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(54) Title: ANTIBODIES AGAINST EPIDERMAL GROWTH FACTOR RECEPTOR (EGFR) AND USES THEREOF

(57) Abstract: Anti- EGFR antibodies, therapeutic compositions comprising combinations of anti-EGFR antibodies, as well as methods for using such antibodies and compositions to treat EGFR-related disorders (e.g., cancers), are disclosed.

## ANTIBODIES AGAINST EPIDERMAL GROWTH FACTOR RECEPTOR (EGFR) AND USES THEREOF

### Cross-Reference to Related Applications

5           This application claims the benefit of priority of U.S. Provisional Application No. 61/504633 (filed July 5, 2011) and U.S. Provisional Application No. 61/558945 (filed November 11, 2011), both of which are incorporated herein by reference.

### Background

10           The natural immune system has evolved to make antibodies for efficient neutralization of pathogens. Natural antibody preparations isolated from immunized animals are polyclonal in origin, and exhibit immunodominance as compared to individual antibodies, which are restricted to one or a few epitopes of a particular antigen. Anti-tumor antibodies are able to block growth or kill tumor cells to which they  
15 bind have been developed as highly effective cancer therapeutic agents. Mixtures of anti-tumor antibodies may achieve tumor suppressive effects that are greater than achieved by any individual antibody in the mixture

          Such results have been achieved by combining two or more neutralizing antibodies against the epidermal growth factor receptor, EGFR (ErbB1). Antibodies that  
20 bind to and inhibit EGFR have proven to provide useful anti-cancer benefits and are of great medical and commercial value. Particular combinations of pairs of antagonistic, yet non-competitive, anti-EGFR antibodies resulted in downregulation of EGFR which was faster and more effective than application of either antibody alone (Friedman *et al.* (2005) PNAS 102:1915-1920). The combination of two cross-competitive (*i.e.*,  
25 competitive with each other for binding to antigen) anti-EGFR antibodies has shown to be non-synergistic. It is possible that binding of a plurality of antibodies to distinct epitopes of EGFR forms lattices of complexed receptors on cell surfaces, leading to more efficient internalization and degradation than obtained with antibodies targeting a single epitope. The combination of a particular pair of anti-EGFR receptor antibodies  
30 have also been reported to result in additive and in some cases synergistic, antitumor activity *in vivo* (Perera *et al.* (2005) Clin Cancer Res 11:6390-6399). Monoclonal antibody 806, raised against the mutant de2-7 EGFR, combined with antagonistic antibody 528 displayed significantly higher anti-tumor activity in a glioma xenograft model than treatment with either antibody alone. The mechanism of the synergistic anti-

tumor activity was shown to be associated with rapid downregulation of EGFR, which was not induced by treatment with the individual antibodies. Similarly EGFR phosphorylation was greatly reduced in the presence of another pair of anti-EGFR antibodies, cetuximab and EMD55900 (Kamat *et al.* (2008) *Cancer Biol Ther* 7:726-33).

5           Certain combinations of antibodies targeting the related receptor, ErbB2, have also been shown to function in synergy (Friedman *et al.* (2005). Trastuzumab combined with pertuzumab inhibited the survival of BT474 breast cancer cells at doses in which individual antibodies are ineffective (Nahta *et al.* (2004) *Cancer Res* 64:2343-2346). In another study three non-competitive anti-ErbB2 antibodies demonstrated far more  
10 effective *in vitro* killing of BT474 cells in combination than individually and similar results were obtained in a BT474 *in vivo* xenograft model (Spiridon *et al.* (2002) *Clin Cancer Res* 8:1699-701).

Other evidence that combining more than one antibody may enhance the growth suppressive (*e.g.*, cytotoxic) effect of antibodies on tumor cells has been reported. For  
15 example, monoclonal antibodies to the tumor antigen 17-1A were combined, tumor cell lysis was studied, and it was found that monoclonal antibodies, as well as combinations of competing antibodies, were ineffective, whereas combinations of two or more non-competing antibodies resulted in complete tumor cell lysis.

In addition to combining antibodies, higher antibody potency has also been  
20 achieved by increasing the antigen affinity of recombinantly expressed anti-tumor antibodies through recombinant DNA techniques known as affinity maturation.

Accordingly, additional approaches and methods for producing anti-tumor antibody action so as to enhance the responsiveness of tumors to anti-EGFR antibodies and antibody combinations are still needed, including anti-EGFR antibodies with higher  
25 tumor affinity and combinations of such high-affinity anti-EGFR antibodies that enhance signaling inhibition and provide more effective cytostatic or cytotoxic anti-tumor outcomes.

### **Summary**

Novel monoclonal antibodies that bind to EGFR and inhibit various EGFR  
30 functions are provided herein. These antibodies provide useful therapeutic effects, and when combined with each other or with other anti-ErbB receptor antibodies (*e.g.*, other anti-EGFR antibodies), are capable of exhibiting a synergistic or additive therapeutic effect compared to the administration of each antibody alone. These antibodies, when

administered individually or in combinations as herein provided, are useful for treating a variety of disorders (*e.g.*, cancers) associated with EGFR-mediated cellular signaling. Accordingly, isolated novel monoclonal antibodies that exhibit the properties of binding to EGFR and inhibiting various EGFR functions, and combinations of such antibodies  
5 that exhibit such properties are also provided herein. Uses of these antibodies for diagnostic and therapeutic purposes are also provided, as are uses of the antibodies and antibody combinations herein disclosed.

In one embodiment, a monoclonal antibody is provided which binds EGFR extracellular domain and comprises heavy and light chain CDR1, CDR2, and CDR3,  
10 sequences, wherein the heavy and light chain CDR1, CDR2, and CDR3, sequences are selected from the group consisting of:

- (a) heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 1, 2, and 3 respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 4, 5, and 6, respectively;
- 15 (b) heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 7, 8, and 9, respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 10, 11 and 12, respectively; and
- (c) heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 13, 14, and 15, respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID  
20 NOs: 16, 17, and 18, respectively.

In another embodiment, a monoclonal antibody is provided that binds to EGFR extracellular domain and comprises a heavy chain variable region and a light chain variable region, wherein the heavy and light chain variable region sequences are selected from the group consisting of:

- 25 (a) a heavy chain variable region comprising SEQ ID NO: 19 and a light chain variable region comprising SEQ ID NO: 20;
- (b) a heavy chain variable region comprising SEQ ID NO: 21 and a light chain variable region comprising SEQ ID NO: 22; and
- (c) a heavy chain variable region comprising SEQ ID NO: 23 and a light chain  
30 variable region comprising SEQ ID NO: 24.

The aforementioned monoclonal antibodies can bind to EGFR with a  $K_D$  of, for example, better than 100 nM, or better than 10 nM, or better than 1 nM, or better than 100 pM, or better than 10 pM, or better than 1 pM. The monoclonal antibodies can

exhibit one or more of the functional properties disclosed herein. The monoclonal antibody can be, for example, a human antibody. In other embodiments, the antibody can be a bispecific antibody, immunoconjugate, Fab, Fab'2, ScFv, affibody®, avimer, nanobody or a domain antibody. In other embodiments, the monoclonal antibody can be, e.g., an IgG1, IgG2, IgG3, IgG4, IgM, IgA1, IgA2, IgAsec, IgD, or IgE isotype antibody.

Also provided are pharmaceutical compositions comprising any one or more of the aforementioned anti-EGFR monoclonal antibodies and a pharmaceutically acceptable carrier. Kits are also provided. The kit can comprise, for example, a pharmaceutical composition in a container. Methods of treating cancer in a subject, comprising administering to the subject an effective amount of the pharmaceutical composition comprising any one or more of the aforementioned anti-EGFR monoclonal antibodies are also provided. The aforementioned anti-EGFR monoclonal antibodies or combinations thereof for the the treatment of a cancer (or for manufacture of a medicament for the treatment of a cancer) are also provided.

In another embodiment, a composition comprising two or three monoclonal antibodies which bind to EGFR extracellular domain is provided, wherein the two or three monoclonal antibodies are selected from the group consisting of:

(a) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 1, 2, and 3 respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 4, 5, and 6, respectively;

(b) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 7, 8, and 9, respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 10, 11 and 12, respectively and

(c) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 13, 14, and 15, respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 16, 17 and 18, respectively;

and wherein the composition comprises (a) and (b), (a) and (c), (b) and (c) or (a), (b) and (c).

In yet another embodiment, a composition comprising two or three monoclonal antibodies which bind to EGFR extracellular domain is provided, wherein the two or three monoclonal antibodies are selected from the group consisting of:

(a) a monoclonal antibody comprising a heavy chain variable region comprising SEQ ID NO: 19 and a light chain variable region comprising SEQ ID NO: 20;

(b) a monoclonal antibody comprising a heavy chain variable region comprising SEQ ID NO: 21 and a light chain variable region comprising SEQ ID NO: 22; and

5 (c) a monoclonal antibody comprising a heavy chain variable region comprising SEQ ID NO: 23 and a light chain variable region comprising SEQ ID NO: 24; and wherein the composition comprises (a) and (b), (a) and (c), (b) and (c) or (a) (b) and (c).

Each of monoclonal antibodies (a), (b) and (c) in the aforementioned  
10 compositions comprising two or three antibodies can bind to EGFR with a  $K_D$  of, for example, better than 100 nM, or better than 10 nM or better than 1 nM. Each of monoclonal antibodies (a), (b) and (c) can exhibit one or more of the functional properties disclosed herein. Each of monoclonal antibodies (a), (b) and (c) can be, for example, a human antibody. In other embodiments, one or more of monoclonal  
15 antibodies (a), (b), and (c) is independently selected from the group consisting of a bispecific antibody, immunoconjugate, Fab, Fab'2, ScFv, affibody®, avimer, nanobody, and a domain antibody. In other embodiments, each of monoclonal antibodies (a), (b), and (c) is independently selected from the group consisting of IgG1, IgG2, IgG3, IgG4, IgM, IgA1, IgA2, IgAsec, IgD and IgE isotype antibodies. Monoclonal antibodies (a),  
20 (b) and (c) may also be in the form of IgY and camelid antibodies .

Also provided is a pharmaceutical composition comprising any one of the aforementioned compositions comprising two or three anti-EGFR monoclonal antibodies and a pharmaceutically acceptable carrier. Kits are also provided. The kit can comprise, for example, a pharmaceutical composition in a container. Methods of  
25 treating cancer in a subject, comprising administering to the subject an effective amount of the pharmaceutical composition comprising any one of the aforementioned compositions comprising two or three anti-EGFR monoclonal antibodies are also provided. The aforementioned compositions comprising two or three anti-anti-EGFR monoclonal antibodies (and their use for the manufacture of a medicament) for the  
30 treatment of a cancer are also provided.

In another embodiment, a composition is provided comprising three monoclonal anti-EGFR antibodies, said composition comprising a first antibody, a second antibody and a third antibody, wherein (i) the first antibody comprises heavy chain CDR1, CDR2,

and CDR3 sequences of SEQ ID NOs: 1, 2, and 3 respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 4, 5, and 6, respectively; (ii) the second antibody comprises heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 7, 8, and 9, respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 10, 11 and 12, respectively; and (iii) the third antibody comprises heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 13, 14, and 15 respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 16, 17, and 18, respectively, and wherein the first second and third antibodies are present at a molar ratio of 2:2:1 to each other.

10 In yet another embodiment, a composition is provided comprising three monoclonal anti-EGFR antibodies, said composition comprising a first antibody, a second antibody and a third antibody, wherein (i) the first antibody comprises a heavy chain variable region comprising SEQ ID NO: 19 and a light chain variable region comprising SEQ ID NO: 20; (ii) the second antibody comprises a heavy chain variable region comprising SEQ ID NO: 21 and a light chain variable region comprising SEQ ID NO: 22; and (iii) the third antibody comprises a heavy chain variable region comprising SEQ ID NO: 23 and a light chain variable region comprising SEQ ID NO: 24, and wherein the first second and third antibodies are present at a molar ratio of 2:2:1 to each other.

20 Each of the first, second and third antibodies in the aforementioned compositions can bind to EGFR with a  $K_D$  of, for example, better than 100 nM, or better than 10 nM or better than 1 nM. In another embodiment, the first antibody binds to EGFR with a  $K_D$  in a range of  $1 \times 10^{-9}$  M to  $1.1 \times 10^{-11}$  M, the second antibody binds to EGFR with a  $K_D$  in a range of  $1 \times 10^{-9}$  M to  $7.0 \times 10^{-11}$  M and the third antibody binds to EGFR with a  $K_D$  in a range of  $1 \times 10^{-9}$  M to  $3.6 \times 10^{-10}$  M. Each of the first, second and third antibodies in the aforementioned compositions can exhibit one or more of the functional properties disclosed herein. Each of the first, second and third antibodies in the aforementioned compositions can be, for example, a human antibody. In other embodiments, one or more of the first antibody, the second antibody and the third antibody is independently selected from the group consisting of a bispecific antibody, immunoconjugate, Fab, Fab'2, ScFv, affibody, avimer, nanobody, and a domain antibody. In other  
30 embodiments, each of the first antibody, the second antibody and the third antibody is

independently selected from the group consisting of IgG1, IgG2, IgG3, IgG4, IgM, IgA1, IgA2, IgAsec, IgD and IgE isotype antibodies.

Also provided are pharmaceutical compositions comprising any one of the aforementioned anti-EGFR compositions comprising a first antibody, a second antibody  
5 and a third antibody at a 2:2:1 ratio, and a pharmaceutically acceptable carrier. In one embodiment, the pharmaceutical composition is a sterile composition. In another embodiment, the pharmaceutical composition is suitable for injection. In yet another embodiment, the pharmaceutical composition is a sterile composition suitable for intravenous injection. Kits are also provided. The kit can comprise, for example, a  
10 pharmaceutical composition in a container. Methods of treating cancer in a subject, comprising administering to the subject an effective amount of the pharmaceutical composition comprising any one of the aforementioned anti-EGFR compositions comprising first, second and third antibodies at a 2:2:1 ratio are also provided. Use of  
15 antibodies at a 2:2:1 ratio for the manufacture of a medicament for the treatment of a cancer are also provided.

In another embodiment, a method of preparing an anti-EGFR antibody composition is provided, the method comprising combining in a single composition:

(a) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3  
20 sequences of SEQ ID NOs: 1, 2, and 3 respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 4, 5, and 6, respectively;

(b) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 7, 8, and 9, respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 10, 11 and 12, respectively; and

25 (c) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 13, 14, and 15 respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 16, 17, and 18, respectively;

wherein (a), (b) and (c) are combined at a molar ratio of 2:2:1 to each other.

In another embodiment, a method of preparing an anti-EGFR antibody  
30 composition is provided, the method comprising combining in a single composition:

(a) a monoclonal antibody comprising a heavy chain variable region comprising SEQ ID NO: 19 and a light chain variable region comprising SEQ ID NO:20;

(b) a monoclonal antibody comprising a heavy chain variable region comprising SEQ ID NO: 21 and a light chain variable region comprising SEQ ID NO: 22; and

(c) a monoclonal antibody comprising a heavy chain variable region comprising SEQ ID NO: 23 and a light chain variable region comprising SEQ ID NO: 24;

5 wherein (a), (b) and (c) are combined at a molar ratio of 2:2:1 to each other.

In another embodiment, a method of treating a subject with anti-EGFR antibodies is provided, the method comprising administering to the subject:

(a) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 1, 2, and 3 respectively, and light chain CDR1, CDR2, and  
10 CDR3 sequences of SEQ ID NOs: 4, 5, and 6, respectively;

(b) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 7, 8, and 9, respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 10, 11 and 12, respectively; and

(c) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3  
15 sequences of SEQ ID NOs: 13, 14, and 15 respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 16, 17, and 18, respectively;

wherein (a), (b) and (c) are administered to the subject at a molar ratio of 2:2:1 to each other.

In another embodiment, a method of treating a subject with anti-EGFR  
20 antibodies is provided, the method comprising administering to the subject:

(a) a monoclonal antibody comprising a heavy chain variable region comprising SEQ ID NO: 19 and a light chain variable region comprising SEQ ID NO:20;

(b) a monoclonal antibody comprising a heavy chain variable region comprising SEQ ID NO: 21 and a light chain variable region comprising SEQ ID NO: 22; and

25 (c) a monoclonal antibody comprising a heavy chain variable region comprising SEQ ID NO: 23 and a light chain variable region comprising SEQ ID NO: 24;

wherein (a), (b) and (c) are administered to the subject at a molar ratio of 2:2:1 to each other.

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

### **Brief Description of the Figures**

Figure 1A is a bar graph showing the results of a direct ELISA epitope binning experiment with the P1X, P2X and P3X antibodies using wild-type EGFR-ECD antigen (WT), a Bin 1 epitope mutant (Bin 1 MT) and a Bin 3 epitope mutant (Bin 3 MT).

Figure 1B is a graph showing the results of a surface plasmon resonance epitope binning experiment using the ICR10 epitope (Bin 2) conjugated on a Biacore chip, with injection of wild-type EGFR-ECD antigen, followed by sequential injection of the P1X, P2X and P3X antibodies.

Figure 2A is a graph showing the results of a surface plasmon resonance epitope binning experiment using the P1X antibody conjugated on a Biacore chip, with injection of wild-type EGFR-ECD antigen, followed by sequential injection of the P3X, P2X and P1X antibodies.

Figure 2B is a graph showing the results of a surface plasmon resonance epitope binning experiment using the P2X antibody conjugated on a Biacore chip, with injection of wild-type EGFR-ECD antigen, followed by sequential injection of the P3X, P2X and P1X antibodies.

Figure 2C is a graph showing the results of a surface plasmon resonance epitope binning experiment using the P3X antibody conjugated on a Biacore chip, with injection of wild-type EGFR-ECD antigen, followed by sequential injection of the P3X, P2X and P1X antibodies.

Figure 3 is a graph showing the results of P1X, P2X and P3X antibody binding kinetics to EGFR on A431 cells as measured via flow cytometry (FACS plot).

Figure 4 is a graph showing the results of a phospho-EGFR (pEGFR) ELISA, demonstrating pEGFR inhibition by single antibodies: single-agent treatment with P1X, P2X or P3X antibody.

Figure 5A is a graph showing the results of a phospho-ERK (pERK) ELISA, demonstrating the effect of affinity maturation on pERK inhibition by comparison of pERK inhibition by parental (ca antibody) and affinity matured P1X antibody.

Figure 5B is a graph showing the results of a phospho-ERK (pERK) ELISA, comparing pERK inhibition by parental (ca and ch antibodies) and affinity matured P1X+P3X antibodies.

Figure 5C is a graph showing the results of a phospho-ERK (pERK) ELISA, comparing pERK inhibition by parental (ca and cd antibodies) and affinity matured P1X+P2X antibodies.

Figure 6A is a graph showing the results of a phospho-ERK (pERK) ELISA, demonstrating pERK inhibition by P1X antibody, with an IC<sub>50</sub> value of approximately 25 nM.

Figure 6B is a graph showing the results of a phospho-ERK (pERK) ELISA for  
5 A431 cells treated with a dilution series of 5 combination ratios of P3X + P2X in combination with a constant P1X concentration of 25nM.

Figure 6C is a graph showing the results of a phospho-ERK (pERK) ELISA for A431 cells treated with a dilution series of 6 combination ratios of P1X:P2X:P3X.

Figure 6D is a graph showing the results of a phospho-ERK (pERK) ELISA for  
10 A431 cells treated with a dilution series of 5 combination ratios of P1X:P2X.

Figure 7A is a graph showing the results of a phospho-EGFR (pEGFR) ELISA (circles) and a phospho-ERK (pERK) ELISA (triangles), demonstrating inhibition by a 2:2:1 combination of P1X:P2X:P3X.

Figure 7B is a graph showing the results of a phospho-ERK (pERK) ELISA,  
15 demonstrating inhibition by a 2:2:1 formulation of P1X:P2X:P3X (P1X+P2X+P3X) versus P1X single antibody alone.

Figure 7C is a graph showing the results of a phospho-ERK (pERK) ELISA, demonstrating inhibition by P1X+P2X+P3X versus P2X single antibody alone.

Figure 8A is a bar graph showing western blot analysis results for total EGFR  
20 (tEGFR) internalization kinetics of H1975 cells pre-treated with P1X+P2X+P3X antibodies for various periods of time before stimulation with EGF.

Figure 8B is a bar graph showing western blot analysis results for H1975 cells pre-treated with P1X+P2X+P3X antibodies before stimulation with EGF, showing levels of tEGFR, pERK, phospho-AKT (pAKT) and phospho-c-Jun (p-c-Jun) in the cells,  
25 normalized to the loading control (PCNA) and to lysates of control untreated cells.

Figure 9A is a graph showing the results of a cell viability assay for HCC827 cells, demonstrating inhibition of tumor cell proliferation by treatment with P1X+P2X+P3X antibodies, as compared to cetuximab, in the presence of EGF ligand.

Figure 9B is a graph showing the results of a cell viability assay for H1975 cells,  
30 demonstrating inhibition of tumor cell proliferation by treatment with P1X+P2X+P3X antibodies, as compared to cetuximab, in the presence of EGF ligand.

Figure 9C is a graph showing the results of a cell viability assay for HCC827 cells, demonstrating inhibition of tumor cell proliferation by treatment with

P1X+P2X+P3X antibodies, as compared to cetuximab, in the presence of amphiregulin (AREG) ligand.

Figure 9D is a graph showing the results of a cell viability assay for H1975 cells, demonstrating inhibition of tumor cell proliferation by treatment with P1X+P2X+P3X antibodies, as compared to cetuximab, in the presence of AREG ligand.

Figure 10A is a graph showing the results of a DU145 tumor xenograft mouse model experiment, demonstrating decreased tumor volume *in vivo* in mice treated with P1X+P2X+P3X antibodies, as compared to PBS and cetuximab controls.

Figure 10B is a graph showing the results of an H1975 tumor xenograft mouse model experiment, demonstrating decreased tumor volume *in vivo* in mice treated with P1X+P2X+P3X antibodies, as compared to PBS control.

Figure 11 is a graph showing the results of a ligand antagonism cell binding assay, demonstrating the EGF ligand blocking ability of P1X, P2X or P3X alone at low doses.

Figure 12A is a graph showing the results of a ligand antagonism cell binding assay, demonstrating the EGF ligand blocking ability of P1X, P2X or P3X alone, or in triple combination, at high doses.

Figure 12B is a graph showing the results of a ligand antagonism cell binding assay, demonstrating the EGF ligand blocking ability of P1X Fab, P2X Fab or P3X Fab alone, or in triple combination, at high doses.

Figure 13A is a graph showing the results of a phospho-EGFR inhibition assay, demonstrating the inhibitory ability of triple combinations of P1X+P2X+P3X or P1X Fab+P2X Fab+P3X Fab at low doses (50 ng/ml; 8 nM).

Figure 13B is a graph showing the results of a phospho-EGFR inhibition assay, demonstrating the inhibitory ability of triple combinations of P1X+P2X+P3X or P1X Fab+P2X Fab+P3X Fab at high doses (500 ng/ml; 80 nM).

Figure 13C is a graph showing the results of a phospho-ERK inhibition assay, demonstrating the inhibitory ability of triple combinations of P1X+P2X+P3X or P1X Fab+P2X Fab+P3X Fab at low doses (50 ng/ml; 8 nM).

Figure 13D is a graph showing the results of a phospho-ERK inhibition assay, demonstrating the inhibitory ability of triple combinations of P1X+P2X+P3X or P1X Fab+P2X Fab+P3X Fab at high doses (500 ng/ml; 80 nM).

Figure 14 is an immunoblot of an EGF-receptor downregulation assay in cells pre-treated with triple combinations of P1X+P2X+P3X or P1X Fab+P2X Fab+P3X Fab or with cetuximab. The housekeeping protein pcna was used as a control.

## 5 **Detailed Description**

### I. **Definitions**

The terms “EGFR,” “ErbB1,” and “EGF receptor” are used interchangeably herein to refer to human EGFR protein; see UniProtKB/Swiss-Prot entry P00533. The amino acid sequence of the extracellular domain of human EGFR (EGFR-ECD) is  
10 shown in Example 1 and in SEQ ID NO:33.

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 statistically significant decrease of about 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, or about 100% in biological activity.

15 Inhibition of phosphorylation, as used herein, refers to the ability of an antibody to statistically significantly decrease the phosphorylation of a substrate protein relative to the signaling in the absence of the antibody (control). As is known in the art, intracellular signaling pathways include, for example, phosphoinositide 3'-kinase/Akt (PI3K/Akt/*PTEN* or “AKT”) and/or mitogen-activated protein kinase (MAPK/ERK or  
20 “ERK”) pathways. As is also known in the art, EGFR mediated signaling can be measured by assaying for the level phosphorylation of the substrate (*e.g.*, phosphorylation or no phosphorylation of AKT and/or ERK). Accordingly, in one embodiment, anti-EGFR antibody combinations and compositions provide statistically significant inhibition of the level of phosphorylation of either or both of AKT and ERK  
25 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% relative to the level of phosphorylation of AKT and/or ERK in the absence of such antibody (control). Such EGFR mediated signaling can be measured using art recognized techniques which measure a protein in a cellular cascade involving EGFR, *e.g.*, ELISA, western, or  
30 multiplex methods, such as Luminex®.

The phrase “inhibition of the growth of cells expressing EGFR,” as used herein, refers to the ability of an antibody to statistically significantly decrease the growth of a cell expressing EGFR relative to the growth of the cell in the absence of the antibody

(control) either *in vivo* or *in vitro*. In one embodiment, the growth of a cell expressing EGFR (*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 about 100% when the cells are contacted with an antibody composition of combination disclosed herein, relative to the growth measured in the absence of the antibody composition of combination (control). Cellular growth can be assayed using art recognized techniques which measure the rate of cell division, the fraction of cells within a cell population undergoing cell division, and/or the rate of cell loss from a cell population due to terminal differentiation or cell death (*e.g.*, using a cell titer glow assay or thymidine incorporation).

The phrase “inhibition of an EGFR ligand binding to EGFR,” as used herein, refers to the ability of an antibody to statistically significantly decrease the binding of an EGFR ligand to its receptor, EGFR, relative to the EGFR ligand binding in the absence of the antibody (control). This means that, in the presence of the antibody, the amount of the EGFR ligand that binds to EGFR relative to a control (no antibody), is statistically significantly decreased. The amount of an EGFR ligand which binds EGFR may be decreased in the presence of an antibody composition or combination disclosed herein 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% relative to the amount in the absence of the antibody (control). A decrease in EGFR ligand binding can be measured using art-recognized techniques that measure the level of binding of labeled EGFR ligand (*e.g.*, radiolabelled EGF or radiolabeled betacellulin) to cells expressing EGFR in the presence or absence (control) of the antibody.

The phrase “inhibition of EGFR dimerization,” as used herein, refers to the ability of an antibody to statistically significantly decrease EGFR dimerization (pairing with another ErbB receptor to form homodimers, *e.g.*, ErbB1 / ErbB1 pairings, or heterodimers, *e.g.*, ErbB1 / ErbB3 pairings) relative to EGFR dimerization in the absence of the antibody (control). In one embodiment, dimerization of EGFR 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 about 100% when cells expressing EGFR are contacted with an antibody composition or combination disclosed herein, relative to dimerization of EGFR measured in the absence of the antibody (control). A decrease in EGFR dimerization can be measured using art-

recognized techniques that measure the level of EGFR dimerization in the presence or absence (control) of the antibody.

The phrase “downregulation of EGFR expression,” as used herein, refers to the ability of an antibody to statistically significantly decrease the expression of EGFR on a cell surface, for example, by increasing internalization of EGFR and/or by decreasing recycling of EGFR from intracellular vesicles relative to EGFR expression in the absence of the antibody (control). In one embodiment, expression of EGFR 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 about 100% when cells expressing EGFR are contacted with an antibody composition of combination provided herein, relative to expression of EGFR on the cell surface measured in the absence of the antibody (control). Downregulation of EGFR expression on a cell surface includes, for example, an increase in internalization / recycling of the receptor, and/or an increase in internalization / degradation of the receptor. An increase in EGFR internalization can be measured using art-recognized techniques that measure the level of EGFR internalization in the presence or absence (control) of the antibody.

With respect to combinations of EGFR antibodies (described herein), the words “additive” or “additivity,” as used herein, refer to the activity of two or more antibodies wherein their combined activity (relative to a particular function, *e.g.*, inhibition of cell growth) is equal to the sum of their individual activities. That is, the sum of the activities of two or more antibodies provided herein, when acting individually on a cell expressing EGFR, is approximately equivalent to the combined effect of the same antibodies acting together on the same cell. In one embodiment, the additive effect is measured with respect to any of the properties discussed above (*e.g.*, inhibition of AKT or ERK phosphorylation, inhibition of the growth of cells expressing EGFR, *etc.*).

The words “synergy” or “synergistic,” as used herein, refer to the activity of two or more antibodies wherein their combined activity (relative to a particular function, *e.g.*, inhibition of cell growth) is greater than the expected additive effect of their individual activities. For example, the expected additive effect can be defined according to Bliss independence criteria. In accordance with the Bliss criteria, the effect of two or more drugs (*e.g.*, antibodies) is equal to the sum of the effects of the individual drugs minus the multiplication of the effects of the individual drugs:

$$E_{12} = E_1 + E_2 - E_1 * E_2$$

where  $E_1$  is the % inhibition by drug 1,  $E_2$  is the % inhibition by drug 2, and  $E_{12}$  is the expected % inhibition by the combination.

5           The synergistic effect can apply to any of the properties discussed herein (*e.g.*, inhibition of EGFR-dependant AKT or ERK phosphorylation, inhibition of the growth of cells expressing EGFR, *etc.*). In a particular embodiment, 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 greater increase in activity of the combined antibodies  
10 relative to the additive effect of their individual activities is achieved.

          The term “antibody” or “immunoglobulin,” as used interchangeably herein, includes whole antibodies and any antigen binding fragment (antigen-binding portion) or single chain cognates thereof. An “antibody” comprises at least one heavy (H) chain and one light (L) chain. In naturally occurring IgGs, for example, these heavy and light  
15 chains are inter-connected by disulfide bonds and there are two paired heavy and light chains, these two also 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  
20 (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) or Joining (J) regions (JH or JL in heavy and light chains respectively).  
25 Each  $V_H$  and  $V_L$  is composed of three CDRs three FRs and a J domain, arranged from amino-terminus to carboxy-terminus in the following order: FR1, CDR1, FR2, CDR2, FR3, CDR3, J. The variable regions of the heavy and light chains bind 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  
30 cells) or humoral factors such as the first component (C1q) of the classical complement system. Thus one or more fragments of an antibody that retain the ability to specifically bind to an antigen (*e.g.*, EGFR) may be used in the combinations disclosed herein. It has been shown that fragments of a full-length antibody can perform the antigen-binding function of an antibody. Examples of binding fragments denoted as an antigen-binding

portion or fragment of an antibody include (i) a Fab fragment, a monovalent fragment consisting of the V<sub>L</sub>, V<sub>H</sub>, CL and CH1 domains; (ii) a F(ab')<sub>2</sub> 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<sub>H</sub> and CH1 domains; (iv) a Fv fragment consisting of the V<sub>L</sub> and V<sub>H</sub> domains of a single arm of an antibody, (v) a dAb including V<sub>H</sub> and VL domains; (vi) a dAb fragment (Ward *et al.* (1989) *Nature* 341, 544-546), which consists of a V<sub>H</sub> domain; (vii) a dAb which consists of a V<sub>H</sub> or a V<sub>L</sub> 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<sub>L</sub> and V<sub>H</sub>, 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<sub>L</sub> and V<sub>H</sub> regions are paired to form monovalent molecules (such a single chain cognate of an immunoglobulin fragment is known as a single chain Fv (scFv)). Such single chain antibodies are also intended to be encompassed within the term “antibody”. 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 general 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 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. Antigen binding fragments (including scFvs) of such immunoglobulins are also encompassed by the term “monoclonal antibody” as used herein. 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 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, a transgenic animal, 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, US Patent No. 7,388,088 and US patent application Ser. No. 09/856,907 (PCT

Int. Pub. No. WO 00/31246). Monoclonal antibodies include chimeric antibodies, human antibodies and humanized antibodies and may occur naturally or be produced recombinantly.

The term “recombinant antibody,” refers to antibodies that are prepared,  
5 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  
10 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  
15 embodiments, however, such recombinant human antibodies can be subjected to *in vitro* mutagenesis and thus the amino acid sequences of the V<sub>H</sub> and V<sub>L</sub> regions of the recombinant antibodies are sequences that, while derived from and related to human germline V<sub>H</sub> and V<sub>L</sub> sequences, may not naturally exist within the human antibody germline repertoire *in vivo*.

20 The term “chimeric immunoglobulin” or 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.

25 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).  
30 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.

