fragment comprising two Fab fragments linked by a disulfide bridge at the hinge region; (iii) a Fd fragment consisting of the V_H and CH1 domains; (iv) a Fv fragment consisting of the V_L and V_H domains of a single arm of an antibody, (v) a dAb including VH and VL domains; (vi) a dAb fragment (Ward *et al.* (1989) *Nature* 341, 544-546), which consists of a V_H domain; (vii) a dAb which consists of a VH or a VL domain; and (viii) an isolated complementarity determining region (CDR) or (ix) a combination of two or more isolated CDRs which may optionally be joined by a synthetic linker. Furthermore, although the two domains of the Fv fragment, V_L and V_H, are coded for by separate genes, they can be joined, using recombinant methods, by a synthetic linker that enables them to be made as a single protein chain in which the V_L and V_H regions pair to form monovalent molecules (known as single chain Fv (scFv); see *e.g.*, Bird *et al.* (1988) *Science* 242, 423-426; and Huston *et al.* (1988) *Proc. Natl. Acad. Sci. USA* 85, 5879-5883). Such single chain antibodies are also intended to be encompassed within the term "antigen-binding portion" of an antibody. These antibody fragments are obtained using conventional techniques known to those with skill in the art, and the fragments are screened for utility in the same manner as are intact antibodies. Antigen-binding portions can be produced by recombinant DNA techniques, or by enzymatic or chemical cleavage of intact immunoglobulins.

The term "monoclonal antibody" as used herein refers to an antibody obtained from or prepared as a population of substantially homogeneous antibodies, *i.e.*, the individual antibodies comprising the population are identical except for possible naturally occurring mutations that may be present in minor amounts. Monoclonal antibodies are highly specific, being directed against a single antigenic site. Furthermore, in contrast to conventional (polyclonal) antibody preparations which typically include different antibodies directed against different determinants (epitopes), each monoclonal antibody is typically directed against a single determinant on the antigen. Monoclonal antibodies can be prepared using any art recognized technique and those described herein such as, for example, a hybridoma method, as described by Kohler *et al.* (1975) *Nature*, 256:495, a transgenic animal, as described by, for example, (see *e.g.*, Lonberg, *et al.* (1994) Nature 368(6474): 856-859), recombinant DNA methods (see, *e.g.*, U.S. Pat. No. 4,816,567), or using phage antibody libraries using the techniques described in, for example, Clackson *et al.*, *Nature*, 352:624-628 (1991) and Marks *et al.*, *J. Mol. Biol.*, 222:581-597 (1991). Monoclonal antibodies include chimeric antibodies, human antibodies and humanized antibodies and may occur naturally or be recombinantly produced.

The term "recombinant antibody," refers to antibodies that are prepared, expressed, created or isolated by recombinant means, such as (a) antibodies isolated

from an animal (*e.g.*, a mouse) that is transgenic or transchromosomal for immunoglobulin genes (*e.g.*, human immunoglobulin genes) or a hybridoma prepared therefrom, (b) antibodies isolated from a host cell transformed to express the antibody, *e.g.*, from a transfectoma, (c) antibodies isolated from a recombinant, combinatorial antibody library (*e.g.*, containing human antibody sequences) using phage display, and (d) antibodies prepared, expressed, created or isolated by any other means that involve splicing of immunoglobulin gene sequences (*e.g.*, human immunoglobulin genes) to other DNA sequences. Such recombinant antibodies may have variable and constant regions derived from human germline immunoglobulin sequences. In certain embodiments, however, such recombinant human antibodies can be subjected to *in vitro* mutagenesis and thus the amino acid sequences of the V_H and V_L regions of the recombinant antibodies are sequences that, while derived from and related to human germline V_H and V_L sequences, may not naturally exist within the human antibody germline repertoire *in vivo*.

The term "chimeric immunoglobulin" or "chimeric antibody" refers to an immunoglobulin or antibody whose variable regions derive from a first species and whose constant regions derive from a second species. Chimeric immunoglobulins or antibodies can be constructed, for example by genetic engineering, from immunoglobulin gene segments belonging to different species.

The term "human antibody," as used herein, is intended to include antibodies having variable regions in which both the framework and CDR regions are derived from human germline immunoglobulin sequences as described, for example, by Kabat et al. (See Kabat, *et al.* (1991) *Sequences of proteins of Immunological Interest, Fifth Edition*, U.S. Department of Health and Human Services, NIH Publication No. 91-3242). Furthermore, if the antibody contains a constant region, the constant region also is derived from human germline immunoglobulin sequences. The human antibodies may include amino acid residues not encoded by human germline immunoglobulin sequences (*e.g.*, mutations introduced by random or site-specific mutagenesis *in vitro* or by somatic mutation *in vivo*). However, the term "human antibody", as used herein, is not intended to include antibodies in which CDR sequences derived from the germline of another mammalian species, such as a mouse, have been grafted onto human framework sequences.

The human antibody can have at least one ore more amino acids replaced with an amino acid residue, *e.g.*, an activity enhancing amino acid residue which is not encoded by the human germline immunoglobulin sequence. Typically, the human antibody can have up to twenty positions replaced with amino acid residues which are not part of the human germline immunoglobulin sequence. In a particular embodiment, these replacements are within the CDR regions as described in detail below.

The term "humanized immunoglobulin" or "humanized antibody" refers to an immunoglobulin or antibody that includes at least one humanized immunoglobulin or antibody chain (*i.e.*, at least one humanized light or heavy chain). The term "humanized immunoglobulin chain" or "humanized antibody chain" (*i.e.*, a "humanized immunoglobulin light chain" or "humanized immunoglobulin heavy chain") refers to an immunoglobulin or antibody chain (*i.e.*, a light or heavy chain, respectively) having a variable region that includes a variable framework region substantially from a human immunoglobulin or antibody and complementarity determining regions (CDRs) (*e.g.*, at least one CDR, preferably two CDRs, more preferably three CDRs) substantially from a non-human immunoglobulin or antibody, and further includes constant regions (*e.g.*, at least one constant region or portion thereof, in the case of a light chain, and preferably three constant regions in the case of a heavy chain). The term "humanized variable region" (*e.g.*, "humanized light chain variable region" or "humanized heavy chain variable region") refers to a variable region that includes a variable framework region substantially from a human immunoglobulin or antibody and complementarity determining regions (CDRs) substantially from a non-human immunoglobulin or antibody.

A "bispecific" or "bifunctional" antibody is an artificial hybrid antibody having two different heavy/light chain pairs and two different binding sites. Bispecific antibodies can be produced by a variety of methods including fusion of hybridomas or linking of Fab' fragments. See, *e.g.*, Songsivilai & Lachmann, (1990) *Clin. Exp. Immunol.* 79, 315-321; Kostelny *et al.* (1992) *J. Immunol.* 148, 1547-1553. In a particular embodiment, a bispecific antibody according to the present invention includes binding sites for both ErbB3 and IGF1-R (*i.e.*, insulin-like growth factor 1-receptor). In another embodiment, a bispecific antibody according to the present invention includes binding sites for both ErbB3 and C-MET. In other embodiments, a bispecific antibody includes a binding site for ErbB3 and a binding site for ErbB2, ERbB3, ErbB4, EGFR, Lewis Y, MUC-1, EpCAM, CA125, prostate specific membrane antigen, PDGFR-α, PDGFR-β, C-KIT, or any of the FGF receptors.

As used herein, a "heterologous antibody" is defined in relation to the transgenic non-human organism or plant producing such an antibody.

An "isolated antibody," as used herein, is intended to refer to an antibody which is substantially free of other antibodies having different antigenic specificities (*e.g.*, an isolated antibody that specifically binds to ErbB3 is substantially free of antibodies that specifically bind antigens other than ErbB3). In addition, an isolated antibody is typically substantially free of other cellular material and/or proteins. In one embodiment of the invention, a combination of "isolated" antibodies having different ErbB3 binding specificities are combined in a well defined composition.

As used herein, "isotype" refers to the antibody class (*e.g.*, IgM or IgGl) that is encoded by heavy chain constant region genes. In one embodiment, an antibody or antigen binding portion thereof is of an isotype selected from an IgG1, an IgG2, an IgG3, an IgG4, an IgM, an IgA1, an IgA2, an IgAsec, an IgD, or an IgE antibody isotype. In some embodiments, an antibody is of the IgG1 isotype. In other embodiments, an antibody is of the IgG2 isotype.

As used herein, "isotype switching" refers to the phenomenon by which the class, or isotype, of an antibody changes from one Ig class to one of the other Ig classes.

As used herein, "nonswitched isotype" refers to the isotypic class of heavy chain that is produced when no isotype switching has taken place; the CH gene encoding the nonswitched isotype is typically the first CH gene immediately downstream from the functionally rearranged VDJ gene. Isotype switching has been classified as classical or non-classical isotype switching. Classical isotype switching occurs by recombination events which involve at least one switch sequence regions in a gene encoding an antibody. Non-classical isotype switching may occur by, for example, homologous recombination between human σ_μ and human Σ_μ (δ-associated deletion). Alternative non-classical switching mechanisms, such as intertransgene and/or interchromosomal recombination, among others, may occur and effectuate isotype switching.

As used herein, the term "switch sequence" refers to those DNA sequences responsible for switch recombination. A "switch donor" sequence, typically a μ switch region, will be 5' (*i.e.*, upstream) of the construct region to be deleted during the switch recombination. The "switch acceptor" region will be between the construct region to be deleted and the replacement constant region (*e.g.*, γ, ε, etc.). As there is no specific site where recombination always occurs, the final gene sequence will typically not be predictable from the construct.

An "antigen" is an entity (*e.g.*, a proteinaceous entity or peptide) to which an antibody or antigen-binding portion thereof binds. In various embodiments disclosed herein, the antigen is ErbB3 or a ErbB3-like molecule. In a particular embodiment according to the invention, the antigen is human ErbB3.

The term "epitope" or "antigenic determinant" refers to a site on an antigen to which an immunoglobulin or antibody specifically binds. Epitopes can be formed both from contiguous amino acids or noncontiguous amino acids juxtaposed by tertiary folding of a protein. Epitopes formed from contiguous amino acids are typically retained on exposure to denaturing solvents, whereas epitopes formed by tertiary folding are typically lost on treatment with denaturing solvents. An epitope typically includes at least 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 or 15 amino acids in a unique spatial conformation. Methods of determining spatial conformation of epitopes include techniques in the art and those described herein, for example, x-ray crystallography and

2-dimensional nuclear magnetic resonance. See, *e.g.*, *Epitope Mapping Protocols in Methods in Molecular Biology,* Vol. 66, G. E. Morris, Ed. (1996).

Also encompassed by the present invention are antibodies that bind the same or an overlapping epitope as the antibodies for which amino acid sequences are disclosed herein, *i.e.*, antibodies that compete for binding to ErbB3, or bind epitopes which overlap with epitopes bound by the antibodies described herein, *i.e.*, an epitope located on ectodomain of ErbB3, preferably on Domain I of the ectodomain of ErbB3. Antibodies that recognize the same epitope can be identified using routine techniques such as an immunoassay, for example, by showing the ability of one antibody to block the binding of another antibody to a target antigen, *i.e.*, a competitive binding assay. Competitive binding is determined in an assay in which the immunoglobulin under test inhibits specific binding of a reference antibody to a common antigen, such as ErbB3. Numerous types of competitive binding assays are known, for example: solid phase direct or indirect radioimmunoassay (RIA), solid phase direct or indirect enzyme immunoassay (EIA), sandwich competition assay (see Stahli *et al.*, (1983) *Methods in Enzymology* 9:242); solid phase direct biotin-avidin EIA (see Kirkland *et al.*, (1986) *J. Immunol.* 137:3614); solid phase direct labeled assay, solid phase direct labeled sandwich assay (see Harlow and Lane, (1988) *Antibodies: A Laboratory Manual*, Cold Spring Harbor Press); solid phase direct label RIA using I-125 label (see Morel *et al.*, (1988) *Mol. Immunol.* 25(1):7); solid phase direct biotin-avidin EIA (Cheung *et al.*, (1990) *Virology* 176:546); and direct labeled RIA. (Moldenhauer *et al.*, (1990) *Scand. J. Immunol.* 32:77). Typically, such an assay involves the use of purified antigen (*e.g.*, ErbB3) bound to a solid surface or cells bearing either of these, an unlabeled test immunoglobulin and a labeled reference immunoglobulin. Competitive inhibition is measured by determining the amount of label bound to the solid surface or cells in the presence of the test immunoglobulin. Usually the test immunoglobulin is present in excess. Usually, when a competing antibody is present in excess, it will inhibit specific binding of a reference antibody to a common antigen by at least 50-55%, 55-60%, 60-65%, 65-70% 70-75% or more.

The term "paratope" refers to the parts, or amino acid residues, of an antibody that appear to be directly involved in recognizing and contacting the epitope on an antigen to which the antibody specifically binds. Paratopes typically comprise some but not all amino acid residues within the complementarity determining regions (CDRs) of the heavy and light chains. A paratope may involve amino acid residues in all of the V_H and V_L CDRs or only some of the CDRs (*e.g.*, certain CDRs may not be involved in binding antigen). The paratope for a particular antigen can be defined, for example, by scanning mutagenesis (*e.g.*, alanine scanning mutagenesis) of amino acid residues within the antibody, particularly the CDRs, that are thought to be surface exposed (*e.g.*, as

determined by crystallographic modeling) and possibly involved in antigen binding. Evaluation of the binding of the mutants to the antigen then can determine whether the mutated amino acid position is involved in antigen binding and thus forms part of the paratope of the antibody. Methods for determining an antibody paratope are described in further detail in Example 20.

In a preferred embodiment, an anti-ErbB3 antibody comprises a heavy chain paratope comprising CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 63 or 76 (CDR1), 64 (CDR2) and 65 (CDR3), respectively, with the proviso that the antibody is not: (i) Ab #6 as disclosed herein; (ii) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 1 and 2, respectively; or (iii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 7, 8 and 9, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 10, 11 and 12, respectively.

In another preferred embodiment, an anti-ErbB3 antibody comprises a light chain paratope comprising CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 69 or 78 (CDR1), 70 (CDR2) and 71 or 80 (CDR3), respectively, with the proviso that the antibody is not: (i) Ab #6 as disclosed herein; (ii) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 1 and 2, respectively; or (iii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 7, 8 and 9, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 10, 11 and 12, respectively.

In another embodiment, the anti-ErbB3 antibody comprises a heavy chain paratope comprising CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 63, 64 and 65, respectively, and a light chain paratope comprising CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 69, 70 and 71, respectively, with the proviso that the antibody is not: (i) Ab #6 as disclosed herein; (ii) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 1 and 2, respectively; or (iii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 7, 8 and 9, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 10, 11 and 12, respectively.

In another embodiment, the anti-ErbB3 antibody comprises a heavy chain paratope comprising CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 76, 64 and 65, respectively, and a light chain paratope comprising CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 78, 70 and 80, respectively, with the proviso that the antibody is not: (i) Ab #6 as disclosed herein; (ii) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 1 and 2, respectively; or (iii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 7, 8 and

9, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 10, 11 and 12, respectively.

The term "consensus sequence", as used herein with respect to complementarity determining regions (CDRs), refers to a composite or genericized sequence for a CDR that has been defined based on information as to which amino acid residues within the CDR are amenable to modification without detriment to antigen binding. Thus, in a "consensus sequence" for a CDR, certain amino acid positions are occupied by one of multiple possible amino acid residues at that position. For example, within a CDR, if antigen binding has been found to be unaffected by the presence of either a tyrosine or a phenylalanine at a particular position, then that particular position within the consensus sequence can be either tyrosine or phenylalanine (T/F). Consensus sequences for CDRs can be defined, for example, by scanning mutagenesis (*e.g.*, alanine scanning mutagenesis) of amino acid residues within the antibody CDRs, followed by evaluation of the binding of the mutants to the antigen to determine whether the mutated amino acid position affects antigen binding. Methods for determining antibody CDR consensus sequences are described in further detail in Example 20.

In a preferred embodiment, an anti-ErbB3 antibody comprises a heavy chain variable region comprising consensus heavy chain CDR1, CDR2 and CDR3 sequences shown in SEQ ID NOs: 60 or 75 (CDR1), 61 (CDR2) and 62 (CDR3), respectively, with the proviso that the antibody is not: (i) Ab #6 as disclosed herein; (ii) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 1 and 2, respectively; or (iii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 7, 8 and 9, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 10, 11 and 12, respectively.

In another preferred embodiment, an anti-ErbB3 antibody comprises a light chain variable region comprising consensus light chain CDR1, CDR2 and CDR3 sequences shown in SEQ ID NOs: 66 or 77 (CDR1), 67 (CDR2) and 68 or 79 (CDR3), respectively, with the proviso that the antibody is not: (i) Ab #6 as disclosed herein; (ii) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 1 and 2, respectively; or (iii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 7, 8 and 9, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 10, 11 and 12, respectively.

In another embodiment, the anti-ErbB3 antibody comprises a heavy chain variable region comprising consensus heavy chain CDR1, CDR2 and CDR3 sequences shown in SEQ ID NOs: 60, 61 and 62, respectively, and a light chain variable region comprising consensus light chain CDR1, CDR2 and CDR3 sequences shown in SEQ ID NOs: 66, 67 and 68, respectively, with the proviso that the antibody is not: (i) Ab #6 as disclosed herein; (ii) an antibody comprising V_H and V_L sequences as shown in SEQ ID

NOs: 1 and 2, respectively; or (iii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 7, 8 and 9, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 10, 11 and 12, respectively.

In another embodiment, the anti-ErbB3 antibody comprises a heavy chain variable region comprising consensus heavy chain CDR1, CDR2 and CDR3 sequences shown in SEQ ID NOs: 75, 61 and 62, respectively, and a light chain variable region comprising consensus light chain CDR1, CDR2 and CDR3 sequences shown in SEQ ID NOs: 77, 67 and 79, respectively, with the proviso that the antibody is not: (i) Ab #6 as disclosed herein; (ii) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 1 and 2, respectively; or (iii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 7, 8 and 9, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 10, 11 and 12, respectively.

As used herein, the terms "specific binding," "specifically binds," "selective binding," and "selectively binds," mean that an antibody or antigen-binding portion thereof, exhibits appreciable affinity for a particular antigen or epitope and, generally, does not exhibit significant cross-reactivity with other antigens and epitopes. "Appreciable" or preferred binding includes binding with an affinity of at least 10^6, 10^7, 10^8, 10^9 M^{-1}, or 10^{10} M^{-1}. Affinities greater than 10^7 M^{-1}, preferably greater than 10^8 M^{-1} are more preferred. Values intermediate of those set forth herein are also intended to be within the scope of the present invention and a preferred binding affinity can be indicated as a range of affinities, for example, 10^6 to 10^{10} M^{-1}, preferably 10^7 to 10^{10} M^{-1}, more preferably 10^8 to 10^{10} M^{-1}. An antibody that "does not exhibit significant cross-reactivity" is one that will not appreciably bind to an undesirable entity (*e.g.*, an undesirable proteinaceous entity). For example, in one embodiment, an antibody or antigen-binding portion thereof that specifically binds to ErbB3 will appreciably bind that ErbB3 molecule but will not significantly react with other ErbB molecules and non-ErbB proteins or peptides. Specific or selective binding can be determined according to any art-recognized means for determining such binding, including, for example, according to Scatchard analysis and/or competitive binding assays.

The term "K_D," as used herein, is intended to refer to the dissociation equilibrium constant of a particular antibody-antigen interaction or the affinity of an antibody for an antigen, preferably as measured using a surface plasmon resonance assay (e.g., as determined in a BIACORE 3000 instrument (GE Healthcare) using recombinant ErbB3 as the analyte and the antibody as the ligand) or a cell binding assay. Both such assays are detailed in Example 3, below. In one embodiment, the antibody or antigen binding portion thereof according to the present invention binds an antigen (*e.g.*, ErbB3) with an affinity (K_D) of 50 nM or better (i.e., or less) (*e.g.*, 40 nM or 30 nM or 20 nM or 10 nM or less),. In a particular embodiment, an antibody or antigen binding portion thereof

according to the present invention binds ErbB3 with an affinity (K_D) of 8 nM or better (*e.g.*, 7 nM, 6 nM, 5 nM, 4 nM, 2 nM, 1.5 nM, 1.4 nM, 1.3 nM, 1nM or less. In other embodiments, an antibody or antigen binding portion thereof binds an antigen (*e.g.*, ErbB3) with an affinity (K_D) of approximately less than 10^{-7} M, such as approximately less than 10^{-8} M, 10^{-9} M or 10^{-10} M or even lower, and binds to the predetermined antigen with an affinity that is at least two-fold greater than its affinity for binding to a non-specific antigen (*e.g.*, BSA, casein) other than the predetermined antigen or a closely-related antigen.

The term "K_{off}," as used herein, is intended to refer to the off rate constant for the dissociation of an antibody from the antibody/antigen complex.

The term "EC50," as used herein, refers to the concentration of an antibody or an antigen-binding portion thereof, which induces a response, either in an *in vitro* or an *in vivo* assay, which is 50% of the maximal response, *i.e.*, halfway between the maximal response and the baseline.

As used herein, "glycosylation pattern" is defined as the pattern of carbohydrate units that are covalently attached to a protein, more specifically to an immunoglobulin protein.

The term "naturally-occurring" as used herein as applied to an object refers to the fact that an object can be found in nature. For example, a polypeptide or polynucleotide sequence that is present in an organism (including viruses) that can be isolated from a source in nature and which has not been intentionally modified by man in the laboratory is naturally-occurring.

The term "rearranged" as used herein refers to a configuration of a heavy chain or light chain immunoglobulin locus wherein a V segment is positioned immediately adjacent to a D-J or J segment in a conformation encoding essentially a complete V_H or V_L domain, respectively. A rearranged immunoglobulin gene locus can be identified by comparison to germline DNA; a rearranged locus will have at least one recombined heptamer/nonamer homology element.

The term "unrearranged" or "germline configuration" as used herein in reference to a V segment refers to the configuration wherein the V segment is not recombined so as to be immediately adjacent to a D or J segment.

The term "nucleic acid molecule," as used herein, is intended to include DNA molecules and RNA molecules. A nucleic acid molecule may be single-stranded or double-stranded, but preferably is double-stranded DNA.

The term "isolated nucleic acid molecule," as used herein in reference to nucleic acids encoding antibodies or antibody portions (*e.g.*, V_H, V_L, CDR3) that bind to ErbB3, is intended to refer to a nucleic acid molecule in which the nucleotide sequences encoding the antibody or antibody portion are free of other nucleotide sequences

encoding antibodies that bind antigens other than ErbB3, which other sequences may naturally flank the nucleic acid in human genomic DNA.

The term "modifying," or "modification," as used herein, is intended to refer to changing one or more amino acids in the antibodies or antigen-binding portions thereof. The change can be produced by adding, substituting or deleting an amino acid at one or more positions. The change can be produced using known techniques, such as PCR mutagenesis. For example, in some embodiments, an antibody or an antigen-binding portion thereof identified using the methods of the present disclosure can be modified, to thereby modify the binding affinity of the antibody or antigen-binding portion thereof to ErbB3.

The present invention also encompasses "conservative amino acid substitutions" in the sequences of the antibodies or fragments therof of the invention, *i.e.*, nucleotide and amino acid sequence modifications which do not abrogate the binding of the antibody encoded by the nucleotide sequence or containing the amino acid sequence, to the antigen, *i.e.*, ErbB3. Conservative amino acid substitutions include the substitution of an amino acid in one class by an amino acid of the same class, where a class is defined by common physicochemical amino acid side chain properties and high substitution frequencies in homologous proteins found in nature, as determined, for example, by a standard Dayhoff frequency exchange matrix or BLOSUM matrix. Six general classes of amino acid side chains have been categorized and include: Class I (Cys); Class II (Ser, Thr, Pro, Ala, Gly); Class III (Asn, Asp, Gln, Glu); Class IV (His, Arg, Lys); Class V (Ile, Leu, Val, Met); and Class VI (Phe, Tyr, Trp). For example, substitution of an Asp for another class III residue such as Asn, Gln, or Glu, is a conservative substitution. Thus, a predicted nonessential amino acid residue in an anti-ErbB3 antibody is preferably replaced with another amino acid residue from the same class. Methods of identifying nucleotide and amino acid conservative substitutions which do not eliminate antigen binding are well-known in the art (see, *e.g.*, Brummell *et al.*, *Biochem.* 32:1180-1187 (1993); Kobayashi *et al. Protein Eng.* 12(10):879-884 (1999); and Burks *et al. Proc. Natl. Acad. Sci. USA* 94:.412-417 (1997)).

