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(54) Title: MULTIFUNCTIONAL ANTIBODIES BINDING TO EGFR AND MET

(57) Abstract: Provided are multifunctional antibodies, and/or antigen-binding fragments, that bind to, and inhibit the activity of, both human epidermal growth factor receptor (EGFR) and MET, and that are effective in treating cancers and other diseases, disorders, or conditions where pathogenesis is mediated by EGFR and MET.



WO 2015/100104 A1

Multifunctional Antibodies Binding to EGFR and MET

The present invention relates to multifunctional antibodies that bind to human epidermal growth factor receptor (EGFR) and MET, methods for their production,
5 pharmaceutical compositions containing the multifunctional antibodies, and uses thereof.

EGFR is a member of the type 1 tyrosine kinase family of growth factor receptors, which plays critical roles in cellular growth, differentiation, and survival. Activation of these receptors typically occurs via specific ligand binding with subsequent autophosphorylation of the tyrosine kinase domain. This activation triggers a cascade of
10 intracellular signaling pathways involved in both cellular proliferation and survival.

Various strategies of cancer therapy to target EGFR and block EGFR signaling pathways have been established. Small-molecule tyrosine kinase inhibitors, e.g., gefitinib and erlotinib, block autophosphorylation of EGFR in the intracellular tyrosine kinase region, thereby inhibiting downstream signaling events. One of the major challenges
15 facing the clinical use of anti-EGFR tyrosine kinase inhibitors is the inherent and acquired resistance of cancers to this class of therapeutics. Certain therapeutic monoclonal antibodies (mAbs), on the other hand, target the extracellular portion of EGFR, which results in blocking ligand binding and thereby inhibits downstream events leading to the inhibition of cell proliferation. The chimeric mouse/human anti-EGFR
20 monoclonal antibody C225 (or cetuximab), and panitumumab, a fully human anti-EGFR mAb, have been approved for treatment of metastatic colorectal and head and neck cancer which target the external part of EGFR. However, patients whose tumor contains a KRAS mutation often do not benefit from cetuximab or panitumumab therapy. KRAS mutations alter signaling properties in the tumor cells by continuously sending a growth signal even
25 if EGFR has been blocked.

MET, a member of the tyrosine kinase superfamily, is the human receptor for human hepatocyte growth factor (HGF). Binding of HGF to MET leads to receptor dimerization or multimerization, phosphorylation of multiple tyrosine residues in the intracellular region, catalytic activation, and downstream signaling. MET is also
30 activated via ligand-independent mechanisms, including receptor over-expression, amplification, and mutation. MET activation enhances cellular proliferation, migration, morphogenesis, and survival, which are associated with invasive cell phenotype and poor

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clinical outcomes. Thus, MET is also a target for anti-cancer therapy. For example, onartuzumab, also known in the art as one-armed 5D5, OA5D5 or MetMAb, has been developed for the potential treatment of cancer, and is a humanized, monovalent, antagonistic anti-MET antibody derived from the MET agonistic monoclonal antibody

5 5D5 (see, for example, Spigel, D.R., *et al.*, Randomized Phase II Trial of Onartuzumab in Combination With Erlotinib in Patients With Advanced Non Small-Cell Lung Cancer, *J. Clinical Oncology*, 31(32):4105-4114 (November 2013) and Xiang H., *et al.*, Onartuzumab (MetMAb): Using Nonclinical Pharmacokinetic and Concentration – Effect Data to Support Clinical Development, *Clin Cancer Res.*, (2013)). Onartuzumab binds to

10 MET and remains on the cell surface with MET, preventing HGF binding and subsequent MET phosphorylation as well as downstream signaling activity and cellular responses.

WO 2010/059654 describes various MET antibodies including high-affinity antagonistic antibodies that bind to an epitope within the α -chain of MET and which induce internalization and/or degradation of MET in the presence or absence of HGF and

15 in tumors characterized by gain of function mutations which are generally resistant to known MET antagonists. One of the MET antibodies disclosed in WO 2010/059654, LY2875358 has been reported to have no or otherwise negligible agonist activity on MET (see, for example, Zeng, W., *et al.*, 104rd AACR Annual Meeting, poster #5465 (2013)).

United States Patent No. 7,723,484 describes humanized and affinity optimized

20 EGFR specific antibodies, and antigen-binding portions thereof, that inhibit activation of EGFR. More specifically, this patent describes, *inter alia*, full-length monoclonal antibodies that bind to human epidermal growth factor receptor (EGFR) with subpicomolar binding affinities (Kd) as measured by a Sapidyme KINEXA performed at room temperature.

25 MET and EGFR are co-expressed in many tumors. Blocking one receptor tends to up-regulate the other, frequently and often quickly leading to resistance to single agent treatment (Engelman, J.A., *et al.* MET amplification leads to gefitinib resistance in lung cancer by activating ERBB3 signaling. *Science*, 2007;316:1039–43). Conversely, MET-amplified lung cancer cells exposed to MET-inhibiting agents for a prolonged period

30 develop resistance via the EGFR pathway (McDermott, U., *et al.*, Acquired resistance of non-small cell lung cancer cells to MET kinase inhibition is mediated by a switch to epidermal growth factor receptor dependency, *Cancer Res.*, (2010); 70(4):1625-34).

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Co-administration of a MET antibody and an EGFR antibody requires injections of two separate products or a single injection of a co-formulation of two different antibodies.

Two injections would permit flexibility of dose amount and timing, but would be inconvenient to patients both for compliance and pain. A co-formulation might also

5 provide some flexibility of dose amounts, but it is often quite challenging or impossible to find formulation conditions that permit chemical and physical stability of both antibodies due to different molecular characteristics of the two different antibodies.