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

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

20           "Isolated," as used herein, is intended to refer to an antibody or combination of two, three or four antibodies that is substantially free of other antibodies having different antigenic specificities (*e.g.*, an isolated composition of antibodies ca, cf, and ch, each of which specifically bind to EGFR, is substantially free of antibodies that specifically bind antigens other than EGFR). In addition, an isolated antibody is typically substantially  
25 free of other cellular material and/or chemicals. In one embodiment, a combination of "isolated" monoclonal antibodies having different EGFR binding specificities are combined in a well-defined composition.

          As used herein, "isotype" refers to the antibody class (*e.g.*, IgM or IgG1) that is encoded by heavy chain constant region genes. In some embodiments, a monoclonal  
30 antibody composition provided herein comprises only antibodies of the IgG1 isotype. In other embodiments, a monoclonal antibody composition provided herein comprises only antibodies of the IgG2 isotype. In other embodiments, a monoclonal antibody composition provided herein comprises antibodies of two or three different isotypes.

An “antigen” is an entity (*e.g.*, a proteinaceous entity or peptide) to which an antibody binds. In various embodiments, an antigen is EGF. In a particular embodiment, an antigen is human EGFR.

Accordingly, also encompassed by the present disclosure are combinations of  
5 antibodies that bind to epitopes on EGFR which comprise all or a portion of the epitopes recognized by the particular antibodies of the combinations described herein. In another embodiment, the antibodies are provided that compete for binding to EGFR with the antibodies described herein. Competing antibodies and antibodies that recognize the same or an overlapping epitope can be identified using routine techniques such as an  
10 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 may be determined using an assay such as described in the Examples below.

The terms “specific binding,” “specifically binds,” “selective binding,” and “selectively binds,” mean that an antibody exhibits appreciable affinity for a particular  
15 antigen or epitope and, generally, does not exhibit significant cross-reactivity with other antigens and epitopes. “Appreciable” or preferred binding includes binding with a  $K_D$  of  $10^6$ ,  $10^7$ ,  $10^8$ ,  $10^9$ , or  $10^{10} M^{-1}$  or better. The  $K_D$  of an antibody antigen interaction (the affinity constant) indicates the concentration of antibody at which 50% of antibody and antigen molecules are bound together. Thus, at a suitable fixed antigen concentration,  
20 50% of a higher (*i.e.*, stronger) affinity antibody will bind antigen molecules at a lower antibody concentration than would be required to achieve the same percent binding with a lower affinity antibody. Thus a lower  $K_D$  value indicates a higher (stronger) affinity. As used herein, “better” affinities are stronger affinities, and are of lower numeric value than their comparators, with a  $K_D$  of  $10^7 M^{-1}$  being of lower numeric value and therefore representing a better affinity than a  $K_D$  of  $10^6 M^{-1}$ . Affinities better (*i.e.*, with a lower  $K_D$   
25 value and therefore stronger) than  $10^7 M^{-1}$ , preferably better than  $10^8 M^{-1}$ , are generally preferred. Values intermediate to those set forth herein are also contemplated, and a preferred binding affinity can be indicated as a range of affinities, for example preferred binding affinities for anti-EGFR antibodies disclosed herein are,  $10^6$  to  $10^{12} M^{-1}$ ,  
30 preferably  $10^7$  to  $10^{12} M^{-1}$ , more preferably  $10^8$  to  $10^{12} M^{-1}$ . An antibody that “does not exhibit significant cross-reactivity” is one that will not appreciably bind to an off target antigen (*e.g.*, a non-EGFR protein). For example, in one embodiment, an antibody that specifically binds to EGFR will exhibit at least a two, and preferably three, or four or

more orders of magnitude better binding affinity (i.e., binding exhibiting a two, three, or four or more orders of magnitude lower  $K_D$  value) for EGFR than for ErbB molecules other than ErbB1 (EGFR) or for 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 (competition) binding assays as described herein.

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. In one embodiment, the antibody provided herein binds an antigen (e.g., EGFR) with an affinity ( $K_D$ ) of 100 nM or better (i.e., or less) (e.g., 90 nM, 80 nM, 70 nM, 60nM, 50nM, 40nM, 30nM, 20nM, 10 nM, 5 nM, 1 nM or less), as measured using a surface plasmon resonance assay, a cell binding assay, or an equilibrium dialysis assay. In a particular embodiment, an antibody binds EGFR with an affinity (as represented by dissociation constant  $K_D$ ) 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, 1.2nM, 1.1nM, 1nM or lower), as measured by a surface plasmon resonance assay or a cell binding assay. In other embodiments, an antibody binds an antigen (e.g., EGFR) 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 when determined by surface plasmon resonance (SPR) technology in a BIACORE 3000 instrument using recombinant EGFR as the analyte and the antibody as the ligand, 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. Other methods for determining  $K_D$  include equilibrium binding to live cells expressing EGFR via flow cytometry (FACS) or in solution using KinExA® technology.

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 terms "IC50" and "IC90," as used herein, refer to the measure of the effectiveness of a compound (e.g., an anti-EGFR antibody) in inhibiting a biological or biochemical function (e.g., the function or activity of EGFR) by 50% and 90%, respectively. For example, IC50 indicates how much of an anti-EGFR antibody is needed to inhibit the activity of EGFR (e.g., the growth of a cell expressing EGFR) by half. That is, it is the half maximal (50%) inhibitory concentration (IC) of an anti-EGFR

antibody (50% IC, or IC<sub>50</sub>). According to the FDA, IC<sub>50</sub> represents the concentration of a drug that is required for 50% inhibition *in vitro*. The IC<sub>50</sub> and IC<sub>90</sub> can be determined by techniques known in the art, for example, by constructing a dose-response curve and examining the effect of different concentrations of the antagonist  
5 (*i.e.*, the anti-EGFR antibody) on reversing EGFR activity.

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 “nucleic acid molecule,” as used herein, is intended to include DNA  
10 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 fragments (*e.g.*, V<sub>H</sub>, V<sub>L</sub>, CDR3), is intended to refer to a nucleic acid molecule in which the nucleotide sequences are essentially free of  
15 other genomic nucleotide sequences, *e.g.*, those encoding antibodies that bind antigens other than EGFR, 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.  
20 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 provided herein can be modified, to thereby modify the binding affinity of the antibody or antigen-binding portion thereof to EGFR.

“Conservative amino acid substitutions” in the sequences of the antibodies are  
25 provided, *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.*, EGFR. Conservative amino acid substitutions include the substitution of an amino acid in one class by an amino acid of the same class, where  
30 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-EGFR 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.

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-EGFR antibody coding sequence, such as by saturation mutagenesis, and the resulting modified anti-EGFR 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. 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 EGFR antibodies provided 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 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.

5           The nucleic acid compositions, while often comprising a native sequence (except for modified restriction sites and the like), from either cDNA, genomic or mixtures thereof may alternately be mutated, in accordance with standard techniques to provide altered gene sequences. For coding sequences, these mutations, may modify the encoded amino acid sequence as desired. In particular, DNA sequences substantially  
10 homologous to native V, D, J, constant, switches and other such sequences described herein are contemplated.

          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  
15 expressed as a pre-protein 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  
20 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  
25 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  
30 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  
5 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  
10 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, other forms of expression vectors, such as viral vectors (*e.g.*, replication defective retroviruses, adenoviruses and adeno-associated viruses), which serve equivalent functions are also contemplated.

15 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,  
20 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 antibody pair or trio disclosed herein, for  
25 example, a subject having a disease or disorder associated with EGFR 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.

30 The term “disease associated with EGFR dependent signaling,” or “disorder associated with EGFR dependent signaling,” as used herein, includes disease states and/or symptoms associated with a disease state, where increased levels of EGFR and/or activation of cellular cascades involving EGFR are found. The term “disease associated

with EGFR dependent signaling,” also includes disease states and/or symptoms associated with the activation of alternative EGFR signaling pathways. In general, the term “disease associated with EGFR dependent signaling,” refers to any disorder, the onset, progression or the persistence of the symptoms of which requires the participation of EGFR. Exemplary EGFR-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 “effective amount,” as used herein, refers to that amount of an antibody or an antigen binding portion thereof that binds EGFR, which is sufficient to effect treatment, prognosis or diagnosis of a disease associated with EGFR dependent signaling, as described herein, when administered to a subject. Therapeutically effective amounts of antibodies provided herein, when used alone or in combination, will vary depending upon the relative activity of the antibodies and combinations (*e.g.*, in inhibiting cell growth) and 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  $\mu$ g to about 3,500 mg, about 5  $\mu$ g to about 3,000 mg, about 10  $\mu$ g to about 2,600 mg, about 20  $\mu$ g to about 2,575 mg, about 30  $\mu$ g to about 2,550 mg, about 40  $\mu$ g to about 2,500 mg, about 50  $\mu$ g to about 2,475 mg, about 100  $\mu$ g to about 2,450 mg, about 200  $\mu$ g to about 2,425 mg, about 300  $\mu$ g to about 2,000, about 400  $\mu$ g to about 1,175 mg, about 500  $\mu$ g 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. Dosage regimens 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 are minimized and/or outweighed by the beneficial effects.

The term “therapeutic agent” is intended to encompass any and all compounds that have an ability to decrease or inhibit the severity of the symptoms of a disease or disorder, or increase the frequency and/or duration of symptom-free or symptom-reduced periods in a disease or disorder, or inhibit or prevent impairment or disability due to a disease or disorder affliction, or inhibit or delay progression of a disease or disorder, or inhibit or delay onset of a disease or disorder, or inhibit or prevent infection in an infectious disease or disorder. Non-limiting examples of therapeutic agents include small organic molecules, monoclonal antibodies, bispecific antibodies, recombinantly engineered biologics, RNAi compounds, tyrosine kinase inhibitors, and commercial antibodies. In certain embodiments, tyrosine kinase inhibitors include, *e.g.*, one or more of erlotinib, gefitinib, and lapatinib, which are currently marketed pharmaceuticals. Commercially available pharmaceutical anti-EGFR antibodies include cetuximab and panitumumab. Other pharmaceutical anti-EGFR antibodies include zalutumumab, nimotuzumab, and matuzumab, which are in development.

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

The term “subject” includes any mammal, *e.g.*, a primate. For example, the methods and compositions herein disclosed can be used to treat a subject having cancer. In a particular embodiment, the subject is a human.

The term “sample” refers to tissue, body fluid, or a cell (or a fraction of any of the foregoing) taken 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 (*e.g.*, leukemic cells from blood) and appropriately prepared. Other samples, including urine, tears, serum, plasma, cerebrospinal fluid, feces, sputum, cell extracts *etc.* can also be useful for particular cancers.

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

**II. Anti-EGFR Antibodies and Combinations Thereof**

Novel anti-EGFR monoclonal antibodies are disclosed herein, including three referred to in the Examples as P1X, P2X and P3X. The P1X, P2X and P3X monoclonal antibodies are affinity matured antibodies of parental antibodies referred to as ca, cd and ch, respectively, disclosed in PCT Application No. PCT/US2011/35238. The CDR amino acid sequences of the parental and affinity matured antibodies are shown below, with the changed amino acids in the affinity matured antibodies bolded and underlined:

25	ca V <sub>H</sub>	<u>CDR1</u> SYAIS (SEQ ID NO: 1)	<u>CDR2</u> IPIFGTANY (SEQ ID NO: 27)	<u>CDR3</u> DPSVDL (SEQ ID NO: 28)
30	P1X V <sub>H</sub>	<u>CDR1</u> SYAIS (SEQ ID NO: 1)	<u>CDR2</u> IPIFGT <u>V</u> NY (SEQ ID NO: 2)	<u>CDR3</u> DPSV <u>N</u> L (SEQ ID NO: 3)
	ca V <sub>L</sub>	<u>CDR1</u> QSISSWLA (SEQ ID NO: 29)	<u>CDR2</u> DASSL (SEQ ID NO: 5)	<u>CDR3</u> QQFAAHA (SEQ ID NO: 30)
35	P1X V <sub>L</sub>	<u>CDR1</u> QSISSW <u>W</u> A (SEQ ID NO: 4)	<u>CDR2</u> DASSL (SEQ ID NO: 5)	<u>CDR3</u> QQ <u>Y</u> H <u>A</u> H <u>P</u> (SEQ ID NO: 6)

5	cd V <sub>H</sub>	<u>CDR1</u> SYAIS (SEQ ID NO: 7)	<u>CDR2</u> IPIFGTANY (SEQ ID NO: 27)	<u>CDR3</u> MGRGKV (SEQ ID NO: 9)
10	P2X V <sub>H</sub>	<u>CDR1</u> SYAIS (SEQ ID NO: 7)	<u>CDR2</u> IPIFGAANP (SEQ ID NO: 8)	<u>CDR3</u> MGRGKV (SEQ ID NO: 9)
15	cd V <sub>L</sub>	<u>CDR1</u> QSVLYSSNNKNYLA (SEQ ID NO: 31)	<u>CDR2</u> WASTR (SEQ ID NO: 11)	<u>CDR3</u> QQYYGSP (SEQ ID NO: 12)
15	P2X V <sub>L</sub>	<u>CDR1</u> QSVLYSPNNKNYLA (SEQ ID NO: 10)	<u>CDR2</u> WASTR (SEQ ID NO: 11)	<u>CDR3</u> QQYYGSP (SEQ ID NO: 12)
20	ch V <sub>H</sub>	<u>CDR1</u> SYGIN (SEQ ID NO: 13)	<u>CDR2</u> ISAYNGNTNY (SEQ ID NO: 32)	<u>CDR3</u> DLGGYGSGS (SEQ ID NO: 15)
25	P3X V <sub>H</sub>	<u>CDR1</u> SYGIN (SEQ ID NO: 13)	<u>CDR2</u> ISAYNGNTYY (SEQ ID NO: 14)	<u>CDR3</u> DLGGYGSGS (SEQ ID NO: 15)
30	ch V <sub>L</sub>	<u>CDR1</u> QSVSSNLA (SEQ ID NO: 16)	<u>CDR2</u> GASTR (SEQ ID NO: 17)	<u>CDR3</u> QDYRTWPR (SEQ ID NO: 18)
35	P3X V <sub>L</sub>	<u>CDR1</u> QSVSSNLA (SEQ ID NO: 16)	<u>CDR2</u> GASTR (SEQ ID NO: 17)	<u>CDR3</u> QDYRTWPR (SEQ ID NO: 18)

The full-length V<sub>H</sub> and V<sub>L</sub> amino sequences for P1X are shown in SEQ ID NO: 19 and 20, respectively. The full-length V<sub>H</sub> and V<sub>L</sub> amino sequences for P2X are shown in SEQ ID NO: 21 and 22, respectively. The full-length V<sub>H</sub> and V<sub>L</sub> amino sequences for P3X are shown in SEQ ID NO: 23 and 24, respectively. Additionally, the V<sub>H</sub> and V<sub>L</sub> CDR segments as presented herein are arranged, *e.g.*, in the amino to carboxy terminal order of CDR1, CDR2 and CDR3.

In one embodiment, a monoclonal antibody is provided which binds EGFR extracellular domain and comprises heavy and light chain CDR1, CDR2, and CDR3, sequences, wherein the heavy and light chain CDR1, CDR2, and CDR3, sequences are selected from the group consisting of:

5 (a) heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 1, 2, and 3 respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 4, 5, and 6, respectively;

(b) heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 7, 8, and 9, respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 10,  
10 11 and 12, respectively; and

(c) heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 13, 14, and 15, respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 16, 17, and 18, respectively.

In another embodiment, a monoclonal antibody is provided that binds to EGFR  
15 extracellular domain and comprises a heavy chain variable region and a light chain variable region, wherein the heavy and light chain variable region sequences are selected from the group consisting of:

(a) a heavy chain variable region comprising SEQ ID NO: 19 and a light chain variable region comprising SEQ ID NO: 20;

20 (b) a heavy chain variable region comprising SEQ ID NO: 21 and a light chain variable region comprising SEQ ID NO: 22; and

(c) a heavy chain variable region comprising SEQ ID NO: 23 and a light chain variable region comprising SEQ ID NO: 24.

Combinations of the aforementioned anti-EGFR antibodies are also provided.  
25 Such combinations can contain, for example, any combination of two of the aforementioned anti-EGFR antibodies. Another combination can comprise all three of the aforementioned anti-EGFR antibodies. Accordingly, in another aspect, a composition comprising two or three monoclonal antibodies which bind to EGFR extracellular domain is provided, wherein the two or three monoclonal antibodies are  
30 selected from the group consisting of:

(a) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 1, 2, and 3 respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 4, 5, and 6, respectively;

(b) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 7, 8, and 9, respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 10, 11 and 12, respectively and

(c) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3  
5 sequences of SEQ ID NOs: 13, 14, and 15, respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 16, 17 and 18, respectively;  
and wherein the composition comprises (a) and (b), (a) and (c), (b) and (c) or (a), (b) and (c).

In yet another embodiment, a composition comprising two or three monoclonal  
10 antibodies which bind to EGFR extracellular domain is provided, wherein the two or three monoclonal antibodies are selected from the group consisting of:

(a) a monoclonal antibody comprising a heavy chain variable region comprising SEQ ID NO: 19 and a light chain variable region comprising SEQ ID NO: 20;

(b) a monoclonal antibody comprising a heavy chain variable region comprising  
15 SEQ ID NO: 21 and a light chain variable region comprising SEQ ID NO: 22; and

(c) a monoclonal antibody comprising a heavy chain variable region comprising SEQ ID NO: 23 and a light chain variable region comprising SEQ ID NO: 24;

and wherein the composition comprises (a) and (b), (a) and (c), (b) and (c) or (a) (b) and (c).

20 The anti-EGFR antibodies disclosed herein, whether as a single antibody or in a combination of antibodies, can bind to EGFR with a  $K_D$  of, for example, better than 100 nM, or better than 10 nM or better than 1 nM. As used herein with respect to  $K_D$ , the term "better than \_\_\_ nM" means that an antibody has a  $K_D$ , expressed as a nanomolar concentration, that is lower than the indicated number. For example, a  $K_D$  that is "better  
25 than" 100 nM indicates a  $K_D$ , expressed as a nanomolar concentration, that is lower in value than 100 nM (e.g., is 50 nM).

In other embodiments, a PIX-related antibody, such as an antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 1, 2, and 3 respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 4, 5,  
30 and 6, respectively, or an antibody comprising  $V_H$  and  $V_L$  sequences of SEQ ID NOs: 19 and 20, respectively, can bind to EGFR with a  $K_D$  in a range of about  $1 \times 10^{-9}$  M to  $1.1 \times 10^{-11}$  M or better.

In other embodiments, a P2X-related antibody, such as an antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 7, 8 and 9 respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 10, 11, and 12, respectively, or an antibody comprising V<sub>H</sub> and V<sub>L</sub> sequences of SEQ ID NOs: 21 and 22, respectively, can bind to EGFR with a K<sub>D</sub> in a range of about 1 x 10<sup>-9</sup> M to 7.0 x 10<sup>-11</sup> M or better.

In other embodiments, a P3X-related antibody, such as an antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 13, 14 and 15 respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 16, 17, and 18, respectively, or an antibody comprising V<sub>H</sub> and V<sub>L</sub> sequences of SEQ ID NOs: 23 and 24, respectively, can bind to EGFR with a K<sub>D</sub> in a range of about 1 x 10<sup>-9</sup> M to 3.6 x 10<sup>-10</sup> M or better.

The anti-EGFR antibodies disclosed herein, whether as a single antibody or in a combination of antibodies, can exhibit one or more other functional properties as disclosed herein, including but not limited to

- (a) inhibition of AKT or ERK phosphorylation, *e.g.*, EGFR-dependant AKT or ERK phosphorylation, as measured in a cell-based assay;
- (b) inhibition of the growth of cells expressing EGFR;
- (c) inhibition of EGF ligand binding to EGFR (*e.g.*, inhibition of binding of one or more ligands that bind EGFR, including EGF, heparin binding EGF-like growth factor (HB-EGF), transforming growth factor (TGF), epigen, epiregulin, betacellulin, or amphiregulin);
- (d) inhibition of EGFR dimerization;
- (e) downregulation of EGFR on cell surfaces (*e.g.*, by internalization and recycling of the receptor, and/or internalization and degradation of the receptor);
- (f) inhibition of *in vitro* tumor cell proliferation; and/or
- (g) inhibition of *in vivo* tumor growth.

Antibodies disclosed herein 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, an immunoconjugate, 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, affibody®, avimer, nanobody, or a domain antibody. The antibody also can have any isotype, including any

of the following isotypes: IgG1, IgG2, IgG3, IgG4, IgM, IgA1, IgA2, IgAsec, IgD, and IgE. IgG antibodies are preferred. Full-length antibodies can be prepared from V<sub>H</sub> and V<sub>L</sub> sequences using standard recombinant DNA techniques and nucleic acid encoding the desired constant region sequences to be operatively linked to the variable region  
5 sequences. Non-limiting examples of suitable constant region sequences include the kappa light chain constant region disclosed in SEQ ID NO: 25 and the IgG1 heavy chain constant region disclosed in SEQ ID NO: 26.

As disclosed in the examples, it has been discovered that triple combinations of the P1X + P2X + P3X antibodies are particularly efficacious when used at a  
10 P1X:P2X:P3X molar ratio of 2:2:1. Thus, for such a triple antibody combination, 40% of the total concentration is selected to be P1X, 40% of the total concentration is selected to be P2X and 20% of the total concentration is selected to be P3X.

Accordingly, in another embodiment, a composition is provided comprising three monoclonal anti-EGFR antibodies, said composition comprising a first antibody, a  
15 second antibody and a third antibody, wherein (i) the first antibody comprises heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 1, 2, and 3 respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 4, 5, and 6, respectively; (ii) the second antibody comprises heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 7, 8, and 9, respectively, and light chain CDR1, CDR2, and  
20 CDR3 sequences of SEQ ID NOs: 10, 11 and 12, respectively; and (iii) the third antibody comprises heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 13, 14, and 15 respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 16, 17, and 18, respectively, and wherein the first second and third antibodies are present at a molar ratio of 2:2:1 to each other.

25 In yet another embodiment, a composition is provided comprising three monoclonal anti-EGFR antibodies, said composition comprising a first antibody, a second antibody and a third antibody, wherein (i) the first antibody comprises a heavy chain variable region comprising SEQ ID NO: 19 and a light chain variable region comprising SEQ ID NO: 20; (ii) the second antibody comprises a heavy chain variable  
30 region comprising SEQ ID NO: 21 and a light chain variable region comprising SEQ ID NO: 22; and (iii) the third antibody comprises a heavy chain variable region comprising SEQ ID NO: 23 and a light chain variable region comprising SEQ ID NO: 24, and

wherein the first second and third antibodies are present at a molar ratio of 2:2:1 to each other.

Methods of preparing anti-EGFR antibody compositions comprising three antibodies are provided, wherein the antibodies are prepared at a 2:2:1 ratio. More specifically, in another embodiment, a method of preparing an anti-EGFR antibody composition is provided, the method comprising combining in a single composition:

(a) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 1, 2, and 3 respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 4, 5, and 6, respectively;

10 (b) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 7, 8, and 9, respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 10, 11 and 12, respectively; and

(c) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 13, 14, and 15 respectively, and light chain CDR1, CDR2, 15 and CDR3 sequences of SEQ ID NOs: 16, 17, and 18, respectively;

wherein (a), (b) and (c) are combined at a molar ratio of 2:2:1 to each other.

In another embodiment, a method of preparing an anti-EGFR antibody composition is provided, the method comprising combining in a single composition:

(a) a monoclonal antibody comprising a heavy chain variable region comprising 20 SEQ ID NO: 19 and a light chain variable region comprising SEQ ID NO:20;

(b) a monoclonal antibody comprising a heavy chain variable region comprising SEQ ID NO: 21 and a light chain variable region comprising SEQ ID NO: 22; and

(c) a monoclonal antibody comprising a heavy chain variable region comprising SEQ ID NO: 23 and a light chain variable region comprising SEQ ID NO: 24;

25 wherein (a), (b) and (c) are combined at a molar ratio of 2:2:1 to each other.

Methods of treating a subject with three anti-EGFR antibodies wherein the antibodies are administered to the subject at a 2:2:1 ratio are also provided. More specifically, a method of treating a subject with anti-EGFR antibodies is provided, the method comprising administering to the subject:

30 (a) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 1, 2, and 3 respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 4, 5, and 6, respectively;

(b) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 7, 8, and 9, respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 10, 11 and 12, respectively; and

(c) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 13, 14, and 15 respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 16, 17, and 18, respectively;

wherein (a), (b) and (c) are administered to the subject at a molar ratio of 2:2:1 to each other.

In another embodiment, a method of treating a subject with anti-EGFR antibodies is provided, the method comprising administering to the subject:

(a) a monoclonal antibody comprising a heavy chain variable region comprising SEQ ID NO: 19 and a light chain variable region comprising SEQ ID NO:20;

(b) a monoclonal antibody comprising a heavy chain variable region comprising SEQ ID NO: 21 and a light chain variable region comprising SEQ ID NO: 22; and

(c) a monoclonal antibody comprising a heavy chain variable region comprising SEQ ID NO: 23 and a light chain variable region comprising SEQ ID NO: 24;

wherein (a), (b) and (c) are administered to the subject at a molar ratio of 2:2:1 to each other.

Further details on formulating anti-EGFR antibodies into pharmaceutical compositions and methods of using such compositions in EGFR-related diseases are described in subsections below.

### **III. Methods for Producing Antibodies**

#### **(i) Monoclonal Antibodies**

The monoclonal antibodies of provided herein most typically are prepared by standard recombinant DNA techniques based on the amino acid sequences of the V<sub>H</sub> and V<sub>L</sub> regions disclosed herein.

Additionally or alternatively, monoclonal antibodies can be produced using a variety of known techniques, such as the standard somatic cell hybridization technique, viral or oncogenic transformation of B lymphocytes, or yeast or phage display techniques 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 EGFR. 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  
5 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. 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,  
10 affinity, and/or activity, the clones may be subcloned by limiting dilution procedures and grown by standard methods. 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  
15 conventional immunoglobulin purification procedures such as, for example, protein A-Sepharose, hydroxylapatite chromatography, gel electrophoresis, dialysis, or affinity chromatography.

In another embodiment, antibodies that bind EGFR can be isolated from antibody libraries generated using well know techniques such as those described in, for  
20 example, 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, as well as combinatorial  
25 infection and *in vivo* recombination as a strategy for constructing very large phage libraries may also be used. See, e.g., US patent application Ser. No. 09/856,907 (PCT Int. Pub. No. WO 00/31246)

In a particular embodiment, the monoclonal antibody that binds EGFR is produced using phage display. This technique involves the generation of a human Fab  
30 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 EGFR.

In yet another embodiment, human monoclonal antibodies directed against EGFR can be generated using transgenic or transchromosomal mice carrying parts of the human immune system rather than the mouse system (see *e.g.*, 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 5,814,318; 5,874,299; and 5,770,429; all to Lonberg and Kay; U.S. Patent 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 can be raised using a mouse that 10 carries human immunoglobulin sequences on transgenes and transchromosomes, 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-EGFR 15 antibodies. 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. Patent Nos. 5,939,598; 6,075,181; 6,114,598; 6,150,584 and 6,162,963 to Kucherlapati *et al.*

Moreover, alternative transchromosomal animal systems expressing human immunoglobulin genes are available in the art and can be used to raise anti-EGFR 20 antibodies. For example, mice carrying both a human heavy chain transchromosome and a human light chain transchromosome can be used. Furthermore, cows carrying human heavy and light chain transchromosomes have been described in the art and can be used to raise anti-EGFR antibodies.

In yet another embodiment, antibodies can be prepared using a transgenic plant 25 and/or cultured plant cells (such as, for example, tobacco, maize and duckweed) that produce such antibodies. For example, transgenic tobacco leaves expressing antibodies can be used to produce such antibodies by, for example, using an inducible promoter. Also, transgenic maize can be used to express such antibodies and antigen binding portions thereof. Antibodies can also be produced in large amounts from transgenic 30 plant seeds including antibody portions, such as single chain antibodies (scFv's), for example, using tobacco seeds and potato tubers.

The binding specificity of monoclonal antibodies (or portions thereof) that bind EGFR 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 monoclonal antibody or portion thereof also can be determined by Scatchard analysis.

In certain embodiments, an EGFR antibody produced using any of the methods  
5 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 EGFR antibody may be used to produce structurally and functionally related antibodies. For example,  
10 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  
15 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. Such framework sequences can be obtained from public DNA databases that include germline antibody gene sequences.

20 Thus, one or more structural features of an anti-EGFR antibody, such as the CDRs, can be used to create structurally related anti-EGFR antibodies that retain at least one desired functional property, *e.g.*, inhibiting growth of cells expressing EGFR.

In a particular embodiment, one or more CDR regions disclosed herein is combined recombinantly with known human framework regions and CDRs to create  
25 additional, recombinantly-engineered, anti-EGFR antibodies. 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  
30 antigen. Accordingly, in certain embodiments, antibodies are generated that include the heavy and/or light chain CDR3s of the particular antibodies described herein. The antibodies can further include the heavy and/or light chain CDR1 and/or CDR2s of the antibodies disclosed herein.

The CDR 1, 2, and/or 3 regions of the engineered antibodies described above can comprise the exact amino acid sequence(s) as those disclosed herein. However, the ordinarily skilled artisan will appreciate that some deviation from the exact CDR sequences may be possible, particularly for CDR1 and CDR2 sequences, which can tolerate more variation than CDR3 sequences without altering epitope specificity (such deviations are, e.g., conservative amino acid substitutions). Accordingly, in another embodiment, the engineered antibody may be composed of one or more CDR1s and CDR2s that are, for example, 90%, 95%, 98%, 99% or 99.5% identical to the corresponding CDRs of an antibody named herein.

10 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,  $10^{10} \text{ M}^{-1}$  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.

20 Modifications can also be made within one or more of the framework or joining regions of the heavy and/or the light chain variable regions of an antibody, so long as antigen binding affinity subsequent to these modifications is better than  $10^6 \text{ M}^{-1}$ .

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). Homodimeric antibodies with enhanced anti-tumor activity may also be prepared using heterobifunctional cross-linkers. Alternatively, an antibody can be engineered which has dual Fc regions and may thereby have enhanced complement lysis and ADCC capabilities.

30 Also provided are bispecific antibodies and immunoconjugates, as discussed below.

(ii) Bispecific Antibodies

Bispecific antibodies herein include at least two binding specificities for EGFR which preferably bind non-overlapping or non-competing epitopes. Such bispecific antibodies can include additional binding specificities, *e.g.*, a third EGFR binding specificity and/or a binding specificity for another ErbB receptor (*e.g.*, ErbB3) or 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')<sub>2</sub> 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 paired immunoglobulin heavy chain-light chains, where the two chains have different specificities. 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. Another strategy for making bispecific antibody fragments by the use of single-chain Fv (sFv) dimers has also been reported.

In a particular embodiment, the bispecific antibody comprises a first antibody (or binding portion thereof) which binds to EGFR derivatized or linked to another functional molecule, *e.g.*, another peptide or protein (*e.g.*, another antibody or ligand for a receptor) to generate a bispecific molecule that binds to at least two different binding sites or target molecules. An antibody may be derivatized or linked to more than one other functional molecule to generate multispecific molecules that bind to more than two different binding sites and/or target molecules; such multispecific molecules are also intended to be encompassed by the term “bispecific molecule” as used herein. To create a bispecific molecule, an antibody disclosed herein can be functionally linked (*e.g.*, by chemical coupling, genetic fusion, noncovalent association or otherwise) to one or more other binding molecules, such as another antibody, antibody fragment, peptide or binding mimetic, such that a bispecific molecule results.

Accordingly, bispecific molecules comprising at least one first binding specificity for EGFR and a second binding specificity for a second target epitope are contemplated. In a particular embodiment, the second target epitope is an Fc receptor, *e.g.*, human FcγRI (CD64) or a human Fcα receptor (CD89). Therefore, bispecific molecules capable of binding both to FcγR, FcαR or FcεR expressing effector cells (*e.g.*,

monocytes, macrophages or polymorphonuclear cells (PMNs)), and to target cells expressing EGFR are also provided. These bispecific molecules target EGFR expressing cells to effector cell and trigger Fc receptor-mediated effector cell activities, such as phagocytosis of an EGFR expressing cells, antibody dependent cell-mediated cytotoxicity (ADCC), cytokine release, or generation of superoxide anion.

In one embodiment, the bispecific molecules comprise as a binding specificity at least one antibody, or an antibody fragment thereof, including, *e.g.*, an Fab, Fab', F(ab')<sub>2</sub>, Fv, or a single chain Fv. The antibody may also be a light chain or heavy chain dimer, or any minimal fragment thereof such as a Fv or a single chain construct as described in Ladner *et al.* U.S. Patent No. 4,946,778.