The term "non-conservative amino acid substitution" refers to the substitution of an amino acid in one class with an amino acid from another class; for example, substitution of an Ala, a class II residue, with a class III residue such as Asp, Asn, Glu, or Gln.

Alternatively, in another embodiment, mutations (conservative or non-conservative) can be introduced randomly along all or part of an anti-ErbB3 antibody coding sequence, such as by saturation mutagenesis, and the resulting modified anti-ErbB3 antibodies can be screened for binding activity.

A "consensus sequence" is a sequence formed from the most frequently occurring amino acids (or nucleotides) in a family of related sequences (See *e.g.*, Winnaker, From Genes to Clones (Verlagsgesellschaft, Weinheim, Germany 1987). In a family of proteins, each position in the consensus sequence is occupied by the amino acid occurring most frequently at that position in the family. If two amino acids occur equally frequently, either can be included in the consensus sequence. A "consensus framework" of an immunoglobulin refers to a framework region in the consensus immunoglobulin sequence.

Similarly, the consensus sequence for the CDRs of can be derived by optimal alignment of the CDR amino acid sequences of ErbB3 antibodies for which CDR amino acid sequences are disclosed herein.

For nucleic acids, the term "substantial homology" indicates that two nucleic acids, or designated sequences thereof, when optimally aligned and compared, are identical, with appropriate nucleotide insertions or deletions, in at least about 80% of the nucleotides, usually at least about 90% to 95%, and more preferably at least about 98% to 99.5% of the nucleotides. Alternatively, substantial homology exists when the segments will hybridize under selective hybridization conditions, to the complement of the strand.

The percent identity between two sequences is a function of the number of identical positions shared by the sequences (*i.e.*, % homology = # of identical positions/total # of positions x 100), taking into account the number of gaps, and the length of each gap, which need to be introduced for optimal alignment of the two sequences. The comparison of sequences and determination of percent identity between two sequences can be accomplished using a mathematical algorithm, as described in the non-limiting examples below.

The percent identity between two nucleotide sequences can be determined using the GAP program in the GCG software, using a NWSgapdna.CMP matrix and a gap weight of 40, 50, 60, 70, or 80 and a length weight of 1, 2, 3, 4, 5, or 6. The percent identity between two nucleotide or amino acid sequences can also be determined using the algorithm of E. Meyers and W. Miller (CABIOS, 4:11-17 (1989)) which has been incorporated into the ALIGN program (version 2.0), using a PAM120 weight residue table, a gap length penalty of 12 and a gap penalty of 4. In addition, the percent identity between two amino acid sequences can be determined using the Needleman and Wunsch (*J. Mol. Biol.* (48):444-453 (1970)) algorithm which has been incorporated into the GAP program in the GCG software package, using either a Blossum 62 matrix or a PAM250 matrix, and a gap weight of 16, 14, 12, 10, 8, 6, or 4 and a length weight of 1, 2, 3, 4, 5, or 6.

The nucleic acid and protein sequences of the present disclosure can further be used as a "query sequence" to perform a search against public databases to, for example, identify related sequences. Such searches can be performed using the NBLAST and XBLAST programs (version 2.0) of Altschul, *et al.* (1990) *J. Mol. Biol.* 215:403-10. BLAST nucleotide searches can be performed with the NBLAST program, score = 100, wordlength = 12 to obtain nucleotide sequences homologous to the nucleic acid molecules of the invention. BLAST protein searches can be performed with the XBLAST program, score = 50, wordlength = 3 to obtain amino acid sequences homologous to the protein molecules of the invention. To obtain gapped alignments for comparison purposes, Gapped BLAST can be utilized as described in Altschul *et al.*, (1997) *Nucleic Acids Res.* 25(17):3389-3402. When utilizing BLAST and Gapped BLAST programs, the default parameters of the respective programs (*e.g.*, XBLAST and NBLAST) can be used.

The nucleic acids may be present in whole cells, in a cell lysate, or in a partially purified or substantially pure form. A nucleic acid is "isolated" or "rendered substantially pure" when purified away from other cellular components or other contaminants, *e.g.*, other cellular nucleic acids or proteins, by standard techniques, including alkaline/SDS treatment, CsCl banding, column chromatography, agarose gel electrophoresis and others well known in the art. *See*, F. Ausubel, *et al.*, ed. Current Protocols in Molecular Biology, Greene Publishing and Wiley Interscience, New York (1987).

The nucleic acid compositions of the present disclosure, while often in a native sequence (except for modified restriction sites and the like), from either cDNA, genomic or mixtures thereof may be mutated, in accordance with standard techniques to provide gene sequences. For coding sequences, these mutations, may affect amino acid sequence as desired. In particular, DNA sequences substantially homologous to or derived from native V, D, J, constant, switches and other such sequences described herein are contemplated (where "derived" indicates that a sequence is identical or modified from another sequence).

The term "operably linked" refers to a nucleic acid sequence placed into a functional relationship with another nucleic acid sequence. For example, DNA for a presequence or secretory leader is operably linked to DNA for a polypeptide if it is expressed as a preprotein that participates in the secretion of the polypeptide; a promoter or enhancer is operably linked to a coding sequence if it affects the transcription of the sequence; or a ribosome binding site is operably linked to a coding sequence if it is positioned so as to facilitate translation. Generally, "operably linked" means that the DNA sequences being linked are contiguous, and, in the case of a secretory leader, contiguous and in reading phase. However, enhancers do not have to be contiguous.

Linking is accomplished by ligation at convenient restriction sites. If such sites do not exist, the synthetic oligonucleotide adaptors or linkers are used in accordance with conventional practice. A nucleic acid is "operably linked" when it is placed into a functional relationship with another nucleic acid sequence. For instance, a promoter or enhancer is operably linked to a coding sequence if it affects the transcription of the sequence. With respect to transcription regulatory sequences, operably linked means that the DNA sequences being linked are contiguous and, where necessary to join two protein coding regions, contiguous and in reading frame. For switch sequences, operably linked indicates that the sequences are capable of effecting switch recombination.

The term "vector," as used herein, is intended to refer to a nucleic acid molecule capable of transporting another nucleic acid to which it has been linked. One type of vector is a "plasmid," which refers to a circular double stranded DNA loop into which additional DNA segments may be ligated. Another type of vector is a viral vector, wherein additional DNA segments may be ligated into the viral genome. Certain vectors are capable of autonomous replication in a host cell into which they are introduced (*e.g.*, bacterial vectors having a bacterial origin of replication and episomal mammalian vectors). Other vectors (*e.g.*, non-episomal mammalian vectors) can be integrated into the genome of a host cell upon introduction into the host cell, and thereby are replicated along with the host genome. Moreover, certain vectors are capable of directing the expression of genes to which they are operatively linked. Such vectors are referred to herein as "recombinant expression vectors"(or simply, "expression vectors"). In general, expression vectors of utility in recombinant DNA techniques are often in the form of plasmids. The terms, "plasmid" and "vector" may be used interchangeably. However, the invention is intended to include such other forms of expression vectors, such as viral vectors (*e.g.*, replication defective retroviruses, adenoviruses and adeno-associated viruses), which serve equivalent functions.

The term "recombinant host cell" (or simply "host cell"), as used herein, is intended to refer to a cell into which a recombinant expression vector has been introduced. It should be understood that such terms are intended to refer not only to the particular subject cell but to the progeny of such a cell. Because certain modifications may occur in succeeding generations due to either mutation or environmental influences, such progeny may not, in fact, be identical to the parent cell, but are still included within the scope of the term "host cell" as used herein.

The terms "treat," "treating," and "treatment," as used herein, refer to therapeutic or preventative measures described herein. The methods of "treatment" employ administration to a subject, an antibody or antigen binding portion disclosed herein, for example, a subject having a disease or disorder associated with ErbB3 dependent

signaling or predisposed to having such a disease or disorder, in order to prevent, cure, delay, reduce the severity of, or ameliorate one or more symptoms of the disease or disorder or recurring disease or disorder, or in order to prolong the survival of a subject beyond that expected in the absence of such treatment.

The term "disease associated with ErbB3 dependent signaling," or "disorder associated with ErbB3 dependent signaling," as used herein, includes disease states and/or symptoms associated with a disease state, where increased levels of ErbB3 and/or activation of cellular cascades involving ErbB3 are found. It is understood that ErbB3 heterodimerizes with other ErbB proteins such as, EGFR and ErbB2, when increased levels of ErbB3 are found. Accordingly, the term "disease associated with ErbB3 dependent signaling," also includes disease states and/or symptoms associated with disease states where increased levels of EGFR/ErbB3 and/or ErbB2/ErbB3 heterodimers are found. In general, the term "disease associated with ErbB3 dependent signaling," refers to any disorder, the onset, progression or the persistence of the symptoms of which requires the participation of ErbB3. Exemplary ErbB3-mediated disorders include, but are not limited to, for example, cancer.

The terms "cancer" and "cancerous" refer to or describe the physiological condition in mammals that is typically characterized by unregulated cell growth. Examples of cancer include but are not limited to, carcinoma, lymphoma, blastoma, sarcoma, and leukemia. More particular examples of such cancers include squamous cell cancer, small-cell lung cancer, non-small cell lung cancer, gastric cancer, pancreatic cancer, glial cell tumors such as glioblastoma and neurofibromatosis, cervical cancer, ovarian cancer, liver cancer, bladder cancer, hepatoma, breast cancer, colon cancer, melanoma, colorectal cancer, endometrial carcinoma, salivary gland carcinoma, kidney cancer, renal cancer, prostate cancer, vulval cancer, thyroid cancer, hepatic carcinoma and various types of head and neck cancer. In a particular embodiment, a cancer treated or diagnosed using the methods disclosed herein is selected from melanoma, breast cancer, ovarian cancer, renal carcinoma, gastrointestinal/colon cancer, lung cancer, and prostate cancer.

The term "KRAS mutation", as used herein, refers to mutations found in certain cancers in a human homolog of the v-Ki-ras2 Kirsten rat sarcoma viral oncogene. Non-limiting examples of human KRAS gene mRNA sequences include Genbank Accession Nos. NM_004985 and NM_033360. It has been reported that KRAS mutations are found in 73% of pancreatic tumors, 35% of colorectal tumors, 16% of ovarian tumors and 17% of lung tumors.

The term "PI3K mutation", as used herein, refers to mutations found in certain cancers in a phosphatidyl-inositol-3-kinase gene, typically leading to activation of PI3K

in the cancer cells. It has been reported that PI3K mutations are found in 12% of colorectal tumors, 15% of head and neck tumors and 26% of breast tumors.

The term "effective amount," as used herein, refers to that amount of an antibody or an antigen binding portion thereof that binds ErbB3, which is sufficient to effect treatment, prognosis or diagnosis of a disease associated with ErbB3 dependent signaling, as described herein, when administered to a subject. A therapeutically effective amount will vary depending upon the subject and disease condition being treated, the weight and age of the subject, the severity of the disease condition, the manner of administration and the like, which can readily be determined by one of ordinary skill in the art. The dosages for administration can range from, for example, about 1 ng to about 10,000 mg, about 5 ng to about 9,500 mg, about 10 ng to about 9,000 mg, about 20 ng to about 8,500 mg, about 30 ng to about 7,500 mg, about 40 ng to about 7,000 mg, about 50 ng to about 6,500 mg, about 100 ng to about 6,000 mg, about 200 ng to about 5,500 mg, about 300 ng to about 5,000 mg, about 400 ng to about 4,500 mg, about 500 ng to about 4,000 mg, about 1 μg to about 3,500 mg, about 5 μg to about 3,000 mg, about 10 μg to about 2,600 mg, about 20 μg to about 2,575 mg, about 30 μg to about 2,550 mg, about 40 μg to about 2,500 mg, about 50 μg to about 2,475 mg, about 100 μg to about 2,450 mg, about 200 μg to about 2,425 mg, about 300 μg to about 2,000, about 400 μg to about 1,175 mg, about 500 μg to about 1,150 mg, about 0.5 mg to about 1,125 mg, about 1 mg to about 1,100 mg, about 1.25 mg to about 1,075 mg, about 1.5 mg to about 1,050 mg, about 2.0 mg to about 1,025 mg, about 2.5 mg to about 1,000 mg, about 3.0 mg to about 975 mg, about 3.5 mg to about 950 mg, about 4.0 mg to about 925 mg, about 4.5 mg to about 900 mg, about 5 mg to about 875 mg, about 10 mg to about 850 mg, about 20 mg to about 825 mg, about 30 mg to about 800 mg, about 40 mg to about 775 mg, about 50 mg to about 750 mg, about 100 mg to about 725 mg, about 200 mg to about 700 mg, about 300 mg to about 675 mg, about 400 mg to about 650 mg, about 500 mg, or about 525 mg to about 625 mg, of an antibody or antigen binding portion thereof, according to the invention. Dosage regimen may be adjusted to provide the optimum therapeutic response. An effective amount is also one in which any toxic or detrimental effects (*i.e.*, side effects) of an antibody or antigen binding portion thereof are minimized and/or outweighed by the beneficial effects. Additional preferred dosages regimens are described further below in the section pertaining to pharmaceutical compositions.

The term "patient" includes human and other mammalian subjects that receive either prophylactic or therapeutic treatment.

As used herein, the term "subject" or "patient"includes any human or non-human animal. For example, the methods and compositions disclosed herein can be used to treat a subject having cancer. In a preferred embodiment, the subject is a human. The

term "non-human animal" includes all vertebrates, *e.g.*, mammals and non-mammals, such as non-human primates, sheep, dog, cow, *etc.*

The term "sample" refers to tissue, body fluid, or a cell from a patient or a subject. Normally, the tissue or cell will be removed from the patient, but *in vivo* diagnosis is also contemplated. In the case of a solid tumor, a tissue sample can be taken from a surgically removed tumor and prepared for testing by conventional techniques. In the case of lymphomas and leukemias, lymphocytes, leukemic cells, or lymph tissues can be obtained and appropriately prepared. Other patient samples, including urine, tear drops, serum, cerebrospinal fluid, feces, sputum, cell extracts *etc.* can also be useful for particular tumors.

The terms "anti-cancer agent" and "antineoplastic agent" refer to drugs used to treat malignancies, such as cancerous growths. Drug therapy may be used alone, or in combination with other treatments such as surgery or radiation therapy. Several classes of drugs may be used in cancer treatment, depending on the nature of the organ involved. For example, breast cancers are commonly stimulated by estrogens, and may be treated with drugs which inactive the sex hormones. Similarly, prostate cancer may be treated with drugs that inactivate androgens, the male sex hormone. Anti-cancer agents for use in certain methods of the present invention include, among others, the following agents:

Anti-Cancer Agent	**Comments**	**Examples**
Antibodies (a) antibodies other than anti-ErbB3 antibodies; and (b) anti-ErbB3 antibodies which bind different epitopes	Antibodies which bind IGF-1R (insulin-like growth factor type 1 receptor), which is expressed on the cell surface of must human cancers	A12 (fully humanized mAb) 19D12 (fully humanized mAb) CP751-871 (fully humanized mAb) H7C10 (humanized mAb) alphaIR3 (mouse) scFV/FC (mouse/human chimera) EM/164 (mouse) AMG 479 (fully humanized mAb; Amgen) IMCA 12 (fully humanized mAb; Imclone) NSC-742460 (Dyax) MR-0646, F50035 (Pierre Fabre Medicament, Merck)
	Antibodies which bind EGFR; Mutations affecting EGFR expression or activity can	matuzumab (EMD72000) Erbitux® / cetuximab (Imclone) Vectibix® / panitumumab (Amgen) mAb 806

	result in cancer	nimotuzumab (TheraCIM) INCB7839 (Incyte) panitumumab (Vectibix®; Amgen)
	Antibodies which bind cMET (mesenchymal epithelial transition factor); a member of the MET family of receptor tyrosine kinases)	AVEO (AV299) (AVEO) AMG102 (Amgen) 5D5 (OA-5D5) (Genentech)
	Anti-ErbB3 antibodies which bind different epitopes	Ab #14 described herein 1B4C3; 2D1D12 (U3 Pharma AG) U3-1287/AMG888 (U3 Pharma/Amgen)
	Anti-ErbB2 (HER2) antibodies	Herceptin® (trastuzumab; Genentech/Roche) binds ectodomain Domain II of ErbB2; Omnitarg® (pertuzumab; 2C4,R1273; Genentech/Roche) binds Domain IV of ErbB2
Small Molecules Targeting IGF1R	IGF-1R (insulin-like growth factor type 1 receptor), which is expressed on the cell surface of must human cancers	NVP-AEW541-A BMS-536,924 (1H-benzoimidazol-2-yl)-1H-pyridin-2-one) BMS-554,417 Cycloligan TAE226 PQ401
Small Molecules Targeting EGFR	EGFR; Mutations affecting EGFR expression or activity can result in cancer	Iressa® / gefitinib (AstraZeneca) CI-1033 (PD 183805) (Pfizer) TYVERB / lapatinib (GlaxoSmithKline) Tykerb® / lapatinib ditosylate (SmithKline Beecham) Tarceva®/ Erlotinib HCL (OSI Pharma) PKI-166 (Novartis) PD-158780 EKB-569 Tyrphostin AG 1478(4-(3-Chloroanillino)-

		6,7-dimethoxyquinazoline)
Small Molecules Targeting ErbB2	ErbB2, also known as HER2, a member of the ErbB family of receptors, which is expressed on certain cancer cells	HKI-272 (neratinib; Wyeth) KOS-953 (tanespimycin; Kosan Biosciences)
Small Molecules Targeting cMET	cMET (Mesenchymal epithelial transition factor); a member of the MET family of receptor tyrosine kinases)	PHA665752 ARQ 197 (ArQule) ARQ-650RP (ArQule)
Antimetabolites	An antimetabolite is a chemical with a similar structure to a substance (a metabolite) required for normal biochemical reactions, yet different enough to interfere with the normal functions of cells, including cell division.	flourouracil (5-FU) capecitabine / XELODA® (HLR Roche) 5-trifluoromethyl-2'-deoxyuridine methotrexate sodium (Trexall) (Barr) raltitrexed / Tomudex® (AstraZaneca) pemetrexed / Alimta® (Lilly) tegafur cytosine arabinoside (Cytarabine, Ara-C) / tioguanine / Lanvis® (GlaxoSmithKline) 5-azacytidine 6-mercaptopurine (Mercaptopurine, 6-MP) azathioprine / Azasan® (AAIPHARMA LLC) 6-thioguanine (6-TG) / Purinethol® (TEVA) pentostatin / Nipent® (Hospira Inc.) fludarabine phosphate / Fludara® (Bayer Health Care) cladribine / Leustatin® (2-CdA, 2-chlorodeoxyadenosine) (Ortho Biotech) floxuridine (5-fluoro-2'-deoxyuridine) / FUDR® (Hospira, Inc,)
Alkylating agents	An alkylating antineoplastic agent is an	Ribonucleotide Reductase Inhibitor (RNR) cyclophosphamide / Cytoxan® (BMS) /

alkylating agent that attaches an alkyl group to DNA. Since cancer cells generally proliferate unrestrictively more than do healthy cells they are more sensitive to DNA damage, and alkylating agents are used clinically to treat a variety of tumors.	Neosar® (TEVA) ifosfamide /Mitoxana® (ASTA Medica) ThioTEPA (Bedford, Abraxis, Teva) BCNU→ 1,3-bis(2-chloroethyl)-1-nitrosourea CCNU→ 1,-(2-chloroethyl)-3-cyclohexyl-1-nitrosourea (methyl CCNU) hexamethylmelamine (altretamine, HMM) / Hexalen® (MGI Pharma Inc.) busulfan / Myleran® (GlaxoSmithKline) procarbazine HCL / Matulane® (Sigma Tau) Dacarbazine (DTIC®) chlorambucil / Leukaran® (SmithKline Beecham) Melphalan / Alkeran® (GlaxoSmithKline) cisplatin (Cisplatinum, CDDP) / Platinol (Bristol Myers) carboplatin / Paraplatin (BMS) oxaliplatin / Eloxitan® (Sanofi-Aventis US) Bendamustine carboquone carmustine chloromethine dacarbazine (DTIC) fotemustine lomustine mannosulfan nedaplatin nimustine prednimustine ranimustine satraplatin semustine streptozocin temozolomide treosulfan triaziquone triethylene melamine triplatin tetranitrate

		trofosfamide uramustine
Topoisomerase inhibitors	Topoisomerase inhibitors are chemotherapy agents designed to interfere with the action of topoisomerase enzymes (topoisomerase I and II), which are enzymes that control the changes in DNA structure by catalyzing the breaking and rejoining of the phosphodiester backbone of DNA strands during the normal cell cycle.	doxorubicin HCL / Doxil® (Alza) daunorubicin citrate / Daunoxome® (Gilead) mitoxantrone HCL/Novantrone (EMD Serono) actinomycin D etoposide / Vepesid® (BMS)/ Etopophos® (Hospira, Bedford, Teva Parenteral, Etc.) topotecan HCL / Hycamtin® (GlaxoSmithKline) teniposide (VM-26) / Vumon® (BMS) irinotecan HCL(CPT-11) / camptosar® (Pharmacia & Upjohn) camptothecin (CPT) belotecan rubitecan
Microtubule targeting agents	Microtubules are one of the components of the cytoskeleton. They have diameter of ~ 24 nm and length varying from several micrometers to possibly millimeters in axons of nerve cells. Microtubules serve as structural components within cells and are involved in many cellular processes including mitosis, cytokinesis, and vesicular transport.	vincristine / Oncovin® (Lilly) vinblastine sulfate/Velban®(discontinued) (Lilly) vinorelbine tartrate / Navelbine® (PierreFabre) vindesine sulphate / Eldisine® (Lilly) paclitaxel / Taxol® (BMS) docetaxel / Taxotere® (Sanofi Aventis US) Nanoparticle paclitaxel (ABI-007) / Abraxane® (Abraxis BioScience, Inc.) ixabepilone / IXEMPRA™ (BMS) larotaxel ortataxel tesetaxel vinflunine
Kinase inhibitors	Tyrosine kinases are enzymes within the cell that function to attach	imatinib mesylate / Gleevec (Novartis) sunitinib malate / Sutent® (Pfizer) sorafenib tosylate / Nexavar® (Bayer)

	phosphate groups to the amino acid tyrosine. By blocking the ability of protein tyrosine kinases to function, these compounds provide a tool for controlling cancerous cell growth.	nilotinib hydrochloride monohydrate / Tasigna® (Novartis) AMG 386 (Amgen) axitinib (AG-013736; Pfizer, Inc.) bosutinib (SKI-606; Wyeth) brivanib alalinate (BMS-582664; BMS) cediranib (AZD2171; Recentin, AstraZeneca) dasatinib (BMS-354825: Sprycel®; BMS) lestaurtinib (CEP-701; Cephalon) motesanib diphosphage (AMG-706; Amgen/Takeda) pazopanib HCL (GW786034; Armala, GSK) semaxanib (SU5416; Pharmacia) vandetanib (AZD647; Zactima; AstraZeneca) vatalanib (PTK-787; Novartis, Bayer Schering Pharma) XL184 (NSC718781; Exelixis, GSK)
Protein synthesis inhibitors	Induces cell apoptosis	L-asparaginase / Elspar® (Merck & Co.)
Immunotherapeutic agents	Induces cancer patients to exhibit immune responsiveness	Alpha interferon Angiogenesis Inhibitor / Avastin® (Genentech) IL-2→ Interleukin 2 (Aldesleukin) / Proleukin® (Chiron) IL-12→ Interleukin 12
Hormonal therapies	Hormonal therapies associated with menopause and aging seek to increase the amount of certain hormones in the body to compensate for age- or disease-related hormonal declines. Hormonal therapy as a cancer	Ttoremifene citrate / Fareston® (GTX, Inc.) fulvestrant / Faslodex® (AstraZeneca) raloxifene HCL / Evista® (Lilly) anastrazole / Arimidex® (AstraZeneca) letrozole / Femara® (Novartis) fadrozole (CGS 16949A) exemestane / Aromasin® (Pharmacia & Upjohn) leuprolide acetate / Eligard® (QTL USA) Lupron® (TAP Pharm.)

treatment generally either reduces the level of one or more specific hormones, blocks a hormone from interacting with its cellular receptor or otherwise alters the cancer's ability to be stimulated by hormones to grow and spread. Such hormonal therapies thus include hormone antagonists and hormone synthesis inhibitors. In some instances hormone agonists may also be used as anticancer hormonal therapies.

goserelin acetate / Zoladex® (AstraZeneca)
triptorelin pamoate / Trelstar® (Watson Labs)
buserelin / Suprefact® (Sanofi Aventis)
nafarelin
cetrorelix / Cetrotide® (EMD Serono)
bicalutamide / Casodex® (AstraZeneca)
nilutamide / Nilandron® (Aventis Pharm.)
megestrol acetate / Megace® (BMS)
somatostatin Analogs (e.g., Octreotide acetate / Sandostatin® (Novartis))
abarelix (Plenaxis™ ; Amgen)
abiraterone acetate (CB7630; BTG plc)
afimoxifene (TamoGel; Ascend Therapeutics, Inc.)
aromatase inhibitor (Atamestane plus toremifene; Intarcia Therapeutics, Inc.)
arzoxifene (Eli Lilly & Co)
Asentar™; DN-101 (Novacea; Oregon Health Sciences U)
flutamide (Eulexin®, Schering; Prostacur, Laboratorios Almirall, S.A)
letrozole (CGS20267) (Femara®, Chugai; Estrochek®, (Jagsonpal Pharmaceuticals Ltd;)
Delestrogen®, estradiol valerate (Jagsonpal)
magestrol acetate / Megace®
medroxyprogesteone acetate (Veraplex®; Combiphar)
MT206 (Medisyn Technologies, Inc.)
nandrolone decanoate (Zestabolin®; Mankind Pharma Ltd)
tamoxifen (Taxifen®, Yung Shin Pharmaceutical; Tomifen®, Alkem Laboratories Ltd.)
tamoxifen citrate (Nolvadex, AstraZeneca; soltamox, EUSA Pharma Inc;
tamoxifen citrate SOPHARMA, Sopharma JSCo.)