WO 199509917 discloses a method for producing bispecific, tetravalent antibodies using recombinant DNA technology by producing a single chain fragment variable (scFv) antibody fused to a complete antibody having a different specificity. This
10 gene fusion is expressed by transfection resulting in a tetravalent antibody having dual specificity. However, it is generally recognized in the art that when the teachings in the art, including WO 199509917, are followed while attempting to create useful bispecific antibodies skilled artisans frequently encounter significant problems associated with
15 chemical and physical stability of the resulting bispecific antibody(ies). Oftentimes, amino acid changes are required in the resulting bispecific antibody(ies) to sufficiently overcome these problems. Neither the need for amino acid changes, nor the actual changes that will overcome the resulting problems are suggested in the art. Further, the changes that are required are most often not routine or derived from common general
20 knowledge. Likewise, bispecific antibodies generated from known antibodies are often found to be less desirable in at least one important functional pharmacokinetic or pharmacodynamic property as compared to the parental antibodies themselves.

PCT International Publication WO 2010/115551 discloses a trivalent, bispecific anti-human EGFR and MET antibody (BsAB01), in which a single chain Fab fragment,
25 i.e., one-armed 5D5, was fused to the carboxyl-terminus of one of the two heavy chains of cetuximab. It has been reported that BsAB01 reduces the internalization of MET, compared to the internalization of MET induced by the monospecific, monovalent parent MET antibody. In OVCAR-8 proliferation assays, BsAB01 led to 8% inhibition compared to 2% inhibition with the combination of cetuximab and onartuzumab. In the
30 presence of HGF, BsAB01 led to 15% inhibition compared to 10% inhibition with the combination of cetuximab and onartuzumab.

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Additionally, the generation of a bispecific antibody targeting both EGFR and cMET, EM1-mAb, using controlled Fab Arm Exchange (cFAE), a process that involves mixing two parental antibodies (in this case, with specificity for either EGFR or MET) under reducing conditions, followed by re-oxidation has been disclosed (Moore, S., et al., EORTC Annual Meeting, poster #B241 (2013)). EM1-mAb was reported, *inter alia*, to exhibit superior activity compared to the combination of monovalent control antibodies in at least one *in vitro* ERK phosphorylation assay.

United States Patent Application Publication US 2014/0302029 describes the generation of bispecific antibodies targeting both EGFR and cMET which were constructed by fusing an anti-EGFR scFv based on the sequence of cetuximab to the C-terminus of the IgG2 Fc of an affinity matured and humanized derivative of a mouse antibody (i.e., AbF46) to c-Met.

Thus, a multifunctional antibody that binds MET and EGFR with high affinity, effectively neutralizes MET activation by HGF and EGFR activation by EGF family ligands, and/or provides superior activity in internalizing and/or degrading MET and EGFR (both wild-type and mutants) relative to combinations of single-agents is needed as an effective pharmacological intervention for certain cancers. Particularly, desirable are such anti-MET/EGFR antibodies that i) may more effectively treat cancers characterized by having one or more KRAS mutations, ii) demonstrate superior activity in preventing or delaying the development of resistance to other MET and/or EGFR inhibitors including, but not limited to, erlotinib, gefitinib, lapatinib and vemurafenib, as compared to relevant combinations of single-agents, iii) elicit minimal or no measurable agonist activity, and/or iv) demonstrate *in vivo* stability, physical and chemical stability including, but not limited to, thermal stability, solubility, low self-association, and pharmacokinetic characteristics which are acceptable for development and/or use in the treatment of cancer. However, while generally following the teachings in WO 199509917 when attempting to create tetravalent, multifunctional anti-MET/EGFR antibodies comprising certain anti-MET antibodies of WO 2010/059654 and certain anti-EGFR antibodies of United States Patent No. 7,723,484, the present inventors encountered significant problems associated with chemical and physical stability and the loss of desired binding properties with respect to one or both of the target receptors, MET and EGFR. Therefore, an extensive engineering effort involving many amino acid changes were required to sufficiently overcome these

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problems. Neither the need for nor the actual changes are suggested in the art. Further, the several changes are not routine or derived from common general knowledge.

Likewise, the parental antibodies themselves did not have these problems, suggesting that the local environment around critical areas differed in the context of multifunctional anti-MET/EGFR antibodies.

Accordingly, the present invention provides tetravalent, multifunctional antibodies that bind to EGFR and MET. These multifunctional antibodies induce co-localization of EGFR and MET on the cell surface, internalization and/or degradation of MET, and, surprisingly, even greater internalization and degradation of EGFR compared with cetuximab in tumor cells with high MET expression. Moreover, these anti-MET/EGFR multifunctional antibodies exhibit higher avidity binding to MET than the parent anti-MET antibody in tumor cells with low to moderate MET expression.

Accordingly, the present invention provides tetravalent, multifunctional antibodies that bind to EGFR and MET. These multifunctional antibodies induce co-localization of EGFR and MET on the cell surface, internalization and/or degradation of MET, and, surprisingly, even greater internalization and degradation of EGFR compared with cetuximab in tumor cells with high MET expression. Moreover, these anti-MET/EGFR multifunctional antibodies exhibit higher avidity binding to MET than the parent anti-MET antibody in tumor cells with low to moderate MET expression. Furthermore, these multifunctional anti-MET/EGFR antibodies exhibit superior activities compared to the combination of two individual antibodies in inhibition of tumor cell growth in cell culture as well as in mouse xenograft models. They also appear to have superior activity than the combination of individual MET and EGFR antibodies in restoring tumor cell sensitivity to various target therapies, including erlotinib and PLX4032 (i.e., a B-Raf inhibitor) in the presence of HGF and/or EGF. Such anti-MET/EGFR antibodies may also prove more effective against a high EGFR expressing tumor or a tumor which is resistant, or has become resistant, to one or more anti-EGFR antibodies (e.g., cetuximab, panitumumab, etc.) and/or one or more small molecule inhibitors of EGFR (e.g., erlotinib), including, but not limited to, tumors harboring KRAS mutations. In various embodiments of the present invention, these multifunctional antibodies bind to MET and EGFR simultaneously, neutralize activation of MET by HGF, and EGFR by EGF, inhibit ligand dependent and independent cell proliferation of many types of cancer cells expressing

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MET and EGFR, induce co-localization of EGFR and MET on the cell surface, induce internalization and/or degradation of MET, and, surprisingly, induce even greater internalization and degradation of EGFR compared with cetuximab in tumor cells with high MET expression.