The bispecific molecules can be prepared by conjugating the constituent binding specificities, *e.g.*, the anti-FcR and anti-EGFR binding specificities, using methods known in the art. For example, each binding specificity of the bispecific molecule can be generated separately and then conjugated to one another. When the binding specificities are proteins or peptides, a variety of coupling or cross-linking agents can be used for covalent conjugation. Examples of cross-linking agents include protein A, carbodiimide, N-succinimidyl-S-acetyl-thioacetate (SATA), 5,5'-dithiobis(2-nitrobenzoic acid) (DTNB), o-phenylenedimaleimide (oPDM), N-succinimidyl-3-(2-pyridyldithio)propionate (SPDP), and sulfosuccinimidyl 4-(N-maleimidomethyl) cyclohexane-1-carboxylate (sulfo-SMCC). Preferred conjugating agents are SATA and sulfo-SMCC, both available from Pierce Chemical Co. (Rockford, IL).

When the binding specificities are antibodies, they can be conjugated via sulfhydryl bonding of the C-terminus hinge regions of the two heavy chains. In a particularly preferred embodiment, the hinge region is modified to contain an odd number of sulfhydryl residues, preferably one, prior to conjugation.

Alternatively, both binding specificities can be encoded in the same vector and expressed and assembled in the same host cell. This method is particularly useful where the bispecific molecule is a mAb x mAb, mAb x Fab, Fab x F(ab')<sub>2</sub> or ligand x Fab fusion protein. A bispecific molecule can be a single chain molecule comprising one single chain antibody and a binding determinant, or a single chain bispecific molecule comprising two binding determinants. Bispecific molecules may comprise at least two single chain molecules. Methods for preparing bispecific molecules are described for example in U.S. Patent Number 5,260,203; U.S. Patent Number 5,455,030; U.S. Patent

Number 4,881,175; U.S. Patent Number 5,132,405; U.S. Patent Number 5,091,513; U.S. Patent Number 5,476,786; U.S. Patent Number 5,013,653; U.S. Patent Number 5,258,498; and U.S. Patent Number 5,482,858.

Binding of the bispecific molecules to their specific targets can be confirmed by, for example, enzyme-linked immunosorbent assay (ELISA), radioimmunoassay (RIA), FACS analysis, bioassay (*e.g.*, growth inhibition), or western blot assay. Each of these assays generally detects the presence of protein-antibody complexes of particular interest by employing a labeled reagent (*e.g.*, an antibody) specific for the complex of interest. For example, the FcR-antibody complexes can be detected using *e.g.*, an enzyme-linked antibody or antibody fragment which recognizes and specifically binds to the antibody-FcR complexes. Alternatively, the complexes can be detected using any of a variety of other immunoassays. For example, the antibody can be radioactively labeled and used in a radioimmunoassay (RIA). The radioactive isotope can be detected by such means as the use of a  $\alpha$   $\gamma$ - $\beta$ counter or a scintillation counter or by autoradiography.

(iii) Immunoconjugates

Immunoconjugates provided herein can be formed by conjugating the antibodies 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-EGFR antibodies. Examples include  $^{212}\text{Bi}$ ,  $^{131}\text{I}$ ,  $^{131}\text{In}$ ,  $^{90}\text{Y}$  and  $^{186}\text{Re}$ .

Immunoconjugates can be made using a variety of bifunctional protein coupling agents such as N-succinimidyl-3-(2-pyridyldithiol) propionate (SPDP), iminothiolane

(IT), bifunctional derivatives of imidoesters (such as dimethyl adipimidate HCL), active esters (such as disuccinimidyl suberate), aldehydes (such as glutaraldehyde), bis-azido compounds (such as bis (p-azidobenzoyl) hexanediamine), bis-diazonium derivatives (such as bis-(p-diazoniumbenzoyl)-ethylenediamine), diisocyanates (such as tolyene 2,6-  
5 diisocyanate), and bis-active fluorine compounds (such as 1,5-difluoro-2,4-dinitrobenzene). 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).

#### 10 IV. Methods for Screening Antibodies

Subsequent to producing antibodies they 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 are screened (*e.g.*, by flow cytometry or ELISA) for binding to EGFR using, for example, purified EGFR and/or EGFR-  
15 expressing cells, such as A431 cells. The epitopes bound by the anti-EGFR antibodies can further be identified and compared, for example, to identify non-competing antibodies (*e.g.*, antibodies that bind different epitopes), as well as antibodies which compete for binding and/or bind the same or overlapping epitopes.

Competitive antibodies and non-competitive antibodies can be identified using  
20 routine techniques. Such techniques include, for example, an immunoassay, which shows the ability of one antibody to block (or not 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 EGFR. Numerous types of  
25 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; solid phase direct biotin-avidin EIA; solid phase direct labeled assay, solid phase direct labeled sandwich assay; solid phase direct <sup>125</sup>I labeled RIA; solid phase direct biotin-avidin EIA; and direct labeled RIA.. The surface plasmon  
30 resonance technique set forth in the Materials and Methods of the Examples and in Example 2, below, can also be used advantageously for this purpose. Typically, such an assay involves the use of purified antigen 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.

Other screening techniques for determining the epitope bound by antibodies disclosed herein include, for example, x-ray analysis of crystals of antigen:antibody complexes, which provides atomic resolution of the epitope. Other methods monitor the binding of the antibody to antigen fragments or mutated variations of the antigen where loss of binding due to a modification of an amino acid residue within the antigen sequence is often considered an indication of an epitope component. In addition, computational combinatorial methods for epitope mapping can also be used. These methods rely on the ability of the antibody of interest to affinity isolate specific short peptides from combinatorial phage display peptide libraries. The peptides are then regarded as leads for the definition of the epitope corresponding to the antibody used to screen the peptide library. For epitope mapping, computational algorithms have also been developed which have been shown to map conformational discontinuous epitopes.

In another embodiment, the antibodies (*e.g.*, non-competing antibodies anti-EGFR antibodies) are screened for the ability to bind to epitopes exposed upon binding to ligand, *e.g.*, EGF (*i.e.*, do not inhibit the binding of EGFR-binding ligands to EGFR). Such antibodies can be identified by, for example, contacting cells which express EGFR (*e.g.* A431 cells) with a labeled EGFR ligand (*e.g.*, radiolabeled or biotinylated EGF) in the absence (control) or presence of the anti-EGFR antibody. If the antibody does not inhibit EGF binding to EGFR, then no statistically significantly decrease in the amount of label recovered, relative to the amount in the absence of the antibody, will be observed. Alternatively, if the antibody inhibits EGF binding to EGFR, then a statistically significantly decrease in the amount of label recovered, relative to the amount in the absence of the antibody, will be observed.

Antibodies also can be screened (tested) for their binding affinity. This can be done, for example, using a plasmon resonance assay, *e.g.*, as described below.

Antibodies also can be screened for their ability to inhibit signaling through EGFR using signaling assays, such as, those described herein. For example, the ability of an antibody to inhibit EGFR ligand mediated phosphorylation of EGFRs can be

assessed by treating cells expressing EGFR with an EGFR ligand (*e.g.*, EGF) in the presence and absence of the antibody. The cells can then be lysed, crude lysates centrifuged to remove insoluble material, and EGFR phosphorylation measured, for example, by western blotting followed by probing with an anti-phosphotyrosine  
5 antibody.

Alternatively, the ability of an antibody to inhibit downstream signaling through EGFR can be measured by kinase assays for known substrates of EGFR such as, for example, AKT and/or ERK, following EGFR stimulation by EGF ligand. For example, cells expressing EGFR can be incubated with a candidate antibody and stimulated with  
10 EGF ligand. Cell lysates subsequently prepared from such cells can be immunoprecipitated with an antibody for a substrate of EGFR (or a protein in a cellular pathway involving EGFR) such as, an anti-AKT antibody, and assayed for kinase activity (*e.g.*, AKT kinase activity) using art-recognized techniques. A decrease in or complete disappearance in level or activity (*e.g.*, kinase activity) of a EGFR substrate or  
15 protein in a pathway involving EGFR in the presence of the antibody, relative to the level or activity in the absence of the antibody is indicative of an antibody which inhibits EGFR signaling.

Antibodies that decrease levels of EGFR on cell surfaces can be identified by their ability to downregulate or inhibit EGFR expression on tumor cells. In certain  
20 embodiments, the antibodies decrease EGFR on cell surfaces by inducing internalization (or increasing endocytosis) of EGFR (*e.g.*, by internalization and recycling of the receptor and/or internalization and degradation of the receptor) or by inhibiting recycling of internalized EGFR. To test this, EGFR can be biotinylated and the number of EGFR molecules on the cell surface can be readily determined, for example, by measuring the  
25 amount of biotin on a monolayer of cells in culture in the presence or absence of an antibody, followed by immunoprecipitation of EGFR and probing with streptavidin. A decrease in detection of biotinylated EGFR over time in the presence of an antibody is indicative of an antibody that decreases EGFR levels on cell surfaces.

Antibodies and antibody combinations can also be tested for their ability to  
30 inhibit growth of cells expressing EGFR (either *in vivo* or *in vitro*), such as tumor cells, using art recognized techniques, including the Cell Titer-Glo Assay described in the Examples below and Tritium-labeled thymidine incorporation assay. Antibodies also can be screened for the ability to inhibit spheroid growth of cells expressing EGFR.

This can be done by using an assay that approximates conditions of a developing tumor growth as described herein.

In another embodiment, combinations of anti-EGFR antibodies are screened for IC<sub>50</sub> and/or IC<sub>90</sub> values relative to inhibiting a particular EGFR activity or function, such as EGFR-mediated signaling (*e.g.*, as measured by ELISA, Western, or multiplex methods, such as Luminex®). Combinations of antibodies, each of which possesses a particularly desired IC<sub>50</sub> and/or IC<sub>90</sub> value (*e.g.*, an IC<sub>90</sub> of about 80nM for inhibiting EGFR signaling) can then be selected. In one embodiment, the combination has a greater IC<sub>50</sub> or IC<sub>90</sub> value than a known reference antibody (*e.g.*, cetuximab). In another embodiment, the combination has an additive IC<sub>50</sub> or IC<sub>90</sub> (*i.e.*, the sum of the activities of the antibodies, when acting individually on a cell expressing EGFR, is approximately equivalent to the combined effect of the same antibodies acting together on the same cell) In another embodiment, the combination has a synergistic IC<sub>50</sub> or IC<sub>90</sub> (*i.e.*, the sum of the effects of the antibodies, when acting individually on a cell expressing EGFR, is less than the combined effect of the same antibodies acting together on the same cell).

## V. Pharmaceutical Compositions

In another aspect, herein provided is a composition, *e.g.*, a pharmaceutical composition, containing one or a combination of the anti-EGFR monoclonal antibodies disclosed herein, formulated together with a pharmaceutically acceptable carrier. In one embodiment, the compositions include a combination of multiple (*e.g.*, two or three) isolated antibodies that bind different epitopes on EGFR. Such antibodies preferably have an additive or synergistic effect relative to inhibiting a particular EGFR activity or function, such as EGFR-mediated signaling. Preferred pharmaceutical compositions are sterile compositions, compositions suitable for injection, and sterile compositions suitable for injection by a desired route of administration, such as by intravenous injection.

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 compound, *i.e.*, antibody, bispecific and multispecific molecule, may be coated in a material to protect the compound from the action of acids and other natural conditions that may inactivate the compound.

Compositions can be administered alone or in combination therapy, *i.e.*,  
5 combined with other agents. For example, the combination therapy can include a composition provided herein with at least one or more additional therapeutic agents, such as the anti-cancer agents described herein. In one embodiment, combination therapy can use a composition provided herein of two or three of the anti-EGFR antibodies disclosed herein. In another embodiment, combination therapy can use a  
10 composition comprising at least one of the anti-EGFR antibodies disclosed herein combined with one or more other antibodies, such as one or more other anti-EGFR antibodies known in the art (*e.g.*, anti-EGFR antibodies as disclosed in PCT Application No. PCT/US2011/3528). The compositions can also be administered in conjunction with radiation therapy and/or surgery. Particular combinations of anti-EGFR antibodies  
15 may also be administered separately or sequentially, with or without additional therapeutic agents.

Compositions 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 antibodies can be prepared with carriers  
20 that will protect the antibodies 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  
25 known to those skilled in the art.

To administer compositions by certain routes of administration, it may be necessary to coat the constituents, *e.g.*, antibodies, with, or co-administer the compositions with, a material to prevent its inactivation. For example, the compositions may be administered to a subject in an appropriate carrier, for example, liposomes, or a  
30 diluent. Acceptable diluents include saline and aqueous buffer solutions. Liposomes include water-in-oil-in-water CGF emulsions as well as conventional liposomes.

Acceptable carriers include sterile aqueous solutions or dispersions and sterile powders for the extemporaneous preparation of sterile injectable solutions or dispersion.

The use of such media and agents for pharmaceutically active substances is known in the art. Except insofar as any conventional medium or agent is incompatible with the antibodies, use thereof in compositions provided herein is contemplated. Supplementary active constituents can also be incorporated into the compositions.

- 5           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  
10 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.
- 15 Including in the composition an agent that delays absorption, for example, monostearate salts and gelatin can bring about prolonged absorption of the injectable compositions.

Sterile injectable solutions can be prepared by incorporating the monoclonal antibodies in the required amount in an appropriate solvent with one or a combination of ingredients enumerated above, as required, followed by sterilization microfiltration.

- 20 Generally, dispersions are prepared by incorporating the antibodies 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  
25 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,  
30 human antibodies may be administered once or twice weekly by subcutaneous injection or once or twice monthly by subcutaneous injection.

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 antibodies calculated to produce the desired therapeutic effect in association with the required pharmaceutical carrier.

The specification for the dosage unit forms provided herein are dictated by and directly  
5 dependent on (a) the unique characteristics of the antibodies and the particular therapeutic effect to be achieved, and (b) the limitations inherent in the art of compounding such antibodies for the treatment of sensitivity in individuals.

Examples of pharmaceutically-acceptable antioxidants include: (1) water soluble  
10 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.

15 For the therapeutic compositions, formulations include those suitable for oral, nasal, topical (including buccal and sublingual), rectal, and parenteral administration. Parenteral administration is the most common route of administration for therapeutic compositions comprising antibodies. The formulations may conveniently be presented in unit dosage form and may be prepared by any methods known in the art of pharmacy.  
20 The amount of antibodies that 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. This amount of antibodies will generally be an amount sufficient to produce 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 antibody by  
25 mass, 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.

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,  
30 intraarterial, intrathecal, intraventricular, 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 provided herein 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  
5 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  
10 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 heagglutinin and neuraminidase derived from the influenza virus).

Prevention of presence of microorganisms may be ensured both by sterilization  
15 procedures 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 one or more agents that delay absorption  
20 such as aluminum monostearate or gelatin.

When compositions 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.

25 Regardless of the route of administration selected, compositions provided herein, may be used in a suitable hydrated form, and they may be formulated into pharmaceutically acceptable dosage forms by conventional methods known to those of skill in the art.

Actual dosage levels of the antibodies in the pharmaceutical compositions  
30 provided herein 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 level will depend upon a variety of pharmacokinetic factors including

the activity of the particular compositions employed, or the ester, salt or amide thereof, the route of administration, the time of administration, the rate of excretion of the particular compound 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 composition required. For example, the physician or veterinarian could start doses of the antibodies at levels lower than that required to achieve the desired therapeutic effect and gradually increasing the dosage until the desired effect is achieved. In general, a suitable daily dose of compositions provided herein will be that amount of the antibodies which is 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 antibodies to be administered alone, it is preferable to administer antibodies as a formulation (composition).

Therapeutic compositions can be administered with medical devices known in the art, such as, for example, those disclosed in U.S. Patent Nos. 5,399,163, 5,383,851, 5,312,335, 5,064,413, 4,941,880, 4,790,824, 4,596,556, 4,487,603, 4,486,194, 4,447,233, 4,447,224, 4,439,196, and 4,475,196.

In certain embodiments, the monoclonal antibodies 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 antibodies cross the BBB (if desired), they can be formulated, for example, in liposomes. For methods of manufacturing liposomes, see, *e.g.*, U.S. Patents 4,522,811; 5,374,548; 5,399,331; 5,891,468; 6,056,973; 6,210,707, 6,224,903; 6,316,024; 7,122,202; 7,135,177; and 7,507,407 and US Patent Publication 20070116753. The liposomes may comprise one or more moieties that attach to and/or are selectively transported into specific cells or organs, thus enhance targeted drug delivery.

Pharmaceutical compositions are provided that comprise trios of anti-EGFR antibodies at a 2:2:1 ratio, that is the composition comprises three different anti-EGFR antibodies, in particular a P1X-related antibody, a P2X-related antibody and a P3X-related antibody, which bind to different EGFR epitopes, formulated at a specific 2:2:1 ratio. In addition to the three antibodies, these pharmaceutical compositions can comprise a pharmaceutically acceptable carrier and/or other excipient(s) such as those described in detail above. The pharmaceutical composition can be supplied in a single container containing all three antibodies or, alternatively, the pharmaceutical composition can comprise a package comprising three distinct containers each containing one of the three different anti-EGFR antibodies (as well as a pharmaceutically acceptable carrier and/or other excipient(s) as described above).

Uses of the above-described anti-EGFR antibodies are provided, either alone (as single agents), in pair combinations (two antibodies), or in triple combinations (three antibodies) in the manufacture of a medicament for the treatment of a disease associated with EGFR dependent signaling. The above-described anti-EGFR antibodies are also provided, either alone (as single agents), in pair combinations (two antibodies), or in triple combinations (three antibodies) for the treatment of cancer (or to be used in the manufacture of a medicament for the treatment of cancer), such as an EGFR-expressing cancer, such as a cancer including, but not limited to melanoma, breast cancer, ovarian cancer, renal carcinoma, gastrointestinal cancer, colon cancer, lung cancer, pancreatic cancer, skin cancer, head and neck cancer glioblastoma, prostate cancer and other solid and/or metastatic tumors.

Additionally, contemplated compositions may further include, or be prepared for use as a medicament in combination therapy with, an additional therapeutic agent, *e.g.*, an additional anti-cancer agent. An “anti-cancer agent” is a drug used to treat tumors, cancers, malignancies, and the like. Drug therapy (*e.g.*, with antibody compositions disclosed herein) may be administered without other treatment, or in combination with other treatments such as surgery, heat, or radiation therapy (*e.g.*, with ionizing radiation). Several classes of anti-cancer agents may be used in cancer treatment, depending on the nature of the organ or tissue involved. For example, breast cancers are commonly stimulated by estrogens, and may be treated with drugs which inactivate sex hormones. Similarly, prostate cancer may be treated with drugs that inactivate androgens. Anti-cancer agents for use in combination with antibody compositions

disclosed herein include, among others, those listed in Appendix A, which should not be construed as limiting. One or more anti-cancer agents may be administered either simultaneously or before or after administration of an antibody composition disclosed herein. Antibody compositions disclosed herein can be administered sequentially or  
5 together with the additional anti-cancer agent, *e.g.*, an anti cancer agent disclosed in Appendix A, below.

Also provided are kits comprising one or more anti-EGFR antibodies disclosed herein, optionally contained in a single vial or container, and include, *e.g.*, instructions for use in treating or diagnosing a disease associated with EGFR upregulation and/or  
10 EGFR dependent signaling (*e.g.*, a cancer such as those described in subsection VI below). The kits may include a label indicating the intended use of the contents of the kit. The term label includes any writing, marketing materials or recorded material supplied on or with the kit, or which otherwise accompanies the kit. Such kits may comprise the antibody composition in unit dosage form, such as in a single dose vial or a  
15 single dose pre-loaded syringe. Kits comprising a combination of the anti-EGFR antibodies disclosed herein (*e.g.*, a combination of a P1X-related antibody, a P2X-related antibody, and a P3X-related antibody) can comprise a single vial containing all components of the combination or, alternatively, the kit can comprise each component in separate vials with instructions for administration of the antibodies in combination  
20 therapy. In a preferred embodiment, a P1X-related antibody, a P2X-related antibody, and a P3X-related antibody are supplied in a 2:2:1 ratio in a single vial or, alternatively, are supplied each in separate vials with instructions for administering the three antibodies at a 2:2:1 ratio.

## 25 VI. Methods of Using Antibodies

Antibodies and compositions disclosed herein can be used in a broad variety of therapeutic and diagnostic applications, particularly oncological applications. Accordingly, in another aspect, provided herein are methods for inhibiting EGFR activity in a subject by administering one or more antibodies or compositions described  
30 herein in an amount sufficient to inhibit EGFR-mediated activity. Particular therapeutic indications which can be treated include, for example, cancers of organs or tissues such as skin, brain and central nervous system, head and neck, esophagus, stomach, colon, rectum, anus, liver, pancreas, bile duct, gallbladder, lung or bronchus, breast, ovary,

uterus, cervix, vagina, testis, germ cells, prostate, kidney, ureter, urinary bladder, adrenal, pituitary, thyroid, bone, muscle or other connective tissues, leukemia, multiple myeloma, Hodgkin's lymphoma and non-Hodgkin's lymphoma.

Antibodies of disclosed herein also can be used to diagnose or prognose diseases  
5 (*e.g.*, cancers) associated with EGFR, for example, by contacting one or more antibodies, antibody pairs or antibody trios disclosed herein (*e.g.*, *ex vivo* or *in vivo*) with cells from the subject, and measuring the level of binding to EGFR on the cells, wherein abnormally high levels of binding to EGFR indicate that the subject has a cancer associated with EGFR.

10 Also provided are methods of using the anti-EGFR antibodies disclosed herein in a variety of *ex vivo* and *in vivo* diagnostic and therapeutic applications involving EGFR dependent signaling, including a variety of cancers.

Accordingly, in one embodiment, a method is provided for treating a disease associated with EGFR dependent signaling by administering to a subject an antibody or  
15 preferably a combination of antibodies provided herein 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, pancreatic cancer, skin cancer, head and neck cancer glioblastoma, prostate cancer and other solid and/or metastatic tumors.

20 The antibody can be administered alone or with another therapeutic agent that acts in conjunction with or synergistically with the antibody to treat the disease associated with EGFR mediated signaling. Such therapeutic agents include those described herein, for example, small organic molecules, monoclonal antibodies, bispecific antibodies, recombinantly engineered biologics, RNAi compounds, tyrosine  
25 kinase inhibitors, and commercial antibodies, as well as anticancer agents (*e.g.*, cytotoxins, chemotherapeutic agents, small molecules and radiation). Non-limiting examples of anti-cancer agents that can be used in combination therapy with one or more of the anti-EGFR antibodies disclosed herein include those listed in Appendix A.

Other embodiments are described in the following non-limiting Examples.  
30

## Examples

### Materials and Methods for The Examples

In general, in the following examples, unless otherwise indicated, conventional  
5 techniques of chemistry, molecular biology, recombinant DNA technology, immunology  
(especially, *e.g.*, antibody technology), and standard techniques in recombinant  
immunoglobulin preparation were used.

### Cell Lines

10 All the cell lines to be used in the experiments described below are obtained  
from the National Cancer Institute or ATCC.

#### Cell Lines:

A431 – epidermoid carcinoma

DU145 – prostate carcinoma

15 H1975 – lung adenocarcinoma; non-small cell lung cancer

HCC827 – lung adenocarcinoma; non-small cell lung cancer

### Protein Purification of EGFR Extracellular Domain (EGFR-ECD) Mutants

20 Mutants of the EGFR extracellular domain (EGFR-ECD) are generated for mAb  
epitope binning. Mutations were designed based upon both the cetuximab (Li S. *et al.*,  
Cancer Cell. **7**: 301-311, 2005) and H11 (Spangler J. *et al.* PNAS. **107**: 13252-13257,  
2010) epitopes and upon structural analysis of the EGFR-ECD structure (Protein Data  
Bank ID: 1NQL; Ferguson K.M. *et al.* Mol Cell. **11**: 507-517, 2003). Residues are  
25 mutated to alanines as noted in the protein sequences included in this application. DNA  
synthesis of expression constructs may be commercially obtained from DNA2.0  
(www.dna20.com). Subsequent DNA subcloning, protein expression in 293F cells and  
protein purification are completed using conventional methods.

### 30 Inhibition of EGF-Mediated Signaling of EGFR or ERK in Tumor Cells

Inhibition of ligand-mediated tumor cell signaling is investigated as follows:  
A431 or Du145 cells are seeded at a density of 35,000 cells/well or 17,500 cells per half  
well in 96 well tissue culture plates and grown in DMEM or RPMI-1640 medium  
supplemented with antibiotics, 2 mM L-glutamine and 10% fetal bovine serum (FBS)

for 24 hours at 37°C and 5% carbon dioxide. Cells are serum starved in 1% FBS medium with antibiotics and 2mM L-glutamine for about 20 hours at 37°C and 5% carbon dioxide. Cells are then preincubated with varying concentrations of anti-EGFR antibodies for 2 hrs, and then stimulated with human EGF ligand (50 ng/ml) (PeproTech, cat # AF-100-15) for 10 minutes at 37°C and 5% carbon dioxide. Cells are washed with ice-cold PBS and lysed in 50µl ice-cold Lysis buffer (Mammalian Protein Extract Lysis buffer (MPER-Pierce, #78505) amended with 150mM NaCl and protease inhibitor cocktail (Sigma, P714)) by incubating on ice for 30 minutes. Lysates are either analyzed immediately by ELISA for ERK (a downstream effector of EGFR) and EGFR phosphorylation, or frozen at -80°C until use.

### ELISA Assays

For the phospho-EGFR sandwich ELISA, 96-half well GREINER high binding plates (Cat. #675077; GREINER BIO-ONE, Monroe, NC) are coated with 50 µL of an EGFR antibody (EGFR Ab-11, Clone: 199.12, without BSA and azide, Fisher Scientific, cat# MS396P1ABX), and incubated overnight at room temperature. The next morning, the plates are washed 3 times with 100 µl/well PBST (0.05% Tween-20) on a BIOTEK plate washer. Plates are subsequently blocked for about 1 hour at room temperature with 2 % BSA in PBS. The plates are washed 3 times with 100 µl/well PBST (0.05% Tween-20) on the BIOTEK plate washer. Cell lysates (50µl) or standards (pEGFR pY1068 ELISA kit, R&D Systems, cat# DYC3570) are diluted in 50% Lysis buffer and 1% BSA-PBS (per the manufacturer's recommendations) and are added to the plates in duplicates and incubated for 2 hrs at room temperature or overnight at 4°C with shaking. Plates are then washed 3 times with 100 µl/well in the BIOTEK plate washer with PBST (PBS with 0.05% Tween-20). About 50 µl of a detection antibody conjugated to horse radish peroxidase (HRP) (pEGFR pY1068 ELISA kit, R&D Systems, cat# DYC3570) diluted in 2% BSA, PBS is added and incubated for about 2 hour at room temperature. The plate is washed 3 times with 100 µl/well in the BIOTEK plate washer with PBST (0.05% Tween-20). About 50 µL of SUPERSIGNAL PICO ELISA substrate is added and the plate is read using an Envision (Perkin Elmer) plate reader. For data analysis, duplicate samples are averaged and error bars are used to represent the standard deviation between the two replicates. Inhibition curves and corresponding IC50 values are calculated using GraphPad Prism software (GraphPad

Software, Inc.) via regression of the data to a 4 parameter logistic equation.

The phospho-ERK ELISA is performed similarly to the phospho-EGFR ELISA with the following changes: Human pERK ELISA DuoSet kit is purchased from R&D Systems (cat# DYC1018-5) and used as recommended by the manufacturer.

5 A direct ELISA is performed using EGFR-ECD wild-type (WT), a Bin1 epitope mutant, or a Bin3 epitope mutant as capture reagents (4 $\mu$ g/ml). 96-half well GREINER high binding plates (Cat. #675077; GREINER BIO-ONE, Monroe, NC) are coated with 50  $\mu$ L of capture reagent and incubated overnight at room temperature. Next morning, plates are washed 3 times with 100  $\mu$ l/well in a BIOTEK plate washer with PBST  
10 (0.05% Tween-20) and blocked for about 1 hour at room temperature with 1% BSA in PBS, pH7.2. Varying concentrations (1, 0.25, 0.06, and 0.02  $\mu$ g/ml) of monoclonal antibodies (mAbs) diluted in 1 % BSA in PBS, pH7.2 are incubated with the capture reagents at room temperature for 2 hours, followed by detection with 1:50,000 dilution in 1 % BSA in PBS, pH7.2 of Peroxidase-Conjugated AffiniPure Goat Anti-Human IgG  
15 Fc Fragment (Jackson Immunoresearch Catalog #109-035-008) for 2 hours. About 50  $\mu$ L of Supersignal PICO ELISA substrate is added and the plate is read using an Envision (Perkin Elmer) plate reader. For data analysis, duplicate samples are averaged and error bars are used to represent the standard deviation between the two replicates.

#### 20 Binding Affinity: Kinetic Exclusion Assay (KinExA)

Affinities and cross reactivity of antibodies are measured in solution with recombinant EGF receptor using KinExA instrumentation (SAPIDYNE Instruments, Boise, ID). Materials used for this assay are a KinExA 3000 instrument and software (Sapidyne Instruments, Boise, ID), polymethylmethacrylate (PMMA) beads (Sapidyne  
25 Instruments), human anti-EGFR IgG, recombinant human EGFR, Cy5-conjugated goat anti-human IgG (Jackson ImmunoResearch, West Grove, PA), phosphate buffered saline (PBS), and bovine serum albumin in PBS (100 mg/ml).

To couple the recombinant EGF receptor to PMMA beads, 100  $\mu$ g of recombinant EGFR is added to a pre-measured aliquot of 200 mg PMMA beads, and  
30 PBS is added to make the total volume 1 ml. The beads are incubated for 1 hr at room temperature on a rotating wheel. Then the beads are briefly centrifuged and the supernatant is removed. 100  $\mu$ l of 100 mg/ml BSA in PBS is added to the beads, with further addition of PBS to make a total volume of 1 ml. The beads are incubated again

for 1 hr at room temperature on a rotating wheel. The beads are then transferred to a glass bottle containing 27 mL of PBS.

To determine the monovalent antibody binding affinity, a twelve-step dilution series of recombinant EGFR (75 nM, 25 nM, 8.3 nM, 2.8 nM, 0.9 nM, 0.3 nM, 100 pM, 5 33 pM, 11 pM, 4 pM, 1.3 pM, 0 pM) is prepared in 5 ml PBS having a constant concentration of anti-EGFR antibody. For accurate affinity measurement, the total antibody binding site concentration (“ABC”; twice the molar concentration of antibody, due to valence) should be less than the monovalent affinity of the antibody for EGFR. The antibody-receptor mixtures are incubated for 2 hr at room temperature in order to 10 achieve equilibrium. Depending upon the expected affinity of the antibody-receptor complex, this equilibration time may be adjusted accordingly. In a separate tube, 15 mL of 2 µg/mL Cy5-conjugated anti-human IgG secondary antibody is prepared, using a 1:1000 dilution of stock (2 mg/mL) antibody into PBS. Then, the KinExA instrument lines are attached to each of the 12 antibody-receptor solution tubes. Each solution is 15 injected through a packed EGFR-bead column. (The KinExA instrument automatically packs a fresh bead column for each injection.) After a wash step, the labeled secondary antibody is passed through the column. Finally, using the measured amount of uncomplexed receptor at different receptor concentrations, the equilibrium titration data is fit to a 1:1 binding model in the KinExA software to yield an affinity value  $K_D$ . The 20 lower the value of  $K_D$  the better (stronger, sometimes stated as higher) the binding affinity. Therefore a recitation that an antibody binds with a  $K_D$  of x nM or better means it binds with a  $K_D$  value of, e.g.,  $1 \times 10^{-8}$  M (10 nM) or with a lower  $K_D$  value, e.g.,  $1 \times 10^{-10}$  M (0.1 nM), with the lower  $K_D$  value indicating better (higher) affinity.

To determine the binding on-rate using the KinExA “direct method”, the 25 equilibrium monovalent binding affinity ( $K_D$ ) is determined using the above approach and total antibody binding site concentration (ABC). Then, using the “Theoretical Binding Curve Demonstration” software (Sapidyne Instruments), the starting antigen concentration ( $L_0$ ) is determined for the kinetics experiment. To do this, the affinity and ABC values determined in the monovalent binding affinity experiment are entered, and 30 a starting antigen concentration is selected as that concentration where roughly 20% of antibody will be unbound to antigen at equilibrium. This assures good signal-to-noise ratio in the experiment. 15 mL of 2 µg/mL Cy5-conjugated anti-human IgG secondary antibody is prepared, using a 1:1000 dilution of stock (2 mg/mL) antibody into PBS. In

a separate tube, 8 mL of anti-EGFR antibody solution is prepared at a concentration of 2 x ABC. This concentration is double the running concentration, since it is mixed with 8 mL of antigen solution prior to the experiment. In a separate tube, 8 mL of recombinant EGFR solution is prepared at a concentration of 2 x L0. This concentration is also double the running concentration, since it is mixed with 8 mL of antibody solution prior to the experiment. Then, the EGFR coated beads and secondary antibody solution are placed in the appropriate container and line, respectively. The antibody and antigen solution are mixed thoroughly and immediately connected to the appropriate line, and the KinExA software is used to measure the amount of free antibody as a function of time in the resulting solution. To determine the association constant  $k_{on}$  ( $K_{on}$ ), the KinExA software is used to fit the depletion of the amount of free antibody as a function of time to a reversible bimolecular rate equation. The dissociation constant  $K_{off}$  ( $K_{off}$ ) is equal to the  $K_{on} * K_D$  ( $K_d$ ).