Glucocorticoids	Anti-inflammatory drugs used to reduce swelling that causes cancer pain.	predinsolone dexamethasone / Decadron® (Wyeth) prednisone (Deltasone, Orasone, Liquid Pred, Sterapred®)
Aromatase inhibitors	Includes imidazoles	ketoconazole
mTOR inhibitors	The mTOR signaling pathway was originally discovered during studies of the immunosuppressive agent rapamycin. This highly conserved pathway regulates cell proliferation and metabolism in response to environmental factors, linking cell growth factor receptor signaling via phosphoinositide-3-kinase (PI-3K) to cell growth, proliferation, and angiogenesis.	sirolimus (Rapamycin) /Rapamune® (Wyeth) Temsirolimus (CCI-779) / Torisel® (Wyeth) Deforolimus (AP23573) (Ariad Pharm.) Everolimus (RAD001) /Certican® (Novartis)
Chemotherapeutic agents		adriamycin, 5-fluorouracil, cytoxin, bleomycin, mitomycin C, daunomycin, carminomycin, aminopterin, dactinomycin, mitomycins, esperamicins, clofarabine, mercaptopurine, pentostatin, thioguanine, cytarabine, decitabine, floxuridine, gemcitabine (Gemzar), enocitabine, sapacitabine
Protein Kinase B (PKB) Inhibitors		AKT Inhibitor Astex® (Astex Therapeutics) AKT Inhibitors NERVIANO (Nerviano Medical Sciences) AKT Kinase Inhibitor TELIK (Telik Inc) AKT DECIPHERA (Deciphera

	Pharmaceuticals, LLC)
	perifosine (KRX0401, D-21266; Keryx Biopharmaceuticals Inc, AEterna Zentaris Inc)
	perifosine with Docetaxel (Keryx Biopharmaceuticals Inc, AEterna Zentaris Inc)
	perifosine with Gemcitabine (AEterna Zentaris Inc)
	perifosine with paclitaxel (AEterna Zentaris Inc)
	protein kinase-B inhibitor DEVELOGEN (DeveloGen AG)
	PX316 (Oncothyreon, Inc.)
	RX0183 (Rexahn Pharmaceuticals Inc)
	RX0201 (Rexahn Pharmaceuticals Inc)
	VQD002 (VioQuest Pharmaceuticals Inc)
	XL418 (Exelixis Inc)
	ZEN027 (AEterna Zentaris Inc)
Phosphatidylinositol 3-Kinase (PI3K) Inhibitors	BEZ235 (Novartis AG)
	BGT226 (Novartis AG)
	CAL101 (Calistoga Pharmaceuticals, Inc.)
	CHR4432 (Chroma Therapeutics Ltd)
	Erk/PI3K Inhibitors ETERNA (AEterna Zentaris Inc)
	GDC0941 (Genentech Inc/Piramed Limited/Roche Holdings Ltd)
	enzastaurin HCL (LY317615; Enzastaurin; Eli Lilly)
	LY294002/Wortmannin
	PI3K Inhibitors SEMAFORE (Semafore Pharmaceuticals)
	PX866 (Oncothyreon, Inc.)
	SF1126 (Semafore Pharmaceuticals)
	VMD-8000 (VM Discovery, Inc.)
	XL147 (Exelixis Inc)
	XL147 with XL647 (Exelixis Inc)

		XL765 (Exelixis Inc) PI-103 (Roche/Piramed)
Cyclin Dependent Kinase Inhibitors		CYC200, R-roscovitine (Seliciclib; Cyclacel Pharma) NSC-649890, L86-8275, HMR-1275 (alvocidib; NCI)
TLr9, CD289		IMOxine (Merck KGaA) HYB2055 (Idera) IMO-2055 (Isis Pharma) 1018 ISS (Dynavax Technologies/UCSF) PF-3512676 (Pfizer)
Enzyme Inhibitor		lonafarnib(SCH66336; Sarasar; SuperGen, U Arizona)
Anti-TRAIL		AMG-655 (Aeterna Zentaris, Keryx Biopharma) Apo2L/TRAIL, AMG951 (Genentech, Amgen) APOMAB (fully humanized mAb; Genentech)
MEK Inhibitors	[Mitogen-Activated Protein Kinase Kinase 1 (MAP2K1); Mitogen-Activated Protein Kinase Kinase 2 (MAP2K2)]	ARRY162 (Array BioPharma Inc) ARRY704 (Array BioPharma Inc) ARRY886 (Array BioPharma Inc) AS703026 (Merck Serono S.A) AZD6244 (AstraZeneca Plc) AZD8330 (AstraZeneca Plc) RDEA119 (Ardea Biosciences, Inc.) RDEA436 (Ardea Biosciences, Inc.) XL518 (Exelixis Inc; Genentech Inc)
Miscellaneous Inhibitors		Imprime PGG (Biothera) CHR-2797 (AminopeptidaseM1 inhibitor; Chroma Therapeutics) E7820, NSC 719239 (Integrin-alpha2

inhibitor, Eisai)
INCB007839 (ADAM 17, TACE Inhibitor; Incyte)
CNF2024,BIIB021 (Hsp90 Inhibitor; Biogen Idec)
MP470, HPK-56 (Kit/Mel/Ret Inhibitor; Schering-Plough)
SNDX-275/MS-275 (HDAC Inhibitor; Syndax)
Zarnestra™,Tipifarnib, R115777 (Ras Inhibitor; Janssen Pharma)
volociximab; Eos 200-4,M200 (alpha581 integrin inhibitor; Biogen Idec; Eli Lilly/UCSF/PDL BioPharma)
apricoxib (TP2001; COX-2 Inhibitor, Daiichi Sankyo; Tragara Pharma)

One or more anti-cancer agents may be administered either simultaneously or before or after administration of an antibody or antigen binding portion thereof disclosed herein.

Various aspects of the present invention are described in further detail in the following subsections.

II. Methods for Producing Antibodies

(i) Monoclonal Antibodies

Monoclonal antibodies of the present disclosure can be produced using a variety of known techniques, such as the standard somatic cell hybridization technique described by Kohler and Milstein (1975) *Nature* 256: 495, viral or oncogenic transformation of B lymphocytes or phage display technique using libraries of human antibody genes. In particular embodiments, the antibodies are fully human monoclonal antibodies.

Accordingly, in one embodiment, a hybridoma method is used for producing an antibody that binds ErbB3. In this method, a mouse or other appropriate host animal can be immunized with a suitable antigen in order to elicit lymphocytes that produce or are capable of producing antibodies that will specifically bind to the antigen used for immunization. Alternatively, lymphocytes may be immunized *in vitro*. Lymphocytes can then be fused with myeloma cells using a suitable fusing agent, such as polyethylene glycol, to form a hybridoma cell (Goding, Monoclonal Antibodies: Principles and Practice, pp.59-103 (Academic Press, 1986)). Culture medium in which hybridoma cells

are growing is assayed for production of monoclonal antibodies directed against the antigen. After hybridoma cells are identified that produce antibodies of the desired specificity, affinity, and/or activity, the clones may be subcloned by limiting dilution procedures and grown by standard methods (Goding, 1986 *supra*). Suitable culture media for this purpose include, for example, D-MEM or RPMI-1640 medium. In addition, the hybridoma cells may be grown *in vivo* as ascites tumors in an animal. The monoclonal antibodies secreted by the subclones can be separated from the culture medium, ascites fluid, or serum by conventional immunoglobulin purification procedures such as, for example, protein A-SEPHAROSE, hydroxylapatite chromatography, gel electrophoresis, dialysis, or affinity chromatography.

In another embodiment, antibodies and antibody portions that bind ErbB3 can be isolated from antibody phage libraries generated using the techniques described in, for example, McCafferty *et al.*, *Nature*, 348:552-554 (1990). Clackson *et al.*, Nature, 352:624-628 (1991), Marks *et al.*, *J. Mol. Biol.*, 222:581-597 (1991) and Hoet *et al* (2005) *Nature Biotechnology* 23, 344-348 ; U.S. Patent Nos. 5,223,409; 5,403,484; and 5,571,698 to Ladner *et al.*; U.S. Patent Nos. 5,427,908 and 5,580,717 to Dower *et al.*; U.S. Patent Nos. 5,969,108 and 6,172,197 to McCafferty *et al.*; and U.S. Patent Nos. 5,885,793; 6,521,404; 6,544,731; 6,555,313; 6,582,915 and 6,593,081 to Griffiths *et al.*. Additionally, production of high affinity (nM range) human antibodies by chain shuffling (Marks *et al.*, *Bio/Technology*, 10:779-783 (1992)), as well as combinatorial infection and *in vivo* recombination as a strategy for constructing very large phage libraries (Waterhouse *et al.*, *Nuc. Acids. Res.*, 21:2265-2266 (1993)) may also be used.

In a particular embodiment, the antibody or antigen binding portion thereof that binds ErbB3 is produced using the phage display technique described by Hoet *et al.*, *supra*. This technique involves the generation of a human Fab library having a unique combination of immunoglobulin sequences isolated from human donors and having synthetic diversity in the heavy-chain CDRs is generated. The library is then screened for Fabs that bind to ErbB3.

In yet another embodiment, human monoclonal antibodies directed against ErbB3 can be generated using transgenic or transchromosomic mice carrying parts of the human immune system rather than the mouse system (see *e.g.*, Lonberg, *et al.* (1994) Nature 368(6474): 856-859; Lonberg, N. *et al.* (1994), *supra*; reviewed in Lonberg, N. (1994) *Handbook of Experimental Pharmacology* 113:49-101; Lonberg, N. and Huszar, D. (1995) *Intern. Rev. Immunol.* 13: 65-93, and Harding, F. and Lonberg, N. (1995) *Ann. N.Y. Acad. Sci.* 764:536-546. See further, U.S. Patent Nos. 5,545,806; 5,569,825; 5,625,126; 5,633,425; 5,789,650; 5,877,397; 5,661,016; 5,814,318; 5,874,299; and 5,770,429; all to Lonberg and Kay; U.S. Pat. No. 5,545,807 to Surani *et al.*; PCT Publication Nos. WO 92/03918, WO 93/12227, WO 94/25585, WO 97/13852, WO

98/24884 and WO 99/45962, all to Lonberg and Kay; and PCT Publication No. WO 01/14424 to Korman *et al.*).

In another embodiment, human antibodies disclosed herein can be raised using a mouse that carries human immunoglobulin sequences on transgenes and transchomosomes, such as a mouse that carries a human heavy chain transgene and a human light chain transchromosome (see *e.g.*, PCT Publication WO 02/43478 to Ishida *et al.*).

Still further, alternative transgenic animal systems expressing human immunoglobulin genes are available in the art and can be used to raise anti-ErbB3 antibodies or fragments therof of the invention. For example, an alternative transgenic system referred to as the XENOMOUSE (Abgenix, Inc.) can be used; such mice are described in, for example, U.S. Pat. Nos. 5,939,598; 6,075,181; 6,114,598; 6, 150,584 and 6,162,963 to Kucherlapati *et al.*

Moreover, alternative transchromosomic animal systems expressing human immunoglobulin genes are available in the art and can be used to raise anti-ErbB3 antibodies or fragments therof of the invention. For example, mice carrying both a human heavy chain transchromosome and a human light chain transchromosome can be used; as described in Tomizuka *et al.* (2000) *Proc. Natl. Acad. Sci. USA* 97:722-727. Furthermore, cows carrying human heavy and light chain transchromosomes have been described in the art (Kuroiwa *et al.* (2002) *Nature Biotechnology* 20:889-894) and can be used to raise anti-ErbB3 antibodies or fragments therof of the invention.

In yet another embodiment, antibodies disclosed herein can be prepared using a transgenic plant and/or cultured plant cells (such as, for example, tobacco, maize and duckweed) that produce such antibodies. For example, transgenic tobacco leaves expressing antibodies or antigen binding portions thereof can be used to produce such antibodies by, for example, using an inducible promoter (see, *e.g.*, Cramer *et al.*, *Curr. Top. Microbol. Immunol.* 240:95 118 (1999)). Also, transgenic maize can be used to express such antibodies and antigen binding portions thereof (see, *e.g.*, Hood *et al.*, *Adv. Exp. Med. Biol.* 464:127 147 (1999)). Antibodies can also be produced in large amounts from transgenic plant seeds including antibody portions, such as single chain antibodies (e.g., scFvs), for example, using tobacco seeds and potato tubers (see, *e.g.*, Conrad *et al.*, *Plant Mol. Biol.* 38:101 109 (1998)). Methods of producing antibodies or antigen binding portions in plants can also be found in, *e.g.*, Fischer *et al.*, *Biotechnol. Appl. Biochem.* 30:99 108 (1999), Ma *et al.*, *Trends Biotechnol.* 13:522 7 (1995); Ma *et al.*, *Plant Physiol.* 109:341 6 (1995); Whitelam *et al.*, *Biochem. Soc. Trans.* 22:940 944 (1994) and U.S. Pat. Nos. 6,040,498 and 6,815,184.

The binding specificity of antibodies or portions thereof that bind ErbB3 prepared using any technique including those disclosed here, can be determined by

immunoprecipitation or by an *in vitro* binding assay, such as radioimmunoassay (RIA) or enzyme-linked immunoabsorbent assay (ELISA). The binding affinity of a antibody or portion thereof also can be determined by the Scatchard analysis of Munson *et al.*, *Anal. Biochem.*, 107:220 (1980).

In certain embodiments, an ErbB3 antibody or portion thereof produced using any of the methods discussed above may be further altered or optimized to achieve a desired binding specificity and/or affinity using art recognized techniques, such as those described herein.

In one embodiment, partial antibody sequences derived from an ErbB3 antibody may be used to produce structurally and functionally related antibodies. For example, antibodies interact with target antigens predominantly through amino acid residues that are located in the six heavy and light chain complementarity determining regions (CDRs). For this reason, the amino acid sequences within CDRs are more diverse between individual antibodies than sequences outside of CDRs. Because CDR sequences are responsible for most antibody-antigen interactions, it is possible to express recombinant antibodies that mimic the properties of specific naturally occurring antibodies by constructing expression vectors that include CDR sequences from the specific naturally occurring antibody grafted onto framework sequences from a different antibody with different properties (see, *e.g.*, Riechmann, L. *et al.*, 1998, *Nature* 332:323-327; Jones, P. *et al.*, 1986, *Nature* 321:522-525; and Queen, C. *et al.*, 1989, *Proc. Natl. Acad. See.* U.S.A. 86:10029-10033). Such framework sequences can be obtained from public DNA databases that include germline antibody gene sequences.

Thus, one or more structural features of an anti-ErbB3 antibody or fragment therof of the invention, such as the CDRs, can be used to create structurally related anti-ErbB3 antibodies that retain at least one functional property of other antibodies or fragments therof of the invention, e.g., inhibiting EGF-like ligand mediated phosphorylation of ErbB3; inhibiting one or more of heregulin, epiregulin, epigen or biregulin-mediated signaling through ErbB3; inhibiting proliferation or cells expressing ErbB3; and/or decreasing levels of ErbB3 on cell surfaces.

In a particular embodiment, one or more CDR regions selected from SEQ ID NOs:7-12, SEQ ID NOs:13-18, SEQ ID NOs:19-24, SEQ ID NOs:39-44, and SEQ ID NOs:45-50 is combined recombinantly with known human framework regions and CDRs to create additional, recombinantly-engineered, anti-ErbB3 antibodies or fragments therof of the invention. The heavy and light chain variable framework regions can be derived from the same or different antibody sequences.

It is well known in the art that antibody heavy and light chain CDR3 domains play a particularly important role in the binding specificity/affinity of an antibody for an antigen (*see*, Hall *et al.*, *J. Imunol.*, 149:1605-1612 (1992); Polymenis *et al.*, *J.*

Immunol., 152:5318-5329 (1994); Jahn *et al.*, *Immunobiol.*, 193:400-419 (1995); Klimka *et al.*, *Brit. J. Cancer*, 83:252-260 (2000); Beiboer *et al.*, *J. Mol. Biol*, 296:833-849 (2000); Rader *et al.*, *Proc. Natl. Acad. Sci. USA*, 95:8910-8915 (1998); Barbas *et al.*, *J. Am. Chem. Soc.*, 116:2161-2162 (1994); Ditzel *et al.*, *J. Immunol.*, 157:739-749 (1996)).

Accordingly, in certain embodiments, antibodies are generated that include the heavy and/or light chain CDR3s of the particular antibodies described herein (*e.g.*, SEQ ID NOs:9, 15, 21, 41, 47 and/or SEQ ID NOs:12, 18, 24, 44, 50). The antibodies can further include the heavy and/or light chain CDR1 and/or CDR2s of the antibodies specifically disclosed herein (*e.g.*, SEQ ID NOs:7-8 and/or SEQ ID NOs:10-11; SEQ ID NOs:13-14 and/or SEQ ID NOs:16-17; SEQ ID NOs:20-21 and/or SEQ ID NOs:22-23; SEQ ID NOs:39-40 and/or SEQ ID NOs:42-43; or SEQ ID NOs:45-46 and/or SEQ ID NOs:48-49).

The CDR1, 2, and/or 3 regions of the engineered antibodies described above can comprise the exact amino acid sequence(s) as those disclosed herein (*e.g.*, CDRs of Ab #6, Ab #3, Ab #14, Ab #17, or Ab #19, set forth in SEQ ID NOs:7-12, 13-18, 19-24, 39-44, and 45-50, respectively). However, the ordinarily skilled artisan will appreciate that some deviation from the exact CDR sequences may be possible while still retaining the ability of the antibody to bind ErbB3 effectively (*e.g.*, conservative amino acid substitutions). Accordingly, in another embodiment, the engineered antibody may be composed of one or more CDRs that are, for example, 90%, 95%, 98%, 99% or 99.5% identical to one or more CDRs of Ab #6, Ab #3 or Ab #14.

In another embodiment, one or more residues of a CDR may be altered to modify binding to achieve a more favored on-rate of binding. Using this strategy, an antibody having ultra high binding affinity of, for example, 10^{10} M^{-1} or more, can be achieved. Affinity maturation techniques, well known in the art and those described herein, can be used to alter the CDR region(s) followed by screening of the resultant binding molecules for the desired change in binding. Accordingly, as CDR(s) are altered, changes in binding affinity as well as immunogenicity can be monitored and scored such that an antibody optimized for the best combined binding and low immunogenicity are achieved.

As described in further detail in Example 20, mutagenesis (*e.g.*, alanine scanning mutagenesis) has been conducted on the heavy and light chain CDRs of Ab #6 to identify amino acid residues involved in binding to ErbB3 to thereby define the paratope of the antibody.

Paratope CDR sequences for anti-ErbB3 antibodies are shown in Figures 37A and 37B, based on this mutagenesis analysis. As illustrated in Figure 37A, an anti-ErbB3 antibody or fragment therof of the invention can comprise a heavy chain paratope comprising CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 63, 64 and

65, respectively, and a light chain paratope comprising CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 69, 70 and 71, respectively, with the proviso that the antibody is not: (i) Ab #6 as disclosed herein; (ii) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 1 and 2, respectively; or (iii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 7, 8 and 9, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 10, 11 and 12, respectively.

As illustrated in Figure 37B, an anti-ErbB3 antibody or fragment therof of the invention can comprise a heavy chain paratope comprising CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 76, 64 and 65, respectively, and a light chain paratope comprising CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 78, 70 and 80, respectively, with the proviso that the antibody is not: (i) Ab #6 as disclosed herein; (ii) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 1 and 2, respectively; or (iii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 7, 8 and 9, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 10, 11 and 12, respectively.

In yet another embodiment, the invention provides an anti-ErbB3 antibody comprising a heavy chain paratope comprising CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 63 or 76 (CDR1), 64 (CDR2) and 65 (CDR3), respectively, with the proviso that the antibody is not: (i) Ab #6 as disclosed herein; (ii) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 1 and 2, respectively; or (iii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 7, 8 and 9, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 10, 11 and 12, respectively.

In yet another embodiment, the invention provides an anti-ErbB3 antibody comprising a light chain paratope comprising CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 69 or 78 (CDR1), 70 (CDR2) and 71 or 80 (CDR3), respectively, with the proviso that the antibody is not: (i) Ab #6 as disclosed herein; (ii) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 1 and 2, respectively; or (iii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 7, 8 and 9, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 10, 11 and 12, respectively.

Consensus CDR sequences for anti-ErbB3 antibodies or fragments therof of the invention also are shown in Figures 37A and 37B, based on this mutagenesis analysis. As illustrated in Figure 37A, an anti-ErbB3 antibody or fragment therof of the invention can comprise a heavy chain variable region comprising CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 60, 61 and 62, respectively, and a light chain variable region comprising CDR1, CDR2 and CDR3 sequences as shown in SEQ ID

NOs: 66, 67 and 68, respectively, with the proviso that the antibody is not: (i) Ab #6 as disclosed herein; (ii) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 1 and 2, respectively; or (iii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 7, 8 and 9, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 10, 11 and 12, respectively.

As illustrated in Figure 37B, an anti-ErbB3 antibody or fragment therof of the invention can comprise a heavy chain variable region comprising CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 75, 61 and 62, respectively, and a light chain variable region comprising CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 77, 67 and 79, respectively, with the proviso that the antibody is not: (i) Ab #6 as disclosed herein; (ii) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 1 and 2, respectively; or (iii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 7, 8 and 9, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 10, 11 and 12, respectively.