5 An embodiment of the present invention is a multifunctional antibody comprising:

(a) an antibody that binds MET and comprises:

- 10 i) a heavy chain comprising heavy chain complementarity determining regions (CDRs) HCDR1, HCDR2, and HCDR3 consisting of the amino acid sequences of GYTFTDYMH (SEQ ID NO: 11), RVNPNRRGTTYNQKFEG (SEQ ID NO: 12), and ARANWLDY (SEQ ID NO: 13), respectively; and
- 15 ii) a light chain comprising light chain CDRs LCDR1, LCDR2, and LCDR3 consisting of the amino acid sequences of SVSSSVSSIYLH (SEQ ID NO: 14), YSTSNLAS (SEQ ID NO: 15) and QVYSGYPLT (SEQ ID NO: 16), respectively; and

(b) a scFv polypeptide that binds to human EGFR and comprises:

- 20 i) a HCVR domain comprising scFv CDRs scFv-HCDR1, scFv-HCDR2, and scFv-HCDR3 consisting of the amino acid sequences GFSLTNYGVH (SEQ ID NO: 1), VIX₁SGGNTDYNTPF_X₂G (SEQ ID NO: 9), wherein X₁ is Y or W and X₂ is K or T, and ARALDYDYDFAY (SEQ ID NO: 3), respectively; and
- 25 ii) a LCVR domain comprising scFv CDRs scFv-LCDR1, scFv-LCDR2, and scFv-LCDR3 consisting of the amino acid sequences RASYSIGTNIH (SEQ ID NO: 4), X₁YAX₂X₃SIS (SEQ ID NO: 10), wherein X₁ is R or Y, X₂ is K or S, and X₃ is E or R, and QQNNAWPTT (SEQ ID NO: 6), respectively, and wherein the C-terminus of the scFv polypeptide is fused via a peptide linker to the N-terminus of the MET antibody heavy chain.

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Another embodiment of the present invention is a multifunctional antibody comprising:

- (a) an antibody that binds MET and comprises:
 - i) a first heavy chain and a second heavy chain wherein each of the heavy chains comprise heavy chain CDRs HCDR1, HCDR2, and HCDR3 consisting of the amino acid sequences of GYTFTDYMH (SEQ ID NO: 11), RVNPNRRGTTYNQKFEG (SEQ ID NO: 12), and ARANWLDY (SEQ ID NO: 13), respectively; and
 - ii) a first light chain and a second light chain wherein each of the light chains comprises light chain CDRs LCDR1, LCDR2, and LCDR3 consisting of the amino acid sequences of SVSSSVSSIYLH (SEQ ID NO: 14), YSTSNLAS (SEQ ID NO: 15) and QVYSGYPLT (SEQ ID NO: 16), respectively; and
- (b) a first scFv polypeptide and a second scFv polypeptide wherein each of the scFv polypeptides binds to human EGFR and wherein each of the scFv polypeptides comprises:
 - i) a HCVR domain comprising scFv CDRs scFv-HCDR1, scFv-HCDR2, and scFv-HCDR3 consisting of the amino acid sequences GFSLTNYGVH (SEQ ID NO: 1), VIX₁SGGNTDYNTPF_X₂G (SEQ ID NO: 9), wherein X₁ is Y or W and X₂ is K or T, and ARALDYDYDFAY (SEQ ID NO: 3), respectively; and
 - ii) a LCVR domain comprising scFv CDRs scFv-LCDR1, scFv-LCDR2, and scFv-LCDR3 consisting of the amino acid sequences RASYSIGTNIH (SEQ ID NO: 4), X₁YAX₂X₃SIS (SEQ ID NO: 10), wherein X₁ is R or Y, X₂ is K or S, and X₃ is E or R, and QQNNAWPTT (SEQ ID NO: 6), respectively, and wherein the C-terminus of the first scFv polypeptide is fused via a peptide linker to the N-terminus of the first heavy chain and the C-terminus of the second scFv polypeptide is fused via a peptide linker to the N-terminus of the second heavy chain.

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A further embodiment of the present invention is a multifunctional antibody comprising two first polypeptides and two second polypeptides wherein both first polypeptides comprise the amino acid sequence of SEQ ID NO: 25, SEQ ID NO: 26, SEQ ID NO: 27, SEQ ID NO: 29, SEQ ID NO: 31, SEQ ID NO: 52 or SEQ ID NO: 53; and both second polypeptides comprise the amino acid sequence of SEQ ID NO: 33, and wherein said multifunctional antibody binds to EGFR and MET.

Another embodiment of the present invention is a pharmaceutical composition, comprising any one of the foregoing multifunctional antibodies, or MET and EGFR binding fragments thereof, and a pharmaceutically acceptable carrier, diluent, or excipient.

Another embodiment of the present invention is any one of the foregoing multifunctional antibodies, or a MET and EGFR binding fragment thereof, for use in therapy.

Another embodiment of the present invention is any one of the foregoing multifunctional antibodies, or a MET and EGFR binding fragment thereof, for use in treating a cancer.

Another embodiment of the present invention is any one of the foregoing multifunctional antibodies, or a MET and EGFR binding fragment thereof, for use in treating a cancer wherein both MET and EGFR are expressed by the patient's tumor.

Another embodiment of the present invention is any one of the foregoing multifunctional antibodies, or a MET and EGFR binding fragment thereof, for use in treating a cancer wherein MET and/or EGFR are expressed by the patient's tumor at a low, moderate, or high level and/or tumor or a tumor which is resistant, or has become resistant, to one or more anti-EGFR antibodies (e.g., cetuximab, panitumumab, etc.) and/or one or more small molecule inhibitors of EGFR (e.g., erlotinib), including, but not limited to, tumors harboring KRAS mutations. In various embodiments of such an invention, the use of a multifunctional antibody, or a MET and EGFR binding fragment thereof, for treating a cancer wherein MET and/or EGFR are expressed by the patient's tumor at a low, moderate, or high level and/or a tumor which is resistant, or has become resistant, to one or more anti-EGFR antibodies (e.g., cetuximab, panitumumab, etc.) and/or one or more small molecule inhibitors of EGFR (e.g., erlotinib), including, but not limited to, tumors harboring one or more KRAS mutations may further comprise a step of

identifying the patient in need of the treatment of the cancer, prior to the step of administering the multifunctional antibody of the present invention, or a MET and EGFR binding fragment thereof, to the patient.