#### 15 Binding Affinity: Surface Plasmon Resonance Assay

The Surface Plasmon Resonance Assay is performed as follows:

either antibody or antigen (300 RU) is immobilized on a CM5 chip using amine coupling. Different concentrations of antibodies or antigens are then injected to study their association and dissociation with the immobilized protein. Between different injections, the chip is regenerated using suitable regeneration buffer (such as glycine, pH 2.5). The dissociation phase is fitted using Equation 1 to determine  $K_{off}$  (dissociate rate):

$$R = R_0 * \exp(-K_{off} * t) \quad (1)$$

The association phase is fitted using this value of  $K_{off}$  and Equation 2 to determine  $K_{on}$  (association rate) and  $K_D$  (equilibrium constant).

$$R = \frac{R_{max} * C}{K_D + C} (1 - \exp(-(K_{on} * C + K_{off})t)) \quad (2)$$

where  $C$  represents either the antigen or antibody concentration in solution,  $R_{max}$  represents the saturation signal and  $t$  represents the time.

#### Epitope Binning: Surface Plasmon Resonance Assay

30 Epitope binning is performed using surface plasmon resonance assay, as described above. One of the antibodies is immobilized on the surface of the chip. Recombinantly expressed human EGFR extracellular domain (EGFR-ECD) is then injected. As EGFR-ECD associates with the antibody conjugated to the surface of the

chip, the resonance signal increases. Sequential injections of antibodies that belong to the three bins 1, 2 and 3 are performed. If the antibody binds overlapping epitopes with the injected antibody, then the signal will not change compared to the previous injection. If the antibody binds to a non-overlapping epitope, the signal on the chip will be higher than the previous injection. The antibody conjugated to the chip is finally injected as free ligand to confirm lack of binding with overlapping epitopes.

### Cell Binding Assay

Cell binding assays for determining the  $K_D$  values are performed as follows:

10 A431 cells are detached with 3 mLs trypsin-EDTA at 37 °C for 5 minutes. Complete DMEM (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 stain buffer (PBS + 0.2% BSA+ 0.1% sodium azide) at a concentration of  $2 \times 10^6$  cells per ml and 50  $\mu$ l ( $1 \times 10^5$  cells) aliquots are plated in a 96-well titer plate.

15 A 300  $\mu$ l stock solution of 2000 nM anti-EGFR antibody is prepared in stain buffer and 100  $\mu$ l of it is serially diluted into 200  $\mu$ l of stain buffer. The concentrations of the diluted antibody range from 2000 nM to 0.1 nM. 150  $\mu$ l aliquots of the different protein dilutions are then added directly to the 50  $\mu$ l cell suspension giving final concentrations of 1500 nM, 500 nM, 166.7 nM, 55.6 nM, 18.5 nM, 6.17 nM, 2.05 nM, 20 0.68 nM, 0.23 nM and 0.076 nM antibody.

Aliquoted cells in the 96-well plate are incubated with the antibody dilutions for 2 hr at room temperature with shaking and washed 3 times with 300  $\mu$ l stain buffer. Cells are then incubated with 100  $\mu$ l of a 1:750 dilution of Alexa 647-labeled goat anti-human IgG in BD stain buffer for 45 minutes with shaking at 4°C. Finally, cells are washed twice, pelleted and resuspended in 250  $\mu$ l stain buffer + 0.5  $\mu$ g/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-EGFR-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.

30 The  $K_D$  value is calculated based on the formula  $Y = B_{max} * X / K_D + X$  ( $B_{max}$  = fluorescence at saturation.  $X$  = antibody concentration.  $Y$  = degree of binding).

### Measurement of EGFR levels via immunoblotting

To prepare cell lysates, H1975 cells are trypsinized, harvested, counted, and plated in 6 well dishes at  $1 \times 10^6$  cells per well and incubated overnight to allow attachment to the culture plate. Cells are pre-treated with  $1 \mu\text{M}$  concentration of

5 P1X+P2X+P3X (P1X+P2X+P3X or P1X, P2X, & P3X indicates a combination at a 2:2:1 molar ratio of P1X, P2X, and P3X) for 1, 2, 5, and 24 hours before stimulation with rhEGF (Peprotech, cat# 100-15) for 10 minutes. Cells are lysed with  $100 \mu\text{l}$  of Mammalian Protein Extraction Reagent (Pierce, cat# 78505). Protein extraction reagent is supplemented with PhosSTOP (Roche, cat# 04906837001) and Protease Inhibitor

10 Cocktail tablets (Roche, cat# 04693124001). Extracts of H1975 cells are denatured by boiling for 5 minutes in sample buffer, subjected to reducing conditions, and electrophoresed using SDS-PAGE 4-12% polyacrylamide gels for 50 minutes at 200V. Following transfer of proteins to a nitrocellulose membrane, nonspecific sites are blocked by incubation with Odyssey blocking buffer (LI-COR, cat# 927-400-00) for one

15 hour at room temperature. Membranes are incubated as required with mouse monoclonal anti-EGFR (1F4 – labeling tEGFR; Cell Signaling, cat# 2239); rabbit monoclonal anti-phospho44/42 MAPK (Erk1/2, Thr202/Tyr204, D13.14.4E – labeling pERK; Cell Signaling, cat# 4370); rabbit monoclonal anti-phosphoAKT (Ser473, 193H12; Cell Signaling, cat# 4058); rabbit monoclonal phospho-c-Jun (Ser73, D47G9 –

20 labeling p-c-Jun; Cell Signaling, cat# 3270) and rabbit anti-PCNA (FL-261) (Santa Cruz Biotechnology, cat# sc-7907). Following overnight incubation with the primary antibodies, immunoblots are incubated with the appropriate IRDye-labeled secondary antibody (IR800CW goat anti-mouse (Odyssey, cat# 926-3210) or IR800CW goat anti-rabbit (Odyssey, cat#926-3211)) for 10 minutes and vacuumed through the membrane

25 using SNAP i.d., Protein Detection System (Millipore). Bands are detected using LI-COR Odyssey Infrared Imaging System and analyzed using Odyssey software.

### Inhibition of Tumor Cell Proliferation *In Vitro*

Inhibition of cellular proliferation of cells expressing EGFR is examined *in vitro*

30 as follows: HCC827 and H1975 cancer cells are seeded in 96 well tissue culture plates at 5,000 cells per well and grown in RPMI-1640 medium supplemented with antibiotics, 2mM L-glutamine and 10% fetal calf serum (FCS) for 24 hours at  $37^\circ\text{C}$  and 5% carbon dioxide. Medium is then switched to RPMI-1640 (with antibiotics, 2mM L-glutamine,

1% FBS) supplemented with 50ng/mL EGF or 200ng/ml AREG (amphiregulin; R&D Systems) in the presence of varying concentrations of P1X+P2X+P3X or cetuximab (Bristol-Myers Squibb). Cell viability is measured using the CellTiter-Glo® (CTG) Luminescent Cell Viability Assay (Promega Corporation, cat# G7572) according to manufacturer's instructions. The CTG assay measures the number of viable cells in culture based upon quantitation of ATP present, which is an indicator of metabolically active cells. Control treatments include cells treated with RPMI-1640 with antibiotics, 2mM L-glutamine, 1% FCS in the presence (referred to as "+EGF" or "+AREG") or absence (referred to as "-EGF" or "-AREG") of 50ng/mL EGF or 200ng/ml AREG.

10

#### DU145 & H1975 Mouse Xenograft Studies

A combination of P1X, P2X, and P3X Nu/nu mice (Charles River Labs) are injected subcutaneously with cells. The resultant tumors are allowed to grow until they reach an average size of 300mm<sup>3</sup>. Dosing is then initiated with the indicated concentrations of combinations of P1X with P2X, and P3X, cetuximab or matched volume of PBS as vehicle control. Measurements are taken at 4 day intervals and tumor volumes calculated using the formula  $Volume = \pi/6x(WxL^2)$ . Cetuximab and P1X+P2X+P3X doses are normalized to provide uniform serum exposures.

Efficacy of a combination of P1X with P2X, and P3X *in vivo* is assessed in a DU145 prostate cancer cell xenograft murine mouse model. 8x10<sup>6</sup> DU145 cells are injected subcutaneously into the flank of nu/nu mice. Once tumors reach an average size of 300mm<sup>3</sup>, treatment is initiated. Groups of 10 mice are treated with either vehicle control (PBS); 2.075mg/kg of cetuximab, P1X with P2X, and P3X at component concentrations that were at a "murine ratio" designed to provide a 2:2:1 C<sub>max</sub> for P1X, for P2X and for P3X, respectively, in the mouse, as follows : P1X=2.53mg/kg, P2X=7.26mg/kg and P3X=0.66mg/kg. Mice in the cetuximab group are dosed every four days. Mice in the P1X+P2X+P3X group are dosed every two days. These doses and dosing intervals are chosen to give an equivalent serum exposure of cetuximab and the murine ratio antibody trio.

30

### Ligand Antagonism Cell Binding Assay

Cell binding assays for determining the binding of EGF ligand in the presence of single or multiple antibodies are performed as follows: A431 cells are detached with 5 mL trypsin-EDTA at 37 °C for 5 minutes. Complete DMEM (10 mL) is added immediately to the trypsinized cells, resuspended gently and spun down in a Beckman tabletop centrifuge at 1200 rpm for 7 minutes. Cells are resuspended in stain buffer (PBS + 2% FBS + 0.1% sodium azide) at a concentration of  $3 \times 10^5$  cells per ml and 100  $\mu$ l ( $3 \times 10^4$  cells) aliquots are plated in a 96-well titer plate.

A 5 mL 2x stock solution of anti-EGFR antibody is prepared in stain buffer at the concentrations indicated in each example. A 10 mL 3x stock solution of recombinant human EGF ligand conjugated to a biotin tag (biotin-EGF) is prepared in stain buffer and 100  $\mu$ l of it is serially diluted into 200  $\mu$ l of stain buffer. The concentrations of the diluted biotin-EGF range from 600 nM to 9 pM. 100  $\mu$ l aliquots of the anti-EGFR antibody are then added directly to the 100  $\mu$ l cell suspension giving a final concentration as indicated in each example. Aliquoted cells in the 96-well plate are incubated with the antibody dilutions for 1 hr at room temperature. 100  $\mu$ l aliquots of the biotin-EGF are then added directly to the 100  $\mu$ l cell suspension giving a final concentration of 200 nM, 66.67 nM, 22.22 nM, 7.41 nM, 2.47 nM, 0.82 nM, 0.27 nM, 0.09 nM, 0.03 nM, 0.01 nM, and 0.003 nM biotin-EGF. Aliquoted cells in the 96-well plate are incubated with the antibody and biotin-EGF dilutions for 10 min at room temperature, washed 1 time with 100  $\mu$ l stain buffer, and then spun down in a Beckman tabletop centrifuge at 1200 rpm for 7 minutes. Cells are resuspended in 100  $\mu$ l of a 1:500 dilution of Alexa Fluor® 647 Streptavidin conjugate (Invitrogen Life Technologies) in stain buffer for 30 minutes at room temperature in the dark. Finally, cells are washed twice with 100  $\mu$ l stain buffer, pelleted and resuspended in 80  $\mu$ l fixing buffer (PBS + 2% FBS + 2% paraformaldehyde) and transferred to 96-well U-bottom Assay Plates (Becton Dickinson) and sealed with foil and stored at 4°C.

Analysis of 10,000 cells is done in a FACSCALIBUR flow cytometer using the FL4 channel. Data are analyzed using WinList 6.0 software. Mean Fluorescence Intensity (MFI) values and the corresponding concentrations of the biotin-EGF ligand are plotted on the y-axis and x-axis, respectively.

**Example 1: Epitope mapping/binning**

Antibodies P1X, P2X, and P3X were generated via affinity maturation of parental antibodies. Respective parental antibodies ca, cd, and ch are disclosed in copending patent application Serial No. PCT/US2011/3528. Epitope mapping and binning experiments were performed to demonstrate that P1X, P2X, and P3X share the same non-overlapping epitopes as their respective parental molecules.

The Bins were designed so that selected antibodies would span three distinct, non-overlapping epitopes on the extracellular domain (ECD) of EGFR. These are grouped into three bins: Bin1 is mapped to Domain III of EGFR and represents the c225 epitope (the site of cetuximab binding); Bin2 is mapped to Domain I and represents the ICR10 epitope (Abcam Ab231) (Cochran *et al.* (2004) Journal of Immunological Methods, 287:147-158); and Bin3 is mapped to Domain III and represents the clone H11 epitope (Spangler J. *et al.* PNAS. **107**: 13252-13257, 2010). Bin1 (B1-7MT-Ala) and Bin3 (B3-4MT) mutants were generated for epitope mapping at the amino acid positions shown below in bold in the EGFR extracellular domain.

EGFR ECD (SEQ ID NO: 33)

```

1   MRPSGTAGAA LLALLAALCP ASRALEEKV CQGTSNKLTQ LGTFEDHFLS LQRMFNCEV
61  VLGNIETIYV QRNYDLSFLK TIQEVAGYVL IALNTVERIP LENLQIIRGN MYYENSYALA
121 VLSNYDANKT GLKELPMRNL QEILHGAVRF SNNPALCNEVE SIQWRDIVSS DFLSNMSMDF
20 181 QNHLGSCQKC DPSCPNGSCW GAGEENCQKL TKIICAQQCS GRCRGKSPSD CCHNQCAAGC
241 TGPRESDECLV CRKFRDEATC KDTCPPLMLY NPTTYQMDVN PEGKYSFGAT CVKKCPRNYV
301 VTDHGSCVRA CGADSYEMEE DGVRKCKKCE GPCRKVCNGI GIGEFKDSLS INATNIKHFK
361 NCTSISGDLH ILPVAFRGDS FTHTPLDPQ ELDILKTVKE ITGFLLIQAW PENRTDLHAF
421 ENLEIIRGRT KQHGQFSLAV VSLNITSLGL RSLKEISDGD VIISGNKNLC YANTINWKKL
25 481 FGTSGQKTKI ISNRGENSCK ATGQVCHALC SPEGCGWPEP RDCVSCRNVS RGRECVDKCN
541 LLEGEPREFV ENSECIQCHP ECLPQAMNIT CTGRGPDNCI QCAHYIDGPH CVKTCPAGVM
601 GENNTLVWKY ADAGHVCHLC HPNCTYGTCTG PGLEGCPTNG PKIPSHHHHH H
    
```

The following substitution mutants were made at the bolded amino acid positions using standard recombinant DNA technology to create the Bin1 (B1) and Bin3 (B3) epitope mutants with the following mutant residues:

Mutants  
 Bin1 (B1) Mutant Residues  
 B1-7MT-Ala: Q408A, Q432M, H433E, K467A, K489A, I491A, N497A  
 Bin3 (B3) Mutant Residues  
 B3-4MT: S380A, F381G, T382A, H383G

A direct ELISA was performed using EGFR-ECD wild-type (WT), a Bin1 epitope mutant (c225 epitope), or a Bin3 epitope mutant (H11 epitope) as capture reagents. Varying concentrations (1, 0.25, 0.06, and 0.02 µg/ml) of monoclonal

antibodies (mAbs) P1X (Bin1), P2X (Bin2), and P3X (Bin3) were incubated with the capture reagents at room temperature for 2 hours, followed by detection with HRP-conjugated anti-human Fc polyclonal antibody for 1 hour. As shown in Figure 1A, all three antibodies bound to the WT extracellular domain of EGFR, whereas the Bin1 antibody P1X did not bind to the Bin1 mutant epitope, and the P3X antibody did not bind to the Bin3 mutant epitope.

A surface plasmon resonance experiment was performed to demonstrate that P2X associates to the ICR10 epitope on Domain I of EGFR extracellular domain (Figure 1B). ICR10 was conjugated to the surface of a BIACORE chip. 0.5  $\mu$ M EGFR-ECD was injected followed by sequential injections of 0.5  $\mu$ M of antibodies P1X (Bin1), P2X (Bin2), and P3X (Bin3). While P1X and P3X are observed to simultaneously associate with ICR10-bound EGFR-ECD, P2X is shown to not associate.

In order to demonstrate that the epitopes for P1X, P2X, and P3X are distinct and non-overlapping, a series of three surface plasmon resonance binning experiments were performed. P1X (Figure 2A), P2X (Figure 2B), or P3X (Figure 2C) were conjugated to the surface of a BIACORE chip. 0.5  $\mu$ M EGFR-ECD was injected followed by sequential injections of 0.5  $\mu$ M of antibodies P3X, P2X, and P1X. Injection of the same antibody as conjugated on the BIACORE chip serves as a negative control. In all three experiments, the two antibodies from the remaining bins are observed to associate with EGFR-ECD. Thus, the results of the three experiments demonstrate that P1X, P2X, and P3X have non-overlapping, distinct epitopes and can simultaneously associate with EGFR-ECD.

### **Example 2: Binding affinities**

The monovalent affinities of P1X, P2X, and P3X to EGFR were measured by KinExA. Data are shown below in Table 1. Affinities of P1X, P2X, and P3X are all better than 0.4 nM and are all improved relative to the parent molecules. The affinity of P1X (11pM) is 13.18 times better than the Bin 1 parent molecule ca (145pM). The affinity of P2X (70pM) is 7.71 times better than the Bin 2 parent molecule cd (540pM). The affinity of P3X (360pM) is 2.10 times better than the Bin 3 parent molecule ch (757pM).

**Table 1**

Antibody	Association Rate (1/M*sec)	Dissociation Rate (1/sec)	K <sub>D</sub> (M)
P1X	3.73E+06	4.10E-05	1.10E-11
ca (P1X parent)	<i>N.D.</i>	<i>N.D.</i>	1.45E-10
P2X	7.06E+05	4.94E-05	7.00E-11
cd (P2X parent)	9.62E+05	5.20E-04	5.40E-10
P3X	1.16E+06	4.16E-04	3.60E-10
ch (P3X parent)	5.87E+05	4.44E-04	7.57E-10

**Example 3: Cell binding assays with single antibodies**

A cell binding assay was performed to demonstrate that monoclonal antibodies P1X, P2X, and P3X can associate with EGFR on A431 cells (Figure 3). A431 cells were incubated with a dilution series of single antibody for 2 hr and the amount of bound antibody measured by quantitative flow cytometry, as described in the methodology section above. The concentrations used in the dilution series for the antibodies are shown below in Table 2. The ordinarily skilled artisan will understand that each specific concentration value in Table 2 is subject to some minor experimental variability, so that each specific concentration given indicates a value of about the indicated concentration (*e.g.*, a concentration indicated in a table as 0.1 nM represents a value of about 0.1 nM).

**Table 2**

Conc, Log(Molar)	Conc, nM
-7.00	100.00
-7.48	33.33
-7.95	11.11
-8.43	3.70
-8.91	1.23
-9.39	0.41
-9.86	0.14
-10.34	0.05
-10.82	0.02
-11.29	0.01
-11.77	0.00

The on-cell binding affinities under these experimental conditions were calculated, via regression to a 4 parameter logistic equation using GraphPad Prism® software, to be 168pM (P1X), 340pM (P2X) and 748pM (P3X).

**Example 4: Phospho-EGF receptor signaling inhibition by single antibodies**

A431 cells were treated with single antibodies and their ability to inhibit EGF-dependent phospho-EGFR activity was measured by phospho-EGFR ELISA. P1X and P2X potently inhibit phospho-EGFR activity in a dose-dependent manner, with respective IC<sub>50</sub> values of 3.09nM and 4.19nM, while treatment with P3X elicits partial phospho-EGFR inhibition (Figure 4). The concentrations used in the dilution series for the antibodies are shown below in Table 3. The ordinarily skilled artisan will understand that each specific concentration value in Table 3 is subject to some minor experimental variability, so that each specific concentration given indicates a value of about the indicated concentration (*e.g.*, a concentration indicated in a table as 0.1 nM represents a value of about 0.1 nM).

**Table 3**

Conc, Log(Molar)	Conc, nM
-6.60	250.00
-7.20	62.50
-7.81	15.62
-8.41	3.91
-9.01	0.98
-9.61	0.24
-10.21	0.06
-10.82	0.02
-11.42	0.00

15 **Example 5: Phospho-ERK signaling inhibition by single and pairwise combinations of antibodies and comparison to parental antibodies**

A431 cells were treated with a dilution series of single P1X or ca antibody and phospho-ERK inhibition measured by phospho-ERK ELISA (Figure 5A). P1X elicited dose-dependent inhibition of phospho-ERK activity while the ca parental antibody elicited only partial inhibition.

A431 cells were treated with a dilution series of pairwise combinations of P1X+P3X or their respective parent antibodies ca+ch and phospho-ERK inhibition measured by phospho-ERK ELISA (Figure 5B). Both combinations inhibit phospho-ERK generation in a dose-dependent manner, but the combination of P1X+P3X provides superior inhibition. The combination of P1X+P3X elicited 82% inhibition of phospho-

ERK activity while the parental combination elicited only 71%, as calculated by a fit to a 4 parameter logistic equation using GraphPad Prism software.

A431 cells were treated with a dilution series of pairwise combinations of P1X+P2X or their respective parent antibodies ca+cd and phospho-ERK inhibition  
 5 measured by phospho-ERK ELISA (Figure 5C). Both combinations inhibit phospho-ERK generation in a dose-dependent manner, but the combination of P1X+P2X demonstrates an observable improvement in the IC<sub>90</sub> value versus the parental combination.

The concentrations used in the dilution series for the antibodies are shown below  
 10 in Table 4 (for the data in Figure 5A) and in Table 5 (for the data in Figures 5B and 5C). The ordinarily skilled artisan will understand that each specific concentration value in Tables 4 and 5 is subject to some minor experimental variability, so that each specific concentration given indicates a value of about the indicated concentration (*e.g.*, a concentration indicated in a table as 0.1 nM represents a value of about 0.1 nM).

15 **Table 4**

Conc, Log(Molar)	Conc, nM
-5.70	2000.00
-6.18	666.67
-6.65	222.22
-7.13	74.07
-7.61	24.69
-8.21	6.17
-8.81	1.54
-9.41	0.39
-10.02	0.10

**Table 5**

Conc, Log(Molar)	Conc, nM
-5.69897	2000.00
-6.176091	666.67
-6.653213	222.22
-7.130334	74.07
-7.607455	24.69
-8.209515	6.17
-8.811575	1.54
-9.413635	0.39
-10.01569	0.10
-10.61775	0.02

It is noted that the concentrations shown in Table 5 are total concentrations for the pairs of antibodies used. The ratio used is 1:1 so each individual antibody in the pair comprises half of the total concentration.

**Example 6: Phospho-ERK signaling inhibition by different combination ratios of P1X, P2X, and P3X**

A431 cells were treated with a dilution series of P1X and phospho-ERK inhibition measured by ELISA (Figure 6A). The concentrations used in the dilution series for the antibodies are shown below in Table 6. The ordinarily skilled artisan will understand that each specific concentration value in Table 6 is subject to some minor experimental variability, so that each specific concentration given indicates a value of about the indicated concentration (*e.g.*, a concentration indicated in a table as 0.1 nM represents a value of about 0.1 nM).

**Table 6**

Conc, Log(Molar)	Conc, nM
-5.69897	2000.00
-6.176091	666.67
-6.653213	222.22
-7.130334	74.07
-7.607455	24.69
-8.084577	8.23
-8.561698	2.74
-9.038818	0.91
-9.51594	0.30
-9.993061	0.10

The experiment was carried out as described in the methodology section. Under these experimental conditions, P1X inhibits 81% of phospho-ERK activity at saturating doses with an IC<sub>50</sub> value of about 25 nM (27nM). Therefore the approximate location on the plot of the IC<sub>50</sub> is indicated in Figure 6A by “25nM” and 25 nM was set as the constant concentration of P1X in the following experiments.

A431 cells were treated with dilution series of 5 combination ratios of P3X + P2X in combination with a constant P1X concentration of 25nM and phospho-ERK inhibition measured by ELISA (Figure 6B). The concentrations used in the dilution series for the antibodies are shown below in Table 7. The ordinarily skilled artisan will understand that each specific concentration value in Table 7 is subject to some minor experimental variability, so that each specific concentration given indicates a value of

about the indicated concentration (*e.g.*, a concentration indicated in a table as 0.1 nM represents a value of about 0.1 nM).

**Table 7**

Conc, Log(Molar)	Conc, nM
-5.69897	2000.00
-6.176091	666.67
-6.653213	222.22
-7.130334	74.07
-7.607455	24.69
-8.084577	8.23
-8.561698	2.74
-9.038818	0.91
-9.51594	0.30
-9.993061	0.10

It is noted that the concentrations shown in Table 7 are total concentrations for

5 P2X+P3X. The individual concentration of P2X and P3X is dependent on the indicated ratio. The experiment was carried out as described in the methodology section. The ratios of P3X:P2X used were 1:0, 0:1, 1:2, 2:1, and 1:1. All ratios inhibited greater than 70% of phospho-ERK activity, with those combinations containing all three antibodies providing the highest degree of inhibition.

10 A431 cells were treated with dilution series of 6 combination ratios of P1X:P2X:P3X and phospho-ERK inhibition measured by ELISA (Figure 6C). The concentrations used in the dilution series for the antibodies are shown below in Table 8. The ordinarily skilled artisan will understand that each specific concentration value in  
 15 concentration given indicates a value of about the indicated concentration (*e.g.*, a concentration indicated in a table as 0.1 nM represents a value of about 0.1 nM).

**Table 8**

LogM	nM	Ratio (P1X:P2X:P3X)					
		1:0.01:1	1:0.1:1	1:1:1	2:0.1:1	2:0.1:1	2:2:1
-10.8148	0.0153	X					
-10.8141	0.0153				X		
-10.7958	0.0160		X				
-10.7889	0.0163					X	
-10.6409	0.0229			X			

-	10.5951	0.0254					X
-	10.3377	0.0460	X				
-	10.3370	0.0460			X		
-	10.3187	0.0480		X			
-	10.3118	0.0488				X	
-	10.1638	0.0686			X		
-	10.1180	0.0762					X
-	-9.8606	0.1379	X				
-	-9.8598	0.1381			X		
-	-9.8415	0.1440		X			
-	-9.8347	0.1463				X	
-	-9.6866	0.2058			X		
-	-9.6409	0.2286					X
-	-9.3834	0.4136	X				
-	-9.3827	0.4143			X		
-	-9.3644	0.4321		X			
-	-9.3576	0.4390				X	
-	-9.2095	0.6173			X		
-	-9.1638	0.6859					X
-	-8.9063	1.2407	X				
-	-8.9056	1.2428			X		
-	-8.8873	1.2963		X			
-	-8.8805	1.3169				X	
-	-8.7324	1.8519			X		
-	-8.6866	2.0576					X
-	-8.4292	3.7222	X				
-	-8.4285	3.7284			X		
-	-8.4102	3.8889		X			
-	-8.4033	3.9506				X	
-	-8.2553	5.5555			X		
-	-8.2095	6.1728					X
-	-7.9521	11.1667	X				
-	-7.9514	11.1852			X		
-	-7.9331	11.6667		X			
-	-7.9262	11.8518				X	
-	-7.7782	16.6667			X		
-	-7.7324	18.5185					X
-	-7.4750	33.5000	X				
-	-7.4742	33.5555			X		
-	-7.4559	35.0000		X			
-	-7.4491	35.5556				X	
-	-7.3010	50.0000			X		

-7.2553	55.5556						X
-6.9978	100.5000	X					
-6.9971	100.6667				X		
-6.9788	104.9999		X				
-6.9720	106.6665					X	
-6.8239	149.9999			X			
-6.7782	166.6668						X
-6.5207	301.4998	X					
-6.5200	302.0000				X		
-6.5017	315.0003		X				
-6.4949	320.0000					X	
-6.3468	450.0005			X			
-6.3010	500.0000						X

The experiment was carried out as described in the methodology section. The ratios of P1X:P2X:P3X used were 1:0.01:1, 1:0.1:1, 1:1:1, 2:0.01:1, 2:0.1:1, and 2:2:1. All ratios inhibited greater than 70% of phospho-ERK activity.

A431 cells were treated with dilution series of 5 combination ratios of P1X:P2X and phospho-ERK inhibition measured by ELISA (Figure 6D). The concentrations used in the dilution series for the antibodies are shown below in Table 9. The ordinarily skilled artisan will understand that each specific concentration value in Table 9 is subject to some minor experimental variability, so that each specific concentration given indicates a value of about the indicated concentration (*e.g.*, a concentration indicated in a table as 0.1 nM represents a value of about 0.1 nM).

**Table 9**

Conc, Log(Molar)	Conc, nM
-6.522879	300.00
-7	100.00
-7.477121	33.33
-7.954243	11.11
-8.431364	3.70
-8.908485	1.23
-9.385606	0.41
-9.862727	0.14
-10.33985	0.05
-10.81697	0.02

It is noted that the concentrations shown in Table 9 are total concentrations for P1X+P2X. The individual concentration of P1X and P2X is dependent on the indicated ratio. The experiment was carried out as described in the methodology section. The ratios of P1X:P2X used were 1:2, 5:1, 9:1, 50:1, and 1:5. All ratios except 1:5

(P1X:P2X) inhibited greater than 70% of phospho-ERK activity within the concentration range used in the experiment. However, fitting a 4 parameter logistic inhibition curve to the 1:5 ratio (P1X:P2X) data predicts that this combination will achieve 70% phospho-ERK inhibition at a concentration of 35.7nM, marginally higher than the dose used in the experiment and well within the range achievable under physiological conditions.

**Example 7: Phospho-EGFR and Phospho-ERK signaling inhibition by a 2:2:1 ratio combination of P1X, P2X, and P3X**

A431 cells were treated with a dilution series of a 2:2:1 molar ratio combination of antibodies P1X, P2X, and P3X (this combination at this molar ratio is referred to herein as “P1X+P2X+ P3X”) and phospho-EGFR and phospho-ERK inhibition measured by ELISA (Figure 7A). The concentrations used in the dilution series for the antibodies are shown below in Table 10. The ordinarily skilled artisan will understand that each specific concentration value in Table 10 is subject to some minor experimental variability, so that each specific concentration given indicates a value of about the indicated concentration (*e.g.*, a concentration indicated in a table as 0.1 nM represents a value of about 0.1 nM).

**Table 10**

Conc, Log(Molar)	Conc, nM
-6.30	500.00
-6.78	166.67
-7.26	55.56
-7.73	18.52
-8.21	6.17
-8.69	2.06
-9.16	0.69
-9.64	0.23
-10.12	0.08
-10.60	0.03

It is noted that the concentrations shown in Table 10 are total concentrations for P1X+P2X+P3X. The ratio used is 2:2:1, so the individual concentrations of P1X, P2X and P3X are 40%, 40% and 20%, respectively. Experiments were carried out as described in the methodology section. The combination of three antibodies is a potent

inhibitor of both phospho-EGFR and phospho-ERK activities, with respective IC<sub>50</sub> values of 2.30nM and 9.87nM.

P1X+P2X+ P3X was compared to P1X single (Figure 7B) and P2X single (Figure 7C). A431 cells were treated with a dilution series of antibody and phospho-  
 5 ERK inhibition measured by ELISA. The concentrations used in the dilution series for the antibodies for the experiments shown in Figures 7B and 7C are shown below in Table 11. The ordinarily skilled artisan will understand that each specific concentration value in Table 11 is subject to some minor experimental variability, so that each specific concentration given indicates a value of about the indicated concentration (*e.g.*, a  
 10 concentration indicated in a table as 0.1 nM represents a value of about 0.1 nM).

**Table 11**

Conc, Log(Molar)	Conc, nM
-5.69897	2000.00
-6.176091	666.67
-6.653213	222.22
-7.130334	74.07
-7.607455	24.69
-8.084577	8.23
-8.561698	2.74
-9.038818	0.91
-9.51594	0.30
-9.993061	0.10

It is noted that the concentrations shown in Table 11 are total concentrations for P1X+P2X+P3X. The ratio used is 2:2:1, so the individual concentrations of P1X, P2X and P3X are 40%, 40% and 20%, respectively. Experiments were carried out as  
 15 described in the methodology section with the exception that 80nM of EGF ligand was used to stimulate cells. The 2:2:1 ratio combination of antibodies is a potent inhibitor of phospho-ERK activity compared to P1X and P2X, which respectively provide partial and no inhibition.