In yet another embodiment, the invention provides an anti-ErbB3 antibody comprising a heavy chain variable region comprising CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 60 or 75 (CDR1), 61 (CDR2) and 62 (CDR3), respectively, with the proviso that the antibody is not: (i) Ab #6 as disclosed herein; (ii) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 1 and 2, respectively; or (iii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 7, 8 and 9, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 10, 11 and 12, respectively.

In yet another embodiment, the invention provides an anti-ErbB3 antibody comprising a light chain variable region comprising CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 66 or 77 (CDR1), 67 (CDR2) and 68 or 79 (CDR3), respectively, with the proviso that the antibody is not: (i) Ab #6 as disclosed herein; (ii) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 1 and 2, respectively; or (iii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 7, 8 and 9, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 10, 11 and 12, respectively.

In addition to, or instead of, modifications within the CDRs, modifications can also be made within one or more of the framework regions, FR1, FR2, FR3 and FR4, of the heavy and/or the light chain variable regions of an antibody, so long as these modifications do not eliminate the binding affinity of the antibody.

In another embodiment, the antibody is further modified with respect to effector function, so as to enhance the effectiveness of the antibody in treating cancer, for example. For example cysteine residue(s) may be introduced in the Fc region, thereby allowing interchain disulfide bond formation in this region. The homodimeric antibody

thus generated may have improved internalization capability and/or increased complement-mediated cell killing and antibody-dependent cellular cytotoxicity (ADCC). See Caron *et al.*, *J. Exp Med.* 176:1191-1195 (1992) and Shopes, B. *J. Immunol.* 148:2918-2922 (1992). Homodimeric antibodies with enhanced anti-tumor activity may also be prepared using heterobifunctional cross-linkers as described in Wolff *et al. Cancer Research* 53:2560-2565 (1993). Alternatively, an antibody can be engineered which has dual Fc regions and may thereby have enhanced complement lysis and ADCC capabilities. See Stevenson *et al. Anti-Cancer Drug Design* 3:219-230 (1989).

Mutagenesis of one or more residues in the CDRs, framework regions, Fc regions, or other antibody regions as disclosed herein can be accomplished using standard recombinant DNA techniques, including but not limited to site-directed mutagenesis and PCR-mediated mutagenesis. Screening of the effects of mutation on antigen binding (*e.g.*, binding to ErbB3) and other functional characteristics also can be accomplished using standard methods. For example, the antibody (e.g., an scFv version) containing the mutated CDRs can be expressed on the surface of cells, such as mammalian cells, yeast cells or bacterial cells (*e.g.*, using a phage display system) and binding of the antigen to the cells can be determined using standard methods, for example flow cytometry in which antigen bound to the cells is detected, e.g., using a labeled secondary antibody. Additionally or alternatively, the antibody can be expressed in soluble form and the binding of the antibody to the antigen can be assessed using a standard binding assay such as ELISA or BIACORE analysis. Detailed descriptions of the foregoing and related techniques for such purposes may be found in numerous well known textbooks and laboratory manuals, for example: Handbook of Therapeutic Antibodies Vols. 1-3, Stefan Dubel, ed., Wiley-VCH 2007; Making and Using Antibodies: A Practical Handbook, Gary C. Howard, CRC 2006; Antibody Engineering: Methods and Protocols, Benny K. C. Lo, Humana Press 2003; Therapeutic Antibodies: Methods and Protocols, Antony S. Dimitrov, ed., Humana Press 2009; Antibody Phage Display: Methods and Protocols, 2nd ed. Robert Aitken, ed., Humana Press 2009; Flow Cytometry Protocols, 2nd ed. Teresa S. Hawley and Robert G. Hawley, eds., Humana Press 2004; Flow Cytometry: Principles and Applications, Marion G. Macey, ed., Humana Press 2007. Also see "Selecting and Screening Recombinant Antibody Libraries," H.R. Hoogenboom, Nature Biotechnol. 23:1105-1116; 2005.

Also encompassed by the present invention are bispecific antibodies and immunoconjugates, as discussed below.

(ii) Bispecific Antibodies

Bispecific antibodies of the present disclosure include at least one binding specificity for ErbB3 and at least one binding specificity for another antigen, such as the

product of an oncogene. Bispecific antibodies can be prepared as full length antibodies or antibody fragments (*e.g.* $F(ab')_2$ bispecific antibodies).

Methods for making bispecific antibodies are well known in the art (see, e.g., WO 05117973 and WO 06091209). For example, production of full length bispecific antibodies can be based on the coexpression of two immunoglobulin heavy chain-light chain pairs, where the two chains have different specificities (see, *e.g.*, Millstein *et al.*, *Nature*, 305:537-539 (1983)). Further details of generating bispecific antibodies can be found, for example, in Suresh *et al.*, *Methods in Enzymology*, 121:210 (1986) and in Brennan *et al.*, *Science*, 229: 81 (1985), which describes a chemical linkage process for making bispecific antibodies. Various techniques for making and isolating bispecific antibody fragments directly from recombinant cell culture have also been described. For example, bispecific antibodies have been produced using leucine zippers (see, e.g., Kostelny *et al.*, *J. Immunol.*, 148(5):1547-1553 (1992)). Another strategy for making bispecific antibody fragments by the use of single-chain Fv (scFv) dimers has also been reported (see, *e.g.*, Gruber *et al.*, *J. Immunol.*, 152:5368 (1994)).

In a particular embodiment, the bispecific antibody comprises a first antibody or binding portion thereof which binds to ErbB3 and a second antibody or binding portion thereof which binds to ErbB2, ERbB3, ErbB4, EGFR, IGF1-R, C-MET, Lewis Y, MUC-1, EpCAM, CA125, prostate specific membrane antigen, PDGFR-α, PDGFR-β, C-KIT, or any of the FGF receptors.

(iii) Immunoconjugates

Immunoconjugates of the present disclosure can be formed by conjugating the antibodies or antigen binding portions thereof described herein to another therapeutic agent. Suitable agents include, for example, a cytotoxic agent (e.g., a chemotherapeutic agent), a toxin (*e.g.* an enzymatically active toxin of bacterial, fungal, plant or animal origin, or fragments thereof), and/or a radioactive isotope (*i.e.*, a radioconjugate). Chemotherapeutic agents useful in the generation of such immunoconjugates have been described above. Enzymatically active toxins and fragments thereof which can be used include 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. A variety of radionuclides are available for the production of radioconjugated anti-ErbB3 antibodies. Examples include ^{212}Bi, ^{131}I, ^{131}In, ^{90}Y and ^{186}Re.

Immunoconjugates of the invention can be made using a variety of bifunctional protein coupling agents such as N-succinimidyl-3-(2-pyridyldithiol) propionate (SPDP), 2-iminothiolane (IT), bifunctional derivatives of imidoesters (such as dimethyl adipimidate HCL), active esters (such as disuccinimidyl suberate), aldehydes (such as glutareldehyde), bis-azido compounds (such as bis (p-azidobenzoyl) hexanediamine), bis-diazonium derivatives (such as bis-(p-diazoniumbenzoyl)-ethylenediamine), diisocyanates (such as tolyene 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-methyldiethylene triaminepentaacetic acid (MX-DTPA) is an exemplary chelating agent for conjugation of radionucleotide to the antibody (see, *e.g.*, WO94/11026).

(iv) Antibodies raised against ErbB3 ectodomain peptides

Those if skill will recognize that monoclonal and monospecific polyclonal antibodies having various of the desireable properties of Ab #6 (e.g., antibodies that inhibit cancer cell proliferation and downregulate ErbB3 on cells), or that compete with Ab #6 for binding to ErbB3, can be readily obtained using conventional immunization methods using peptides (e.g., synthetic peptides), or conjugates thereof (e.g., KLH conjugates), as immunogens. Peptide for use as immunogens in this embodiment are those comprising any 10 or more contiguous amino acid residues from residues1-183 of SEQ ID NO: 73. Preferably the 10 or more contiguous amino acid residues are from Domain I of the ectodomain of ErbB3, preferably the residues at least partially fall within or span residues 92-104 of SEQ ID NO: 73.

III. Methods for Screening Antibodies

Subsequent to producing antibodies or antigen binding portions that bind ErbB3, such antibodies, or portions thereof, can be screened for various properties, such as those described herein, using a variety of assays that are well known in the art.

In one embodiment, the antibodies or antigen binding portions thereof are screened for the ability to inhibit EGF-like ligand mediated phosphorylation of ErbB3. This can be done by treating cells expressing ErbB3 with an EGF-like ligand in the presence and absence of the antibody or antigen binding portion thereof. The cells can then be lysed and the crude lysates can be centrifuged to remove insoluble material. ErbB3 phosphorylation can be measured, for example, by Western blotting followed by probing with an anti-phosphotyrosine antibody as described in Kim *et al.*, *supra* and the Examples below.

In other embodiments, the antibodies and antigen binding portions are further screened for one or more of the following properties: (1) inhibition of ErbB3-ligand

(*e.g.*, heregulin, epiregulin, epigen or biregulin) mediated signaling through ErbB3; (2) inhibition of proliferation of cells expressing ErbB3; (3) the ability to decrease levels of ErbB3 on cell surface (*e.g.*, by inducing internalization of ErbB3), (4) inhibition of VEGF secretion of cells expressing ErbB3; (5) inhibition of the migration of cells expressing ErbB3; (6) inhibition of spheroid growth of cells expressing ErbB3; and/or (7) binding to an epitope located on Domain I of the ectodomain of ErbB3, each of which can be readily measured using art recognized techniques and those discussed herein.

Inhibition of one or more of heregulin, epiregulin, epigen or biregulin-mediated signaling through ErbB3 can be readily measured using routine assays, such as, described in Horst *et al. supra*. For example, the ability of an antibody or antigen binding portion thereof to inhibit heregulin, epiregulin, epigen or biregulin-mediated signaling through ErbB3 can be measured by kinase assays for known substrates of ErbB3 such as, for example, SHC and PI3K, as described in, for example, Horst *et al. supra*, Sudo *et al.*, (2000) *Methods Enzymol*, 322:388-92; and Morgan *et al.* (1990) *Eur. J. Biochem.*, 191:761-767, following stimulation by one or more of heregulin, epiregulin, epigen or biregulin. Accordingly, cells expressing ErbB3 can be stimulated with one or more of heregulin, epiregulin, epigen or biregulin, and incubated with a candidate antibody or antigen-binding portion thereof. Cell lysates subsequently prepared from such cells can be immunoprecipitated with an antibody for a substrate of ErbB3 (or a protein in a cellular pathway involving ErbB3) such as, for example, an anti-JNK-1 antibody, and assayed for kinase activity (*e.g.*, JNK kinase activity or PI3-kinase activity) using art recognized techniques. A decrease in or complete disappearance in level or activity (*e.g.*, kinase activity) of a ErbB3 substrate or protein in a pathway involving ErbB3 in the presence of the antibody or antigen binding portion thereof, relative to the level or activity in the absence of the antibody or antigen binding portion thereof, is indicative of an antibody or antigen binding portion which inhibits one or more of heregulin, epiregulin, epigen or biregulin-mediated signaling.

In certain embodiments, the antibody or antigen binding portion thereof inhibits ErbB3-ligand (*e.g.*, heregulin, epiregulin, epigen or biregulin) mediated signaling by decreasing the binding of one or more of heregulin, epiregulin, epigen or biregulin to ERbB3.

In order to select for those antibodies or antigen binding portions thereof which inhibit the binding of one or more of heregulin, epiregulin, epigen or biregulin to ErbB3, cells which express ErbB3 (*e.g.* MALME-3M cells, as described in the Examples *infra)*, can be contacted with a labeled ErbB3-ligand (*e.g.*, radiolabeled heregulin, epiregulin, epigen or biregulin) in the absence (control) or presence of the anti-ErbB3 antibody or antigen binding portion thereof. If the antibody or antigen binding portion thereof

inhibits heregulin, epiregulin, epigen or biregulin binding to ErbB3, then a statistically significantly decrease in the amount of label recovered (*e.g.*, radiolabeled heregulin, epiregulin, epigen or biregulin), relative to the amount in the absence of the antibody or antigen binding portion thereof, will be observed.

The antibody or antigen binding portion thereof may inhibit the binding of the ErbB3-ligand (*e.g.*, heregulin, epiregulin, epigen or biregulin) by any mechanism. For example, the antibody or antigen binding portion thereof may inhibit binding of the ErbB3 ligand (*e.g.*, one or more of heregulin, epiregulin, epigen or biregulin) to ErbB3 by binding to the same site or an overlapping site on ErbB3 as the ErbB3 ligand. Alternatively, the antibody or antigen binding portion thereof may inhibit binding of an ErbB3 ligand by altering or distorting the conformation of ErbB3, such that it is unable to bind to the ErbB3 ligand.

Antibodies and antigen binding portions thereof that decrease levels of ErbB3 on cell surfaces can be identified by their ability to downregulate ErbB3 on tumor cells. In certain embodiments, the antibodies or antigen binding portions thereof decrease ErbB3 cell surface expression by inducing internalization (or increasing endocytosis) of Erbb3. To test this, ErbB3 can be biotinylated and the number of ErbB3 molecules on the cell surface can be readily determined, for example, by measuring the amount of biotin on a monolayer of cells in culture in the presence or absence of an antibody or antigen binding portion thereof, for example, as described in, *e.g.*, Waterman *et al.*, J. Biol. Chem. (1998), 273:13819-27, followed by immunoprecipitation of ErbB3 and probing with streptavidin. A decrease in detection of biotinylated ErbB3 over time in the presence of an antibody or antigen binding portion is indicative of an antibody which decreases ErbB3 levels on cell surfaces.

Antibodies or antigen binding portions thereof of the present disclosure can also be tested for their ability to inhibit proliferation of cells expressing ErbB3, for example, tumor cells, using art recognized techniques, such as the CellTiter-Glo®Assay described in the Examples below (also see, *e.g.*, Macallan *et al.*, *Proc. Natl. Acad. Sci.* (1998) 20;95(2):708-13; Perez *et al.* (1995) *Cancer Research* 55, 392-398).

In another embodiment, the antibodies or antigen binding portions thereof are screened for the ability to inhibit VEGF secretion of cells expressing ErbB3. This can be done by using well-known assays, such as the VEGF ELISA kit available from R&D Systems, Minneapolis, MN, # DY293B. Similarly, the antibodies or portions can be screened for the ability to inhibit the migration of cells expressing ErbB3 (*e.g.*, MCF-7 cells) using a trans-well assay (Millipore Corp., Billerica, MA, # ECM552) as described herein.

In another embodiment, the antibodies or antigen binding portions thereof are screened for the ability to inhibit spheroid growth of cells expressing ErbB3. This can

be done by using an assay which approximates conditions of a developing tumor growth (see, e.g., Herman et al. (2007) Journal of Biomolecular Screening Electronic publication) as described herein.

Antibodies or antigen binding portions thereof that bind to the same or overlapping epitopes as one or more antibodies specifically disclosed herein can also be identified using standard techniques known in the art and described herein. For example, in order to screen for antibodies which bind to the same or an overlapping epitope on ErbB3 bound by an antibody of interest, a cross-blocking assay, such as that described in *Antibodies*, A Laboratory Manual, Cold Spring Harbor Laboratory, Ed Harlow and David Lane (1988), can be performed.

IV. Pharmaceutical Compositions

In another aspect, the present invention provides a composition, *e.g.*, a pharmaceutical composition, containing one or a combination of antibodies, or antigen-binding portion(s) thereof disclosed herein, formulated together with a pharmaceutically acceptable carrier. In one embodiment, the compositions include a combination of multiple (*e.g.*, two or more) isolated antibodies, which bind different epitopes on ErbB3.

As used herein, "pharmaceutically acceptable carrier" includes any and all solvents, dispersion media, coatings, antibacterial and antifungal agents, isotonic and absorption delaying agents, and the like that are physiologically compatible. Preferably, the carrier is suitable for intravenous, intramuscular, subcutaneous, parenteral, spinal or epidermal administration (*e.g.*, by injection or infusion). Depending on the route of administration, the active agent, *i.e.*, antibody, antibody fragment, bispecific and multispecific molecule, may be coated in a material to protect the agent from the action of acids and other natural conditions that may inactivate it.

A "pharmaceutically acceptable salt" refers to a salt that retains the desired biological activity of the parent compound and does not impart any undesired toxicological effects (see *e.g.*, Berge, S.M., *et al.* (1977) *J. Pharm. Sci.* 66:1-19). Examples of such salts include acid addition salts and base addition salts. Acid addition salts include those derived from nontoxic inorganic acids, such as hydrochloric, nitric, phosphoric, sulfuric, hydrobromic, hydroiodic, phosphorous and the like, as well as from nontoxic organic acids such as aliphatic mono- and dicarboxylic acids, phenyl-substituted alkanoic acids, hydroxy alkanoic acids, aromatic acids, aliphatic and aromatic sulfonic acids and the like. Base addition salts include those derived from alkaline earth metals, such as sodium, potassium, magnesium, calcium and the like, as well as from nontoxic organic amines, such as N,N'-dibenzylethylenediamine, N-methylglucamine, chloroprocaine, choline, diethanolamine, ethylenediamine, procaine and the like.

Pharmaceutical compositions of the invention can comprise other agents. For example, the composition can include at least one or more additional therapeutic agents, such as the anti-cancer agents described infra. The pharmaceutical compositions can also be administered in conjunction with radiation therapy and/or surgery. Alternately a composition of the invention can be separately co-administered with at least one or more additional therapeutic agents, such as the anti-cancer agents described infra.

A composition of the present disclosure can be administered by a variety of methods known in the art. As will be appreciated by the skilled artisan, the route and/or mode of administration will vary depending upon the desired results. The active agents can be prepared with carriers that will protect the agents against rapid release, such as a controlled release formulation, including implants, transdermal patches, and microencapsulated delivery systems. Biodegradable, biocompatible polymers can be used, such as ethylene vinyl acetate, polyanhydrides, polyglycolic acid, collagen, polyorthoesters, and polylactic acid. Many methods for the preparation of such formulations are patented or generally known to those skilled in the art. *See, e.g., Sustained and Controlled Release Drug Delivery Systems*, J.R. Robinson, ed., Marcel Dekker, Inc., New York, 1978.

To administer an antibody or fragment thereof of the invention by certain routes of administration, it may be necessary to coat it with, or co-administer it with, a material to prevent its inactivation. For example, it may be administered to a subject in an appropriate carrier, for example, liposomes, or a diluent. Pharmaceutically acceptable diluents include saline and aqueous buffer solutions. Liposomes include water-in-oil-in-water CGF emulsions as well as conventional liposomes (Strejan *et al.* (1984) *J. Neuroimmunol.* 7:27).

Pharmaceutically acceptable carriers include sterile aqueous solutions or dispersions and sterile powders or lyophylysates for the extemporaneous preparation of sterile injectable solutions or dispersion. The use of such media and agents for pharmaceutically active antibodies is known in the art. Except insofar as any conventional media or agent is incompatible with the active agent, use thereof in the pharmaceutical compositions of the invention is contemplated. Supplementary active compounds can also be incorporated into the compositions.

Therapeutic compositions typically must be sterile and stable under the conditions of manufacture and storage. The composition can be formulated as a solution, microemulsion, liposome, or other ordered structure suitable to high drug concentration. The carrier can be a solvent or dispersion medium containing, for example, water, ethanol, polyol (for example, glycerol, propylene glycol, and liquid polyethylene glycol, and the like), and suitable mixtures thereof. The proper fluidity can be maintained, for example, by the use of a coating such as lecithin, by the maintenance

of the required particle size in the case of dispersion and by the use of surfactants. In many cases, it will be preferable to include isotonic agents, for example, sugars, polyalcohols such as mannitol, sorbitol, or sodium chloride in the composition. Prolonged absorption of the injectable compositions can be brought about by including in the composition an agent that delays absorption, for example, monostearate salts and gelatin.

Sterile injectable solutions can be prepared by incorporating the active agent in the required amount in an appropriate solvent with one or a combination of ingredients enumerated above, as required, followed by sterilization microfiltration. Generally, dispersions are prepared by incorporating the active agent into a sterile vehicle that contains a basic dispersion medium and the required other ingredients from those enumerated above. In the case of sterile powders for the preparation of sterile injectable solutions, the preferred methods of preparation are vacuum drying and freeze-drying (lyophilization) that yield a powder of the active ingredient plus any additional desired ingredient from a previously sterile-filtered solution thereof.

Dosage regimens are adjusted to provide the optimum desired response (*e.g.*, a therapeutic response). For example, a single bolus may be administered, several divided doses may be administered over time or the dose may be proportionally reduced or increased as indicated by the exigencies of the therapeutic situation. For example, the human antibodies disclosed herein may be administered once or twice weekly by subcutaneous injection or once or twice monthly by subcutaneous injection.

Non-limiting examples of suitable dosage ranges and regimens include 2-50 mg/kg (body weight of the subject) administered once a week, or twice a week or once every three days, or once every two weeks, and 1-100 mg/kg administered once a week, or twice a week or once every three days, or once every two weeks. In various embodiments, an antibody is administered at a dosage of 3.2 mg/kg, 6 mg/kg, 10 mg/kg, 15 mg/kg, 20 mg/kg, 25 mg/kg, 30 mg/kg, 35 mg/kg or 40 mg/kg at a timing of once a week, or twice a week or once every three days, or once every two weeks. Additional dosage ranges include: 1-1000 mg/kg, 1-500 mg/kg, 1-400 mg/kg, 1-300 mg/kg and 1-200 mg/kg. Suitable dosage schedules include once every three days, once every five days, once every seven days (*i.e.*, once a week), once every 10 days, once every 14 days (*i.e.*, once every two weeks), once every 21 days (*i.e.*, once every three weeks), once every 28 days (*i.e.*, once every four weeks) and once a month.

As demonstrated in the Examples, use of an antibody disclosed herein in combination with an additional therapeutic agent can lead to an additive effect for anti-tumor activity. Accordingly, for combination therapy, suboptimal dosages of the antibody or the second therapeutic agent, or both, can be used to achieve a desired therapeutic outcome due to the additive effects of the agents. For example, when use din

combination with another therapeutic agent, in various embodiments an antibody or fragment therof of the invention may be administered at a dosage that is 90 %, or 80 %, or 70 % or 60 % or 50 % of the dosage used when the antibody is administered alone.

It is especially advantageous to formulate parenteral compositions in dosage unit form for ease of administration and uniformity of dosage. Dosage unit form as used herein refers to physically discrete units suited as unitary dosages for the subjects to be treated; each unit contains a predetermined quantity of active agent calculated to produce the desired therapeutic effect in association with the required pharmaceutical carrier. The specification for the dosage unit forms of the invention are dictated by and directly dependent on (a) the unique characteristics of the active agent and the particular therapeutic effect to be achieved, and (b) the limitations inherent in the art of compounding such an active agent for the treatment of sensitivity in individuals.

Examples of pharmaceutically-acceptable antioxidants include: (1) water soluble antioxidants, such as ascorbic acid, cysteine hydrochloride, sodium bisulfate, sodium metabisulfite, sodium sulfite and the like; (2) oil-soluble antioxidants, such as ascorbyl palmitate, butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), lecithin, propyl gallate, alpha-tocopherol, and the like; and (3) metal chelating agents, such as citric acid, ethylenediamine tetraacetic acid (EDTA), sorbitol, tartaric acid, phosphoric acid, and the like.

For the therapeutic compositions, formulations of the present disclosure include those suitable for oral, nasal, topical (including buccal and sublingual), rectal, vaginal and/or parenteral administration. The formulations may conveniently be presented in unit dosage form and may be prepared by any methods known in the art of pharmacy. The amount of active ingredient which can be combined with a carrier material to produce a single dosage form will vary depending upon the subject being treated, and the particular mode of administration. The amount of active ingredient which can be combined with a carrier material to produce a single dosage form will generally be that amount of the composition which produces a therapeutic effect. Generally, out of one hundred per cent, this amount will range from about 0.001 per cent to about ninety percent of active ingredient, preferably from about 0.005 per cent to about 70 per cent, most preferably from about 0.01 per cent to about 30 per cent.