Another embodiment of the present invention is any one of the foregoing
5 multifunctional antibodies, or a MET and EGFR binding fragment thereof, for use in treating NSCLC, SCLC, gastric cancer, colorectal cancer, cholangiocarcinoma, esophageal cancer, melanoma, including, but not limited to, uveal melanoma, renal cancer, liver cancer, bladder cancer, cervical cancer, or head and neck cancer.

Another embodiment of the present invention is a method of treating a cancer,
10 comprising administering to a human patient in need thereof an effective amount of any one of the foregoing multifunctional antibodies, or a MET and EGFR binding fragment thereof.

Fig. 1 illustrates western blotting results showing that anti-MET/EGFR multifunctional antibodies NH-YK and NH-H9 induce degradation of EGFR and MET in
15 the cancer cell lines H1993 (NSCLC), MKN45 (gastric carcinoma), and H441 (NSCLC). The cancer cell lines were treated overnight with 100 nM of antibody NH-YK, antibody NH-H9 or control antibodies. EGFR and MET degradation was determined by western blotting of cell lysates. The anti-MET/EGFR multifunctional antibodies NH-YK and NH-H9 trigger significant degradation of EGFR whereas cetuximab or a combination of
20 the parental anti-MET antibody and cetuximab did not. Lane 1: hIgG4; Lane 2: anti-MET Ab; Lane 3: cetuximab; Lane 4 anti-MET Ab + cetuximab; Lane 5: NH-YK; Lane 6: NH-H9.

Fig. 2 is a graph showing that administration of the anti-MET/EGFR multifunctional antibody NH-YK results in a significantly greater decrease in tumor
25 volume (T/C% of 28.5%, $p < 0.001$) in a H1993 mouse xenograft model as compared to administration of a vehicle control or a combination of the parental anti-Met antibody and cetuximab (T/C% of 86.1%).

Fig. 3 is a graph showing that administration of the anti-MET/EGFR multifunctional antibody NH-YK results in a significantly greater decrease in tumor
30 volume (T/C% of 28.5%, $p < 0.001$) in a H441 mouse xenograft model as compared to administration of a vehicle control or a combination of the parental anti-Met antibody and cetuximab.

Fig. 4 is a graph showing that administration of the anti-MET/EGFR multifunctional antibody NH-YK results in a significantly greater decrease in tumor volume (T/C% of 32.9% ($p < 0.001$)) in a EBC-1 NSCLC mouse xenograft model as compared to administration of a vehicle control.

5 Fig. 5 is a graph showing that administration of the anti-MET/EGFR multifunctional antibody NH-YK results in comparable anti-tumor efficacy as compared to the administration of a combination of the parental MET antibody and cetuximab (T/C% = 17.4%, $p < 0.001$ and 18.6%, $p < 0.001$, respectively) or a vehicle control in a MKN45 gastric xenograft model.

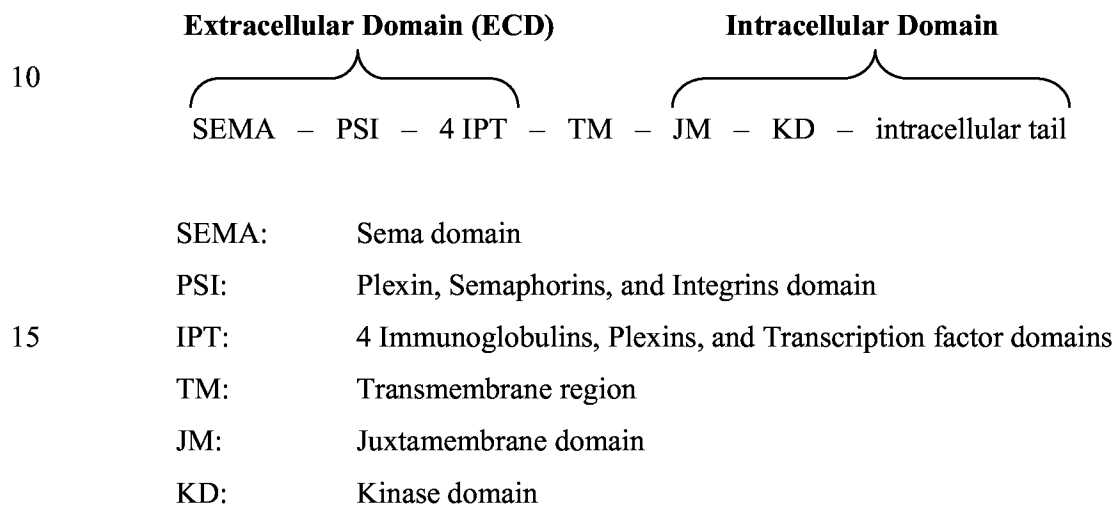
10 Fig. 6 is a graph showing that administration of the anti-MET/EGFR multifunctional antibody H9 at 27 mg/kg resulted in significantly greater antitumor efficacy than any other treatment in immunodeficient mice bearing H1993 NSCLC xenografts. Mice xenografts were treated with either vehicle control, the anti-MET/EGFR multifunctional antibody H9 (4 and 27 mg/kg), anti-MET alone (3 and 20 mg/kg), cetuximab (3 and 20 mg/kg) or the combination of anti-MET plus cetuximab (3 mg/kg and 20 mg/kg of each antibody) once a week for five consecutive weeks.

Fig. 7 is a graph showing that administration of the anti-MET/EGFR multifunctional antibody H9 at 27 mg/kg resulted in significantly greater antitumor efficacy than any other treatment in immunodeficient mice bearing H441 xenografts. Mice xenografts were treated with either vehicle control, the anti-MET/EGFR multifunctional antibody H9 (4 and 27 mg/kg), anti-MET alone (3 and 20 mg/kg), cetuximab (3 and 20 mg/kg) or the combination of anti-MET plus cetuximab (3 mg/kg and 20 mg/kg of each antibody) once a week for five consecutive weeks.