20 **Example 8: EGF receptor down-regulation and inhibition of pERK, pAKT and p-c-Jun signaling in H1975 cells following treatment with P1X+P2X+P3X**

Cells were pre-incubated for 2 hours with of P1X+P2X+P3X equaling 1μM total antibody prior to stimulation with 50 ng/ml rhEGF (PeproTech) for 10 minutes, as described in the methodology section above. Immunoblots of cell lysates were

separately probed with antibodies against tEGFR, pERK, pAKT or p-c-Jun and densitometry of the bands was normalized to the loading control PCNA and to lysates of control untreated cells. EGF receptor down-regulation in response to P1X+P2X+P3X treatment is shown in Figure 8A and inhibition of pERK, pAKT and p-c-Jun signaling in response to P1X+P2X+P3X treatment is shown in Figure 8B.

### **Example 9: Inhibition of tumor cell proliferation in vitro**

Inhibition of tumor cell proliferation *in vitro* was analyzed by the methods described above or minor variations thereof. The non-small cell lung cancer (NSCLC) lines HCC827 and H1975 were plated at 5000 cells/well and treated with antibody combinations ranging from 0.1-1  $\mu$ M (final concentration). Figures 9A-9D show inhibition of cell proliferation using CellTiter-Glo® (CTG) Luminescent Cell Viability Assay (Promega Corporation) that measures the number of viable cells in culture based upon quantitation of ATP present, which is an indicator of metabolically active cells. Figures 9A and 9B show potent inhibition of growth of HCC827 and H1975 cells over a range of P1X+P2X+P3X concentrations, but not by cetuximab treatment or assay medium alone (1% FCS) in the presence of EGF ligand. Figures 9C and 9D show potent inhibition of growth of HCC827 and H1975 cells over a range of concentrations for both P1X+P2X+P3X and cetuximab, but not by assay medium alone (1% FCS) in the presence of AREG ligand. These results demonstrate the ability of P1X+P2X+P3X to inhibit tumor cell proliferation *in vitro* in response to both high-affinity (EGF) and low-affinity (AREG) ligands, whereas cetuximab is only effective in cells treated with low-affinity (AREG) ligand. The concentrations used in the dilution series for the antibodies for the experiments shown in Figures 9A-D are shown below in Table 12. The ordinarily skilled artisan will understand that each specific concentration value in Table 12 is subject to some minor experimental variability, so that each specific concentration given indicates a value of about the indicated concentration (*e.g.*, a concentration indicated in a table as 0.1 nM represents a value of about 0.1 nM).

**Table 12**

Conc, Log(Molar)	Conc, nM
-6.000000	1000.00
-6.301030	500.00
-6.602060	250.00
-6.903090	125.00
-7.204120	62.50

-7.806180	15.63
-8.408240	3.91
-9.010300	0.98
-9.913390	0.12

It is noted that the concentrations shown in Table 12 are total concentrations for P1X+P2X+P3X. The ratio used is 2:2:1, so the individual concentrations of P1X, P2X and P3X are 40%, 40% and 20%, respectively.

5

**Example 10: Inhibition of tumor cell proliferation *in vivo***

Efficacy of P1X+P2X+P3X *in vivo* was assessed in a H1975 lung cancer cell xenograft murine mouse model.  $2 \times 10^6$  NCI-H1975 cells were injected subcutaneously into the flank of nu/nu mice. Once tumors had reached an average size of  $300 \text{mm}^3$  treatment was initiated. Groups of 10 mice were treated with either vehicle control (PBS); or the murine ratio antibody trio at the following component concentrations: murine ratio antibody trio-Low P1X=2.53mg/kg, P2X=7.26mg/kg and P3X=0.66mg/kg or murine ratio antibody trio-Medium P1X=5.06mg/kg, P2X=14.52mg/kg and P3X=1.33mg/kg. Mice were treated every two days.

The results shown in Figure 10A (DU145 xenograft model) and Figure 10B (H1975 xenograft model) demonstrate the ability of P1X+P2X+P3X to inhibit tumor cell proliferation *in vivo*.

**Example 11: Ligand antagonism cell binding assays with single antibodies**

A cell binding assay was performed to demonstrate that monoclonal antibodies P1X, P2X, and P3X can antagonize the interaction of EGF ligand and EGF receptor on A431 cells. A431 cells were incubated with one dose of single antibody for 1 hr followed by a dilution series of biotin-EGF ligand and the amount of bound biotin-EGF ligand measured by quantitative flow cytometry, as described in the methods section above. The concentrations for the antibodies are shown below in Table 13 and represent a sub-saturating concentration (approx. EC90 concentration) of cell binding as determined from the analysis demonstrated in Example 3. The concentrations used in the dilution series for the biotin-EGF are shown below in Table 14. The values in Table 13 and Table 14 are subject to some minor experimental variability, so that each specific

concentration given indicates a value of about the indicated concentration (*e.g.*, a concentration indicated in a table as 0.1 nM represents a value of about 0.1 nM).

**Table 13**

Antibody	Conc, Log(Molar)	Conc, nM
P1X	-9.01	0.97
P2X	-8.70	2.00
P3X	-8.33	4.68

5 **Table 14**

Conc, Log(Molar)	Conc, nM
-6.70	200
-7.18	66.67
-7.65	22.22
-8.13	7.41
-8.61	2.47
-9.08	0.82
-9.56	0.27
-10.04	0.09
-10.52	0.03
-11.00	0.01
-11.52	0.003

The results are shown in Figure 11, which demonstrates that each of the single antibodies (P1X, P2X and P3X) alone are capable of antagonizing the interaction of EGF ligand and EGF receptor on A431 cells, with P1X and P2X exhibiting more potent  
10 inhibitory activity than P3X.

**Example 12: Ligand antagonism cell binding assays with single and combinations of antibodies or Fabs**

A cell binding assay was performed to determine the extent to which single  
15 antibodies and multiple antibody combinations of monoclonal antibodies P1X, P2X, and P3X and single and multiple combinations of monovalent Fab fragments P1X Fab, P2X Fab, and P3X Fab can antagonize the interaction of EGF ligand and EGF receptor on A431 cells. A431 cells were incubated with one dose of antibody or Fab for 1 hr followed by a dilution series of biotin-EGF ligand and the amount of bound biotin-EGF  
20 ligand measured by quantitative flow cytometry, as described in the methodology section above. The concentration of antibodies and Fab was 10nM. The combinations of three antibodies (P1X+P2X+P3X) and three antibodies (P1X Fab + P2X Fab + P3X

Fab) were formulated in a ratio of 2:2:1 and were dosed at a total concentration of 10 nM. The concentrations used in the dilution series for the biotin-EGF are shown above in Table 14. The ordinarily skilled artisan will understand that each specific concentration value in Table 14 is subject to some minor experimental variability, so that each specific concentration given indicates a value of about the indicated concentration (*e.g.*, a concentration indicated in a table as 0.1 nM represents a value of about 0.1 nM).

The results are shown in Figure 12A (single and combinations of monoclonal antibodies P1X, P2X, and P3X) and Figure 12B (single and combinations of monovalent Fab fragments P1X Fab, P2X Fab, and P3X Fab). The results in Figure 12A demonstrate that again all three antibodies alone were capable of antagonizing the interaction of EGF ligand and EGF receptor on A431 cells, with P1X and P2X exhibiting more potent inhibitory activity than P3X, and the triple combination of P1X+P2X+P3X also showed potent inhibitory activity. The results in Figure 12B demonstrate that P1X Fab showed the strongest inhibitory activity alone, with P3X Fab alone showing intermediate inhibitory activity alone and P2X Fab showing only minimal inhibitory activity alone. The triple combination of P1X Fab + P2X Fab + P3X Fab also showed strong inhibitory activity, although less potent than P1X Fab alone.

**Example 13: Phospho-EGFR and Phospho-ERK signaling inhibition by a 2:2:1 molar ratio combination of P1X, P2X, and P3X antibodies or Fabs**

A431 cells were treated with a dilution series of a 2:2:1 molar ratio combination of antibodies P1X, P2X, and P3X (“P1X+P2X+P3X”) or Fabs P1X Fab, P2X Fab, P3X Fab (this combination at this molar ratio is referred to herein as “P1X Fab+P2X Fab+P3X Fab”) and phospho-EGFR and phospho-ERK inhibition measured by ELISA. Experiments were performed with rhEGF (PeproTech) dosed at a concentration of 50ng/mL or 500 ng/mL. The concentrations used in the dilution series for the antibodies and Fabs are shown below in Table 15. The ordinarily skilled artisan will understand that each specific concentration value in Table 15 is subject to some minor experimental variability, so that each specific concentration given indicates a value of about the indicated concentration (*e.g.*, a concentration indicated in a table as 0.1 nM represents a value of about 0.1 nM).

**Table 15**

Conc, Log(Molar)	Conc, nM
-5.70	2000.00
--6.18	666.67
-6.65	222.22
-7.13	74.07
-7.61	24.70
-8.08	8.23
-8.56	2.74
-9.04	0.91
-9.52	0.30
-9.99	0.10

The results are shown in Figures 13A-D, wherein Figures 13A and 13B show the results of the phospho-EGFR inhibition assay and Figures 13C and 13D show the results of the phosphor-ERK inhibition assay, with Figures 13A and 13C showing the results at low doses (50 ng/ml or 8 nM) and with Figures 13B and 13D showing the results at high doses (500 ng/ml or 80 nM).

With respect to inhibition of phospho-EGFR, the results in Figures 13A and 13B demonstrate that both triple combinations, P1X+P2X+P3X mAbs and P1X Fab+P2X Fab+P3X Fab fragments, exhibited strong inhibition at both the low dose and the high dose tested.

With respect to inhibition of phospho-ERK, the results in Figures 13C and 13D demonstrate that both triple combinations, P1X+P2X+P3X mAbs and P1X Fab+P2X Fab+P3X Fab fragments, exhibited inhibition at both the low dose and the high dose tested, with the P1X+P2X+P3X mAb combination exhibiting more potent inhibition than the P1X Fab+P2X Fab+P3X Fab fragment combination.

**Example 14: EGF receptor down-regulation in DU-145 cells following treatment with P1X+P2X+P3X, P1X Fab +P2X Fab +P3X Fab, or cetuximab**

Cells were pre-incubated for 2, 6, or 24 hours with of P1X+P2X+P3X, P1X Fab +P2X Fab +P3X Fab, or cetuximab equaling 50 nM, 100 nM, and 50 nM, respectively. The Fab combination is dosed at twice the concentration as P1X+P2X+P3X and cetuximab to account for a single binding moiety on a Fab molecule versus two binding moieties on and IgG molecule. Immunoblots of cell lysates were probed with antibodies against transmembrane EGFR (tEGFR) and the pcna housekeeping protein as a control,

as described in the methodology section above. EGF receptor down-regulation in response to treatment is shown in Figure 14. The results demonstrate that treatment with P1X+P2X+P3X led to observable down-regulation of EGFR, in a time dependent manner, whereas treatment with P1X Fab+P2X Fab+P3X Fab or cetuximab did not lead to observable down-regulation of EGFR on visual inspection of the immunoblots.

### **Equivalents**

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

### **Incorporation by Reference**

All, patents, pending patent applications and patent publications referred to hereinabove are hereby incorporated by reference in their entireties.

**APPENDIX A**  
**ANTI-CANCER AGENTS**

<b>Anti-Cancer Agent</b>	<b>Comments</b>	<b>Examples</b>
Antibodies	Antibodies which bind IGF-1R (insulin-like growth factor type 1 receptor), which is expressed on the cell surface of most 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 result in cancer	matuzumab (EMD72000) Erbix® / cetuximab (Imclone) Vectibix® / panitumumab (Amgen) mAb 806 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)	AV299 (AVEO) AMG102 (Amgen) 5D5 (OA-5D5) (Genentech)
	Anti-ErbB3 antibodies	MM-121 (Merrimack Pharmaceuticals) Ab #14 described in WO 2008/100624 1B4C3; 2D1D12 (U3 Pharma AG) U3-1287/AMG888 (U3 Pharma/Amgen)

	Anti-ErbB2 (HER2) antibodies	Herceptin® (trastuzumab; Genentech/Roche); Omnitarg® (pertuzumab; 2C4,R1273; Genentech/Roche)
Small Molecules Targeting IGF1R	IGF-1R (insulin-like growth factor type 1 receptor), which is expressed on the cell surface of most 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)

<p>Antimetabolites</p>	<p>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.</p>	<p>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.)</p>
<p>Alkylating agents</p>	<p>An alkylating antineoplastic agent is an 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.</p>	<p>Ribonucleotide Reductase Inhibitor (RNR)                      cyclophosphamide / Cytosan® (BMS) / 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)</p>

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

doxorubicin HCL / Doxil® (Alza)  
 daunorubicin citrate / Daunoxome®  
(Gilead)  
 mitoxantrone HCL/Novantrone (EMD)

	<p>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.</p>	<p>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 &amp; Upjohn)                  camptothecin (CPT)                  belotecan                  rubitecan                  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</p>
<p>Microtubule targeting agents</p>	<p>Microtubules are one of the components of the cytoskeleton. They have diameter of apporximately 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.</p>	
<p>Kinase inhibitors</p>	<p>Tyrosine kinases are enzymes within the cell that function to attach phosphate groups to the amino acid tyrosine. By blocking the ability of protein tyrosine kinases</p>	<p>imatinib mesylate / Gleevec (Novartis)                  sunitinib malate / Sutent® (Pfizer)                  sorafenib tosylate / Nexavar® (Bayer)                  nilotinib hydrochloride monohydrate / Tassigna® (Novartis)                  AMG 386 (Amgen)                  axitinib (AG-013736; Pfizer, Inc.)</p>

	to function, these compounds provide a tool for controlling cancerous cell growth.	<p>bosutinib (SKI-606; Wyeth)</p> <p>brivanib alalinate (BMS-582664; BMS)</p> <p>cediranib (AZD2171; Recentin, AstraZeneca)</p> <p>dasatinib (BMS-354825; Sprycel®; BMS)</p> <p>lestaurtinib (CEP-701; Cephalon)</p> <p>motesanib diphosphate (AMG-706; Amgen/Takeda)</p> <p>pazopanib HCL (GW786034; Armala, GSK)</p> <p>semaxanib (SU5416; Pharmacia)</p> <p>vandetanib (AZD647; Zactima; AstraZeneca)</p> <p>vatalanib (PTK-787; Novartis, Bayer Schering Pharma)</p> <p>XL184 (NSC718781; Exelixis, GSK)</p>
Protein synthesis inhibitors	Induces cell apoptosis	L-asparaginase / Elspar® (Merck & Co.)
Immunotherapeutic agents	Induces cancer patients to exhibit immune responsiveness	<p>Alpha interferon</p> <p>Angiogenesis Inhibitor / Avastin® (Genentech)</p> <p>IL-2→ Interleukin 2 (Aldesleukin) / Proleukin® (Chiron)</p> <p>IL-12→ Interleukin 12</p>
Hormonal therapies	<p>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.</p> <p>Hormonal therapy as a cancer treatment</p>	<p>Toremifene citrate / Fareston® (GTX, Inc.)</p> <p>fulvestrant / Faslodex® (AstraZeneca)</p> <p>raloxifene HCL / Evista® (Lilly)</p> <p>anastrozole / Arimidex® (AstraZeneca)</p> <p>letrozole / Femara® (Novartis)</p> <p>fadrozole (CGS 16949A)</p> <p>exemestane / Aromasin® (Pharmacia &amp; Upjohn)</p> <p>leuprolide acetate / Eligard® (QTL USA)</p> <p>Lupron® (TAP Pharm.)</p>

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  
 cetorelix / 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®  
 medroxyprogesterone 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.	prednisolone 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)

SEQUENCE LISTING SUMMARY

P1X V <sub>H</sub> CDR1	SYAIS	SEQ ID NO: 1
P1X V <sub>H</sub> CDR2	IIPIFGTVNY	SEQ ID NO: 2
P1X V <sub>H</sub> CDR3	DPSVNL	SEQ ID NO: 3
P1X V <sub>L</sub> CDR1	QSISSWWA	SEQ ID NO: 4
P1X V <sub>L</sub> CDR2	DASSL	SEQ ID NO: 5
P1X V <sub>L</sub> CDR3	QQYHAHP	SEQ ID NO: 6
P2X V <sub>H</sub> CDR1	SYAIS	SEQ ID NO: 7
P2X V <sub>H</sub> CDR2	IIPIFGAANP	SEQ ID NO: 8
P2X V <sub>H</sub> CDR3	MGRGKV	SEQ ID NO: 9
P2X V <sub>L</sub> CDR1	QSVLYSPNNKNYLA	SEQ ID NO: 10
P2X V <sub>L</sub> CDR2	WASTR	SEQ ID NO: 11
P2X V <sub>L</sub> CDR3	QQYYGSP	SEQ ID NO: 12
P3X V <sub>H</sub> CDR1	SYGIN	SEQ ID NO: 13
P3X V <sub>H</sub> CDR2	ISAYNGNTYY	SEQ ID NO: 14
P3X V <sub>H</sub> CDR3	DLGGYGSGS	SEQ ID NO: 15
P3X V <sub>L</sub> CDR1	QSVSSNLA	SEQ ID NO: 16
P3X V <sub>L</sub> CDR2	GASTR	SEQ ID NO: 17
P3X V <sub>L</sub> CDR3	QDYRTWPR	SEQ ID NO: 18
P1X V <sub>H</sub>	MGFGLSWLFLVAILKGVQC QVQLVQSGAEVKKPGSSVKV SCKASGGTFSSYAISWVRQA PGQGLEWMGSIIPFGTVNY AQKFQGRVTITADESTSTAY MELSSLRSEDVAVYYCARDP SVNLYWYFDLWGRGTLTVSS	SEQ ID NO: 19
P1X V <sub>L</sub>	MGTPAQLLFLLLLWLPDTTG DIQMTQSPSTLSASVGDRTV ITCRASQSISSWWAWYQQK GKAPKLLIYDASSLESGVPS RFSGSGSGTEFTLTISSLQP DDFATYYCQQYHAHPTTFGG GTKVEIK	SEQ ID NO: 20
P2X V <sub>H</sub>	MGFGLSWLFLVAILKGVQC QVQLVQSGAEVKKPGSSVKV SCKASGGTFSSYAISWVRQA PGQGLEWMGSIIPFGAANP AQKSQGRVTITADESTSTAY MELSSLRSEDVAVYYCAKMG	SEQ ID NO: 21

	RGKVAFDIWGQGMVTVSS	
P2X V <sub>L</sub>	MGTPAQLLFLLLLWLPDTTG DIVMTQSPDSLAVSLGERAT INCKSSQSVLYSPNNKNYLA WYQQKPGQPPKLLIYWASTR ESGVPDRFSGSGSGTDFTLT ISSLQAEDVAVYYCQQYYGS PITFGGGTKVEIK	SEQ ID NO: 22
P3X V <sub>H</sub>	MGFGLSWLFLVAILKGVQC QVQLVQSGAEVKKPGASVKV SCKASGYAFTSYGINWVRQA PGQGLEWMGWISAYNGNTYY AQKLRGRVTMTTDTSTSTAY MELRSLRSDDTAVYYCARDL GGYGSGSVFPDPWGQGLVTVSS	SEQ ID NO: 23
P3X V <sub>L</sub>	MGTPAQLLFLLLLWLPDTTG EIVMTQSPATLSVSPGERAT LSCRASQSVSSNLAWYQQKP GQAPRLLIYGASTRATGIPA RFSGSGSGTEFTLTISSLQS EDFAVYYCQDYRTWPRRVFG GGTKVEIK	SEQ ID NO: 24
pMP10K_IgG1 Light Chain Kappa-Constant	RTVAAPSVFIFPPSDEQLKS GTASVVCLLNNFYPREAKVQ WKVDNALQSGNSQESVTEQD SKDSTYLSSTLTLSKADYE KHKVYACEVTHQGLSSPVTK SFNRGEC	SEQ ID NO: 25
pMP10K_IgG1 Heavy Chain (EEM)_Constant	ASTKGPSVFPLAPSSKSTSG GTAALGCLVKDYFPEPVTVS WNSGALTSGVHTFPAVLQSS GLYSLSSVVTVPSSSLGTQT YICNVNHKPSNTKVDKKEP KSCDKTHTCPPCPAPELLGG PSVFLFPPKPKDTLMISRTP EVTCVVVDVSHEDPEVKFNW YVDGVEVHNAKTKPREEQYN STYRVVSVLTVLHQDWLNGK EYKCKVSNKALPAPIEKTIS KAKGQPREPQVYTLPPSREE MTKNQVSLTCLVKGFYPSDI	SEQ ID NO: 26

	AVEWESNGQPENNYKTTPPV LDSGDSFFLYSKLTVDKSRW QQGNVFSCSVMHEALHNHYT QKSLSLSPGK	
ca/cd V <sub>H</sub> CDR2	IPIFGTANY	SEQ ID NO: 27
ca V <sub>H</sub> CDR3	DPSVDL	SEQ ID NO: 28
ca V <sub>L</sub> CDR1	QSISSWLA	SEQ ID NO: 29
ca V <sub>L</sub> CDR3	QQFAAHA	SEQ ID NO: 30
cd V <sub>L</sub> CDR1	QSVLYSSNNKNYLA	SEQ ID NO: 31
ch V <sub>H</sub> CDR2	ISAYNGNTNY	SEQ ID NO: 32

EGFR ECD (SEQ ID NO: 33)

1 MRPSGTAGAA LLALLAALCP ASRALEEKKV CQGTSNKLTQ LGTFEDHFLS LQRMFNCEV  
 61 VLGNIETIYV QRNYDLSFLK TIQEVAGYVL IALNTVERIP LENLQIIRGN MYYENSYALA  
 5 121 VLSNYDANKT GLKELPMRNL QEILHGAVRF SNNPALCNVE SIQWRDIVSS DFSLNMSMDF  
 181 QNHLGSCQKC DPSCPNGSCW GAGEENCQKL TKIICAQQCS GRCRGKSPSD CCHNQCAAGC  
 241 TGPRESDCLV CRKFRDEATC KDTCPPLMLY NPTTYQMDVN PEGKYSFGAT CVKKCPRNYV  
 301 VTDHGSCVRA CGADSYEMEE DGVRKCKKCE GPCRKVCNGI GIGEFKDSLS INATNIKHFV  
 361 NCTSIISGLH ILPVAFRGDS **FTH**TPPLDPQ ELDILKTVKE ITGFLLIQAW PENRTDLHAF  
 10 421 ENLEIIRGRT **KQH**GQFSLAV VSLNITSLGL RSLKEISDGD VIISGN**K**NLC YANTINWKKL  
 481 FGTSGQK**TKI** **I**SNRG**ENS**CK ATGQVCHALC SPEGCWGPEP RDCVSCRNVV RGRECVDKCN  
 541 LLEGEPREFV ENSECIQCHP ECLPQAMNIT CTGRGPDNCI QCAHYIDGPH CVKTCPAGVM  
 601 GENNTLVWKY ADAGHVCHLC HPNCTYGCTG PGLEGCPNG PKIPSHHHH H

15

What is claimed is:

1. A monoclonal antibody which binds EGFR extracellular domain and  
5 comprises heavy and light chain CDR1, CDR2, and CDR3 sequences, wherein the  
heavy and light chain CDR1, CDR2, and CDR3 sequences are selected from the group  
consisting of:

(a) heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 1, 2, and 3  
respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 4, 5,  
10 and 6, respectively;

(b) heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 7, 8, and  
9, respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 10,  
11 and 12, respectively; and

(c) heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 13, 14,  
15 and 15, respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID  
NOs: 16, 17, and 18, respectively.

2. A monoclonal antibody that binds to EGFR extracellular domain and  
comprises a heavy chain variable region and a light chain variable region, wherein the  
20 heavy and light chain variable region sequences are selected from the group consisting  
of:

(a) a heavy chain variable region comprising SEQ ID NO: 19 and a light chain  
variable region comprising SEQ ID NO: 20;

(b) a heavy chain variable region comprising SEQ ID NO: 21 and a light chain  
25 variable region comprising SEQ ID NO: 22; and

(c) a heavy chain variable region comprising SEQ ID NO: 23 and a light chain  
variable region comprising SEQ ID NO: 24.

3. The monoclonal antibody of claim 1 or 2, which binds to EGFR with a  $K_D$  of  
30 better than 100 nM.

4. The monoclonal antibody of claim 3, which binds to EGFR with a  $K_D$  of better  
than 10 nM.

5. The monoclonal antibody of claim 3, which binds to EGFR with a  $K_D$  of better than 1 nM.
- 5 6. The monoclonal antibody of claim 1 or 2, which is a human antibody.
7. The monoclonal antibody of claim 1 or 2, wherein the antibody is selected from the group consisting of a bispecific antibody, immunoconjugate, Fab, Fab'2, ScFv, avimer, nanobody and a domain antibody.
- 10 8. The monoclonal antibody of claim 1 or 2, wherein the monoclonal antibody is selected from the group consisting of IgG1, IgG2, IgG3, IgG4, IgM, IgA1, IgA2, IgAsec, IgD and IgE isotype antibodies.
- 15 9. A pharmaceutical composition comprising the monoclonal antibody of claim 1 or 2 and a pharmaceutically acceptable carrier.
10. A kit comprising the pharmaceutical composition of claim 9 in a container.
- 20 11. A method of treating cancer in a subject, comprising administering to the subject an effective amount of the pharmaceutical composition of claim 9.
12. The monoclonal antibody of claim 1 or 2 for the treatment of a cancer.
- 25 13. A composition comprising two or three monoclonal antibodies which bind to EGFR extracellular domain, wherein the two or three monoclonal antibodies are selected from the group consisting of:
- (a) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 1, 2, and 3 respectively, and light chain CDR1, CDR2, and
- 30 CDR3 sequences of SEQ ID NOs: 4, 5, and 6, respectively;
- (b) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 7, 8, and 9, respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 10, 11 and 12, respectively and

(c) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 13, 14, and 15, respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 16, 17 and 18, respectively; and wherein the composition comprises (a) and (b), (a) and (c), (b) and (c) or (a), (b) and (c).

14. A composition comprising two or three monoclonal antibodies which bind to EGFR extracellular domain, wherein the two or three monoclonal antibodies are selected from the group consisting of:

10 (a) a monoclonal antibody comprising a heavy chain variable region comprising SEQ ID NO: 19 and a light chain variable region comprising SEQ ID NO: 20;

(b) a monoclonal antibody comprising a heavy chain variable region comprising SEQ ID NO: 21 and a light chain variable region comprising SEQ ID NO: 22; and

15 (c) a monoclonal antibody comprising a heavy chain variable region comprising SEQ ID NO: 23 and a light chain variable region comprising SEQ ID NO: 24;

and wherein the composition comprises (a) and (b), (a) and (c), (b) and (c) or (a) (b) and (c).

15. The composition of claim 13 or 14, wherein each of monoclonal antibodies (a), (b) and (c) binds to EGFR with a  $K_D$  of better than 100 nM.

16. The composition of claim 15, wherein each of monoclonal antibodies (a), (b) and (c) binds to EGFR with a  $K_D$  of better than 10 nM.

25 17. The composition of claim 15, wherein each of monoclonal antibodies (a), (b) and (c) binds to EGFR with a  $K_D$  of better than 1nM.

18. The composition of claim 13 or 14, wherein each of monoclonal antibodies (a), (b) and (c) is a human antibody.

30 19. The composition of claim 13 or 14, wherein one or more of monoclonal antibodies (a), (b), and (c) is independently selected from the group consisting of a

bispecific antibody, immunoconjugate, Fab, Fab'2, ScFv, avimer, nanobody and a domain antibody.

20. The composition of claim 13 or 14, wherein each of monoclonal antibodies (a),  
5 (b), and (c) is independently selected from the group consisting of IgG1, IgG2, IgG3, IgG4, IgM, IgA1, IgA2, IgAsec, IgD and IgE isotype antibodies.

21. The composition of claim 13 or 14, which further comprises a pharmaceutically acceptable carrier.

10

22. A kit comprising the composition of claim 21 in a container.

23. A method of treating cancer in a subject, comprising administering to the subject an effective amount of the composition of claim 21.

15

24. The composition of claim 13 or 14 for the treatment of a cancer.

25. A composition comprising three monoclonal anti-EGFR antibodies, said composition comprising a first antibody, a second antibody and a third antibody,  
20 wherein (i) the first antibody comprises heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 1, 2, and 3 respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 4, 5, and 6, respectively; (ii) the second antibody comprises heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 7, 8, and 9, respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 10,  
25 11 and 12, respectively; and (iii) the third antibody comprises heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 13, 14, and 15 respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 16, 17, and 18, respectively, and wherein the first second and third antibodies are present at a molar ratio of 2:2:1 to each other.

30

26. A composition comprising three monoclonal anti-EGFR antibodies, said composition comprising a first antibody, a second antibody and a third antibody, wherein (i) the first antibody comprises a heavy chain variable region comprising SEQ

ID NO: 19 and a light chain variable region comprising SEQ ID NO: 20; (ii) the second antibody comprises a heavy chain variable region comprising SEQ ID NO: 21 and a light chain variable region comprising SEQ ID NO: 22; and (iii) the third antibody comprises a heavy chain variable region comprising SEQ ID NO: 23 and a light chain variable region comprising SEQ ID NO: 24, and wherein the first second and third antibodies are present at a molar ratio of 2:2:1 to each other.

27. The composition of claim 25 or 26, wherein each of the first antibody, the second antibody and the third antibody binds to EGFR with a  $K_D$  of better than 100 nM.

10

28. The composition of claim 27, wherein each of the first antibody, the second antibody and the third antibody binds to EGFR with a  $K_D$  of better than 10 nM.

29. The composition of claim 27, wherein each of the first antibody, the second antibody and the third antibody binds to EGFR with a  $K_D$  of better than 1nM.

15

30. The composition of claim 25 or 26, wherein the first antibody binds to EGFR with a  $K_D$  in a range of  $1 \times 10^{-9}$  M to  $1.1 \times 10^{-11}$  M, the second antibody binds to EGFR with a  $K_D$  in a range of  $1 \times 10^{-9}$  M to  $7.0 \times 10^{-11}$  M and the third antibody binds to EGFR with a  $K_D$  in a range of  $1 \times 10^{-9}$  M to  $3.6 \times 10^{-10}$  M.

20

31. The composition of claim 25 or 26, wherein each of the first antibody, the second antibody and the third antibody are human antibodies.

25 32. The composition of claim 25 or 26, wherein one or more of the first antibody, the second antibody and the third antibody are independently selected from the group consisting of a bispecific antibody, immunoconjugate, Fab, Fab'2, ScFv, avimer, nanobody and a domain antibody.

30 33. The composition of claim 25 or 26, wherein each of the first antibody, the second antibody and the third antibody is independently selected from the group consisting of IgG1, IgG2, IgG3, IgG4, IgM, IgA1, IgA2, IgAsec, IgD and IgE isotype antibodies

34. The composition of claim 25 or 26, which further comprises a pharmaceutically acceptable carrier.
35. The composition of claim 34, which is a sterile composition.
- 5
36. The composition of claim 34, which is suitable for injection.
37. The composition of claim 34, which is a sterile composition suitable for intravenous injection.
- 10
38. A kit comprising the composition of claim 34 in a container.
39. A method of treating cancer in a subject, comprising administering to the subject an effective amount of the composition of claim 34.
- 15
40. the composition of claim 25 or 26 for the treatment of a cancer.
41. A method of preparing an anti-EGFR antibody composition, the method comprising combining in a single composition:
- 20
- (a) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 1, 2, and 3 respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 4, 5, and 6, respectively;
- (b) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 7, 8, and 9, respectively, and light chain CDR1, CDR2, and
- 25 CDR3 sequences of SEQ ID NOs: 10, 11 and 12, respectively; and
- (c) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 13, 14, and 15 respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 16, 17, and 18, respectively;
- wherein (a), (b) and (c) are combined at a molar ratio of 2:2:1 to each other.
- 30
42. A method of preparing an anti-EGFR antibody composition, the method comprising combining in a single composition:

(a) a monoclonal antibody comprising a heavy chain variable region comprising SEQ ID NO: 19 and a light chain variable region comprising SEQ ID NO:20;

(b) a monoclonal antibody comprising a heavy chain variable region comprising SEQ ID NO: 21 and a light chain variable region comprising SEQ ID NO: 22; and

5 (c) a monoclonal antibody comprising a heavy chain variable region comprising SEQ ID NO: 23 and a light chain variable region comprising SEQ ID NO: 24;

wherein (a), (b) and (c) are combined at a molar ratio of 2:2:1 to each other.

43. A method of treating a subject with anti-EGFR antibodies, the method  
10 comprising administering to the subject:

(a) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 1, 2, and 3 respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 4, 5, and 6, respectively;

(b) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3  
15 sequences of SEQ ID NOs: 7, 8, and 9, respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 10, 11 and 12, respectively; and

(c) a monoclonal antibody comprising heavy chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 13, 14, and 15 respectively, and light chain CDR1, CDR2, and CDR3 sequences of SEQ ID NOs: 16, 17, and 18, respectively;

20 wherein (a), (b) and (c) are administered to the subject at a molar ratio of 2:2:1 to each other.