Formulations of the present disclosure which are suitable for vaginal administration also include pessaries, tampons, creams, gels, pastes, foams or spray formulations containing such carriers as are known in the art to be appropriate. Dosage forms for the topical or transdermal administration of compositions of this invention include powders, sprays, ointments, pastes, creams, lotions, gels, solutions, patches and inhalants. The active agent may be mixed under sterile conditions with a

pharmaceutically acceptable carrier, and with any preservatives, buffers, or propellants which may be required.

The phrases "parenteral administration" and "administered parenterally" as used herein means modes of administration other than enteral and topical administration, usually by injection, and includes, without limitation, intravenous, intramuscular, intraarterial, intrathecal, intracapsular, intraorbital, intracardiac, intradermal, intraperitoneal, transtracheal, subcutaneous, subcuticular, intraarticular, subcapsular, subarachnoid, intraspinal, epidural and intrasternal injection and infusion.

Examples of suitable aqueous and nonaqueous carriers which may be employed in the pharmaceutical compositions of the invention include water, ethanol, polyols (such as glycerol, propylene glycol, polyethylene glycol, and the like), and suitable mixtures thereof, vegetable oils, such as olive oil, and injectable organic esters, such as ethyl oleate. Proper fluidity can be maintained, for example, by the use of coating materials, such as lecithin, by the maintenance of the required particle size in the case of dispersions, and by the use of surfactants.

These compositions may also contain adjuvants such as preservatives, wetting agents, emulsifying agents and dispersing agents. Particular examples of adjuvants which are well-known in the art include, for example, inorganic adjuvants (such as aluminum salts, e.g., aluminum phosphate and aluminum hydroxide), organic adjuvants (e.g., squalene), oil-based adjuvants, virosomes (e.g., virosomes which contain a membrane-bound hemagglutinin and neuraminidase derived from the influenza virus).

Prevention of presence of microorganisms may be ensured both by sterilization procedures, supra, and by the inclusion of various antibacterial and antifungal agents, for example, paraben, chlorobutanol, phenol sorbic acid, and the like. It may also be desirable to include isotonic agents, such as sugars, sodium chloride, and the like into the compositions. In addition, prolonged absorption of the injectable pharmaceutical form may be brought about by the inclusion of agents which delay absorption such as aluminum monostearate and gelatin.

When the antibodies of the present disclosure are administered as pharmaceuticals, to humans and animals, they can be given alone or as a pharmaceutical composition containing, for example, 0.001 to 90% (more preferably, 0.005 to 70%, such as 0.01 to 30%) of active ingredient in combination with a pharmaceutically acceptable carrier.

Regardless of the route of administration selected, the antibodies of the present disclosure, which may be used in a suitable hydrated form, and/or the pharmaceutical compositions of the present disclosure, are formulated into pharmaceutically acceptable dosage forms by conventional methods known to those of skill in the art.

Actual dosage levels of the active ingredients in the pharmaceutical compositions of the present disclosure may be varied so as to obtain an amount of the active ingredient which is effective to achieve the desired therapeutic response for a particular patient, composition, and mode of administration, without being toxic to the patient. The selected dosage levels will depend upon a variety of pharmacokinetic factors including the activity of the particular compositions employed, or, for compounds co-administered with antibodies or fragments therof provided herein, the ester, salt or amide thereof, the route of administration, the time of administration, the rate of excretion of the particular agent being employed, the duration of the treatment, other drugs, compounds and/or materials used in combination with the particular compositions employed, the age, sex, weight, condition, general health and prior medical history of the patient being treated, and like factors well known in the medical arts. A physician or veterinarian having ordinary skill in the art can readily determine and prescribe the effective amount of the pharmaceutical composition required. For example, the physician or veterinarian could start doses of the antibodies or fragments therof of the invention employed in the pharmaceutical composition at levels lower than that required in order to achieve the desired therapeutic effect and gradually increase the dosage until the desired effect is achieved. In general, a suitable daily dose of a composition of the invention will be that amount which provides the lowest dose effective to produce a therapeutic effect. Such an effective dose will generally depend upon the factors described above. It is preferred that administration be intravenous, intramuscular, intraperitoneal, or subcutaneous, preferably administered proximal to the site of the target. If desired, the effective daily dose of a therapeutic composition may be administered as two, three, four, five, six or more sub-doses administered separately at appropriate intervals throughout the day, optionally, in unit dosage forms. While it is possible for a antibody of the present disclosure to be administered alone, it is preferable to administer the antibody as a pharmaceutical formulation (composition).

Therapeutic compositions can be administered with medical devices known in the art. For example, in a preferred embodiment, a therapeutic composition of the invention can be administered with a needleless hypodermic injection device, such as the devices disclosed in U.S. Pat. Nos. 5,399,163, 5,383,851, 5,312,335, 5,064,413, 4,941,880, 4,790,824, or 4,596,556. Examples of well-known implants and modules useful in the present invention include: U.S. Pat. No. 4,487,603, which discloses an implantable micro-infusion pump for dispensing medication at a controlled rate; U.S. Pat. No. 4.,486,194, which discloses a therapeutic device for administering medications through the skin; U.S. Pat. No. 4,447,233, which discloses a medication infusion pump for delivering medication at a precise infusion rate; U.S. Pat. No. 4,447,224, which discloses a variable flow implantable infusion apparatus for continuous drug delivery;

U.S. Pat. No. 4,439,196, which discloses an osmotic drug delivery system having multi-chamber compartments; and U.S. Pat. No. 4,475,196, which discloses an osmotic drug delivery system. Many other such implants, delivery systems, and modules are known to those skilled in the art.

In certain embodiments, compositions disclosed herein can be formulated to ensure proper distribution *in vivo*. For example, the blood-brain barrier (BBB) excludes many highly hydrophilic compounds. To ensure that therapeutic compounds in compositions of the invention cross the BBB (if desired), they can be formulated, for example, in liposomes. For methods of manufacturing liposomes, see, *e.g.*, U.S. Pat. Nos. 4,522,811; 5,374,548; and 5,399,331. The liposomes may comprise one or more moieties which are selectively transported into specific cells or organs, thus enhance targeted drug delivery (*see, e.g.*, V.V. Ranade (1989) *J. Clin. Pharmacol.* 29:685). Exemplary targeting moieties include folate or biotin (see, *e.g.*, U.S. Pat. No. 5,416,016 to Low *et al.*); mannosides (Umezawa *et al.*, (1988) *Biochem. Biophys. Res. Commun.* 153:1038); antibodies (P.G. Bloeman *et al.* (1995) *FEBS Lett.* 357:140; M. Owais *et al.* (1995) *Antimicrob. Agents Chemother.* 39:180); surfactant protein A receptor (Briscoe *et al.* (1995) *Am. J. Physiol.* 1233:134), different species of which may comprise the formulations of the invention, as well as components of the invented molecules; p120 (Schreier *et al.* (1994) *J. Biol. Chem.* 269:9090); see also K. Keinanen; M.L. Laukkanen (1994) *FEBS Lett.* 346:123; J.J. Killion; I.J. Fidler (1994) *Immunomethods* 4:273.

V. Methods of Using Antibodies

The present invention also provides methods of using antibodies and antigen-binding portions thereof that bind ErbB3 in a variety of *ex vivo* and *in vivo* diagnostic and therapeutic applications. For example, antibodies disclosed herein can be used for treating a disease associated with ErbB3 dependent signaling, including a variety of cancers.

In one embodiment, the present invention provides a method for treating a disease associated with ErbB3 dependent signaling by administering to a subject an antibody or antigen binding portion thereof of the invention in an amount effective to treat the disease. Suitable diseases include, for example, a variety of cancers including, but not limited to, melanoma, breast cancer, ovarian cancer, renal carcinoma, gastrointestinal cancer, colon cancer, lung cancer (e.g., non-small cell lung cancer), and prostate cancer.

In a preferred embodiment, a tumor sample obtained from the patient is tested and treatment is provided in accordance with the methods disclosed in International Application No. PCT/US09/054051, filed August 17, 2009, titled "Methods, Systems And Products For Predicting Response Of Tumor Cells To A Therapeutic Agent And

Treating A Patient According To The Predicted Response" which is incorporated herein by reference. For example, the patient is to be treated for a malignant tumor, a sample of the tumor is obtained, a level of phosoho-ErbB3 (pErbB3) in the sample is determined, and at least one antineoplastic therapeutic agent is subsequently administered to the patient, however, if the level of pErbB3 determined in the sample is no lower than 50% of a level of pErbB3 measured in a culture of ACHN cells following culture for 20-24 hours in serum-free medium then the at least one antineoplastic therapeutic agent subsequently administered to the patient comprises an anti-ErbB3 antibody of the present invention, e.g., Ab #6, and if the level of pErbB3 determined in the sample is lower than 50% of the level of pErbB3 measured in the culture of ACHN cells then the at least one antineoplastic therapeutic agent subsequently administered to the patient does not comprise an anti-ErbB3 antibody.

In one embodiment, the cancer comprises a KRAS mutation. As demonstrated in Example 17, antibodies disclosed herein(*e.g.*, Ab #6) are capable of inhibiting the growth of tumor cells that comprise a KRAS mutation, either when used as a single agent (monotherapy) or in combination with another therapeutic agent. In another embodiment, the cancer comprises a PI3K mutation. As demonstrated in Example 19, antibodies disclosed herein(*e.g.*, Ab #6) are capable of inhibiting the growth of tumor cells that comprise a PI3K mutation, either when used as a single agent (monotherapy) or in combination with another therapeutic agent.

The antibody can be administered alone or with another therapeutic agent which acts in conjunction with or synergistically with the antibody to treat the disease associated with ErbB3 mediated signaling. Such therapeutic agents include, for example, the anticancer agents described infra (e.g., cytotoxins, chemotherapeutic agents, small molecules and radiation). As demonstrated in Examples 16, 17 and 19, antibodies disclosed herein(*e.g.*, Ab #6) when used in combination with another therapeutic agent can exhibit increased tumor growth inhibition as compared to when used in monotherapy. Preferred therapeutic agents for combination therapy include erlotinib (Tarceva®), paclitaxel (Taxol®) and cisplatin (CDDP).

In certain aspects, antibodies disclosed herein are administered to patients

In another embodiment, the present invention provides a method for diagnosing a disease (*e.g.*, a cancer) associated with ErbB3 upregulation in a subject, by contacting antibodies or antigen binding portions disclosed herein(e.g., *ex vivo* or *in vivo*) with cells from the subject, and measuring the level of binding to ErbB3 on the cells. Abnormally high levels of binding to ErbB3 indicate that the subject has a disease associated with ErbB3 upregulation.

Also within the scope of the present invention are kits comprising antibodies and antigen binding portions thereof of the invention. The kits may include a label

indicating the intended use of the contents of the kit and optionally including instructions for use of the kit in treating or diagnosing a disease associated with ErbB3 upregulation and/or ErbB3 dependent signaling, e.g., treating a tumor. The term label includes any writing, marketing materials or recorded material supplied on or with the kit, or which otherwise accompanies the kit.

The present invention is further illustrated by the following examples which should not be construed as further limiting. The contents of Sequence Listing, figures and all references, patents and published patent applications cited throughout this application are expressly incorporated herein by reference.

Examples

Materials and Methods

Throughout the examples, the following materials and methods were used unless otherwise stated.

In general, the practice of the various aspects of the present invention employs, unless otherwise indicated, conventional techniques of chemistry, molecular biology, recombinant DNA technology, immunology (especially, *e.g.*, antibody technology), and standard techniques in polypeptide preparation. See, *e.g.*, Sambrook, Fritsch and Maniatis, *Molecular Cloning: Cold Spring Harbor Laboratory Press* (1989); *Antibody Engineering Protocols (Methods in Molecular Biology)*, 510, Paul, S., Humana Pr (1996); *Antibody Engineering: A Practical Approach* (Practical Approach Series, 169), McCafferty, Ed., Irl Pr (1996); *Antibodies: A Laboratory Manual*, Harlow *et al.*, C.S.H.L. Press, Pub. (1999); and *Current Protocols in Molecular Biology*, eds. Ausubel *et al.*, John Wiley & Sons (1992). *In vitro* and *in vivo* model systems for assaying HCV biology are described, for example, in *Cell culture models and animal models of viral hepatitis. Part II: hepatitis C, Lab. Anim.* (NY).;34(2):39-47 (2005) and in *The chimpanzee model of hepatitis C virus infections, ILAR J.*;42(2):117-26 (2001).

Heregulin

As used in these Examples and in the Figures, HRG refers to the isoform of heregulin variously known as heregulin 1 beta 1, HRG1-B, HRG-β1, neuregulin 1, NRG1, neuregulin 1 beta 1, NRG1-b1, HRG ECD, and the like. HRG is commercially available, e.g., R&D Systems # 377-HB-050/CF.

Cell Lines

All the cell lines used in the experiments described below are obtained, as indicated, from American Type Culture Collection (ATCC, Manassas, VA), National

Cancer Institute (NCI, www.cancer.gov) e.g., from the Division of Cancer Treatment and Diagnostics (DCTD), or from investigator(s), as indicated by citation of publication.

- **MCF7**- ATCC cat. No. HTB-22
- **T47D**- ATCC cat. No. HTB-133
- **Colo357**- Kolb, et al., (2006) Int. J. Cancer, 120:514-523. Also see Morgan, et al., (1980) Int. J. Cancer, 25:591-598.
- **Du145**- ATCC cat. No. HTB-81
- **OVCAR8**- NCI
- **H1975**- ATCC cat. No. CRL-5908
- **A549**- ATCC cat. No.CCL-185
- **MALM-3M**-NCI
- **AdrR**-NCI
- **ACHN**- ATCC cat. No. CRL-1611

Pulverization of Tumor Cells

A cryopulverizer (Covaris Inc) is used for the pulverization of tumors. Tumors are stored in special bags (pre-weighed before the addition of the tumor) and placed in liquid nitrogen while handling them. For small tumors, 200 uL of Lysis buffer is first added to the bag containing the tumor, frozen in liquid nitrogen and then pulverized to improve the recovery of the tumor from the bag. Pulverized tumors are transferred to 2 mL EPPENDORF tubes and placed in liquid nitrogen until ready for further processing

Lysis of Tumor Cells

Tumors are lysed in Lysis buffer supplemented with protease and phosphatase inhibitors. Lysis Buffer is added to the tumor aliquots in a final concentration of about 62.5 mg/mL. Tumor samples are homogenized by vortexing for 30 sec and incubating on ice for about 30 min. The lysates are spun for about 10 min in QIAGEN QIASHREDDER columns for further homogenization of the samples. Cleared lysates are aliquoted into fresh tubes for further processing.

BCA Assay

BCA assay (Pierce) is performed following the manufacturer's protocol on all tumor samples. The total protein concentration (in mg/mL) of each tumor sample is later used in the normalization of the ELISA results

ELISA Assay

All ELISA reagents for the total and phospho-ErbB3 ELISAs are purchased from R&D Systems as DUOSET kits. 96-well NUNC MAXISORB plates are coated with 50 uL of an antibody and incubated overnight at room temperature. Next morning, plates are washed 3 times with 1000 µl/well in the BIOTEK plate washer with Dulbecco's phosphate buffered saline without calcium or magnesium (PBS) with added Tween

detergent (PBST) (0.05% Tween-20). Plates are subsequently blocked for about an 1 hr at room temperature with 2 % BSA in PBS. The plates are washed 3 times with 1000 µl/well in the BIOTEK plate washer with PBST (0.05%Tween-20). 50 µL of cell lysates and standards diluted in 50% Lysis buffer and 1%BSA are used in duplicates for further processing. Samples are incubated for 2hrs at 4°C on a plate shaker and washed as before. About 50 µl of a detection antibody diluted in 2% BSA, PBST is added and incubated for about 1 hr at room temperature. For phosphor-ErbB3, the detection antibody is directly conjugated to horseradish peroxidase (HRP) and incubated for 2 hrs at room temperature. The plate is washed as before. About 50 µl of Streptavidin-HRP is added and incubate for 30 min at room temperature (except for pErbB3). The plates are washed as before. About 50 µL of SUPERSIGNAL ELISA Pico (Thermo Scientific) substrate is added and the plate is read using a FUSION plate reader. The data are analyzed using EXCEL. Duplicate samples are averaged and the error bars are used to represent the standard deviation between the two replicates.

Example 1: Production of Antibodies Using Phage Display

In order to obtain human anti-ErbB3 antibodies referred to herein as Ab #6, Ab #3, Ab #14, Ab #17, and Ab #19, a human Fab-phage library including a unique combination of immunoglobulin sequences obtained from human donors (Hoet *et al.*, *supra*) is initially screened for ErbB3 binders.

Using purified ErbB3 and a Chinese hamster ovary (CHO) cell line expressing cell surface ErbB3, 73 unique Fab sequences from the library (obtained using the methods described above or minor variations thereof) were identified. These 73 clones are then reformatted as Fab only without the phage. Using high throughput methods, these Fabs are expressed on a small scale and tested for binding using ELISA and the FLEXCHIP method which is a high-throughput surface plasmon resonance (SPR) technology. The 73 Fabs without the phage are spotted on a chip surface and the binding kinetics and epitope blocking to a ErbB3-his fusion target protein or a ErbB3-Fc protein (R & D Systems) are measured. The equilibrium binding constant and on/off rates for the Fabs are calculated from the data obtained.

Binding of the various Fabs to MALME-3M cells is next examined using about 500 nM of the Fabs and a 1:750 dilution of a goat anti-human Alexa 647 secondary antibody. As shown in Figures 1A and 1B, data obtained using the methods described above or minor variations thereof indicate that several candidate Fabs exhibited appreciable staining of MALME-3M cells.

Example 2: Optimization of anti-ErbB3 Fabs

Subsequent to the identification of Fabs which block the binding of ErbB3 ligand, heregulin, to ErbB3, the VH and VL sequences of the Fabs are codon-optimized as follows.

The VH and VL regions are reformatted using expression constructs for expression as an IgG1 or IgG2 isotype. The constructs include a SELEXIS backbone which has a cassette designed for substitution of the appropriate heavy and light chain sequences. The SELEXIS vectors include a CMV promoter and a matching poly-A signal.

The nucleic acid sequences for the codon-optimized VH and VL of Ab #6 (obtained using the methods described above or minor variations thereof) are set forth in SEQ ID NOs:25 and 26, respectively, and those for Ab #3 are set forth in SEQ ID NOs:27 and 28, respectively, as shown in Figure 22.

Example 3: Binding Affinity for ErbB3

The dissociation constants of the anti-ErbB3 antibodies are measured using two independent techniques, *i.e.*, a Surface Plasmon Resonance Assay and a cell binding assay using MALME-3M cells.

Surface Plasmon Resonance Assay

The Surface Plasmon Resonance Assay (e.g., a FLEXCHIP assay) is performed substantially as described in Wassaf *et al.* (2006) *Analytical Biochem.*, 351:241-253, in a BIACORE 3000 instrument or the like using recombinant ErbB3 as the analyte and the subject antibody as the ligand. The K_D value is calculated based on the formula $K_D = K_d/K_a$.

The K_D values of Ab #6 and Ab #3, respectively, as measured using the Surface Plasmon Resonance Assay using the methods described above or minor variations thereof, are depicted in Figures 2A and 2B. Ab #6 exhibited a K_D value of about 4 nM and Ab #3 exhibited a K_D value of about 8 nM. Furthermore, surface plasmon resonance demonstrated that Ab #6 competes with HRG for binding to ErbB3.

Cell Binding Assay

The cell binding assay for determining the K_D values of Ab #6 and Ab #3 is performed as follows.

MALME-3M cells are detached with 2 mLs trypsin-EDTA + 2 mLs RMPI + 5mM EDTA at room temperature for 5 minutes. Complete RPMI (10 mLs) is added immediately to the trypsinized cells, resuspended gently and spun down in a Beckman tabletop centrifuge at 1100 rpm for 5 minutes. Cells are resuspended in BD stain buffer

(PBS + 2% FBS + 0.1% sodium azide, Becton Dickinson) at a concentration of 2 x 10^6 cells per ml and 50 µl (1 x 10^5 cells) aliquots are plated in a 96-well titer plate.

A 150 µl solution of 200 nM anti-ErbB3 antibody (Ab #6 or Ab #3) in BD stain buffer is prepared in an EPPENDORF tube and serially diluted 2-fold into 75 µl BD stain buffer. The concentrations of the diluted antibody ranged from 200 nM to 0.4 nM. 50 µl aliquots of the different protein dilutions are then added directly to the 50 ul cell suspension giving the final concentrations of 100 nM, 50 nM, 25 nM, 12 nM, 6 nM, 3 nM, 1.5 nM, 0.8 nM, 0.4 nM and 0.2 nM of the antibody.

Aliquoted cells in the 96-well plate are incubated with the protein dilutions for 30 minutes at room temperature on a platform shaker and washed 3 times with 300 µl BD stain buffer. Cells are then incubated with 100 µl of a 1:750 dilution of Alexa 647-labeled goat anti-human IgG in BD stain buffer for 45 minutes on a platform shaker in the cold room. Finally, cells are washed twice, pelleted and resuspended in 250 µl BD stain buffer + 0.5 µg/ml propidium iodide. Analysis of 10,000 cells is done in a FACSCALIBUR flow cytometer using the FL4 channel. MFI values and the corresponding concentrations of the anti-ErbB3-antibodies are plotted on the y-axis and x-axis, respectively. The K_D of the molecule is determined using GraphPad PRISM software using the one-site binding model for a non-linear regression curve.

The K_D value is calculated based on the formula Y=Bmax* X/ K_D + X (Bmax = fluorescence at saturation. X= antibody concentration. Y = degree of binding). As calculated from the data shown in Figures 2C and 2D, Ab #6 and Ab #3 had K_D values of about 4 nM and 1.3 nM, respectively, were obtained (using the methods described above or minor variations thereof) in a cell binding assay using MALME-3M cells.

KinExA® Assay

In additional experiments to study the binding kinetics of Ab #6, a Kinetic Exclusion Assay (KinExA®) is used to determine the association and dissociation rates for Ab #6. An association rate of 1.43 x 10^5 $M^{-1}s^{-2}$ and a dissociation rate of 1.10 x 10^{-4} s^{-1} was measured using a KinExA® instrument (Sapidyne Instruments, Boise, ID), with the dissociation constant (K_d) determined to be 769 pM.

Example 4: Binding Specificity / Epitope Binding for ErbB3

The binding specificity of an IgG2 isotype of Ab #6 to ErbB3 is assayed using ELISA as follows. Identification of the epitope bound by Ab #6 is also analyzed.

96-well NUNC MAXISORB plates are coated by overnight incubation at room temperature with 50 µl/well of 5 µg/ml of individual proteins. The proteins are recombinant human EGFR ectodomain, BSA, recombinant human ErbB3 ectodomain and TGF-α. The next morning, plates are washed 3 times with 1000 µl/well of PBST

(0.05% Tween-20) in the BIOTEK plate washer. The wells are blocked for 1 hr at room temperature with 2 % BSA in PBS and washed again as before. About 50 µL of the Ab #6 is added at several dilutions (1 µM and serial 2 fold dilutions) in 2% BSA, PBST. All samples are run in duplicate and incubated for 2 hrs at 4°C on a plate shaker. The plates are washed again as before. 50 µl of human IgG-Fc detection antibody (HRP conjugated, Bethyl Laboratories, Inc; 1:75000 dilution in 2% BSA, PBST) is added and the plates are incubated for 1 hr at room temperature. The plates are washed again as before. 50 µL of SUPERSIGNAL ELISA Pico substrate is added and the plate is read on the FUSION plate reader (Packard/Perkin Elmer). The data is analyzed using the EXCEL program. Duplicate samples are averaged and the error bars represent the standard deviation between the two replicates.