The terms “EGFR”, “ErbB1”, and “EGF receptor” are used interchangeably herein to refer to EGFR protein (see, for example, UniProtKB/Swiss-Prot entry P00533). Herein, “EGFR extracellular domain” or “EGFR ECD” refers to a domain of EGFR that is outside of a cell, either anchored to a cell membrane, or in circulation, including fragments thereof. In one embodiment, the extracellular domain of EGFR may comprise four domains: “Domain I” (amino acid residues from about 1-158), “Domain II” (amino acid residues 159-336), “Domain III” (amino acid residues 337-470), and “Domain IV” (amino acid residues 471-645), where the boundaries are approximate, and may vary by about 1-3 amino acids.

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The terms “MET polypeptide”, “MET receptor”, “MET”, “HGF receptor” or “HGFR” are used interchangeably herein and, unless otherwise indicated, are intended to refer to the human receptor tyrosine kinase, as well as functionally active, mutated forms thereof, that bind human hepatocyte growth factor. Specific examples of MET include, e.g., a human polypeptide encoded by the nucleotide sequence provided in GenBank accession no. NM_000245, or the human protein encoded by the polypeptide sequence provided in GenBank accession no. NP_000236. The structure of MET is depicted schematically as:



20 The extracellular domain of human MET (herein, MET-ECD) has the amino acid sequence shown in, for example, SEQ ID NO: 35. However, amino acids 1-24 of SEQ ID NO: 35 comprise the signal sequence. Therefore, unless stated otherwise, the term “MET-ECD” as used herein means the mature protein beginning and ending at amino acids 25 and 932, respectively, of SEQ ID NO: 35 (i.e., SEQ ID NO: 36). The SEMA domain consists of approximately 500 amino acid residues at the N-terminus of MET, and contains the α -chain (amino acid residues 25-307 of SEQ ID NO: 35 (i.e., SEQ ID NO: 37) and part of the β -chain (amino acid residues 308-519 of SEQ ID NO: 35 (i.e., SEQ ID NO: 38)).

30 As used herein, the terms “low”, “moderate”, and “high” in reference to the cell surface expression of MET or EGFR for a tumor or a cell line is intended to mean less than about 0.3 million, greater than about 0.3 million, and greater than about 1 million receptors per cell, respectively.

As used herein, a “multifunctional antibody” refers to a molecule comprising an antibody having one antigen-binding specificity and an antigen-binding fragment having a different antigen-binding specificity. Preferably, a multifunctional antibody refers to a molecule comprising i) an antibody having antigen-binding specificity to MET and ii) a single chain variable fragment (scFv) having antigen-binding specificity to EGFR.

Unless indicated otherwise, the term “antibody”, as used herein, is intended to refer to an immunoglobulin molecule comprising two heavy chains (HC) and two light chains (LC) interconnected by disulfide bonds. The amino terminal portion of each chain includes a variable region of about 100 to about 110 amino acids primarily responsible for antigen recognition via the CDRs contained therein. The carboxy-terminal portion of each chain defines a constant region primarily responsible for effector function.

Unless indicated otherwise, the term “NH-YK”, as used herein in reference to a multifunctional antibody of the invention, is intended to refer to a multifunctional antibody comprising two first polypeptides and two second polypeptides wherein both first polypeptides comprise the amino acid sequence of SEQ ID NO: 27; and both second polypeptides comprise the amino acid sequence of SEQ ID NO: 33, and wherein said multifunctional antibody binds to EGFR and MET.

Unless indicated otherwise, the term “NH-H9”, as used herein in reference to a multifunctional antibody of the invention, is intended to refer to a multifunctional antibody comprising two first polypeptides and two second polypeptides wherein both first polypeptides comprise the amino acid sequence of SEQ ID NO: 29; and both second polypeptides comprise the amino acid sequence of SEQ ID NO: 33, and wherein said multifunctional antibody binds to EGFR and MET.

Unless indicated otherwise, the term “H9”, as used herein in reference to a multifunctional antibody of the invention, is intended to refer to a multifunctional antibody comprising two first polypeptides and two second polypeptides wherein both first polypeptides comprise the amino acid sequence of SEQ ID NO: 52; and both second polypeptides comprise the amino acid sequence of SEQ ID NO: 33, and wherein said multifunctional antibody binds to EGFR and MET.

Unless indicated otherwise, the term “YK”, as used herein in reference to a multifunctional antibody of the invention, is intended to refer to a multifunctional

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antibody comprising two first polypeptides and two second polypeptides wherein both first polypeptides comprise the amino acid sequence of SEQ ID NO: 31; and both second polypeptides comprise the amino acid sequence of SEQ ID NO: 33, and wherein said multifunctional antibody binds to EGFR and MET.

5 The term “antigen-binding fragment” as used herein is intended to mean any antibody fragment that retains the ability to bind to its antigen. Such “antigen-binding fragments” can be selected from the group consisting of Fv, scFv, Fab, F(ab')₂, Fab', scFv-Fc fragments and diabodies. An antigen-binding fragment of an antibody will typically comprise at least one variable region. Preferably, an antigen-binding fragment
10 comprises a heavy chain variable region (HCVR) and a light chain variable region (LCVR). More preferably, an antigen-binding fragment comprises HCVRs and LCVRs which confer antigen-binding specificity to both MET and EGFR (i.e., a “MET and EGFR binding fragment”).

 The term “complementarity determining region” and “CDR” as used herein is
15 intended to mean the non-contiguous antigen combining sites found within the variable region of both HC and LC polypeptides of an antibody or an antigen-binding fragment thereof. These particular regions have been described by others including Kabat, *et al.*, *Ann. NY Acad. Sci.* 190:382-93 (1971); Kabat *et al.*, *J. Biol. Chem.* 252:6609-6616 (1977); Kabat, *et al.*, *Sequences of Proteins of Immunological Interest*, Fifth Edition, U.S.
20 Department of Health and Human Services, NIH Publication No. 91-3242 (1991); Chothia, *et al.*, *J. Mol. Biol.* 196:901-917 (1987); MacCallum, *et al.*, *J. Mol. Biol.*, 262:732-745 (1996); and North, *et al.*, *J. Mol. Biol.*, 406, 228-256 (2011) where the definitions include overlapping or subsets of amino acid residues when compared against each other.