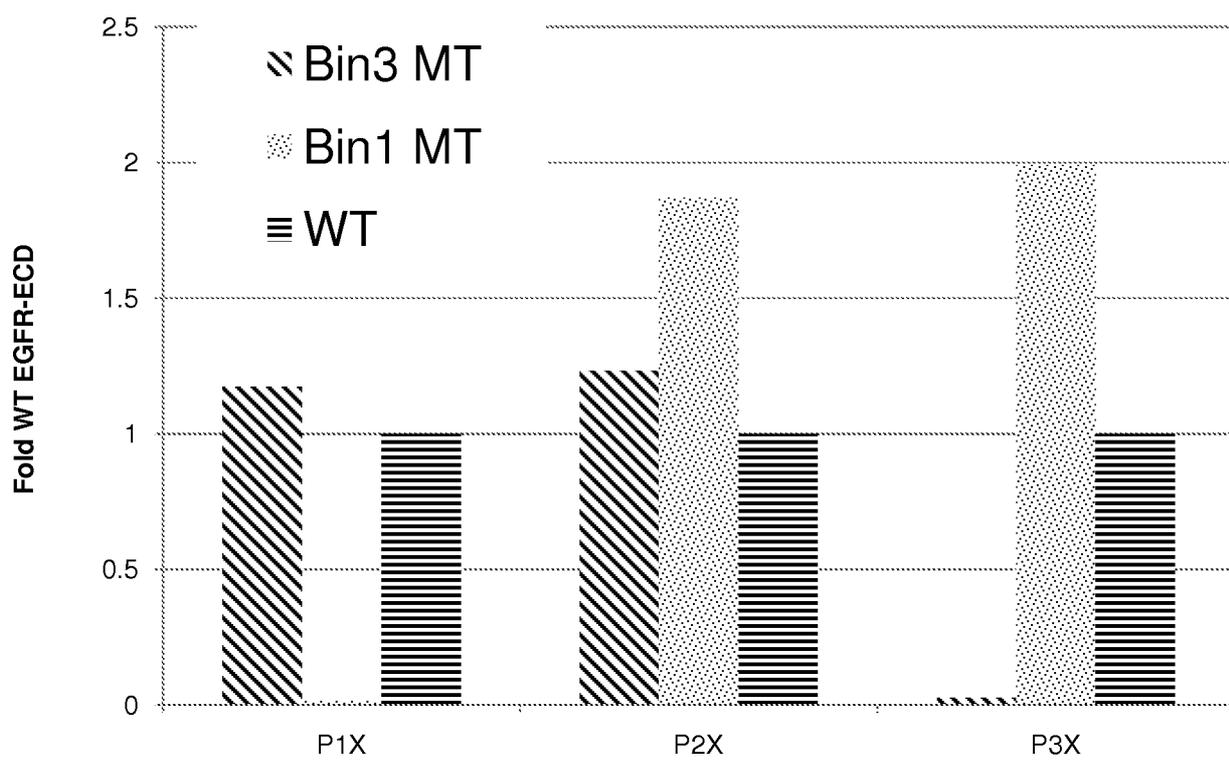
44. A method of treating a subject with anti-EGFR antibodies, the method  
comprising administering to the subject:

25 (a) a monoclonal antibody comprising a heavy chain variable region comprising SEQ ID NO: 19 and a light chain variable region comprising SEQ ID NO:20;

(b) a monoclonal antibody comprising a heavy chain variable region comprising SEQ ID NO: 21 and a light chain variable region comprising SEQ ID NO: 22; and

(c) a monoclonal antibody comprising a heavy chain variable region comprising  
30 SEQ ID NO: 23 and a light chain variable region comprising SEQ ID NO: 24;

wherein (a), (b) and (c) are administered to the subject at a molar ratio of 2:2:1 to each other.



**Fig. 1A**

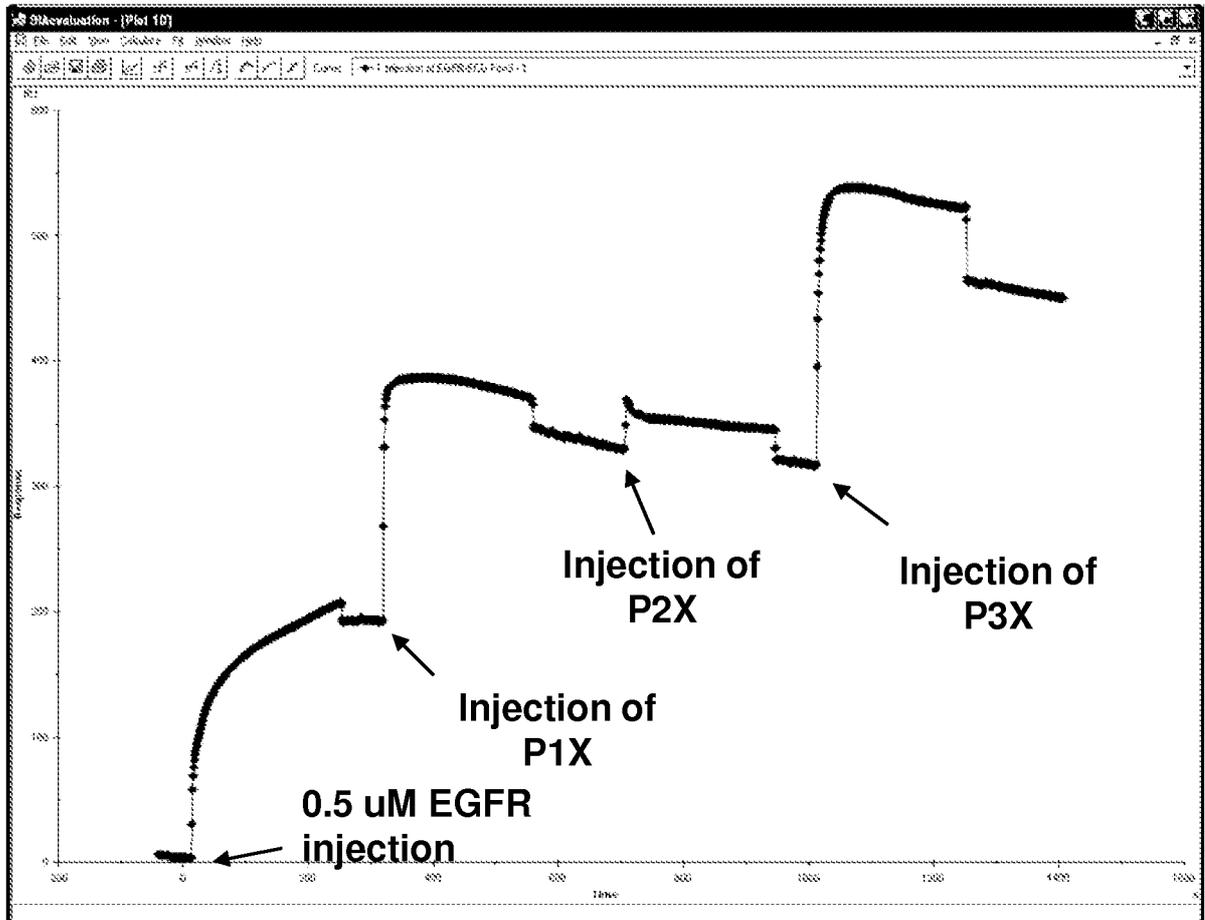
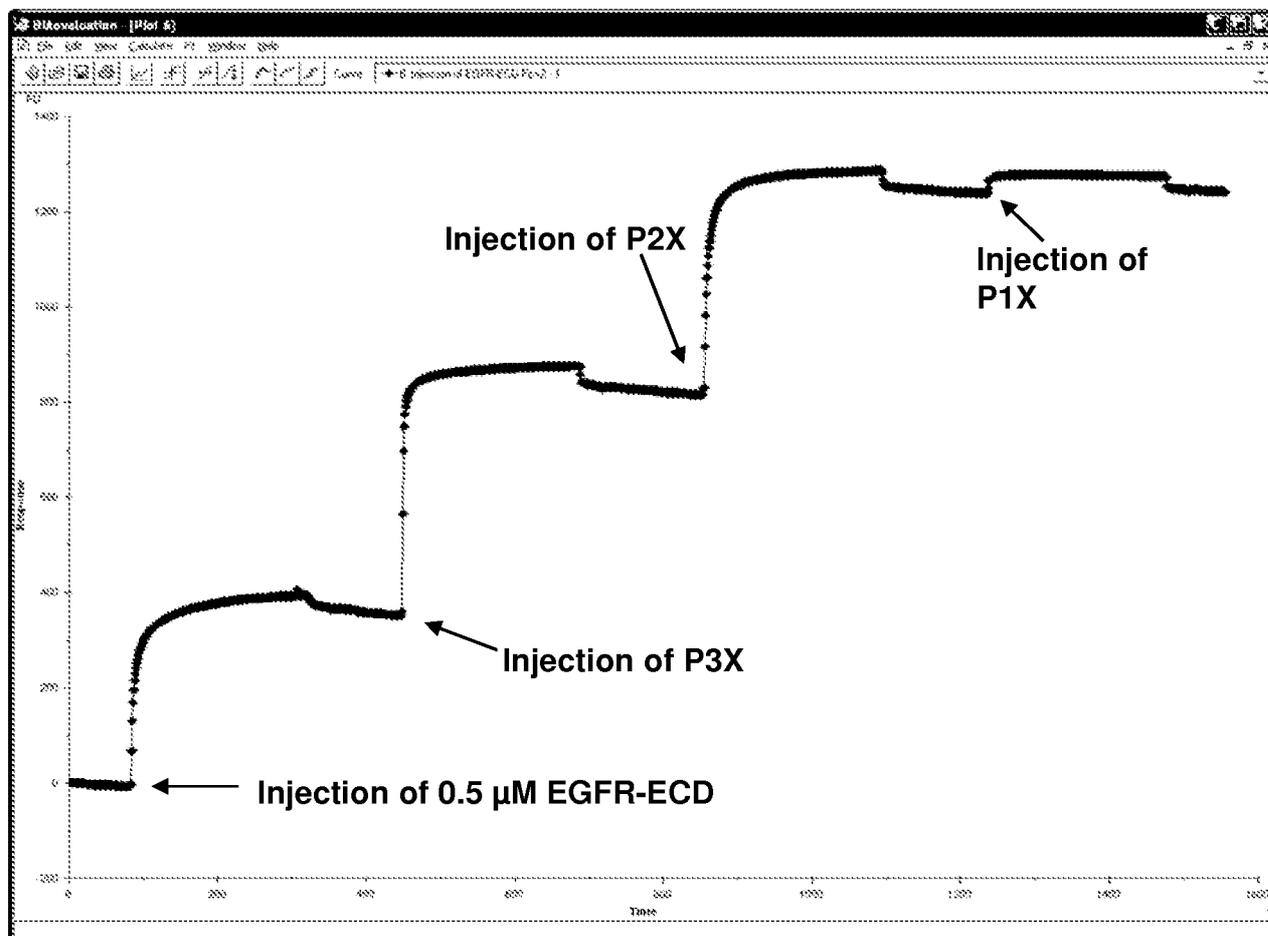
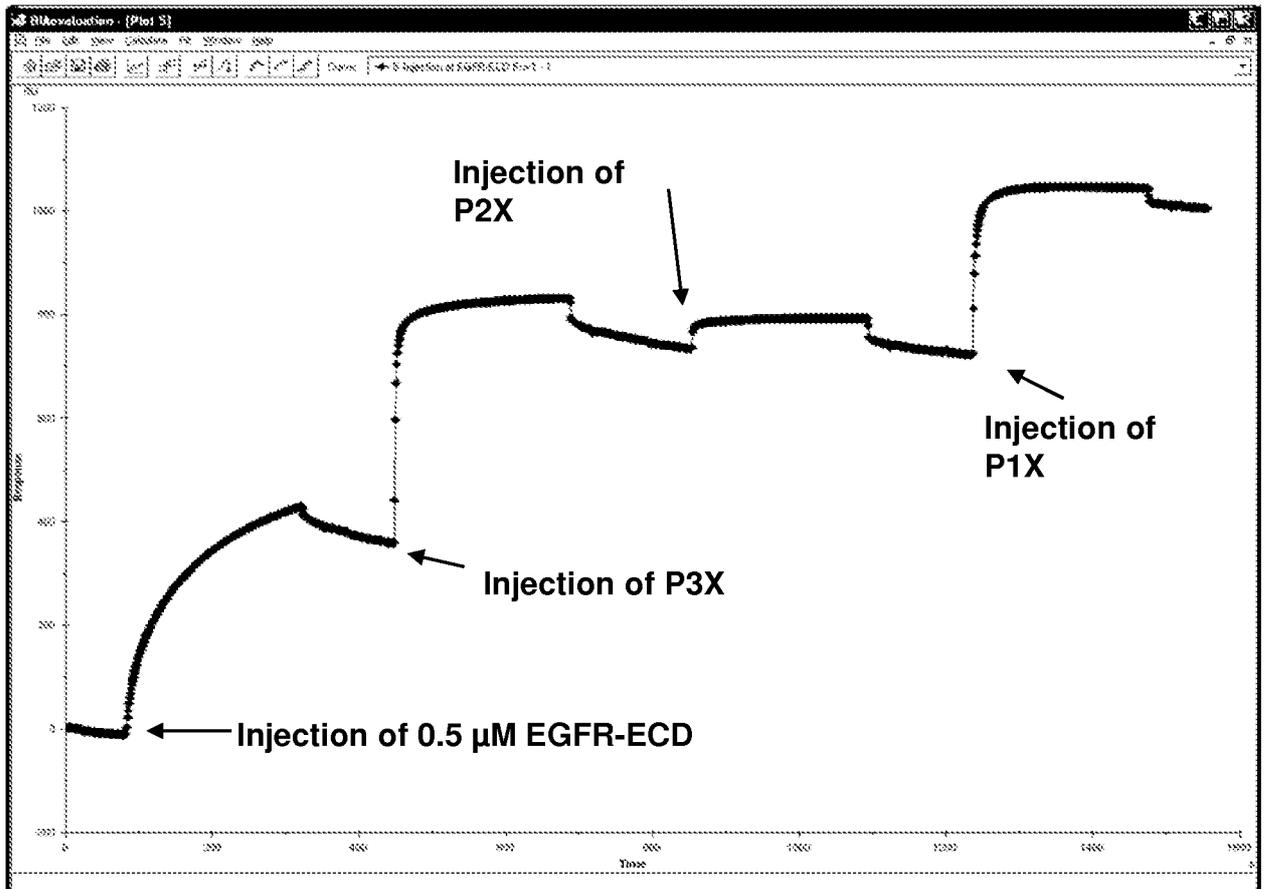


Fig. 1B



**Fig. 2A**



**Fig. 2B**

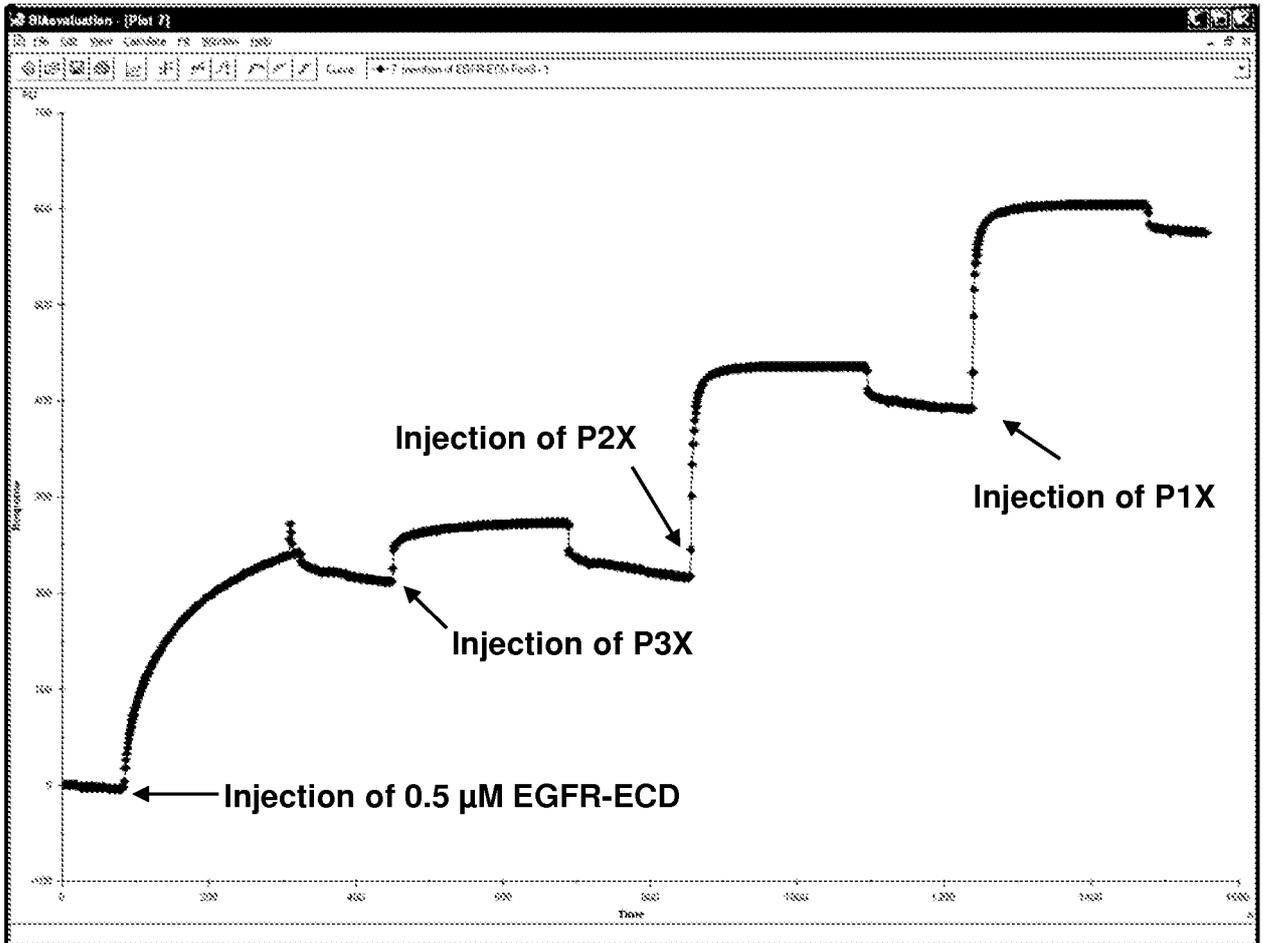
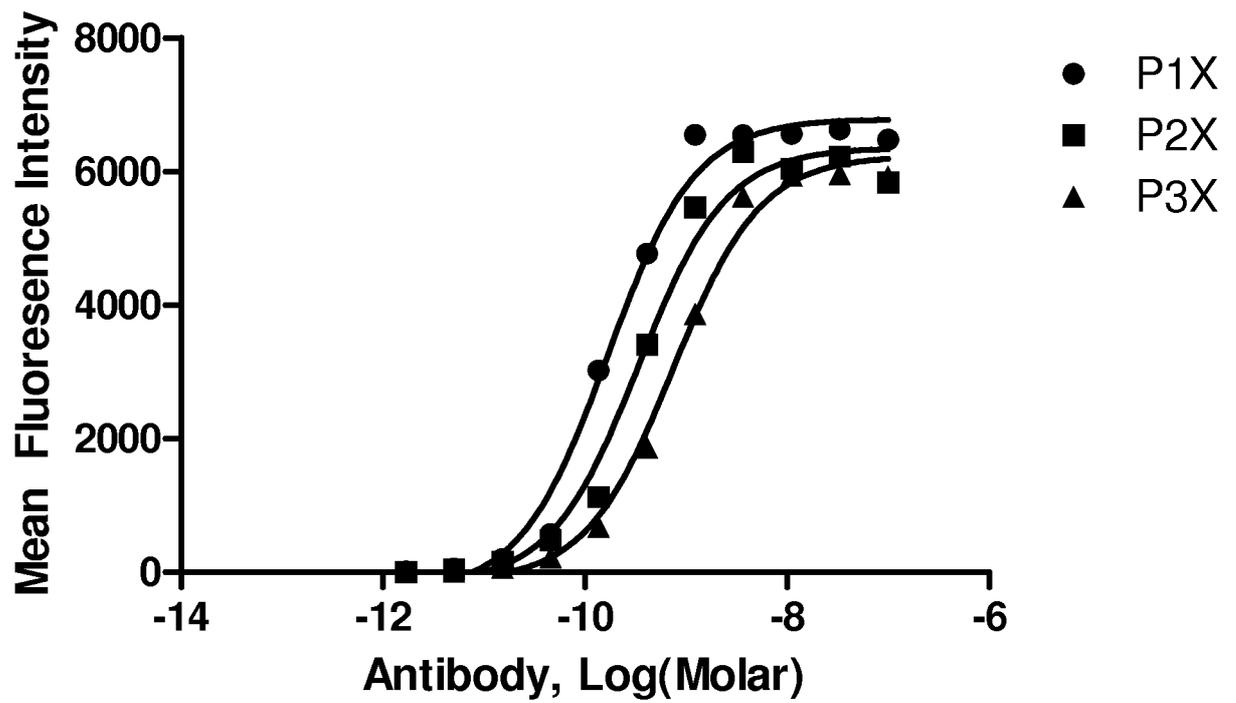
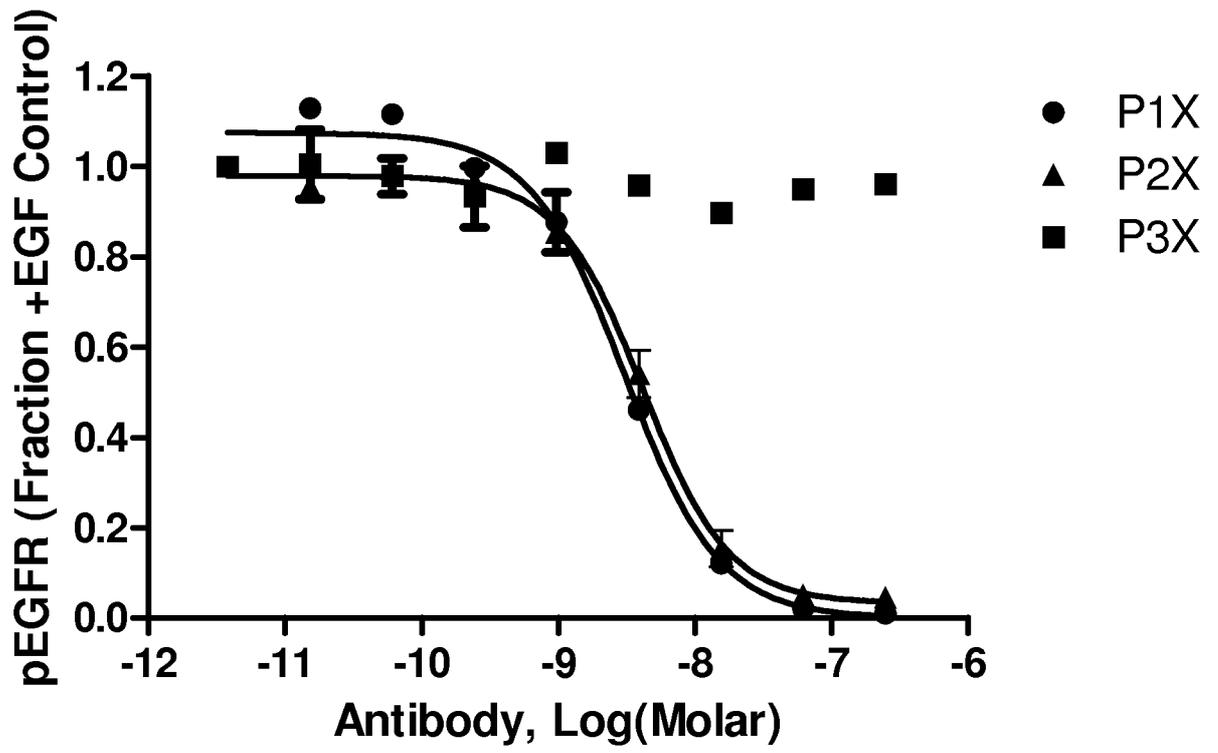