As shown in Figure 3, data obtained using the methods described above or minor variations thereof indicate that Ab #6 bound recombinant ErbB3 in an ELISA, but did not show any appreciable binding to EGFR, BSA or TGF-α.

A DNA fragment encoding an ErbB3 ectodomain fragment corresponding to amino acid residues 1-183 of mature ErbB3 (SEQ ID NO: 73) is cloned into the yeast display vector pYD2 (a modified version of pYD1 (Invitrogen) with a stop codon engineered in front of the His tag) between the Nhe and BsiWI restriction sites. The plasmid is transformed into the yeast strain EBY100 (Invitrogen) and clones containing the plasmid selected on Trp- selective medium. The clone is grown in glucose containing medium overnight at 30°C and expression of the ErbB3 truncation mutant is induced by transfer to a galactose-containing medium for 2 days at 18°C. Yeast displaying the ErbB3 truncation mutant are stained with 50 nM of Ab #6, followed by a goat anti-human antibody labeled with Alexa dye-647. A separate sample is stained with the goat anti-human antibody only to show that there is no non-specific binding to yeast of the secondary antibody. Analysis is performed by flow cytometry on the FACSCALIBUR cell sorter (BD Biosciences).

As shown by the data (obtained using the methods described above or minor variations thereof) presented in Figure 39, Ab #6 bound to the ErbB3 ectodomain, i.e., amino acid residues 1-183 of mature ErbB3 (SEQ ID NO: 73).

Example 5: Downregulation of Total ErbB3 on Tumor Cells

The ability of Ab #6 to downregulate ErbB3 expression both *in vitro* and *in vivo* in tumor cells is tested as follows.

MALME-3M cells are seeded in 96 well tissue culture plates and grown in RPMI-1640 media supplemented with antibiotics, 2mM L-glutamine and 10% fetal bovine serum (FBS) for 24 hours at 37°C and 5% carbon dioxide. Media are then switched to the same medium without FBS and with and without the antibody at

concentrations of 1uM, 250nM, 63nM, 16nM, 4.0nM, 1.0nM, 240pM, 61pM and 15pM. Medium containing no FBS or antibody is used as control. Cells are grown for 24 hours at 37°C and 5% carbon dioxide, washed with cold PBS, then harvested with mammalian protein extract (MPER) lysis buffer (Pierce, 78505) to which 150mM NaCl, 5mM sodium pyrophosphate, 10uM bpV (phen), 50uM phenylarsine, 1mM sodium orthovanadate, and protease inhibitor cocktail (Sigma, P2714) is added. Cell lysates are diluted two-fold with 4% bovine serum albumin in PBST (0.1% tween-20), then analyzed by ELISA with mouse anti-human ErbB3 capture antibody and biotinylated mouse anti-human ErbB3 secondary detection antibody. Signal is generated with streptavidin conjugated to horseradish-peroxidase reacted with SUPERSIGNAL ELISA Pico chemiluminescent substrate (Pierce, 37070). ELISAs are quantitated using a luminometer.

As shown in Figure 4, data obtained using the methods described above or minor variations thereof indicate that Ab #6 decreased total ErbB3 levels by about 46.9% in MALME-3M cells *in vitro*, as measured by ELISA.

In a further experiment, the downregulation of ErbB3 receptors on MALME-3M cells using IgG1 and IgG2 isotypes of Ab #6 is examined using FACS analysis. MALME-3M cells are trypsinized from a 15 cm dish and washed once with RPMI + 10% FBS. Cell pellets are resuspended at a density of 1 x 10^6 cells per ml. Two aliquots of 2 x 10^5 cells are added to separate wells in a 12-well tissue culture plate and each resuspended in a final volume of 800 ul RPMI + 10% FBS. To one well, Ab #6 IgG1 or Ab #6IgG2 isotype is added to a final concentration of 100 nM (treated sample) and to the other well, an equivalent volume of PBS (untreated sample) is added.

The following day, treated and untreated cells are trypsinized, washed and incubated with 100 nM of Ab #6 in BD stain buffer for 30 minutes on ice. Cells are washed twice with 1 ml BD stain buffer and incubated with 100 ul of a 1:500 dilution of Alexa 647-labeled goat anti-human Alexa 647 for 45 minutes on ice. Cells are then washed and resuspended in 300 ul BD stain buffer + 0.5 ug/ml propidium iodide. Analysis of 10,000 cells is done in a FACSCALIBUR flow cytometer using the FL4 channel.

As shown in Figures 5A and 5B, data obtained using the methods described above or minor variations thereof indicate that both IgG1 and IgG2 isotypes of Ab #6 downregulated ErbB3 on MALME-3M cells by about 62% and about 66%, respectively.

In order to determine whether this downregulation of ErbB3 is due to internalization of the ErbB3 receptor on the surface of MALME-3M cells, a cell surface fluorescence quenching assay is preformed. MALME-3M cells are plated overnight on 6-well plates (0.2 x 10^6 per well) in RPMI+10% FBS. The following day, old medium is

removed and cells are preincubated for 60 minutes on ice in RPMI + 2% FBS containing 100 nM of Ab#6 conjugated to the fluorescent dye Alexa 488. Cells are then returned to a 37°C incubator and incubated for 0.5h, 2h or 24h. At the end of each timepoint, cells are trypsinized, washed with PBS+2% BSA+0.1% sodium azide (FACS stain buffer) and stored on ice until all samples are ready. For a 0h timepoint, cells are immediately trypsinized after the 60 minute preincubation and stored on ice. After cells are harvested from all timepoints, samples from each timepoint are divided into two tubes. One set of tubes is incubated with 25 ug/ml anti-Alexa 488 antibody for 60 minutes on ice to quench any fluorescence source (i.e., Alexa 488-conjugated Ab#6) on the cell surface. The other set of tubes is left unquenched and stored on ice during this incubation period. At the end of the quenching period, cells are washed twice with FACS stain buffer and resuspended in a final volume of 300 ul FACS stain buffer. For each sample 10,000 events are collected and analyzed with a FACSCALIBUR flow cytometer. This protocol gives an indication of what proportion of AB #6 (as measured by fluorescence) remains on the cell surface (indicated by the differential between the fluorescence of the quenched and unquenched cells at each timepoint) and how much is internalized (indicated by the level of fluorescence of quenched cells).

As shown in Figure 6, downregulation of ErbB3 in the presence of Ab #6 was measured at 0 hour (Figure 6A), 0.5 hour (Figure 6B), 2 hour (Figure 6C) and 24 hours (Figure 6D). As shown in Figure 6A-6D, of the cell surface ErbB3 receptors were downregulated by about 50% after about 30 minutes and were downregulated by about 93% at about 24 hours.

The ability of Ab #6 to cause ErbB3 downregulation *in vivo* in melanoma cells was also examined as follows.

T-cell deficient nu/nu mice (3-4 week old female mice originated at NIH; outbred; albino background) were purchased from Charles River Labs (Wilmington, MA). MALME-3M cells for implantation were grown in culture (RPMI media, 10% FBS, L-glutamine and antibiotics, 37°C, 5% CO2) to about 80% confluency before harvesting. Cells were kept on ice until implantation. Mice were implanted via subcutaneous injection with 100ul MALME-3M cells (3.5 x 10^6 cells in PBS) via subcutaneous injection on the right flank and allowed to recover while being monitored for initial tumor growth.

The tumors were measured (length by width) by digital caliper and the mice were pretreated with murine IgG2a (Sigma, M7769 - 5mg) by intravenous injection to block

in vivo depletion of tested antibodies by murine Fc receptors. Mice were dosed intra-peritoneally every other day with either 15 μg or 100 μg of Ab # 1, Ab #6, Ab #11, and Ab #13, each separately in both IgG1 and IgG2 form, and tumors were measured three times per week and the measurements recorded in a Microsoft EXCEL spreadsheet.

Final tumor measurements (L x W) were taken, the mice were euthanized by CO_2 asphyxiation and tumors were excised, snap frozen in liquid nitrogen, and were stored at -80^{0}C (for biochemical analysis). Final tumor measurements were analyzed and graphed by tumor area and tumor volume as described, for example, in Burtrum *et al.*, (2003) *Cancer Res.*, 63:8912-8921. The data was also analyzed by "normalized' and "non-normalized" means for both tumor volume and tumor area. For the "normalization" of the data, at each time point of measurement, each tumor in each group was divided by the initial tumor size determined by caliper measurement.

As shown in Figure 7, PBS was used as a control and the various antibodies tested in this xenograft model included Ab #11 in IgG2 isotype and each of AB #1, Ab#6, and Ab #13 in both IgG1 and IgG2 isotypes. Of these, only Ab #6 caused significant downregulation of total ErbB3, an effect that was seen as soon as 24 hours post-injection in tumors treated with either IgG1 or IgG2 isotype versions of Ab #6.

In a further experiment, the ability of Ab #6 to downregulate ErbB3 in AdrR xenografts *in vivo* was examined.

Briefly, the samples were pulverized in a cryopulverizer (Covaris Inc). Tumors were stored in special bags (pre-weighed before the addition of the tumor) and placed in liquid nitrogen while handling them. For small tumors, 200 μL of Lysis buffer was first added to the bag with the tumor, frozen in liquid nitrogen and then pulverized to improve the recovery of the tumor from the bag. Pulverized tumors were transferred to 2 ml EPPENDORF tubes and placed in liquid nitrogen until lysed. Tumors were lysed in Lysis buffer supplemented with protease and phosphatase inhibitors. Lysis Buffer was added to the tumor aliquots in a final concentration of 62.5 mg/ml. Tumor samples were homogenized by vortexing for 30 seconds and letting them sit on ice for 30 min. The lysates were spun for 10 minutes in QIAGEN QIASHREDDER columns for further homogenization of the samples. Cleared lysates were aliquoted into fresh tubes.

The BCA assay is performed as set forth substantially as described in the materials and methods section supra.

The total levels of ErbB3 were determined by ELISA. The ELISA reagents were purchased from R&D Systems as DUOSET kits. 96-well NUNC MAXISORB plates were coated with 50 μl of respective capture antibody and incubated overnight at room temperature. The next morning, the plates were washed 3 times with 1000 μl/well in a BIOTEK plate washer with PBST (0.05% Tween-20) and then blocked for 1 hour at room temperature with 2 % BSA in PBS. The plates were then washed again as before.

Lysates (50 µl) and standards were diluted in 50% Lysis buffer and 1%BSA; all samples were run in duplicate. Plates were incubated for 2 hours at 4° C on a plate shaker and then washed again as before. Fifty microliters of detection antibody diluted in 2% BSA, PBST was added and the plates were incubated for 1 hour at room temperature. Plates were washed again as before. Fifty microliters of Streptavidin-HRP was added and the plates were incubated for 30 minutes at room temperature. Plates were washed again as before. Fifty microliters of SUPERSIGNAL ELISA Pico substrate was added and readout was performed on a Fusion plate reader. Data was analyzed using Microsoft EXCEL. Duplicate samples were averaged and the error bars represent the standard deviation between the two replicates.

The results of this experiment are shown in Figure 8. As shown in Figure 8, Ab #6 downregulated ErbB3 in AdrR xenografts *in vivo*.

Example 6: Inhibition of Tumor Cell Proliferation

The ability of Ab #6 to inhibit cellular proliferation of cells expressing ErbB3 (*e.g.*, cancer cells) is examined as follows.

MALME3M, ACHN and NCI/AdrR cells are seeded in 96 well tissue culture plates and grown in RPMI-1640 media supplemented with antibiotics, 2mM L-glutamine and 10% FBS for 24 hours at 37 degrees Celsius and 5% carbon dioxide. Media are then switched to RPMI-1640 media with antibiotics and 2mM L-glutamine without FBS in the presence or absence of Ab #6 at 1uM, 250nM, 63nM, 16nM, 4.0nM, 1.0nM, 240pM, 61pM and 15pM concentrations. Cells are grown for 96 hours at 37°C and 5% carbon dioxide, then harvested with CellTiter-Glo® Luminescent Cell Viability Assay (Promega, G7573) and analyzed on a luminometer. Media containing no serum and antibody is used as control.

As shown in Figures 9, 10 and 11, data obtained using the methods described above or minor variations thereof indicate that Ab #6 inhibited proliferation of MALME-3M cells (Figure 9), AdrR ovarian cancer cells (Figure 10) and ACHN cells (Figure 11) which express ErbB3. Specifically, Ab #6 inhibited proliferation of MALME-3M cells by about 19.6%, as measured using the CellTiter-Glo® assay, and inhibited proliferation of AdrR ovarian cancer cells by about 30.5%. Also, as shown in Figure 11, Ab #6 inhibited proliferation of ACHN cells by about 25.4%.

Example 7: Inhibition of ErbB3 Phosphorylation in Tumor Cells

The ability of Ab #6 to inhibit ErbB3 phosphorylation *in vivo* is examined as follows.

The samples are pulverized substantially as described in Example 5 *supra*, with respect to Figure 8. The BCA assay is performed substantially as set forth in the

Materials and Methods section *supra*, and the ELISA assay is performed substantially as described in Example 5 *supra* with respect to Figure 8.

The results of this experiment (obtained using the methods described above or minor variations thereof) are shown in Figure 12. As shown in Figure 12, Ab #6 significantly inhibited ErbB3 phosphorylation in AdrR ovarian xenografts *in vivo*, as measured by the amount of phosphorylated ErbB3 (pErbB3) in ng/mg of total protein.

Inhibition of BTC or HRG induced ErbB3 phosphorylation by Ab #6 is examined *in vitro* as follows.

Ovarian AdrR cells are preincubated with Ab #6 for 30 minutes prior to stimulation with 50 mM BTC, 10 mM HRG or 333 nM TGF-α. Following pre incubation, the media are removed and the cells are stimulated for 5 minutes at 37^0C, 5% CO2 with 50nM BTC or 333nM TGF-α. HRG controls (5 minutes, 5nM), 10% serum and 0% serum controls are also used. Cells are washed with 1X cold PBS and lysed in 30µl cold lysis buffer (M-PER buffer (Pierce) plus sodium vanadate (NaVO4, Sigma), 2-glycerophosphate, phenylarsine oxide, BpV and protease inhibitors) by incubating on ice for 30 minutes. Lysates are stored overnight at -80^0C.

As shown in Figures13A-13C, data obtained using the methods described above or minor variations thereof indicate that Ab #6 significantly inhibited both betacellulin and heregulin-mediated phosphorylation of ErbB3.

In a further experiment, the ability of Ab #6 to inhibit ErbB3 phosphorylation in ovarian tumor cell lines OVCAR 5 and OVCAR 8 was examined as follows.

The OVCAR 5 and OVCAR 8 cell lines are obtained from the National Cancer Institute, Division of Cancer Treatment and Diagnostics ("DCTD"). The ELISA is performed as substantially as described in the Materials and Methods section *supra*.

The results of this experiment (obtained using the methods described above or minor variations thereof) are depicted in Figures 14A and 14B. As there depicted, Ab #6 inhibited ErbB3 phosphorylation in both OVCAR 5 and OVCAR 8 ovarian cancer cell lines.

As discussed above, Ab #6 inhibits betacellulin-mediated phosphorylation of ErbB3. In order to investigate whether betacellulin-mediated phosphorylation of ErbB3 occurs through ErbB1 or ErbB3, the following experiment was performed.

AdrR cells or MALME-3M cells (1×10^5) are pre-incubated with 25µM of anti-ErbB3 Ab #6 or 25 µM of cetuximab (anti-ErbB1) in 50µl BD stain buffer for 30 minutes on ice. After 30 minutes, 50 µl of 400 nM biotinylated BTC is added to the cells and incubated for another 30 minutes on ice. This yields a final concentration of 12.5 µM antibodies and 200 nM BTC. Cells are then washed twice with 500 µl BD stain buffer and incubated with 100 µl of a 1:200 dilution of streptavidin-PE (PE=phycoerythrin) (Invitrogen) in BD stain buffer for 45 minutes. Finally, cells are

washed twice, resuspended in 300 µl of BD stain buffer and analyzed in a FACSCALIBUR flow cytometer. As a positive control, 1 x 10^5 AdrR or MALME-3M cells are incubated with 200 nM BTC for 30 minutes on ice, washed twice and incubated with a 1:200 dilution of streptavidin-PE for 45 minutes. To assess background staining from the streptavidin-PE conjugate, cells are incubated with 100 µl of a 1:200 dilution of streptavidin-PE only for 45 minutes.

The results of this experiment (obtained using the methods described above or minor variations thereof) are depicted in Figures 15A-15C. As shown in Figure 15A, BTC does not show any appreciable binding to ErbB1 negative MALME-3M cells. However, as depicted in Figures 15B and 15C, BTC does show binding to ErbB1 positive AdrR cells.

Also, as shown in Figures 15B and 15C, binding to ErbB1 was blocked by cetuximab (Erbitux®), which is an anti-EGFR antibody which specifically binds EGFR and was included as a control to demonstrate that EGF-like ligands bind to EGFR, and which is described in *e.g.*, Adams *et al.* (2005), *Nature Biotechnology* 23, 1147 – 1157.

Example 8: Inhibition of Heregulin-Mediated Signaling in Tumor Cells

The ability of Ab #6 to inhibit heregulin-mediated tumor cell signaling is investigated as follows.

MALME-3M cells and OVCAR8 cells are separately seeded in 96 well tissue culture plates (35,000 cells per well) and grown in RPMI-1640 media supplemented with antibiotics, 2mM L-glutamine and 10% FBS for 24 hours at 37°C and 5% carbon dioxide. Cells are serum-starved in RPMI-1640 media with antibiotics and 2mM L-glutamine for 24 hours at 37°C and 5% carbon dioxide. Cells are pre-treated with and without the anti-ErbB3 antibody (IgG2 isotype of Ab #6) at 1µM, 250nM, 63nM, 16nM, 4.0nM, 1.0nM, 240pM, 61pM and 15pM concentrations for 30 minutes then stimulated with 5nM HRG for 10 minutes at 37°C and 5% carbon dioxide. Controls are HRG without added antibody and untreated cells (no HRG and no Ab). Cells are washed with cold PBS then harvested with mammalian protein extract (M-PER) lysis buffer (Pierce, 78505) containing 150mM NaCl, 5mM sodium pyrophosphate (Sigma, 221368-100G), 10uM bpV(phen) (Calbiochem, 203695), 50µM oxophenylarsine (Calbiochem, 521000), 1mM sodium orthovanadate (Sigma, S6508-10G), and protease inhibitor cocktail (Sigma, P2714). Cell lysates are diluted two-fold with 4% bovine serum albumin in PBST (0.2% tween-20), then analyzed by ELISA for phosphorylation of either ErbB3, or AKT (a downstream effector of ErbB3).

In order to test for AKT phosphorylation, lysates are run on an ELISA plate with a capture antibody specific to AKT and biotinylated detection antibody specific to phospho-serine 473 of phospho-AKT (pAKT). Signal is generated with streptavidin

conjugated to horseradish-peroxidase reacted with SUPERSIGNAL ELISA Pico chemiluminescent substrate (Pierce, 37070). In order to assay for ErbB3 phosphorylation, lysates are run on an ELISA plate with a capture antibody specific for ErbB3 and an anti-phosphotyrosine detection antibody conjugated to horseradish-peroxidase. This is then reacted with the same chemiluminescent substrate. Luminescent signal on the ELISAs is measured using a luminometer.

As shown by the data presented in Figures 16A-D (obtained using the methods described above or minor variations thereof), Ab #6 is a potent inhibitor of heregulin-mediated signaling in MALME-3M cells and OVCAR8 cells, as measured by decreased phosphorylation of ErbB3 (Figure 16A) and AKT (Figure 16B). Notably, essentially complete inhibiton of the phosphorylation of each of AKT and ErbB3 by Ab #6 is observed.

Example 9: Inhibition of Ovarian, Prostate, and Pancreatic Tumor Growth

To assess the efficacy of Ab #6 *in vivo*, several xenograft models of human cancer are established in nude mice and the inhibition of tumor growth is assessed at multiple doses of Ab #6. For example, T-cell deficient nu/nu mice (3-4 week old female mice originated at NIH; outbred; albino background) are purchased from Charles River Labs (Wilmington, MA) for xenograft studies. AdrR cells for implantation are grown in culture (RPMI media, 10% FBS, L-glutamine and antibiotics, 37°C, 5% CO2) to about 85% confluency before harvesting. Cells are kept on ice until implantation. Mice are implanted via subcutaneous injection with 100µl AdrR cells (6 x 10^6 cells in PBS) on the right flank and allowed to recover while being monitored for initial tumor growth.

Tumors are measured (length by width) by digital caliper and the mice are dosed with IgG2a (Sigma, M7769-5MG) by intravenous injection. Mice are dosed intra-peritoneally every third day with either 30 µg or 300 µg of Ab #6 and tumors are measured three times per week and recorded in a Microsoft Excel spreadsheet.

Final tumor measurements (L x W) are taken, the mice are euthanized by CO_2 asphyxiation and tumors are excised, snap frozen in liquid nitrogen, and are stored at -80^0C (for biochemical analysis). Final tumor measurements are analyzed and graphed by tumor area and tumor volume, as described in Burtrum *et al.*, supra. The data are also analyzed by "normalized' and "non-normalized" means for both tumor volume and tumor area. For the "normalization" of the data, at each time point of measurement, each tumor in each group is divided by the initial tumor size determined by caliper measurement.

The data (obtained using the methods described above or minor variations thereof) from three different models derived from human tumor cell lines, AdrR (ovarian), Du145 (prostate) and OvCAR8 (ovarian) data are shown in Figures 17A-C

and Colo357 (pancreatic) xenograft study data are shown in Figure 17D. In each of these figures, the right hand panel shows serum levels achieved at specified dosages of Ab #6 and the left hand panel shows tumor volume changes with different treatments. The data from these studies demonstrate that a 300ug dose of Ab #6 every three days (Q3d) results in significant inhibition of tumor growth ($p<0.05$ for multiple time points during the studies). Moreover, this inhibitory effect of Ab #6 is further elevated when the dose is increased to 600ug Q3d, in the Du145 prostate cancer model as well as a renal (ACHN) and a pancreatic carcinoma (COLO357) xenograft model. However, further elevating the dose to 1500ug Q3d did not result in increased efficacy (OvCAR8-Figure 17C; COLO357-Figure 17D) suggesting that the 600ug is saturating for tumor growth inhibition. Pharmacokinetic (PK) analyses of the serum from the animals from these studies demonstrate a dose-dependent increase in the serum retention of Ab #6. Similarly, biochemical analysis of the intra-tumoral levels of Ab #6 from these different studies showed a dose-dependent range of 0 to ~6 pg Ab #6/ug of total tumor lysate.

Example 10: Inhibition of binding of ErbB3 Ligands to ErbB3 on Tumor Cells

In a further experiment, the specificity of Ab #6 and Ab #3 to inhibit the binding of ErbB3 ligands to ErbB3, and not EGF-like ligands to EGFR, is investigated as follows.

In one experiment, the specificity of Ab #6 and a Fab version of Ab #3 (Ab/Fab #3) to inhibit the binding of ErbB3 ligands (*e.g.*, heregulin and epiregulin) to ErbB3 is investigated in order to investigate the ability of Ab #6 and Ab/Fab #3 to inhibit the binding of heregulin to ErbB3.

MALME3M cells (1×10^5) are incubated with 10 μM of an anti-ErbB3 antibody (*e.g.*, Ab #6 or Ab/Fab #3) in 50 μl BD stain buffer for 30 minutes on ice. After 30 minutes, 50 μl of 40 nM biotinylated heregulin EGF is added to the cells and incubated for another 10 minutes on ice. This yields a final concentration of 5 μM antibody and 20 nM heregulin EGF. Cells are then washed twice with 500 μl BD stain buffer and incubated with 100 μl of a 1:200 dilution of streptavidin-PE (PE=phycoerythrin) (Invitrogen) in BD stain buffer for 45 minutes. Finally, cells are washed twice, resuspended in 300 μl of BD stain buffer and analyzed in a FACSCALIBUR flow cytometer. As a positive control, 1×10^5 MALME3M cells are incubated with 20 nM heregulin EGF for 10 minutes on ice, washed twice and incubated with a 1:200 dilution of streptavidin-PE for 45 minutes. In order to assess background staining from the streptavidin-PE conjugate, 1×10^5 MALME3M cells are incubated with 100 μl of a 1:200 dilution of streptavidin-PE only for 45 minutes.