25 The CDRs are interspersed with regions that are more conserved, termed framework regions (“FR”). Each LCVR and HCVR is composed of three CDRs and four FRs, arranged from amino-terminus to carboxy-terminus in the following order: FR1, CDR1, FR2, CDR2, FR3, CDR3, FR4. The three CDRs of the light chain are referred to as “LCDR1, LCDR2, and LCDR3” and the three CDRs of the heavy chain are referred to
30 as “HCDR1, HCDR2, and HCDR3.” The CDRs contain most of the residues which form specific interactions with the antigen. The numbering and positioning of CDR amino acid residues within the LCVR and HCVR regions is in accordance with known conventions

(e.g., Kabat (1991) Chothia (1987), and/or North (2011)). In different embodiments of the invention, the FRs of the antibody and/or antigen-binding fragment (e.g., scFv) may be identical to the human germline sequences, or may be naturally or artificially modified.

5 A “single chain fragment variable” or “scFv” or “scFv polypeptide” refers to a single folded polypeptide comprising the LCVR domain and the HCVR domain of an antibody linked through a linker molecule. In such a scFv polypeptide, the HCVR domain and LCVR domain can be either in the HCVR - linker - LCVR or LCVR - linker - HCVR order. The linker can be a flexible peptide linker which enables the HCVR
10 domain and LCVR domains to be folded as a functional monomeric unit for recognizing an antigen. The three CDRs of the LCVR domain of the scFv are referred to herein as “scFv-LCDR1, scFv-LCDR2, and scFv-LCDR3” and the three CDRs of the HCVR domain of the scFv are referred to herein as “scFv-HCDR1, scFv-HCDR2, and scFv-HCDR3.”

15 The term “surface plasmon resonance (SPR)”, as used herein, refers to an optical phenomenon that allows for the analysis of real-time interactions by detection of alterations in protein concentrations within a biosensor matrix, for example using the BIAcore™ system (Biacore Life Sciences Division, GE Healthcare, Piscataway, NJ).

 The term “ K_D ”, as used herein, is intended to refer to the equilibrium dissociation
20 constant of a particular antibody-antigen or antibody fragment-antigen interaction.

 The term “specifically binds,” or the like, means that an antibody or antigen-binding fragment thereof forms a complex with an antigen that is relatively stable under physiologic conditions. Methods for determining whether an antibody specifically binds to an antigen are well known in the art and include, for example, equilibrium dialysis,
25 SPR, and the like. For example, an antibody that “specifically binds” MET or EGFR, as used in the context of the present invention, includes antibodies that bind MET-ECD (or a portion thereof) and/or EGFR-ECD (or a portion thereof) with a K_D of less than about 10 nM, less than about 5 nM, less than about 4 nM, less than about 3 nM, less than about 2 nM, less than about 1 nM, less than about 0.5 nM, less than about 0.3 nM, less than about
30 0.2 nM, or less than about 0.1 nM as measured in a SPR assay. (see, e.g., Example 1, herein). Preferably, a multifunctional antibody of the present invention specifically binds MET-ECD (or portion thereof) and EGFR-ECD (or portion thereof) with a K_D of between

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about 10 nM and about 0.1 nM, between about 5 nM and about 0.1 nM, between about 2 nM and about 0.1 nM, between about 1 nM and about 0.1 nM, between about 0.75 nM and about 0.1 nM, between about 0.5 nM and about 0.1 nM as measured in a SPR assay.

The term "epitope" refers to an antigenic determinant that interacts with a specific antigen binding site in the variable region of an antibody molecule known as a paratope. A single antigen may have more than one epitope. Thus, different antibodies may bind to different areas on an antigen and may have different biological effects. Epitopes may be either conformational or linear. A conformational epitope is produced by spatially juxtaposed amino acids from different segments of the linear polypeptide chain. A linear epitope is one produced by adjacent amino acid residues in a polypeptide chain. In certain circumstance, an epitope may include moieties of saccharides, phosphoryl groups, or sulfonyl groups on the antigen.

The term "linker molecule" or "linker" as used within the invention preferably denotes a peptide linker. The peptide linkers utilized in certain embodiments of the invention are used to link the antibody, antigen-binding sites, and/or antibody fragments comprising the different antigen-binding sites (e.g. scFv, full length antibody, a V_H domain and/or a V_L domain) together to form a multifunctional antibody according to the invention. Preferably, the peptide linkers are glycine-rich peptides with at least 5 amino acids, preferably of at least 10 amino acids, more preferably between 10 and 50 amino acids. In some embodiments of the present invention, said glycine-rich peptide linker is $(G_xS)_n$ with G=glycine, S=serine, (x=3 and n=3, 4, 5 or 6) or (x=4 and n=2, 3, 4 or 5). For example, in some embodiments of the present invention, said glycine-rich peptide linker is $(G_xS)_n$ with G=glycine, S=serine, x=4 and n=2, 3, 4 or 5 (i.e., GGGGSGGGGS (SEQ ID NO: 47), GGGGSGGGGS (SEQ ID NO: 48), GGGGSGGGGS (SEQ ID NO: 49), or GGGGSGGGGS (SEQ ID NO: 50), respectively. In certain embodiments of the present invention, additional glycines or threonines, e.g., GSTG, TG, GG, or GGGT can be added to either end of the $(G_xS)_n$ formatted glycine-rich peptide linker. For example, in some embodiments of the present invention, said glycine-rich peptide linker is GGGSGGGGS (SEQ ID NO: 51).

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The term “C-terminus”, and grammatical variations thereof, including, but not limited to, carboxyl-terminus, carboxy-terminus, C-terminal, C-terminal end, or COOH-terminus, are used herein to denote the end of an amino acid chain (protein or polypeptide), which may be terminated by a free carboxyl group (-COOH). When the protein is translated from messenger RNA, it is created from N-terminus to C-terminus. The convention for denoting peptide sequences is to depict the C-terminal end on the right and list the sequence from N- to C-terminus.

The term “N-terminus”, and grammatical variations thereof, including, but not limited to, amino-terminus, NH₂-terminus, N-terminal end or amine-terminus, are used herein to denote the beginning of an amino acid chain (protein or polypeptide), terminated by an amino acid with a free amine group (-NH₂). The convention for denoting peptide sequences is to put the N-terminus on the left and list the sequence from N- to C-terminus.