Fig. 2C

6/33

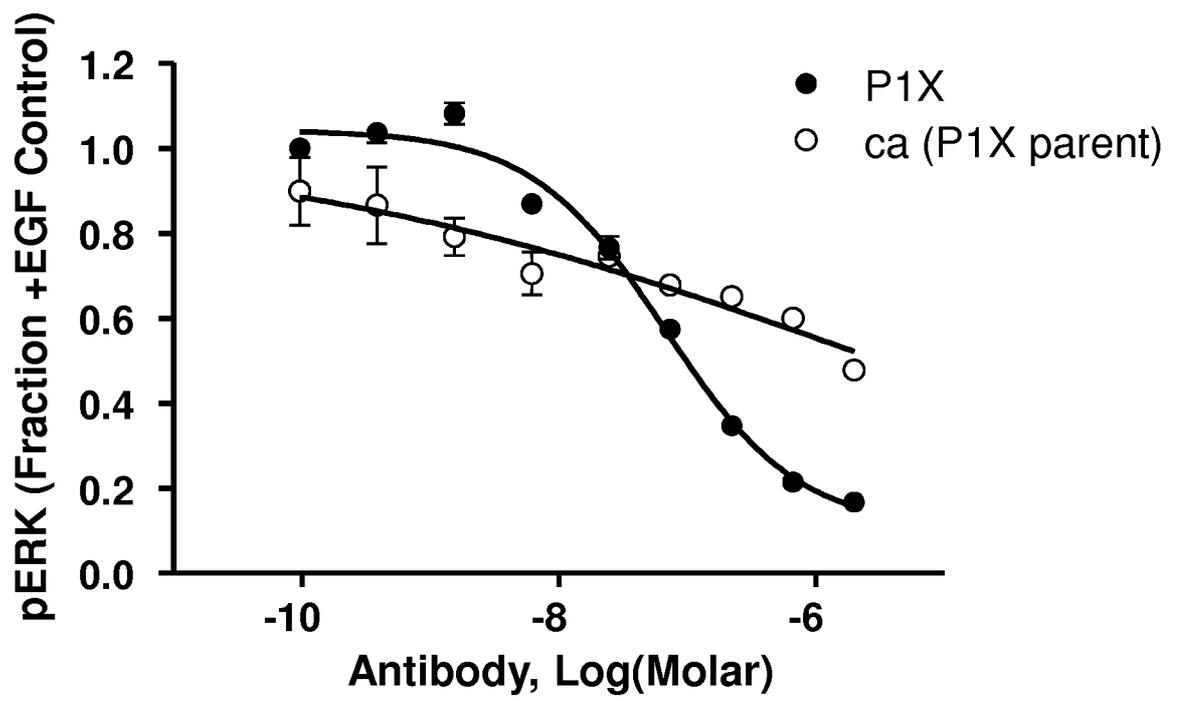
*Fig. 3*

7/33



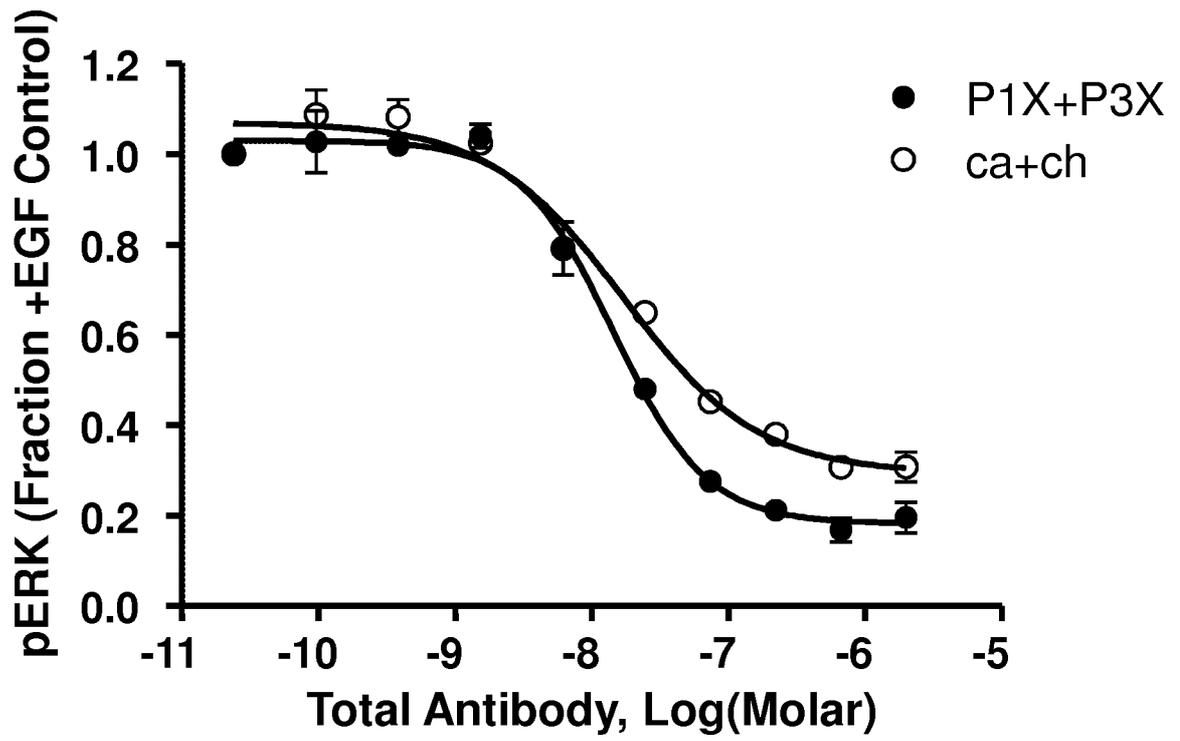
*Fig. 4*

8/33



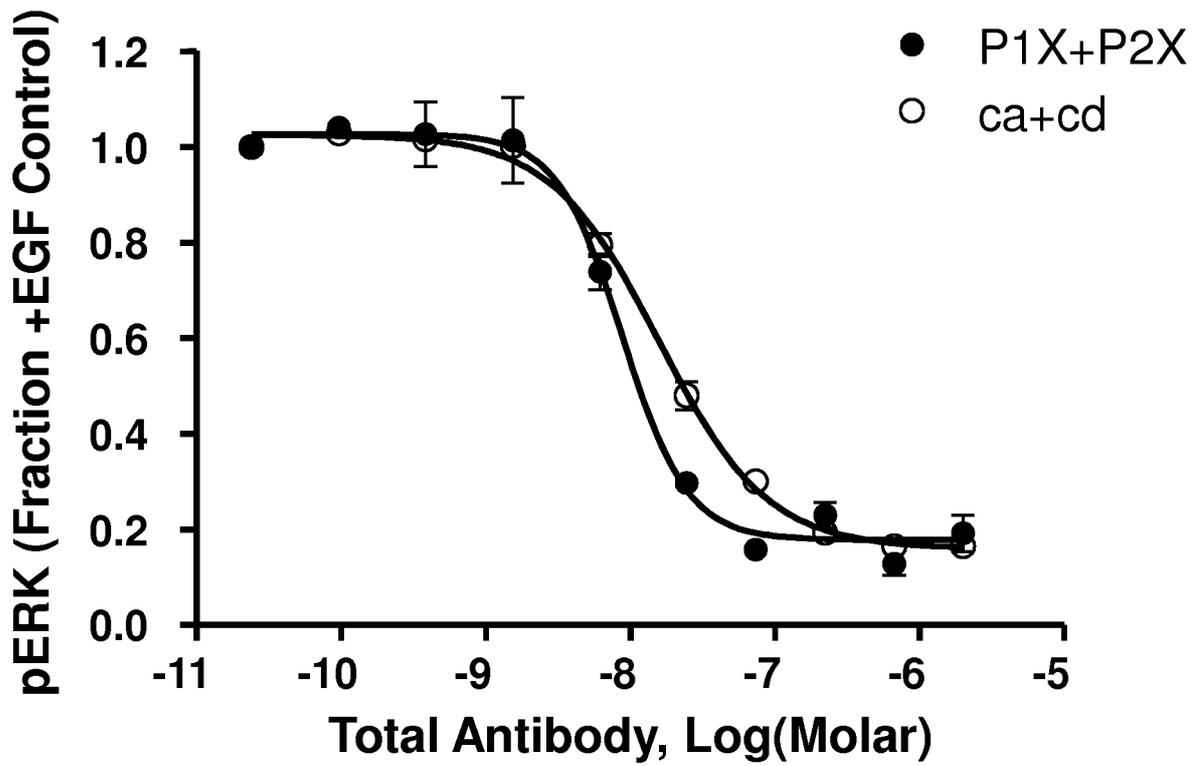
**Fig. 5A**

9/33

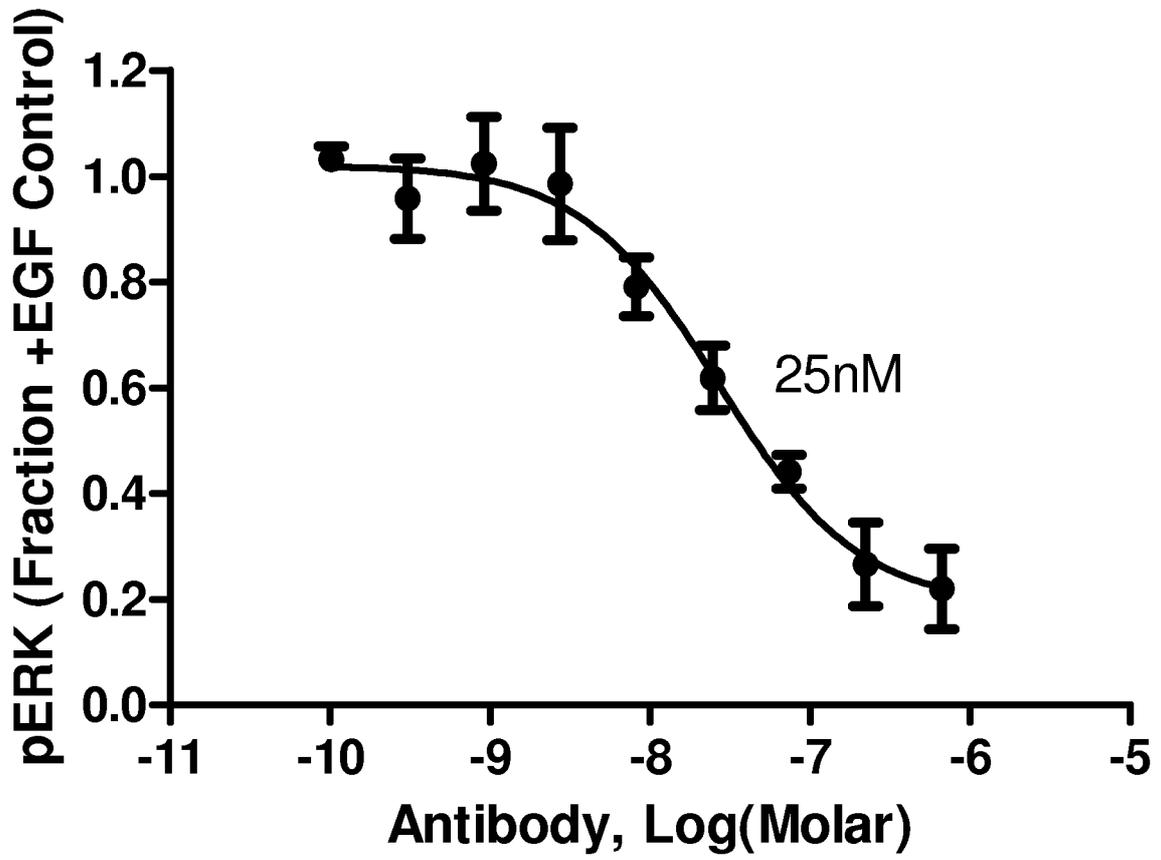


**Fig. 5B**

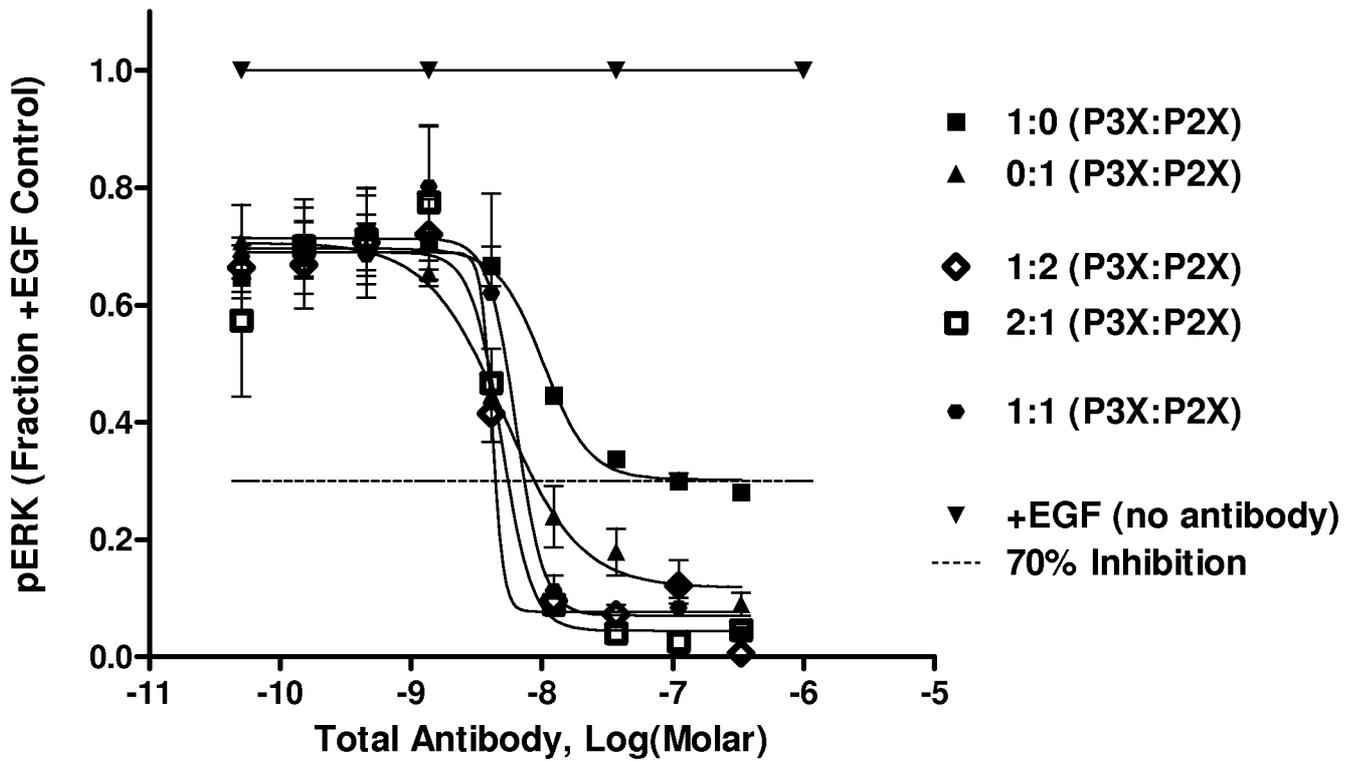
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*Fig. 5C*