The results of this experiment (obtained using the methods described above or minor variations thereof) are shown in Figures 18A and 18B. As depicted in Figures 18A and 18B, both Ab #6 and Ab/Fab #3 are able to inhibit heregulin binding to ErbB3.

Similarly, the ability of Ab #6 to inhibit the binding of another ErbB3-ligand, epiregulin, to ErbB3, is examined as follows.

AdrR cells (1×10^5) are pre-incubated with 25μM of the anti-ErbB3 antibody, Ab #6, or 25 μM of the anti-ErbB1 antibody cetuximab, or with no added antibody (as control) in 50 μl BD stain buffer for 30 minutes on ice. After 30 minutes, 50 μl of 2 μM biotinylated Epi is added to the cells and incubated for another 30 minutes on ice. This yields a final concentration of 12.5 μM antibodies and 1 μM Epi. Cells are then washed twice with 500 μl BD stain buffer and incubated with 100 μl of a 1:200 dilution of streptavidin-PE (PE= phycoerythrin, a fluorescent protein) (Invitrogen) in BD stain buffer for 45 minutes. Finally, cells are washed twice, resuspended in 300 μl of BD stain buffer and analyzed in a FACSCALIBUR flow cytometer. As a positive control, 1×10^5 AdrR cells are incubated with 1 μM Epi for 30 minutes on ice, washed twice and incubated with a 1:200 dilution of streptavidin-PE for 45 minutes. To assess background staining from the streptavidin-PE conjugate, cells are incubated with 100 μl of a 1:200 dilution of streptavidin-PE only for 45 minutes.

The results of this experiment (obtained using the methods described above or minor variations thereof) are depicted in Figures 19A and 19B. As shown in Figure 19A, epiregulin binds to ErbB3 positive AdrR cells. Further, as shown in Figure 19B, this binding is inhibited by both cetuximab and Ab #6, suggesting that epiregulin may bind to both EGFR and ErbB3.

A further experiment is performed to investigate whether Ab #6 is able to inhibit the binding of an EGF-like ligand (*e.g.*, HB-EGF) to tumor cells.

AdrR cells (1×10^5) are pre-incubated with 25μM of Ab #6 or 25 μM of cetuximab (as control) in 50 μl BD stain buffer for 30 minutes on ice. After 30 minutes, 50 μl of 400 nM biotinylated HB-EGF is added to the cells and incubated for another 30 minutes on ice. This yields a final concentration of 12.5 μM antibodies and 200 nM HB-EGF. Cells are then washed twice with 500 μl BD stain buffer and incubated with 100 μl of a 1:200 dilution of streptavidin-PE (PE=phycoerythrin) (Invitrogen) in BD stain buffer for 45 minutes. Finally, cells are washed twice, resuspended in 300 μl of BD stain buffer and analyzed in a FACSCALIBUR flow cytometer. As a positive control, 1×10^5 AdrR cells are incubated with 200 nM HB-EGF for 30 minutes on ice, washed twice and incubated with a 1:200 dilution of streptavidin-PE for 45 minutes. To assess background staining from the streptavidin-PE conjugate, cells are incubated with 100 μl of a 1:200 dilution of streptavidin-PE only for 45 minutes.

As shown by the data set forth in Figure 20 (obtained using the methods described above or minor variations thereof), HB-EGF binds to AdrR cells, presumably to either or both of ErbB1 and ErbB4 on AdrR cells. Ab #6 does not inhibit this binding, evidencing that Ab #6 is specific for inhibiting the binding of ErbB3 ligands (*e.g.*, heregulin and epiregulin) to ErbB3.

Example 11: Inhibition of VEGF Secretion in Tumor Cells

The ability of Ab #6 to inhibit VEGF secretion of cells expressing ErbB3 (*e.g.*, cancer cells) is examined using VEGF secretion assay (VEGF ELISA, R&D Systems DY293B) as described under "ELISA Assay" in Materials and Methods, above,. First, the ability of Ab #6 to inhibit VEGF secretion in untreated and HRG treated MCF-7, T47D and COLO-357 cells is analyzed. As shown in Figure 24A, these studies revealed that COLO-357 secrete the highest amount of VEGF into the media. As these cells also exhibit very high HRG levels, addition of HRG to the media does little to induce VEGF secretion. In contrast, HRG is able to induce more than a doubling of VEGF secretion in MCF-7 and T47D cells. Ab #6 shows a potent inhibitory effect at high levels in all three cell lines with the highest being in COLO-357 (Fig. 24A, FU = Fluorescence Units).

Ab #6 also shows a similar effect *in vivo* by inhibiting VEGF secretion in three different xenografts, the highest being in COLO-357 xenograft (Fig. 24B). Inhibition of VEGF correlates with inhibition of ErbB3 phosphorylation (Fig. 24 C). It has been demonstrated that myeloma cell-secreted factors, such as VEGF and bFGF, trigger angiogenesis (see, e.g., Leung et al. (1989) Science 246(4935):1306-9; Yen et al. (2000) Oncogene 19(31):3460-9). Inhibition of VEGF secretion is also known in the art to correlate with inhibition of tumor induced angiogenesis, a facilitator of tumor growth.

Example 12: Inhibition of Cell Migration

The ability of Ab #6 to inhibit the migration of cells expressing ErbB3 (*e.g.*, MCF-7 cells) is examined using a trans-well assay (Millipore Corp., Billerica, MA, # ECM552). First, MCF-7 cells are serum-starved overnight and then incubated in the presence or absence of Ab #6 (8uM final concentration) for 15 minutes at room temperature. The cells are then transferred to an upper chamber that is separated from a lower chamber by a collagen type I-coated membrane through which the cells can migrate. 10%FBS is added to media in the lower chamber to act as a chemoattractant in the presence of absence of Ab #6. The chambers are incubated at 37°C for 16 hours and then the cells that migrate through the membrane into the lower chamber are removed using a detachment buffer and incubated with a cell-binding fluorescent dye. Fluorescence is quantitated using a fluorescent plate reader. The average fluorescence ± SEM (n=2) is shown in Figure 25.

As shown by the data presented in Figure 25 (obtained using the methods described above or minor variations thereof), 10% FBS stimulates cell migration (lane 3) as compared to untreated control (lane 1) and 8uM Ab #6 inhibits the FBS induced cell migration (lane 4).

Example 13: Inhibition of Spheroid Growth

The ability of Ab #6 to inhibit the spheroid growth of cells expressing ErbB3 is examined using an assay which approximates conditions of developing tumor growth (Herrmann et al. J Biomol Screen. 2008 Jan;13(1):1-8. Epub 2007 Nov 26) AdrR (an ovarian cancer cell line) and DU145 (a prostate cancer cell line) spheroids are initiated at a frequency of 1 spheroid per well of a 96 well plate using a hanging drop method (Herrmann et al., *supra*). Subconfluent cells are trypsinized, counted, and resuspended in filtered medium. The cell concentration is adjusted to 100,000 cells/ml, and one 20 ul drop (containing 2000 cells) is added to each ring on the underside of the lid of a 96-well plate. The lids with these hanging droplets are then placed back on the original 96-well plate, which contained 100 ul of PBS in each well to maintain moisture. Four days after initial plating, the hanging droplets containing the spheroids are replated into new 96-well plates. This replating involves transferring the lid containing the hanging droplets to a fresh 1% agarose/RPMI-coated 96-well plate that contains 150 ul of medium per well. The plate and lid are then centrifuged together at 500 rpm for 1 minute to transfer the spheroid-containing drops from the lids to the wells. Plates are then further incubated at 37° C in a humidified CO2 incubator. Spheroids are photographed in an inverted phase contrast microscope. A micrometer scale is also photographed at the same magnification to determine spheroid size. The diameter of the spheroids is determined using Metamorph Analysis software (MDS Analytical Technologies).

Individual spheroids thus obtained are then treated with either Ab #6 (8 uM final concentration), heregulin-β1 EGF domain (R&D Systems, 396-HB, 3.4 nM final concentration), or a combination of both. The diameters of the spheroids are measured using light microscopy (10X objective) at day 1 and day 13.

Data (obtained using the methods described above or minor variations thereof) presented in Figure 26A and 26B show that Ab #6 inhibits spheroid growth in AdrR cells and that 3.4nM HRG stimulates spheroid growth while Ab #6 inhibits the HRG effect (Fig. 26B). Data (obtained using the methods described above or minor variations thereof) presented in Figure 26C show that spheroids derived from DU145 do not increase in size during 13 days of the experiment; however, growth is significantly stimulated by HRG. In these cells, 8uM Ab #6 inhibits HRG induced spheroid growth.

In additional experiments, the ability of Ab #6 to inhibit spheroid growth of OVCAR8 cells, another human ovarian cancer cell line, is examined. Multicellular tumor spheroids are generated as before. To test the effect of Ab #6 on spheroid growth, the antibody is added to a final concentration of 25 μg/ml on days 1 and 4 of spheroid formation. Data obtained using the methods described above or minor variations thereof showed that Ab #6 caused a 30-40% decrease in OVCAR8 spheroid area.

Example 14: Inhibition of Signaling

The ability of Ab #6 to inhibit the signaling induced by different ligands is examined. For example, the effect of Ab #6 on HRG and BTC binding to AdrR cells expressing ErbB3 receptor is tested. As shown by the FACS analysis results presented in Figures 27A and B, Ab #6 competes with HRG but not BTC for binding to AdrR cells. Accordingly, since Ab #6 does not activate HRG-induced signaling (as is indicated by experiments below) blocking of HRG binding to ErbB3 by Ab #6 will prevent signaling induced by HRG.

Various ligands are tested for inducement of ErBb3 phosphorylation. At least three ligands, HRG, BTC, and HGF, are able to stimulate ErbB3 induced phosphorylation in AdrR cells, while EGF can not. As shown in Figure 28, Ab #6 inhibits HGF induced ErbB3 phosphorylation in AdrR cells. Further, as known in the art (see, e.g., Wallenius et al. (2000) Am J Pathol. 156 (3):821-9), enhanced HGF signaling has been reported in various epithelial and non-epithelial tumors.

ErbB3/c-MET interaction and the role of Ab #6 in modulating this interaction

It has been shown that non-small-cell lung cancers carrying activating mutations in EGFR develop resistance to tyrosine kinase inhibitors by recruiting c-MET and HER3 and thus activating the PI3K-AKT cell survival pathway (Engelmann et al. (2007) Science 316: 1039-1043; Gou (2007) PNAS: 105(2): 692-697). The association between EGFR and c-MET in cell lines that carry activating EGFR mutations has been well established by co-immunoprecipitation (Engelmann et al. 2007; Gou 2007). Guo et al. recently used co-immunoprecipitation to demonstrate that c-MET and ErbB3 also exist in a complex in a gastric cell line MKN45 known to be dependent on amplified c-MET.

c-MET-ErbB3 interactions also occur in AdrR cells carrying the wild type EGFR and is not dependent on amplified c-MET. HGF (Hepatocyte Growth Factor) induces ErbB3 phosphorylation in AdrR cells in a dose dependent manner as shown in Figure 28. In addition, Ab #6 inhibits HGF induced erbB3 phosphorylation.

The effect of HRG and BTC on both ErbB1 and ErbB3 phosphorylation has also been investigated, and HRG and BTC are found to induce phosphorylation of both ErbB1 and ErbB3. HRG is found to be a more potent inducer of ErbB3 phosphorylation

while BTC is a potent inducer of ErbB1 phosphorylation (Fig. 29A). This phosphorylation is likely to be driven by the complex between ErbB1 and ErbB3. HRG binding to ErbB3 induces complex formation between ErbB1 and ErbB3, leading to the activation of both receptors. The same phenomenon appears likely for BTC, where BTC binding to ErbB1 stimulates complex formation between ErbB1 and ErbB3, leading to the phosphorylation of both ErbB1 and ErbB3.

Inhibition of HRG, BTC, EGF, and HGF stimulated ErbB3 phosphorylation.

The ability of Ab #6 to inhibit ligand (HRG, BTC, EGF, and HGF) induced ErbB3 phosphorylation is examined by the following method:

1. AdrR cells are plated into 96 well plate at a density of 30,000 cells/well/100 uL in RPMI medium containing 10% FBS and allowed to grow overnight;
2. The next day, cells are serum-starved by changing medium to FBS-free medium and allowed to grow overnight;
3. Cells are pre-treated with different concentrations of Ab #6 (from 0.01 nM to 100nM), or buffer (un-pretreated, "0"), for 2hours;
4. Pretreated and un-pretreated cells are then stimulated with 10 nM HRG or HGF for 10 minutes, or 10 nM BTC or EGF for 5 minutes, and separate wells of un-pretreated cells are left unstimulated ("Control");
5. The reaction is stopped by removing the culture medium and washing the cells once with ice cold PBS;
6. The cells are then lysed in 25 mM Tris, pH+7.5, 150 mM NaCl, 1mM EDTA, 1.0% Triton X-100, 1.0% CHAPS, 10% v/v glycerol, containing 1X protease inhibitor and 1X phosphatase inhibitor; and
7. ErbB3 phosphorylation is measured in cell lysates using Human Phospho-ErbB3 ELISA kit (R&D Systems, DYC1769) according to manufacturer's instructions.

Results obtained by the methods described above or minor variations thereof are set forth in Figures 38A-D.

Antibody Inhibition of ErbB2-ErbB3 protein complex formation.

AdrR cells are pre-incubated with buffer (control), or 250 nM Ab #6 for 60 minutes at room temperature, then treated with 10 nM HRG or 10 nM BTC or control buffer for 10 minutes. The cells are lysed in 25 mM Tris, pH+7.5, 150 mM NaCl, 1mM EDTA, 1.0% Triton X-100, 1.0% CHAPS, 10% v/v glycerol, containing 0.2mM PMSF, 50mTU/mL aprotinin, and 100 uM leupeptin, and the crude lysate are centrifuged briefly to remove insoluble material. Supernatant is transferred to a new EPPENDORF tube, and anti-ErbB3 antibody (Santa Cruz sc-285) is added at 1:500 dilution. Supernatants are incubated overnight with gentle shaking at 4C. 60 ul of

Immobilized Protein A/G agarose beads (Pierce, Rockford, IL, # 20421) is first washed with 1X PBS. The cell lysate-antibody mixture is added to the PBS washed beads, and incubated for 2 hours with gentle shaking at 4°C. The immunoprecipitates are then washed with ice-cold lysis buffer 3 times, resuspended in 30 ul of 2X SDS sample buffer, heat denatured at 95°C for 7 minutes and run on 4-12% Bis-Tris Gels. SDS-PAGE and electro-transferred to PVDF membrane in Tri-Glycine buffer with 10% MeOH. The membrane is blocked for 1hour in 10ml of blocking buffer (Li-Cor Biosciences, Lincoln, NE, # 927-40000) and then incubated with the anti-ErbB2 antibody at 1:1000 (Cell Signaling Technology, Danvers, MA, # 29D8) in 10 ml of blocking buffer (Li-Cor Biosciences, # 927-40000). The signal is detected using goat anti-rabbit IRDye800 at 1:5000 (2ul) in 10ml of blocking buffer (Li-Cor Biosciences, # 927-40000).

By the methods described above or minor variations thereof, Ab #6 was shown to completely inhibit HRG stimulated ErbB2/3 complex formation (Fig.29B).

Example 15: Inhibition Profile of Ab #6 is Distinct from cetuximab, lapatinib and pertuzumab.

In this example, inhibitor dose response studies are performed with AdrR cells stimulated with either HRG or BTC in the presence of either Ab #6, cetuximab, lapatinib or pertuzumab. Serum starved AdrR cells are pre-incubated for 30 minutes with 4-fold serial dilutions of Ab #6, lapatinib or cetuximab from 2 mM to 7.6 pM or of pertuzumab from 100 nM to 1.5 pM and then stimulated for 10 minutes with 25 nM of HRG or BTC. Phosphorylation of ErbB3 is measured by ELISA (R&D Systems, DYC1769-5, per manufacturers protocol) and IC_{50} values are determined using Prism (GraphPad Software Inc.).

Data obtained using the methods described above or minor variations thereof showed that:

Ab #6 inhibited both HRG -induced ErbB3 phosphorylation and BTC-induced ErbB3 phosphorylation, with IC_{50}s of 2.4 nM and 5.9 nM, respectively (with 95% confidence intervals of 1.5-3.8 nM and 2.5-13.6 nM, respectively).

Lapatinib (a reversible tyrosine kinase inhibitor of ErbB1 and ErbB2) inhibited HRG and BTC-induced ErbB3 phosphorylation with IC_{50}s of 150 nM and 360 nM, respectively (with 95% confidence intervals of 46-504 nM and 119-1069 nM, respectively).

Cetuximab (an anti-ErbB1 antibody) inhibited BTC-induced ErbB3 phosphorylation with an IC_{50} of 1.8 nM (with a 95% confidence interval of 0.9-3.8 nM). but cetuximab did not inhibit HRG-induced ErbB3-induced ErbB3

phosphorylation, confirming earlier observations that HRG signaling is mediated primarily by ErbB2/ErbB3 and not ErbB1/ErbB3 heterodimers.

Pertuzumab (a monoclonal antibody that sterically hinders ErbB2's recruitment into ErbB ligand complexes) inhibited HRG-induced ErbB3 phosphorylation with an IC_{50} of 3.6 nM (with a 95% confidence interval of 1.0-13.5 nM), but did not inhibit BTC-induced ErbB3 phosphorylation.

Thus, Ab #6 was the only inhibitor tested that is capable of potently inhibiting ErbB3 phosphorylation with low nanomolar IC_{50} values for both HRG and BTC stimulation.

Example 16: Combination Therapy with Ab #6 and other Therapeutic Agents

In this example, the efficacy of Ab #6 in inhibiting tumor growth in xenograft tumor models is assessed in combination with other therapeutic agents, namely erlotinib or taxol.

In a first experiment, mice bearing ACHN (a renal tumor cell line) xenograft tumors are prepared by establishing tumors subcutaneously in the flanks of nude mice (Charles River Laboratories). The tumor-bearing mice are dosed intraperitoneally (IP) every three days with either a suboptimal dose of 300 μg Ab #6 or vehicle. Erlotinib (25 mg/kg) is administered orally once daily, either alone or in combination with the Ab #6 treatment. Tumor size (length x width) is measured twice a week and measurements are used to calculate tumor volume (p/6 (L x W2). The data presented in Figure 30 (obtained using the methods described above or minor variations thereof) demonstrate that while Ab #6 or erlotinib alone inhibit tumor growth, inhibition by the combination therapy (Ab #6 plus erlotinib) is greater than either single agent alone resulting in an additive effect.

In a second experiment, mice bearing DU145 (a prostate tumor cell line) xenograft tumors are prepared by establishing tumors subcutaneously in the flanks of nude mice (Charles River Laboratories). The tumor-bearing mice are dosed intraperitoneally (IP) every three days with Ab #6 (300 μg) or vehicle. Taxol (20 mg/kg) is administered IP once per week, either alone or in combination with the Ab #6 treatment. Again, tumor size is measured twice a week and measurements are used to calculate tumor volume. The data presented in Figure 31 (obtained using the methods described above or minor variations thereof) demonstrate that while Ab #6 or taxol alone inhibited tumor growth, inhibition by the combination therapy (Ab #6 plus taxol) is greater than either single agent alone resulting in an additive effect.

Example 17: Inhibition of Growth of KRAS Mutant Tumor Cells

In this example, the ability of Ab #6, either alone or in combination with other agents, to inhibit the growth of tumor cells that comprise a KRAS mutation is examined.

A549 is a lung cancer cell line that comprises a G12S KRAS mutation, a mutation in codon 12 of the human KRAS gene, in which the codon is changed from one coding for glycine (G) to one coding for serine (S). This cell line is insensitive to treatment with erlotinib or taxol alone. To test the ability of Ab #6 alone to inhibit growth of A549 cells *in vitro*, the cells are grown as multicellular tumor spheroids (2000 cells/spheroid/well of a 96 well plate) and then treated with 0, 0.001, 0.01, 0.1 or 1 μM Ab #6 for seven days. The area of the spheroid is measured under 4x magnification using METAMORPH software on day 1 and day 7 and the percent change in spheroid area is calculated ((Initial Area – Final Area/ Initial Area x 100). The results (obtained using the methods described above or minor variations thereof) are shown in the graph of Figure 32A ("-4" on the x axis of the graph corresponds to the "0" dose), and the photographs of Figure 32B. The data of Figure 32A demonstrate that Ab #6 treatment alone is sufficient to inhibit the growth of the KRAS mutant A549 tumor cells *in vitro* and that there is a linear dose response result regarding the percent decrease in spheroid area with the indicated ten-fold increases in Ab #6 concentration. Photographs of representative spheroids are shown in Figure 32B. Untreated spheroids grew approximately 5% in 7 days versus a 35% reduction in size of spheroids treated with 1 μM Ab #6.

To test the ability of Ab #6 alone to inhibit the growth of the KRAS mutant A549 cells *in vivo*, nude mice bearing A549 subcutaneous xenograft tumors are treated with 600 μg of Ab #6 every three days, followed by measurement of tumor volume. The results (obtained using the methods described above or minor variations thereof) are shown in the graph of Figure 32C, which demonstrates significant tumor growth inhibition by Ab #6 treatment alone, which growth inhibition is retained after dosing stopped on day 22. Thus, Ab #6 alone was able to inhibit the growth of KRAS mutant tumor cells *in vivo*.

To test the ability of Ab #6 in combination with either erlotinib or taxol to inhibit the growth of the KRAS mutant A549 cells *in vivo*, nude mice bearing A549 subcutaneous xenograft tumors are treated with either: (i) 300 μg of Ab #6 alone every three day; (ii) 25 mg/kg erlotinib alone every day; (iii) 20 mg/kg taxol alone every 7 days; (iv) Ab #6 and erlotinib in combination (at the same dosing); or (v) Ab #6 and taxol in combination (at the same dosing). The results for the erlotinib experiment and the taxol experiment (all obtained using the methods described above or minor variations thereof) are shown in Figures 33A and 33B. The results from both experiments demonstrate that the KRAS mutant A549 xenografts are insensitive to

treatment with either erlotinib or taxol alone, that growth of the KRAS mutant xenografts is inhibited by Ab #6 treatment alone and that combining Ab #6 treatment with either erlotinib or taxol treatment led to even greater tumor growth inhibition that observed with Ab #6 monotherapy.

Example 18: Epitope Mapping of Ab #6 Binding to ErbB3

In this example, alanine scanning mutagenesis is used to map the epitope within ErbB3 to which Ab #6 binds.

Since Ab #6 inhibits HRG binding to ErbB3, alanine mutagenesis analysis is commenced focusing on the predicted HRG binding site in the extracellular domain (the ectodomain) of ErbB3, and in particular Domain I of the ectodomain, of ErbB3. To assist in selection of which residues to mutate, the crystal structure of EGFR complexed with TGFα (Garret *et al.* (2002) *Cell* 110:763-773) was used as a model, since the crystal structure of ErbB3 complexed with HRG was not available. ErbB3 and EGFR are homologous in structure and thus even if the interacting residues are not identical, the structural elements (certain loops or helix faces) should be the same. Accordingly, the residues in EGFR specified to be involved in ligand binding as described in Garret *et al.*, *supra*, are identified and sequence alignment of ErbB3 and EGFR reveal the corresponding ErbB3 residues. In addition to the ligand binding sites, other faces of Domain I of the ErbB3 ectodomain are mutated using the crystal structure of ErbB3 as a guide (Cho and Leahy (2002) *Science* 297:1330-1333).