The phrase “human engineered antibody” or “humanized antibody” refers to the antibody compounds disclosed herein as well as antibodies and antigen-binding fragments thereof that have binding and functional properties similar to the antibody compounds disclosed herein, and that have framework regions that are substantially human or fully human surrounding CDRs derived from a non-human antibody. “Framework region” or “framework sequence” refers to any one of framework regions 1 to 4. Human engineered antibodies and antigen-binding fragments encompassed by the present invention include compounds wherein any one or more of framework regions 1 to 4 is substantially or fully human, i.e., wherein any of the possible combinations of individual substantially or fully human framework regions 1 to 4, is present. For example, this includes antigen-binding compounds in which framework region 1 and framework region 2, framework region 1 and framework region 3, framework region 1, 2, and 3, etc., are substantially or fully human. Substantially human frameworks are those that have at least about 80% sequence identity to a known human germline framework sequence. Preferably, the substantially human frameworks have at least about 85%, about 90%, or about 95% sequence identity to a known human germline framework sequence.

Fully human frameworks are those that are identical to a known human germline framework sequence. Human framework germline sequences are known in the art and can be obtained from various sources including IMGT®, the international

ImMunoGeneTics information system (see, for example, Marie-Paule Lefranc, et al., Nucleic Acid Research, volume 37, Database issue, D1006-D1012) or from *The Immunoglobulin Facts Book* by Marie-Paule Lefranc and Gerard Lefranc, Academic Press, 2001, ISBN 012441351. For example, germline light chain frameworks can be selected from the group consisting of: A11, A17, A18, A19, A20, A27, A30, LI, L1I, L12, L2, L5, L15, L6, L8, O12, O2, and O8; and germline heavy chain framework regions can be selected from the group consisting of: VH2-5, VH2-26, VH2-70, VH3-20, VH3-72, VHI-46, VH3-9, VH3-66, VH3-74, VH4-31, VHI-18, VHI-69, VI-13-7, VH3-11, VH3-15, VH3-21, VH3-23, VH3-30, VH3-48, VH4-39, VH4-59, and VH5-5I.

Human engineered antibodies exhibiting functional properties similar to the antibody compounds disclosed herein can be generated using several different methods. The specific antibody compounds disclosed herein can be used as templates or parent antibody compounds to prepare additional antibody compounds. In one approach, the parent antibody compound CDRs are grafted into a human framework that has a high sequence identity with the parent antibody compound framework. The sequence identity of the new framework will generally be at least about 80%, at least about 85%, at least about 90%, at least about 95%, or at least about 99% identical to the sequence of the corresponding framework in the parent antibody compound. This grafting may result in a reduction in binding affinity compared to that of the parent antibody. If this is the case, the framework can be back-mutated to the parent framework at certain positions based on specific criteria disclosed by Queen et al. (1991) *Proc. Natl. Acad. Sci. USA* 88:2869. Additional references describing methods useful in humanizing mouse antibodies include U.S. Patent Nos. 4,816,397; 5,225,539, and 5,693,761; computer programs ABMOD and ENCAD as described in Levitt, *J. Mol. Biol.* 168:595-620 (1983); and the method of Winter and co-workers (Jones et al. *Nature* 321:522-525 (1986); Riechmann, et al. *Nature*, 332:323-327 (1988); and Verhoeven, et al. *Science* 239:1534-1536 (1988).

Applying the teachings of the present invention, a person skilled in the art can use common techniques, e.g., site-directed mutagenesis, to substitute amino acids within the presently disclosed CDR and framework sequences and thereby generate further variable region amino acid sequences derived from the present sequences. Up to all 19 alternative naturally occurring amino acids can be introduced at a specific substitution site. The methods disclosed herein can then be used to screen these additional variable region

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amino acid sequences to identify sequences having the indicated *in vivo* functions. In this way, further sequences suitable for preparing human engineered antibodies and antigen-binding portions thereof in accordance with the present invention can be identified.

Preferably, amino acid substitution within the frameworks is restricted to one, two, or

- 5 three positions within any one or more of the three light chain and/or heavy chain framework regions disclosed herein. Preferably, amino acid substitution within the CDRs is restricted to one, two, or three positions within any one or more of the three light chain and/or heavy chain CDRs. Combinations of the various changes within these framework regions and CDRs described above is also contemplated herein.

- 10 Tables 1 and 2 below depict the amino acid sequences and consensus amino acid sequences of the CDRs for the preferred human engineered antibodies disclosed herein, and the SEQ ID NOs for the amino acid sequences of the HCVR and LCVR polypeptides for the preferred human engineered antibodies or antigen-binding fragments thereof, disclosed herein.

15 **Table 1**

	HCDR1	HCDR2	HCDR3	HCVR
Anti-EGFR scFv YK	GFSLTNYGVH (SEQ ID NO: 1)	VIYSGGNTDYNTPF KG (SEQ ID NO: 2)	ARALDYYDYDFA Y (SEQ ID NO: 3)	17
Anti-EGFR scFv H9	GFSLTNYGVH (SEQ ID NO: 1)	VIWSGGNTDYNTPF TG (SEQ ID NO: 7)	ARALDYYDYDFA Y (SEQ ID NO: 3)	19
Anti-EGFR scFv Consensus	GFSLTNYGVH (SEQ ID NO: 1)	VIX ₁ SGGNTDYNTPF X ₂ G (SEQ ID NO: 9)	ARALDYYDYDFA Y (SEQ ID NO: 3)	
Anti-Met Ab	GYTFTDYMH (SEQ ID NO: 11)	RVNPNRRGTTYNQK FEG (SEQ ID NO: 12)	ARANWLDY (SEQ ID NO: 13)	21

In Table 1 above, X₁ is Y or W and X₂ is K or T.