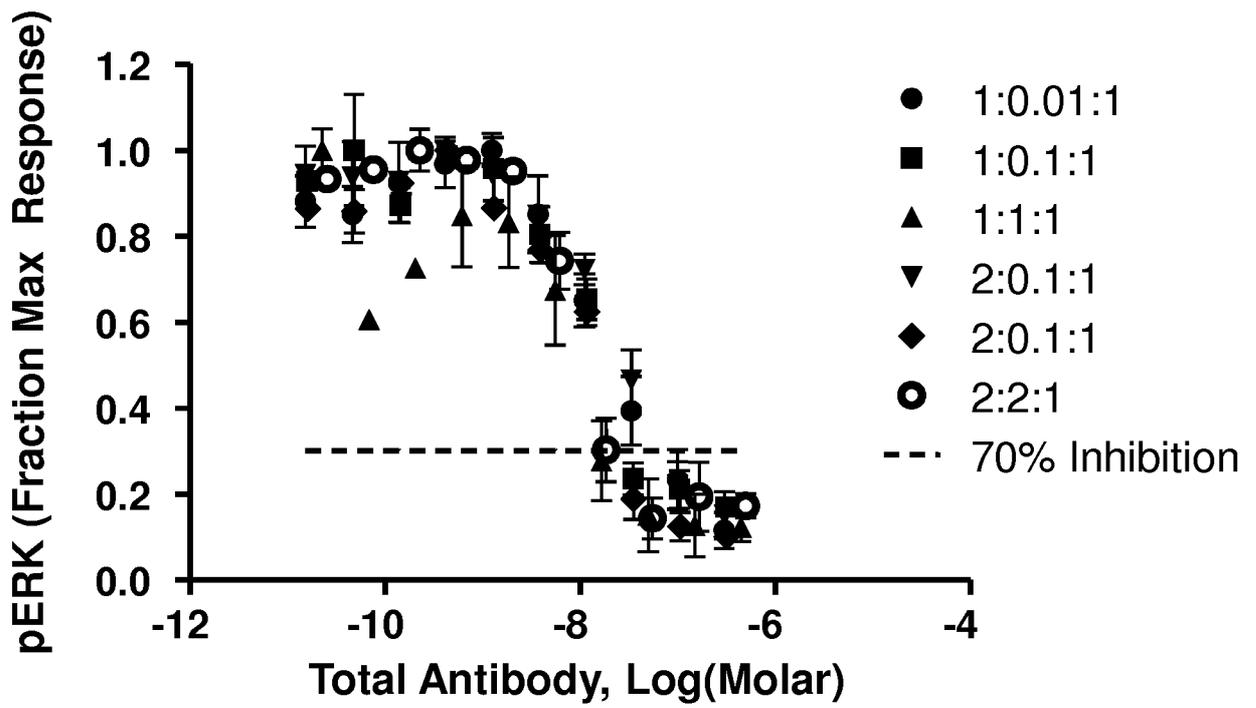
11/33



*Fig. 6A*

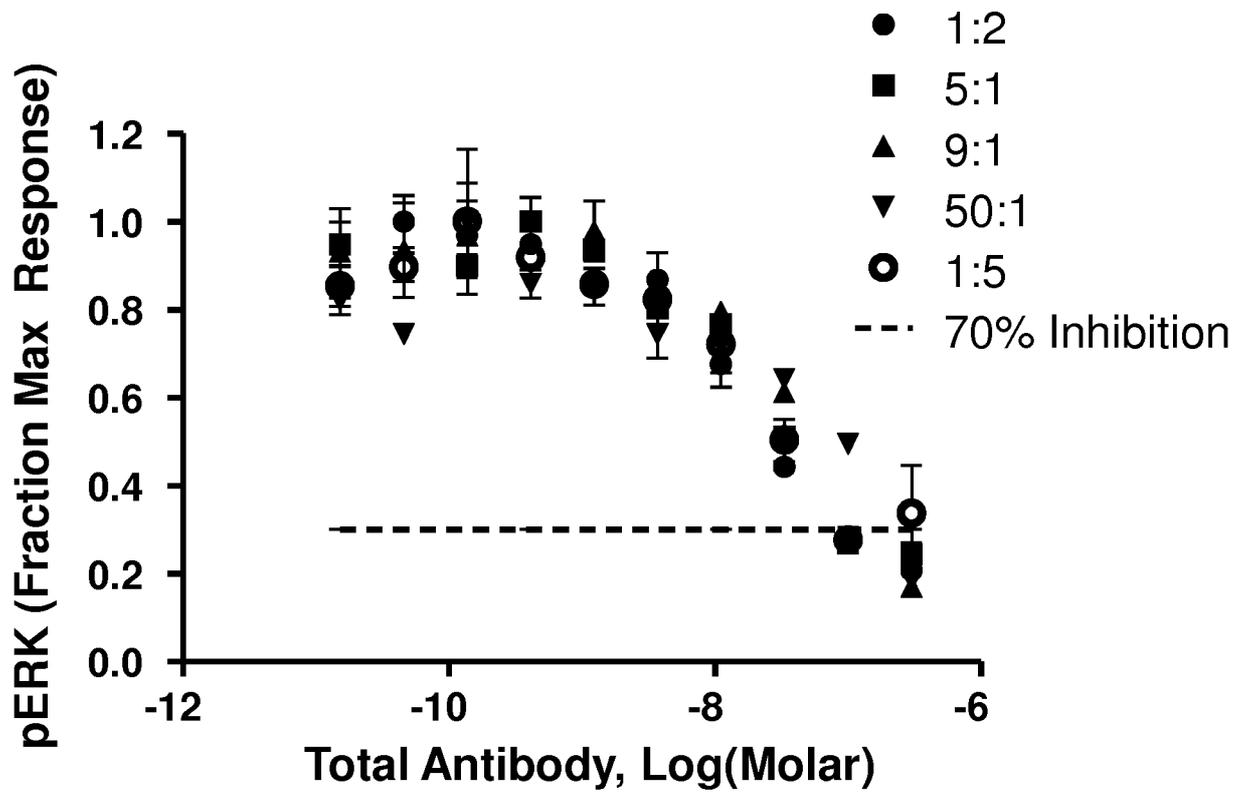


**Fig. 6B**



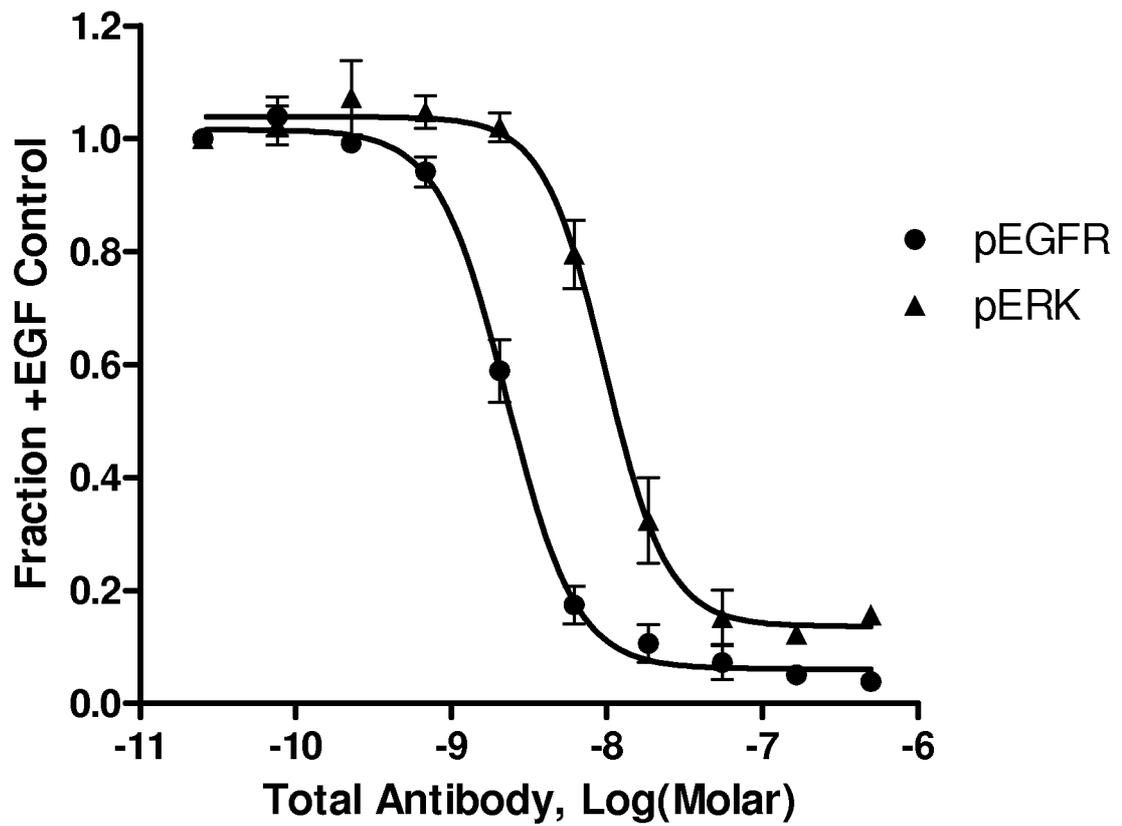
*Fig. 6C*

14/33

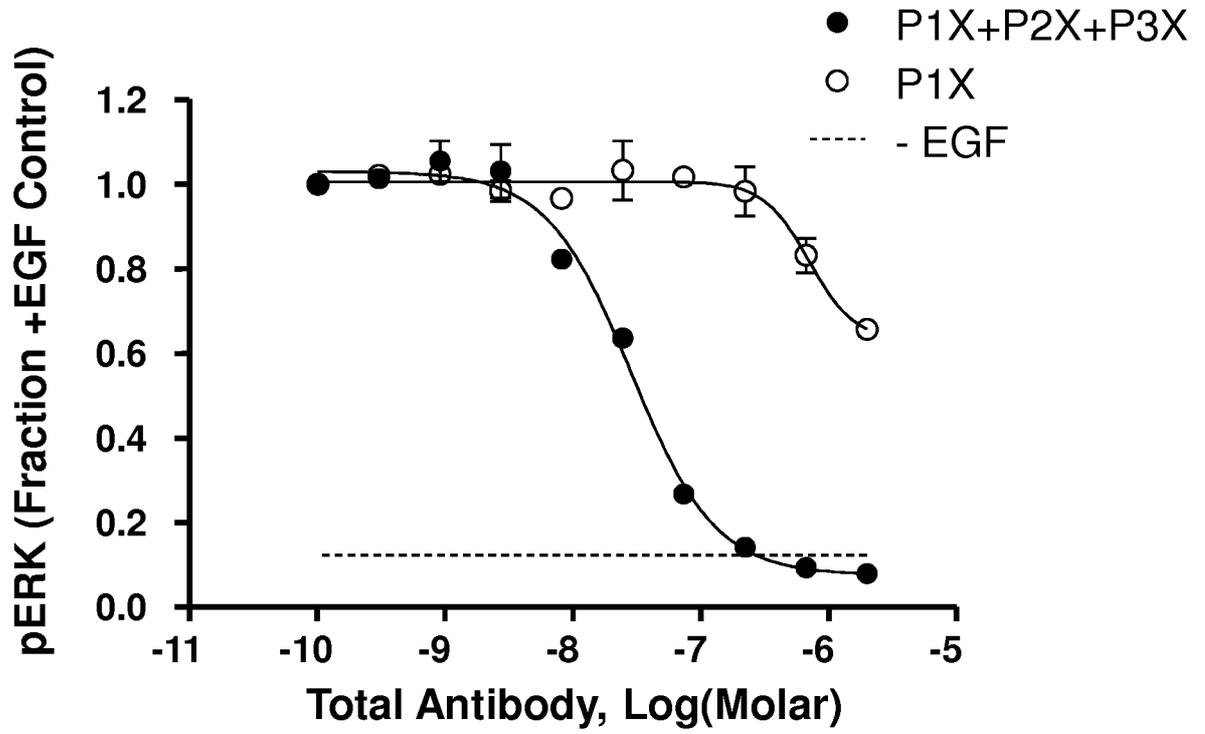


*Fig. 6D*

15/33

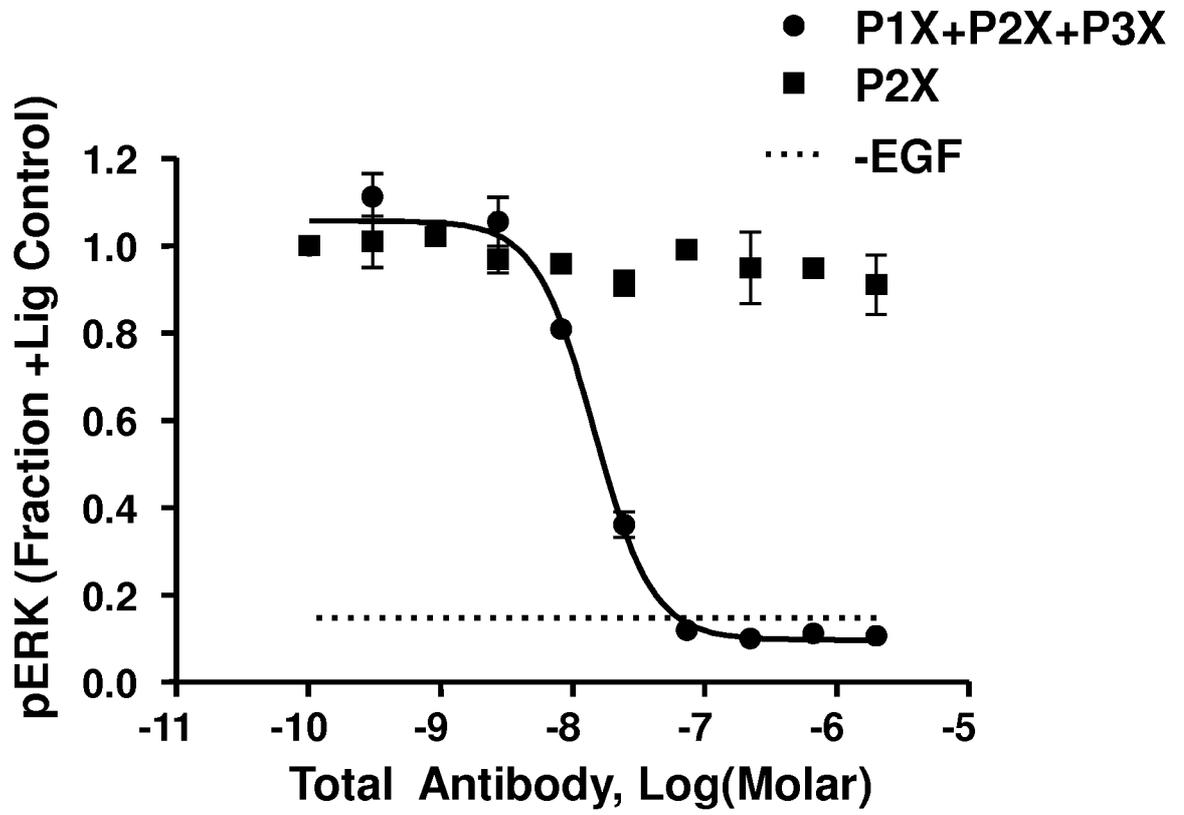
*Fig. 7A*

16/33



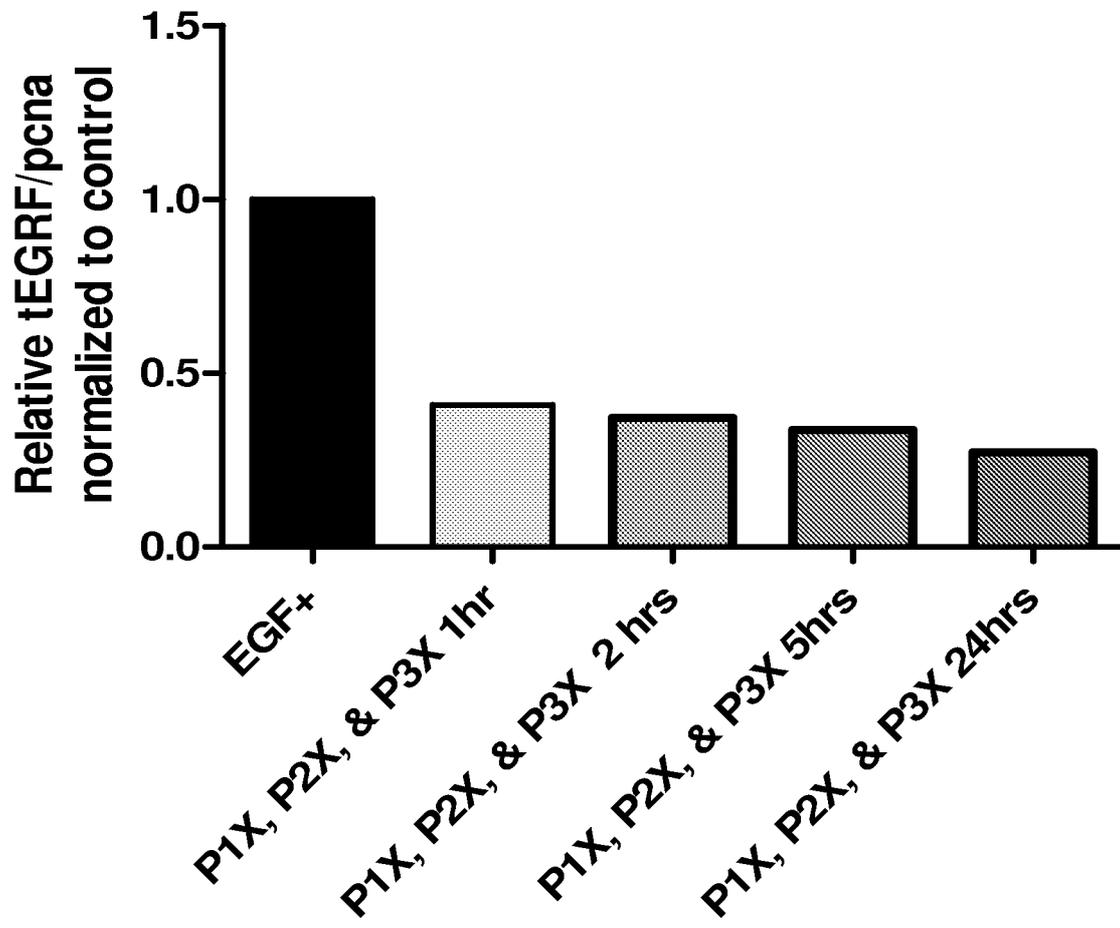
**Fig. 7B**

17/33

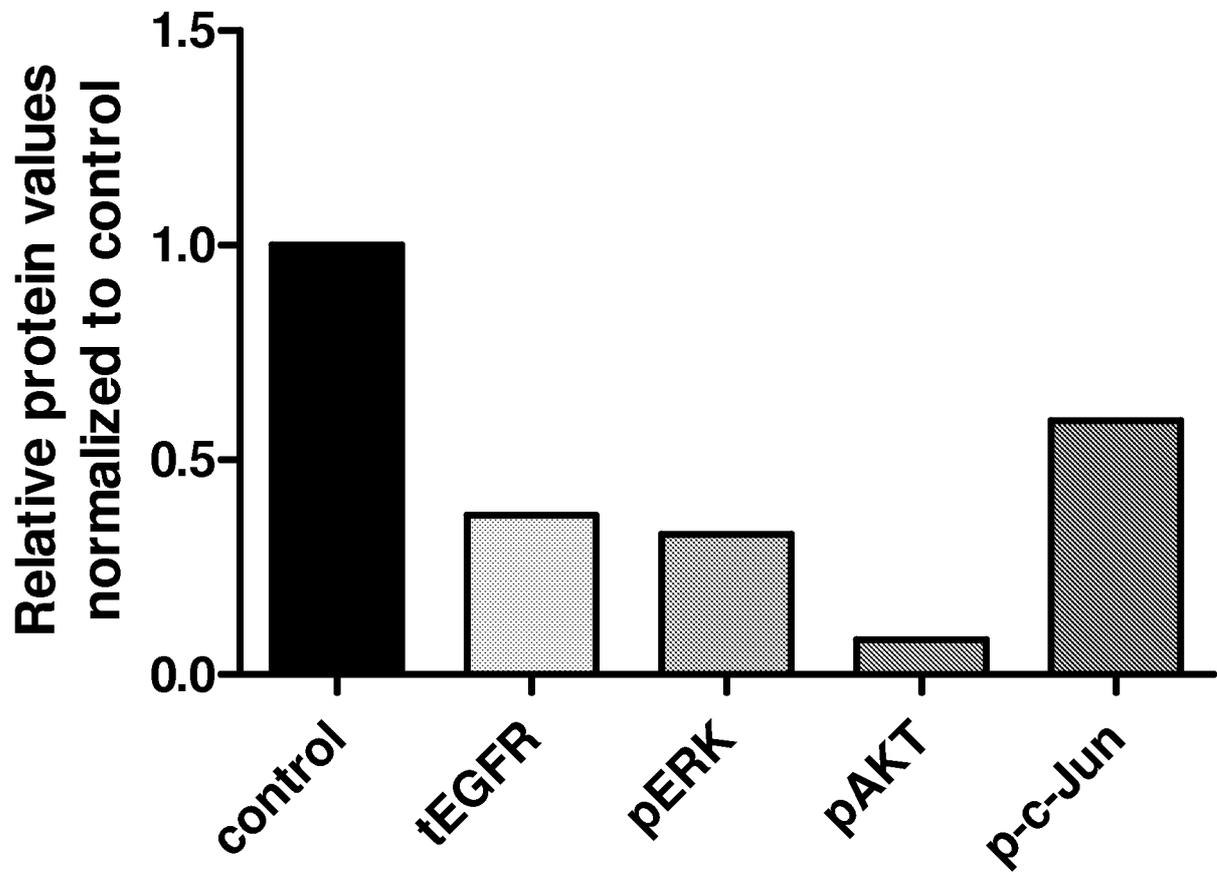


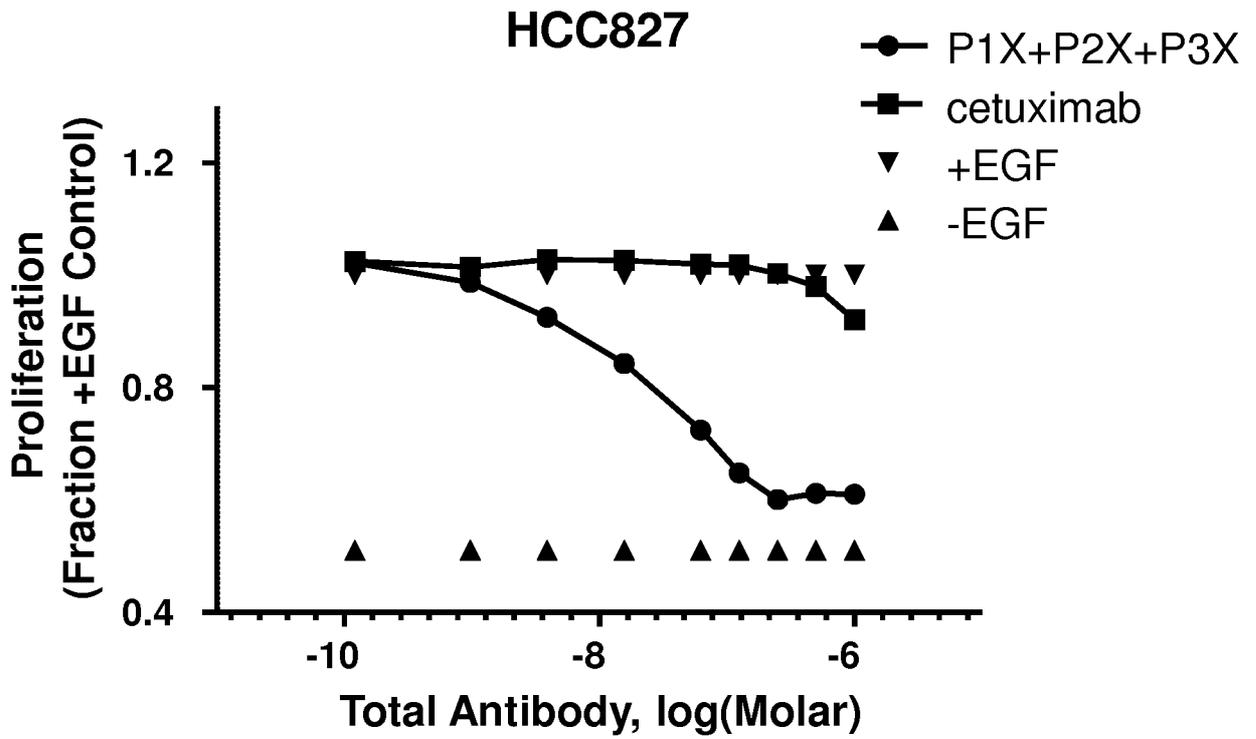
*Fig. 7C*

18/33

*Fig. 8A*

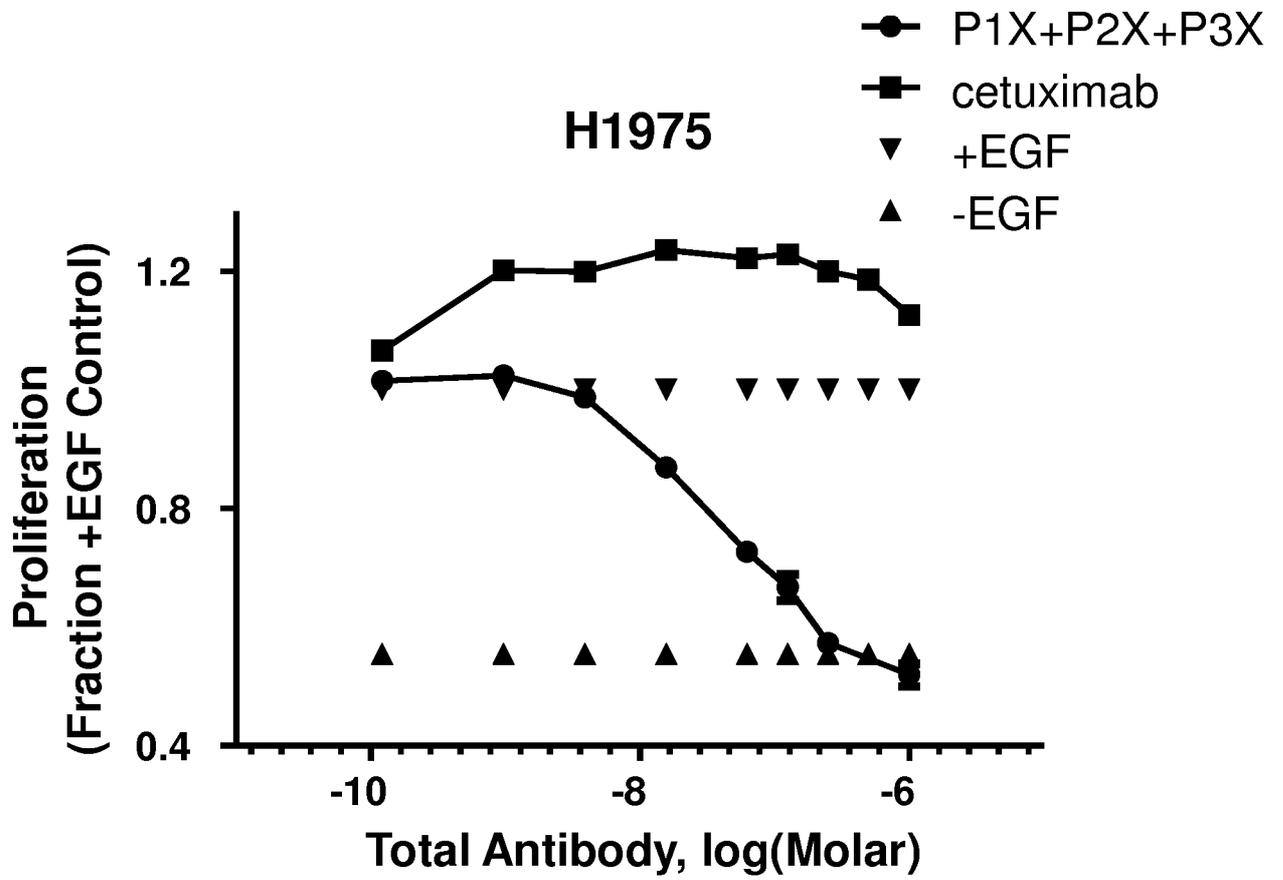
19/33

*Fig. 8B*

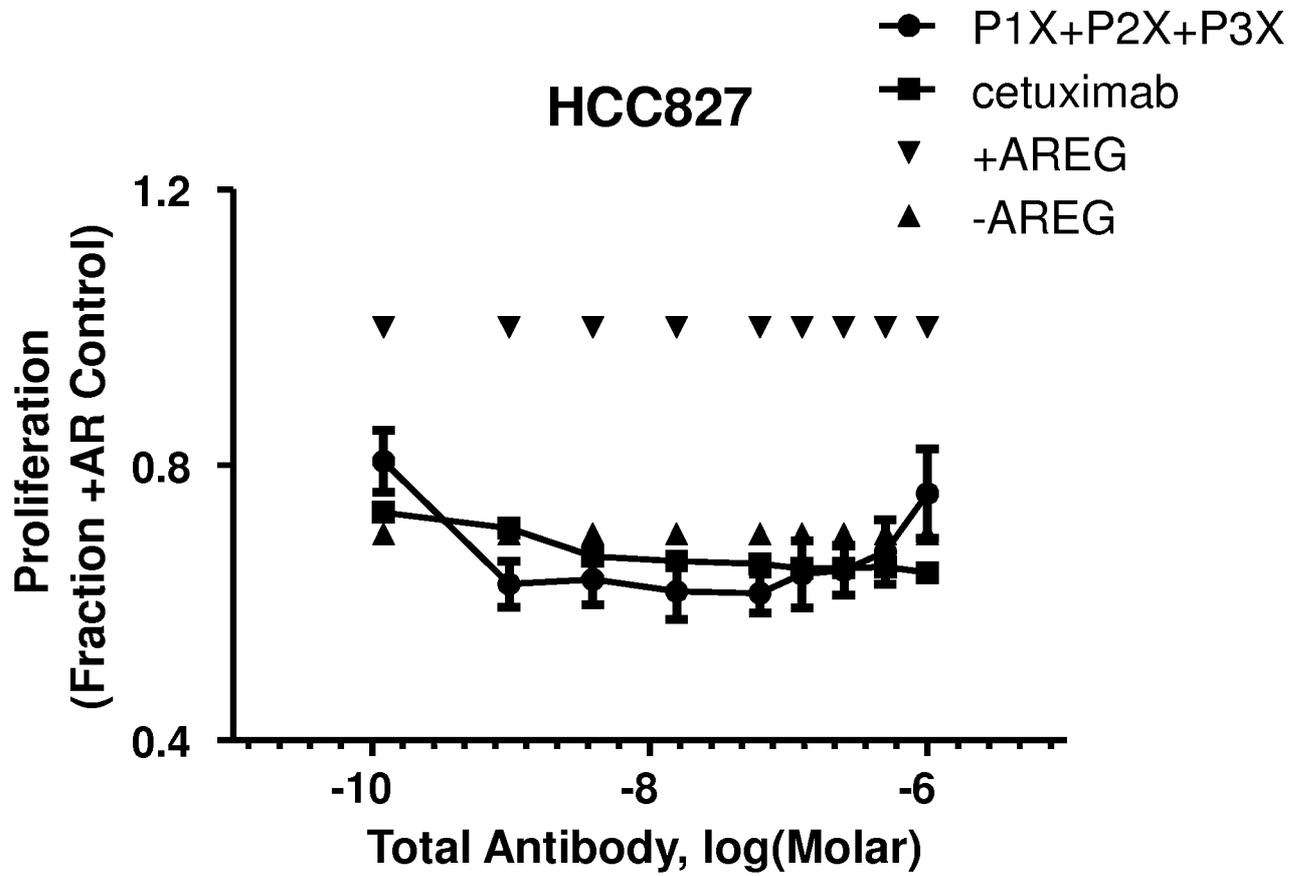


*Fig. 9A*

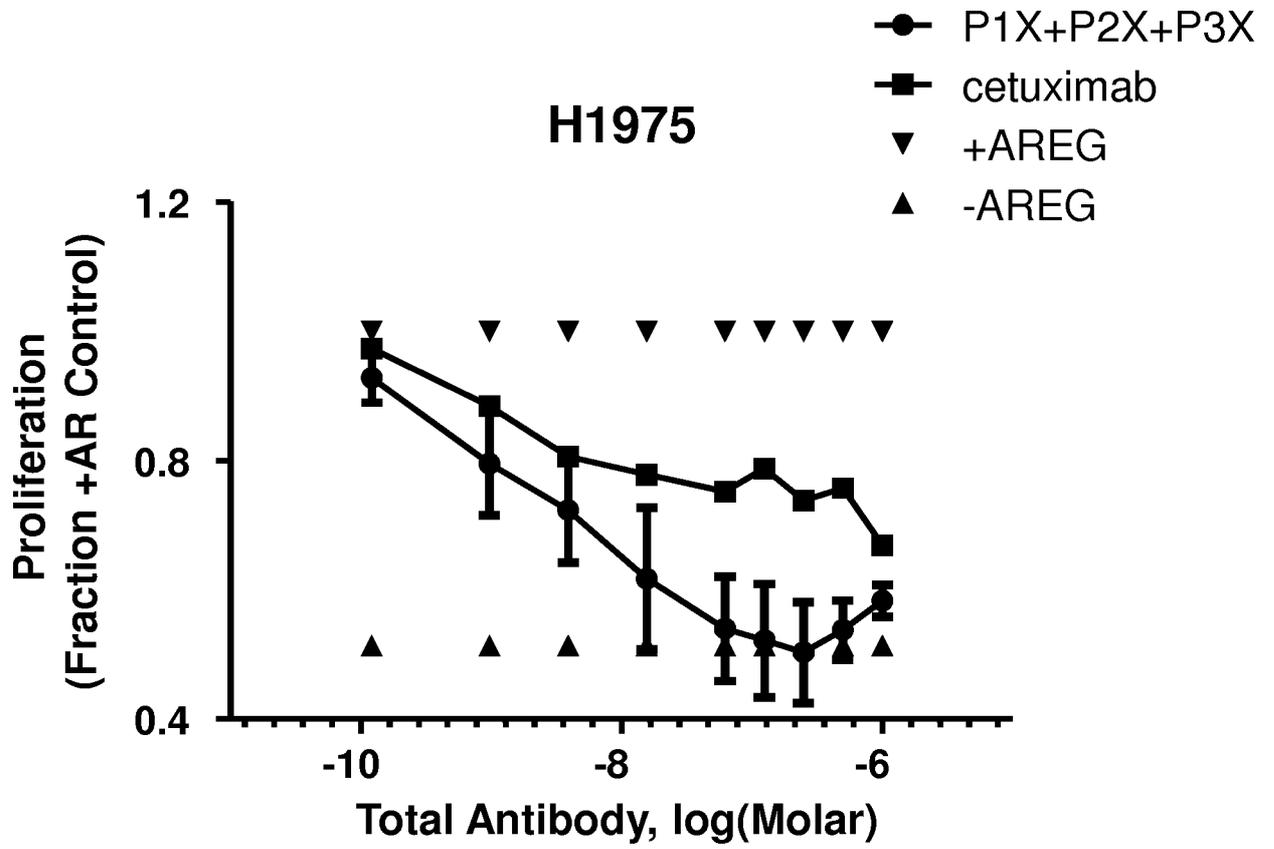
21/33



*Fig. 9B*

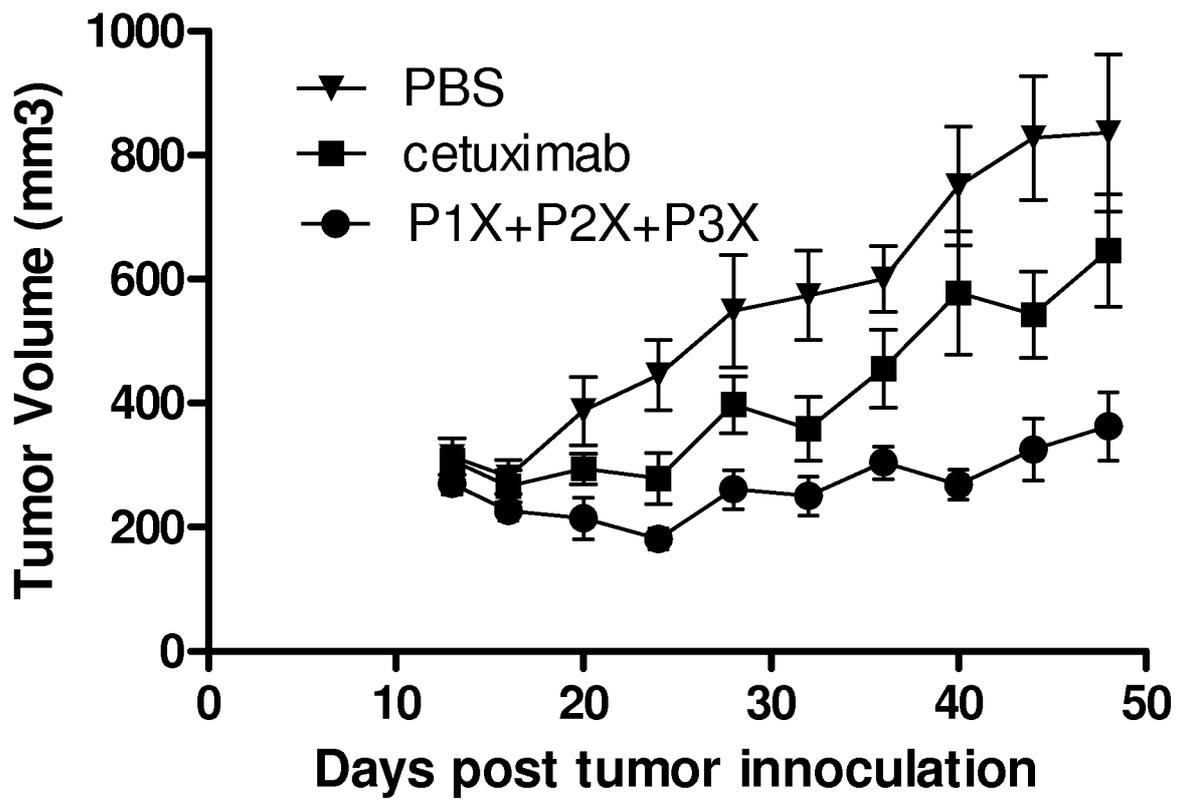


**Fig. 9C**



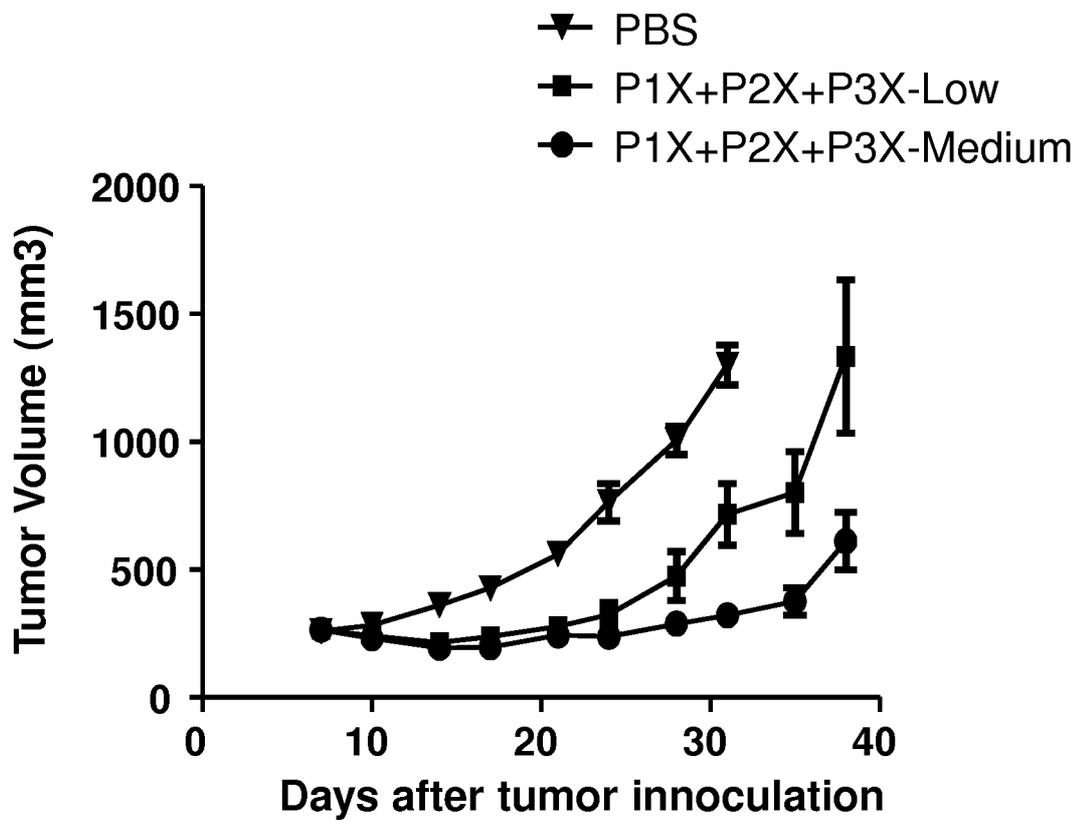
**Fig. 9D**

24/33



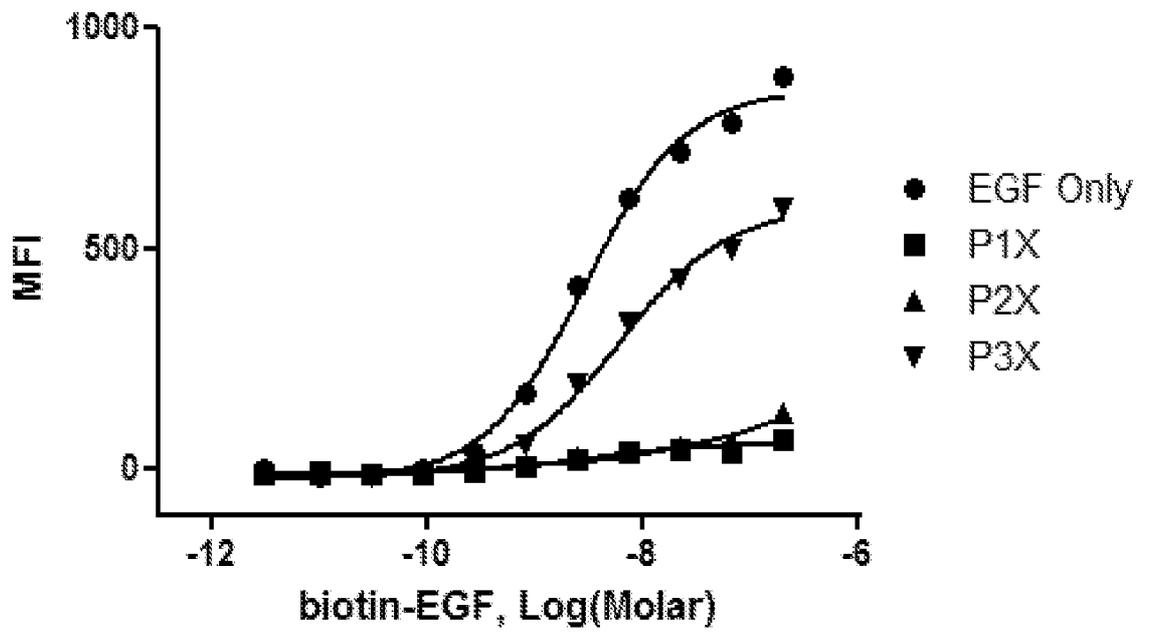
*Fig. 10A*

25/33



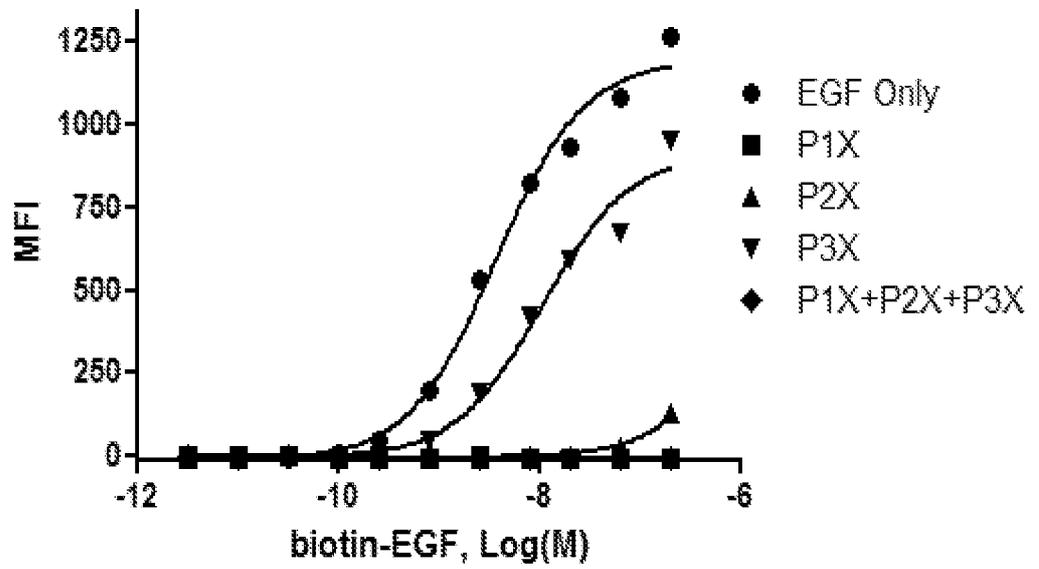
**Fig. 10B**

26/33

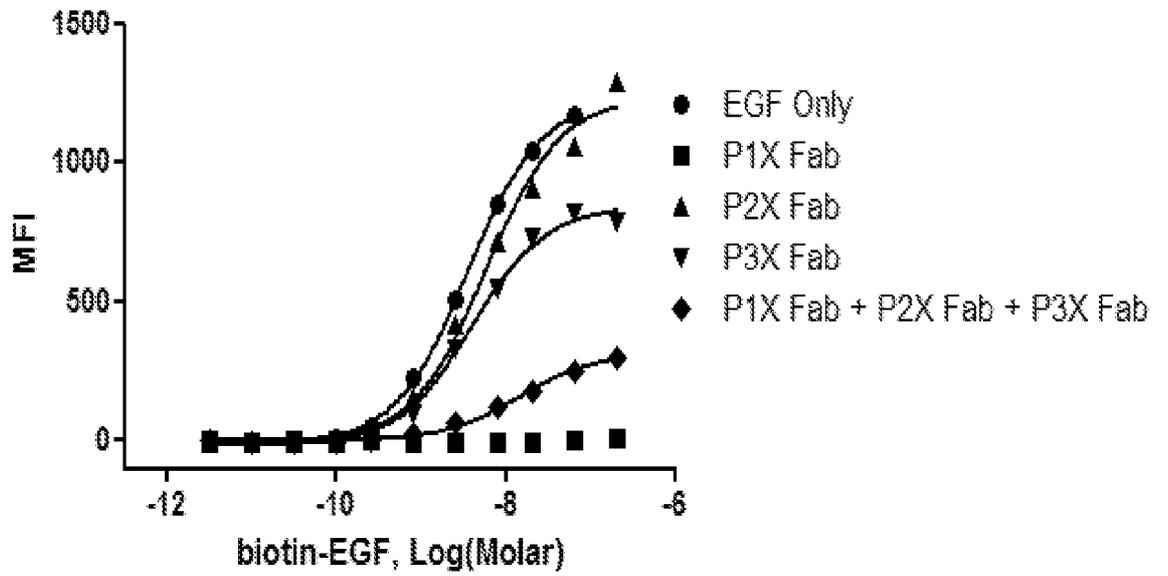


**Fig. 11**

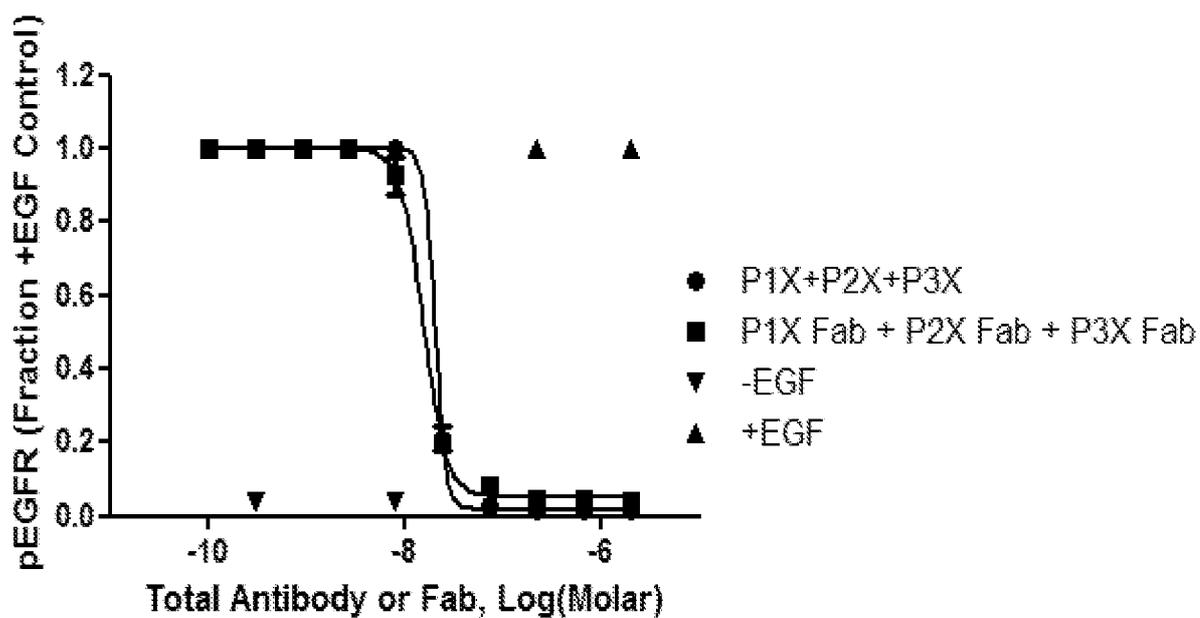
27/33



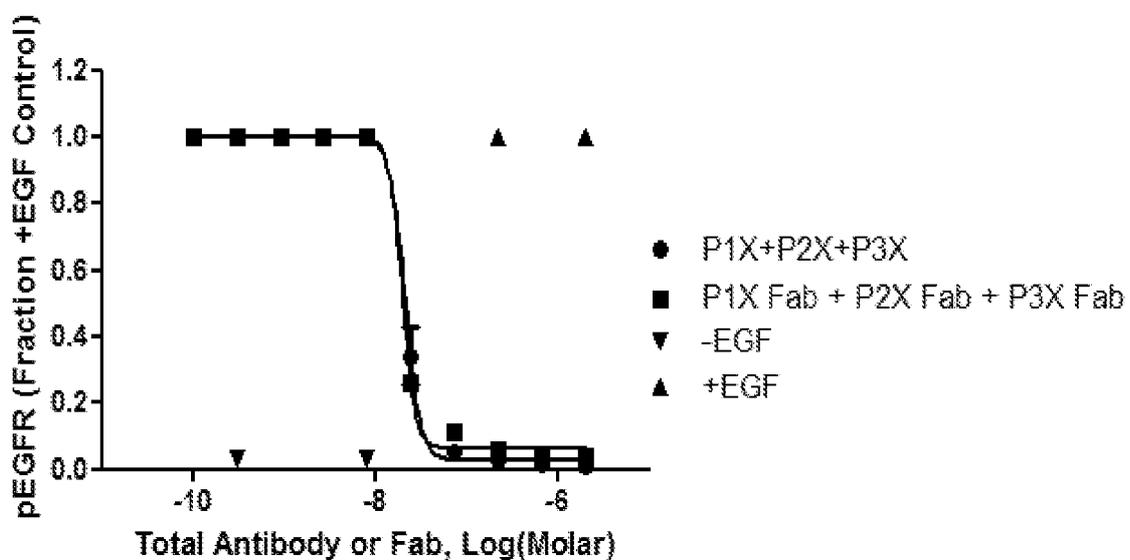
**Fig. 12A**



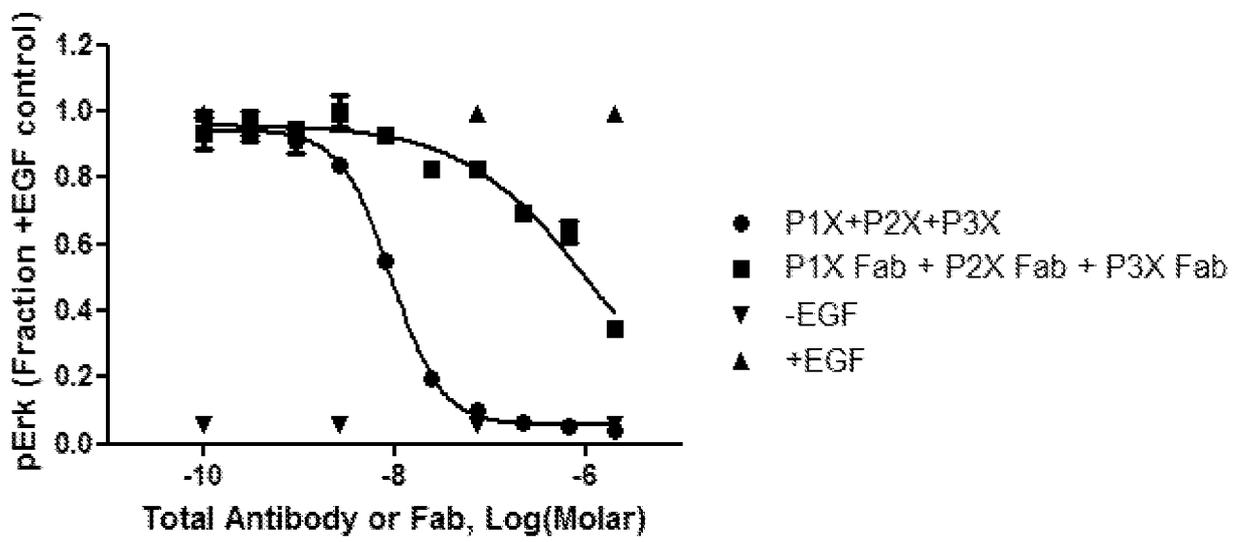
**Fig. 12B**



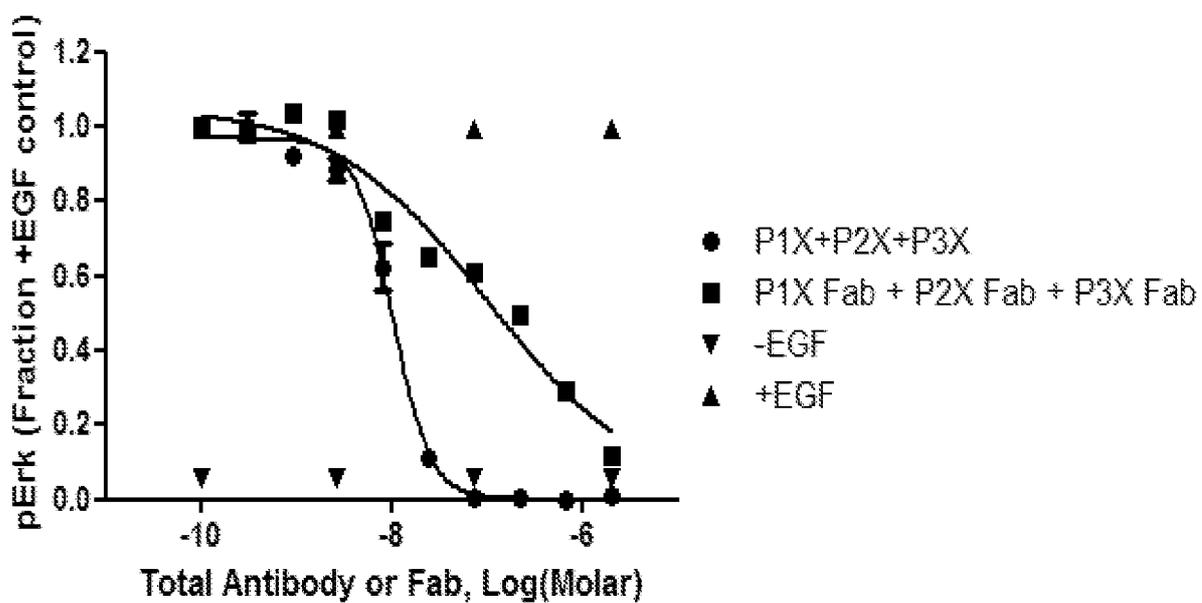
**Fig. 13A**



**Fig. 13B**

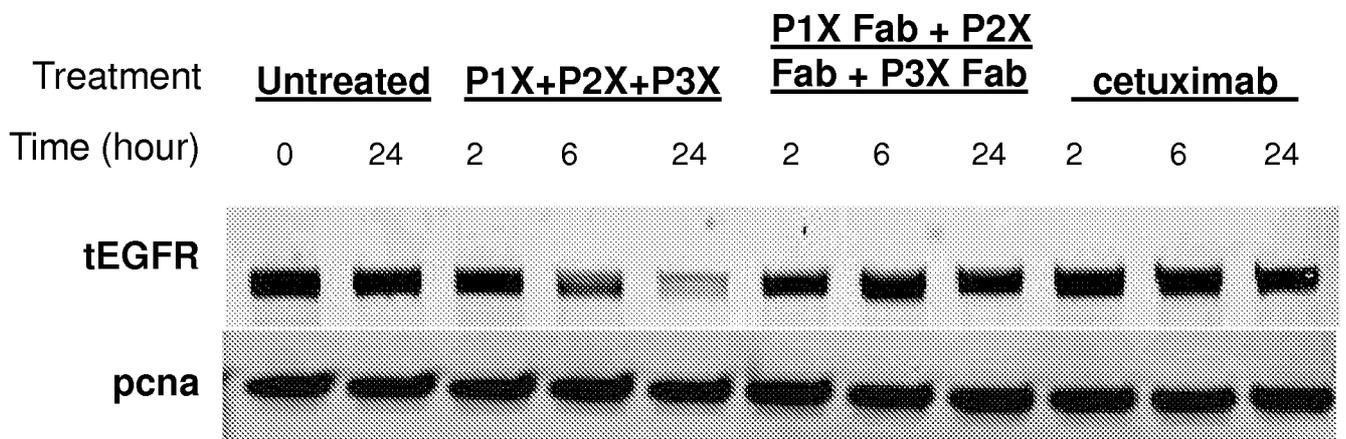


**Fig. 13C**



**Fig. 13D**

33/33



**Fig. 14**