Accordingly, the following ErbB3 point mutations are made: L14A, N15A, L17A, S18A, V19A, T20A, N25A, K32A, L33A, V47A, L48A, M72A, Y92A, Y92P, D93A, M101A, L102A, Y104A, Y104P, N105A, T106A, Y129A, Y129P, K132A, Q59A, T77A, Q90A, Q114A, Q119A, R145A, R151A, V156A, H168A, K172A and L186A. In this notation, which uses the standard single letter amino acid abbreviations, L14A, for example, indicates that leucine (L) at amino acid position 14 of mature ErbB3 (SEQ ID NO: 73) is specifically mutated to alanine (A), with other substitution mutations indicated in the same fashion. Mutagenesis is accomplished using standard methods known in the art and the ErbB3 mutants, within the context of the ErbB3 ectodomain Domain I, are expressed on the surface of yeast cells using standard methods known in the art. All mutants expressed well on the surface of the yeast at levels identical to those of the wild type ErbB3 Domain I. Expression of the ErbB3 Domain I mutants on yeast allows for the examination of binding of Ab #6 to mutants using FACS without first purifying the recombinant proteins.

Binding of Ab #6 to ErbB3 ectodomain Domain I fragments comprising single mutations is determined by standard FACS analysis. A second anti-ErbB3 antibody (SGP1; LabVision), which binds an epitope on ErbB3 which does not overlap with the

epitope bound by Ab #6 (as evidenced by lack of competition for binding to ErbB3), is used as a control to ensure that the mutations are not just generally destabilizing the ErbB3 structure. Thus, ErbB3 mutations that affect the binding of both antibodies are excluded from further characterization. For FACS analysis, yeast cells expressing the different mutant version of ErbB3 Domain I on their surface are labeled simultaneously with Ab #6 (followed by a goat anti-human Ab-Alexa 488 as secondary antibody) and with SGP1-Alexa 647. Data (obtained using the methods described above or minor variations thereof) indicate that four of the alanine point mutations describned above inhibit Ab #6 binding to ErbB3 ectodomain Domain I while not inhibiting the binding of the control anti-ErbB3 antibody (SGP1). These four point mutations are: D93A, M101A, L102A and Y104A.

To further confirm that the Ab #6 epitope comprises residues 93, 101, 102 and 104 of mature ErbB3 (SEQ ID NO: 73), these four mutations (D93A, M101A, L102A, Y104A), are expressed in the context of the full length mature ErbB3 following stable transfection into CHO K1 cells in order to examine their effects in this context. CHO K1 cells expressing wild type full-length ErbB3 serve as a positive control. High expressing clones are selected for each mutant and labeled for standard FACS analysis either with Ab #6 or SGP1 (to confirm proper folding of ErbB3). SGP1 is directly labeled with Alexa 647 dye and Ab #6 is directly labeled with Alexa 488 dye.

The results (obtained using the methods described above or minor variations thereof) are shown in Figures 34A-34E, which show the binding of SGP1 or Ab #6 to wild type ErbB3, the D93A mutant, the M101A mutant, the L102A mutant or the Y104A mutant, respectively. The results demonstrate that the control anti-ErbB3 antibody (SGP1) is able to bind all four mutants, whereas Ab #6 displays essentially no binding to three of the mutants (D93A, L102A and Y104A) and only very minimal binding to the fourth mutant (M101A). Thus, full-length ErbB3 CHO cell expression experiments demonstrate that the Ab #6 epitope on ErbB3 comprises residues 93, 101, 102 and 104 of the mature, human ErbB3 sequence shown in SEQ ID NO: 73. These four residue are located on strand 3 of a 5 stand parallel beta-sheet within ErbB3. Futher experiments performed in analogous fashion yielded data indicating that the epitope further comprises residues 92, 99 and 129 of the mature, human ErbB3 sequence shown in SEQ ID NO: 73. Thus, the epitope bound by Ab #6 may be viewed as comprising the sequence spanning residues 92-104 and 129 (which lies adjacent to 92-104 in the folded protein,), of the mature, human ErbB3 sequence shown in SEQ ID NO: 73.

Example 19: Inhibition of Growth of PI3K Mutant Tumor Cells

In this example, the ability of Ab #6, either alone or in combination with another agent, to inhibit the growth of tumor cells that comprise a PI3K mutation is examined.

SKOV3 (SKOV-3) is an ovarian cancer cell line that comprises a mutation that upregulates PI3K expression. To test the ability of Ab #6 alone to inhibit the growth of the PI3K mutant SKOV3 cells *in vivo*, nude mice bearing SKOV3 subcutaneous xenograft tumors (tumor volume of 150-200 mm^3) are treated with 600 μg of Ab #6 every three days, followed by measurement of tumor volume. The results (obtained using the methods described above or minor variations thereof) are shown in the graph of Figure 35A, and demonstrate that Ab #6 treatment alone results in partial tumor growth inhibition. In this experiment, a "lag phase" in tumor growth of approximately 30 days was observed even in the vehicle-treated mice, indicating that this tumor is slow to grow *in vivo*. Nevertheless, the decrease in the tumor volume after 30 days in the Ab #6 treated mice as compared to the vehicle treated mice demonstrates that Ab #6 treatment alone is able to inhibit the growth of PI3K mutant tumor cells *in vivo*.

To test the ability of Ab #6 in combination with cisplatin to inhibit the growth of the PI3K mutant SKOV3 cells *in vivo*, nude mice bearing SKOV3 subcutaneous xenograft tumors are treated with either: (i) 300 μg of Ab #6 alone every three day (a suboptimal dose of Ab #6); (ii) 1.5 mg/kg cisplatin (CDDP) alone; or (iii) Ab #6 and cisplatin in combination (at the same dosing). Given the 30 day "lag phase" observed in the Ab #6 monotherapy experiment described above, dosing with Ab #6 in the combination experiment is not begun until after the 30 day lag phase had elapsed. The results for the combination therapy experiment (obtained using the methods described above or minor variations thereof) are shown in Figure 35B. The results demonstrate that both Ab #6 and cisplatin alone are able to inhibit the growth of the SKOV3 xenografts and that the combination treatment led to even greater tumor growth inhibition than either agent alone, thereby demonstrating the enhanced effectiveness of Ab #6 treatment when combined with a second therapeutic agent, such as cisplatin.

Example 20: Paratope Mapping of Ab #6

In this example, paratope mapping of Ab #6 is performed using a single chain (scFv) version of the antibody. In this scFv version (SEQ ID NO: 72) the V_H region (SEQ ID NO: 1) and the V_L region (SEQ ID NO: 2) are connected with a $(G4S)_3$ linker (amino acids 123-137 of SEQ ID NO: 72; the linker sequence is also shown in SEQ ID NO: 74), and this scFv still retains the ability to specifically bind ErbB3. This format is used to investigate the effect on ErbB3 binding of alanine (and in some cases phenylalanine) substitution mutations in the CDR loops.

To predict which residues in the CDR loops of Ab #6 are surface exposed, the crystal structures of two very homologous antibodies were examined, since the crystal structure of Ab #6 had yet to be empirically determined. The antibodies for which crystal structures are available that appeared to be most homologous to Ab #6 are 1mhp

(anti-alpha1 integrin, Karpusas *et al.*, *J. Mol. Biol.* 327:1031 (2003)) for the V_H chain and 1mco (Guddat *et al.*, *Proc. Natl. Acad. Sci. USA* 90:4271 (1993)) for the V_L chain. Shown below in Table 1 are the CDR loops of Ab #6, with the residues chosen for mutation highlighted in boldface and underlined. Also shown in Table 1 are the sequences of the V_H CDRs of the 1mhp antibody and of the V_L CDRs of the 1mco antibody, with the number of amino acid mismatches compared to Ab #6 shown in parentheses following the SEQ ID NO for each CDR and the surface residues highlighted in italics, boldface and underlined.

Table 1: CDR Loops in Antibody #6

VH	**Ab #6**
CDR H1	**HYV**MA (SEQ ID NO: 7)
CDR H2	SI**SSS**GG**WTL**YADSVKG (SEQ ID NO: 8)
CDR H3	G**LKMATIFD**Y (SEQ ID NO: 9)
VL	**Ab #6**
CDR L1	TG**TSSD**VG**SYNV**VS (SEQ ID NO: 10)
CDR L2	**EVSQR**PS (SEQ ID NO: 11)
CDR L3	C**SY**AG**SSI**FVI (SEQ ID NO: 12)
VH	**1mhp**
CDR H1	***RYT***MS (SEQ ID NO: 54) (3)
CDR H2	TI***SG***-GG***HTY***YLDSVKG (SEQ ID NO: 55) (6)
CDR H3	G***FGD***G***GY***F***D***V (SEQ ID NO: 56) (7)
VL	**1mco**
CDR L1	TG***TSSD***VG***GYNY***VS (SEQ ID NO: 57) (2)
CDR L2	***EVNKR***PS (SEQ ID NO: 58) (2)
CDR L3	S***SY***EG***SDN***FV (SEQ ID NO: 59) (5)

The mutations made in Ab #6 are summarized below in Table 2. The amino acid residue numbering for the mutations corresponds to the linear numbering of the V_H and V_L residues within the scFv format, not to Kabat numbering. The notation Thr28Ala indicates that threonine (Thr) at amino acid position 28 of the scFv is specifically mutated to alanine (Ala), with the rest of the substitution mutations indicated in the same fashion.

Table 2: Ab #6 Mutations

CDR	Mutation Name	Substitution
H1	M1	Thr28Ala
	M2	Ser30Ala
	M3	His31Ala
	M4	Tyr32Ala
	M5	Tyr32Phe
	M6	Val33Ala
H2	M7	Ser52Ala
	M8	Ser53Ala
	M9	Ser54Ala
	M10	Trp57Ala
	M11	Thr58Ala
	M12	Leu59Ala
H3	M13	Leu100Ala
	M14	Lys101Ala
	M15	Met102Ala
	M16	Thr104Ala
	M17	Ile105Ala
	M18	Asp107Ala
L1	M19	Thr162Ala
	M20	Ser163Ala
	M21	Ser164Ala
	M22	Asp165Ala
	M23	Ser168Ala
	M24	Tyr169Ala
	M25	Tyr169Phe
	M26	Asn170Ala
	M27	Val171Ala

L2	M28	Glu189Ala
	M29	Val190Ala
	M30	Ser191Ala
	M31	Gln192Ala
	M32	Arg193Ala

L3	M33	Ser229Ala
	M34	Tyr230Ala
	M35	Tyr230Phe
	M36	Ser233Ala
	M37	Ser234Ala
	M38	Ile235Ala

As shown in Table 2, all of the mutations are to alanine except that the tyrosine residues are also mutated to phenylalanine because Phe and Tyr are structurally very similar (*e.g.*, both are aromatic) and such mutations are thus expected to be less disruptive in regard to antigen binding. In addition to the mutations made within the CDRs proper, heavy chain residues 28 and 30, outside of the CDRs, are also mutated (mutations M1 and M2 in Table 2) as they fall in the CDR loop regions. All of the mutations are made using standard recombinant DNA techniques and binding of the mutants to ErbB3 is tested using standard screening techniques known in the art.

As shown in Figure 36, several mutations were identified that preferentially affected binding of the scFv to the ErbB3 domain more than they altered the binding of the scFv to Protein A (which binding does not involve the CDRs). Their identities and effects (based on the three groupings shown in Figure 36) are indicated below in Table 3. "No effect on binding" indicates either that binding to ErbB3 is not substantially affected or that there is a corresponding decrease in binding to Protein A attributed to destabilization of the scFv protein. The majority of the binding residues are located in the H1, H2 and H3 loops and some in the L1 and L3 loops. As seen in many other antibody antigen complexes, the L2 CDR does not directly contribute to binding.

Table 3: Effect on ErbB3 Binding of Ab #6 Mutations

H1	M1	Thr28Aal	no effect on binding
	M2	Ser30Ala	no effect on binding
	M3	His31Ala	no effect on binding
	M4	Tyr32Ala	large decrease in binding
	M5	Tyr32Phe	no effect on binding
	M6	Val33Ala	large decrease in binding
H2	M7	Ser52Ala	no effect on binding
	M8	Ser53Ala	no effect on binding
	M9	Ser54Ala	no effect on binding
	M10	Trp57Ala	large decrease in binding
	M11	Thr58Ala	no effect on binding
	M12	Leu59Ala	no effect on binding
H3	M13	Leu100Ala	no effect on binding
	M14	Lys101Ala	no effect on binding
	M15	Met102Ala	large decrease in binding
	M16	Thr104Ala	large decrease in binding
	M17	Ile105Ala	small decrease in binding
	M18	Asp107Ala	no effect on binding
L1	M19	Thr162Ala	no effect on binding
	M20	Ser163Ala	no effect on binding
	M21	Ser164Ala	no effect on binding
	M22	Asp165Ala	small decrease in binding
	M23	Ser168Ala	no effect on binding
	M24	Tyr169Ala	large decrease in binding
	M25	Tyr169Phe	no effect on binding
	M26	Asn170Ala	no effect on binding
	M27	Val171Ala	no effect on binding

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L2	M28	Glu189Ala	no effect on binding
	M29	Val190Ala	no effect on binding
	M30	Ser191Ala	no effect on binding
	M31	Gln192Ala	no effect on binding
	M32	Arg193Ala	no effect on binding

L3	M33	Ser229Ala	no effect on binding
	M34	Tyr230Ala	large decrease in binding
	M35	Tyr230Phe	no effect on binding
	M36	Ser233Ala	no effect on binding
	M37	Ser234Ala	no effect on binding
	M38	Ile235Ala	no effect on binding

Based on the results shown in Table 3, consensus sequences for each of the heavy and light chain CDRs were derived. These consensus sequences are shown in Figures 37A and 37B, below the wild type CDR sequences. The consensus sequences differ from the wild type CDR sequences in that those amino acid residues that are mutated to alanine and found not to substantially affect binding have been genericized to allow any amino acid (Xaa) at those positions. Additionally, for those amino acid positions containing an aromatic tyrosine residue in which mutation to aromatic phenylalanine did not affect binding, but mutation to alanine did affect binding, any of the aromatic amino acids tyrosine, histidine, tryptophan and phenylalanine are allowed at that position in the consensus sequences shown in Figure 37A, while in the consensus sequences shown in Figure 37B those amino acid positions are allowed to be either tyrosine or phenylalanine.

Furthermore, based on the results shown in Table 3, paratope sequences for each of the heavy and light chain CDRs were derived. These paratope sequences are shown in Figures 37A and 37B, below the wild type and consensus CDR sequences. The paratope sequences correspond to those amino acid residue positions within the CDRs that were shown to substantially decrease binding to ErbB3 when mutated to alanine, thereby suggesting a substantial role for these positions in antigen binding. Additionally, for those amino acid positions containing an aromatic tyrosine residue in which mutation to aromatic phenylalanine did not affect binding, but mutation to aliphatic alanine did affect binding, any of the aromatic amino acids tyrosine, histidine, tryptophan and phenylalanine in Figure 37A (or alternately tyrosine and phenylalanine in Figure 37B) are allowed at each such position in the paratope. The other amino acid positions within the CDRs that do not appear to be directly involved in antigen binding are allowed to be any amino acid residue (Xaa) within the paratope.

The wild-type heavy chain CDR1, CDR2 and CDR3 sequences for Ab #6 are also shown in SEQ ID NOs: 7, 8 and 9, respectively, and the wild type light chain CDR1, CDR2 and CDR3 sequences for Ab #6 are also shown in SEQ ID NOs: 10, 11 and 12, respectively. The consensus heavy chain CDR1, CDR2 and CDR3 sequences for Ab #6 are also shown in SEQ ID NOs: 60 and 75 (CDR1), 61 (CDR2) and 62 (CDR3), respectively, and the consensus light chain CDR1, CDR2 and CDR3 sequences for Ab #6 are also shown in SEQ ID NOs: 66 and 77 (CDR1), 67 (CDR2) and 68 and 79 (CDR3), respectively. The heavy chain CDR1, CDR2 and CDR3 paratope sequences for Ab #6 are also shown in SEQ ID NOs: 63 and 76 (CDR1), 64 (CDR2) and 65 (CDR3), respectively, and the light chain CDR1, CDR2 and CDR3 paratope sequences for Ab #6 are also shown in SEQ ID NOs: 69 and 77 (CDR1), 70 (CDR2) and 71 and 80 (CDR3), respectively.

Equivalents

Those skilled in the art will recognize, or be able to ascertain and implement using no more than routine experimentation, many equivalents of the specific embodiments of the invention described herein. Such equivalents are intended to be encompassed by the following claims. Any combination of the embodiments disclosed in the dependent claims are contemplated to be within the scope of the invention.

Incorporation by Reference

The disclosure of each and every US and foreign patent and pending patent application and publication referred to herein is hereby incorporated herein by reference in its entirety.

What is claimed is:

1. An isolated monoclonal antibody or antigen binding portion thereof that binds to Domain I of the ectodomain of human ErbB3 and comprises:

a heavy chain variable region comprising heavy chain CDR1, CDR2, and CDR3 sequences; and

a light chain variable region comprising light chain CDR1, CDR2, and CDR3 sequences, wherein:

the heavy chain CDR1 sequence comprises SEQ ID NO:60 or 75,

the heavy chain CDR2 sequence comprises SEQ ID NO:61,

the heavy chain CDR3 sequence comprises SEQ ID NO:62,

the light chain CDR1 sequence comprises SEQ ID NO:66 or 77,

the light chain CDR2 sequence comprises SEQ ID NO:67,

the light chain CDR3 sequence comprises SEQ ID NO:68 or 79,

with the proviso that the antibody is not: (i) Ab #6 as disclosed herein; (ii) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 1 and 2, respectively; or (iii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 7, 8 and 9, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 10, 11 and 12, respectively.

2. An isolated monoclonal antibody or antigen binding portion thereof which binds an epitope of human ErbB3 comprising residues 92-104 of SEQ ID NO: 73 and is characterized by inhibition of proliferation of a cancer cell expressing ErbB3, with the proviso that the antibody is not: (i) Ab #6 as disclosed herein; (ii) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 1 and 2, respectively; or (iii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 7, 8 and 9, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 10, 11 and 12, respectively.

3. An isolated monoclonal antibody or antigen binding portion thereof which binds an epitope of human ErbB3 comprising residues 92-104 of SEQ ID NO: 73 and is characterized by inhibition of proliferation of a cancer cell expressing ErbB3, with the proviso that the antibody is not: (i) Ab #6 as disclosed herein; (ii) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 1 and 2, respectively; (iii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID

NOs: 7, 8 and 9, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 10, 11 and 12, respectively; (iv) Ab #3 as disclosed herein; (v) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 3 and 4, respectively; (vi) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 13, 14 and 15, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 16, 17 and 18, respectively; (vii) Ab #17 as disclosed herein; (viii) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 35 and 36, respectively; (ix) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 39, 40 and 41, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 42, 43 and 44, respectively; (x) Ab #19 as disclosed herein; (xi) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 37 and 38, respectively; or (xii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 45, 46 and 47, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 48, 49 and 50, respectively.

4. An isolated monoclonal antibody or antigen binding portion thereof of claim 2 or 3, wherein the epitope further comprises residue 129 of SEQ ID NO: 73.

5. The isolated monoclonal antibody or antigen binding portion thereof of claim 2 or claim 3 or claim 4 in which the cancer cell is a MALME-3M cell, an AdrR cell, or an ACHN cell and the proliferation is reduced by at least 10% relative to control.

6. The isolated monoclonal antibody or antigen binding portion thereof of claim 1 or claim 2 or claim 3 or claim 4, wherein, when any one amino acid residue of human ErbB3 selected from residue 93 (asparagine), residue 101 (methionine), residue 102 (leucine) and residue 104 (tyrosine) of SEQ ID NO: 73 is replaced by an alanine to generate a mutant ErbB3 with a single amino acid substitution, there is a substantial reduction in binding of the antibody or antigen binding portion thereof to the mutant ErbB3 as compared to binding of the antibody or antigen binding portion thereof to human ErbB3 comprising the amino acid sequence of SEQ ID NO: 73.

7. The antibody or antigen binding portion thereof of claim 6, wherein the substantial reduction in binding is at least a ten-fold change in K_D value of binding.

8. An isolated monoclonal antibody or antigen binding portion thereof that binds to Domain I of the ectodomain of human ErbB3 and comprises,:

a heavy chain variable region comprising heavy chain CDR1, CDR2, and CDR3 sequences; and

a light chain variable region comprising light chain CDR1, CDR2, and CDR3 sequences, wherein:

the heavy chain CDR1 sequence comprises SEQ ID NO:63 or 76,

the heavy chain CDR2 sequence comprises SEQ ID NO:64,

the heavy chain CDR3 sequence comprises SEQ ID NO:65,

the light chain CDR1 sequence comprises SEQ ID NO:69 or 78,

the light chain CDR2 sequence comprises SEQ ID NO:70,

the light chain CDR3 sequence comprises SEQ ID NO:71 or 80,

with the proviso that the antibody is not: (i) Ab #6 as disclosed herein; (ii) an antibody comprising V_H and V_L sequences as shown in SEQ ID NOs: 1 and 2, respectively; or (iii) an antibody comprising V_H CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 7, 8 and 9, respectively, and V_L CDR1, CDR2 and CDR3 sequences as shown in SEQ ID NOs: 10, 11 and 12, respectively.

9. The antibody of any one of claims 1-8, wherein the antibody is a human antibody, a humanized antibody, a bispecific antibody, or a chimeric antibody.

10. The antigen binding portion of any one of claims 1-8 which is a portion of a human antibody, a humanized antibody, or a chimeric antibody.

11. The antibody or antigen binding portion thereof of claim any one of claims 1-8, wherein the antibody or antigen binding portion thereof is selected from the group consisting of a Fab, Fab'2, scFv, SMIP, affibody, avimer, nanobody, and a domain antibody.

12. The antibody of any one of claims 1-8, wherein the antibody is of an isotype is selected from the group consisting of an IgG1, an IgG2, an IgG3, an IgG4, an IgM, an IgA1, an IgA2, an IgAsec, an IgD, and an IgE.

13. A composition comprising the antibody or antigen binding portion thereof of any one of claims 1-12 in a pharmaceutically acceptable carrier.

14. A method of treating a cancer in a subject, comprising administering to the subject a therapeutically effective amount of the composition of claim 13.

15. The method of claim 14, wherein the cancer comprises cells comprising either or both of a KRAS mutation or a PI3K mutation.

16. The method of claim 14, wherein the subject is human and the KRAS mutation comprises a mutation of codon 12 or codon 13 of a human KRAS gene.

17. The method of claim 14, wherein the subject is human and the PI3K mutation comprises a mutation within exon 9 or exon 20 of a human PIK3CA gene.

18. A method of treating a cancer in a subject comprising administering to the subject a therapeutically effective amount of a first agent which is the monoclonal antibody or antigen binding portion thereof of any one of claims 1-12, in combination with a therapeutically effective amount of a second agent, which is an anti-cancer agent other than the first agent.

19. The method of claim 18 wherein the second agent comprises an antibody or antigen binding portion thereof.

20. The method of claim 18 wherein the second agent is a selected from: a protein synthesis inhibitor, a somatostatin analogue, an immunotherapeutic agent, and an enzyme inhibitor.

21. The method of claim 18 wherein the second agent is a selected from: a small molecule targeting IGF1R, a small molecule targeting EGFR, a small molecule targeting ErbB2, a small molecule targeting cMET, an antimetabolite, an alkylating agent, a topoisomerase inhibitor, a microtubule targeting agent, a kinase inhibitor, a hormonal therapy, a glucocorticoid, an aromatase inhibitor, an mTOR inhibitor, a chemotherapeutic agent, a protein kinase B inhibitor, a phosphatidylinositol 3-kinase inhibitor, a cyclin dependent kinase inhibitor, and an MEK inhibitor,

22. The method of claim 19 wherein the second agent is panitumumab, trastuzumab or cetuximab.

23. The method of claim 21 wherein the second agent is paclitaxel.

24. The method of claim 21 wherein the second agent is cisplatin.

25. The method of claim 21 wherein the second agent is erlotinib or lapatinib.