Table 2

	LCDR1	LCDR2	LCDR3	LCVR
Anti-EGFR scFv YK	RASYSIGTNIH (SEQ ID NO: 4)	RYAKESIS (SEQ ID NO: 5)	QQNNAWPTT (SEQ ID NO: 6)	18
Anti-EGFR scFv H9	RASYSIGTNIH (SEQ ID NO: 4)	YYASRSIS (SEQ ID NO: 8)	QQNNAWPTT (SEQ ID NO: 6)	20
Anti-EGFR scFv Consensus	RASYSIGTNIH (SEQ ID NO: 4)	X ₁ YA X ₂ X ₃ SIS (SEQ ID NO: 10)	QQNNAWPTT (SEQ ID NO: 6)	
Anti-MET Ab	SVSSSVSSIYLH (SEQ ID NO: 14)	YSTSNLAS (SEQ ID NO: 15)	QVYSGYPLT (SEQ ID NO: 16)	22

In Table 2 above, X₁ is R or Y, X₂ is K or S, and X₃ is E or R

5

An embodiment of the present invention is a multifunctional antibody comprising:

(a) an antibody that binds to an epitope within the α -chain of MET at an amino acid sequence selected from the group consisting of:

- i) VVDTTYDDQL (SEQ ID NO: 39),
- 10 ii) ISCGSVNRGTCQRHVFPNHTADIQS (SEQ ID NO: 40),
- iii) ALGAKVLSSVKDRFINF (SEQ ID NO: 41), and
- iv) VRRLKETKDGFM (SEQ ID NO: 42); and

(b) a scFv polypeptide that binds to EGFR and comprises:

- i) a HCVR domain comprising scFv CDRs scFv-HCDR1, scFv-HCDR2, and
15 scFv-HCDR3 consisting of the amino acid sequences GFSLTNYGVH (SEQ ID NO: 1), VIX₁SGGNTDYNTPEFX₂G (SEQ ID NO: 9), wherein X₁ is Y or W and X₂ is K or T, and ARALDYDYDFAY (SEQ ID NO: 3), respectively; and
- ii) a LCVR domain comprising scFv CDRs scFv-LCDR1, scFv-LCDR2, and
20 scFv-LCDR3 consisting of the amino acid sequences RASYSIGTNIH (SEQ ID NO: 4), X₁YAX₂X₃SIS (SEQ ID NO: 10), wherein X₁ is R or Y, X₂ is K or S, and X₃ is E or R, and QQNNAWPTT (SEQ ID NO: 6), respectively, wherein the multifunctional antibody induces internalization and/or degradation of cell surface MET and EGFR.

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In various embodiments of such invention, the multifunctional antibody binds to an epitope within the α -chain of MET at an amino acid sequence i) VVDITYYDDQL (SEQ ID NO: 39), ii) ISCGSVNRGTCQRHVFPNHTADIQS (SEQ ID NO: 40), iii) ALGAKVLSSVKDRFINF (SEQ ID NO: 41), and/or iv) VRRLKETKDGFM (SEQ ID NO: 42). In various embodiments of such invention, the multifunctional antibody may bind to an epitope within the α -chain of MET at an amino acid sequence selected from the group consisting of:

- i) DITYYDD (SEQ ID NO: 43),
- ii) HVFPNHTADIQS (SEQ ID NO: 44),
- 10 iii) FINF (SEQ ID NO: 45), and
- iv) KETKDGFM (SEQ ID NO: 46).

In various embodiments of such invention, the multifunctional antibody may bind a conformational epitope characterized by the amino acids sequence DITYYDD (SEQ ID NO: 43), HVFPNHTADIQS (SEQ ID NO: 44), FINF (SEQ ID NO: 45), and

- 15 KETKDGFM (SEQ ID NO: 46), inclusive. Furthermore, in various embodiments of such invention the multifunctional antibody induces HGF-independent and EGF-independent internalization and/or degradation of cell surface MET and EGFR, respectively. In other embodiments of such an invention, the scFv polypeptide that binds to EGFR comprises:

- i) a HCVR domain comprising scFv CDRs scFv-HCDR1, scFv-HCDR2, and scFv-HCDR3 consisting of the amino acid sequences GFSLTNYGVH (SEQ ID NO: 1), VIYSGGNTDYNTPFKG (SEQ ID NO: 2), and ARALDYDYDFAY (SEQ ID NO: 3), respectively, and ii) a LCVR domain comprising scFv CDRs scFv-LCDR1, scFv-LCDR2, and scFv-LCDR3 consisting of the amino acid sequences RASYSIGTNIH (SEQ ID NO: 4), RYAKESIS (SEQ ID NO: 5), and QQNNAWPTT (SEQ ID NO: 6),
- 25 respectively. In other embodiments of such an invention the scFv polypeptide that binds to EGFR comprises: i) a HCVR domain comprising scFv CDRs scFv-HCDR1, scFv-HCDR2, and scFv-HCDR3 consisting of the amino acid sequences GFSLTNYGVH (SEQ ID NO: 1), VIYSGGNTDYNTPFKG (SEQ ID NO: 2), and ARALDYDYDFAY (SEQ ID NO: 3), respectively; and ii) a LCVR domain comprising scFv CDRs scFv-LCDR1, scFv-LCDR2, and scFv-LCDR3 consisting of the amino acid sequences
- 30 RASYSIGTNIH (SEQ ID NO: 4), RYAKESIS (SEQ ID NO: 5), and QQNNAWPTT

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(SEQ ID NO: 6), respectively, and wherein the C-terminus of the scFv polypeptide is fused via a peptide linker to the N-terminus of the MET antibody heavy chain.

An embodiment of the present invention is a multifunctional antibody comprising:

(a) an antibody that binds MET and comprises:

- 5 i) a heavy chain comprising heavy chain CDRs HCDR1, HCDR2, and HCDR3 consisting of the amino acid sequences of GYTFTDYMH (SEQ ID NO: 11), RVNPNRRGTTYNQKFEG (SEQ ID NO: 12), and ARANWLDY (SEQ ID NO: 13), respectively; and
- ii) a light chain comprising light chain CDRs LCDR1, LCDR2, and LCDR3
10 consisting of the amino acid sequences of SVSSSVSSIYLH (SEQ ID NO: 14), YSTSNLAS (SEQ ID NO: 15) and QVYSGYPLT (SEQ ID NO: 16), respectively; and

(b) a scFv polypeptide that binds to EGFR and comprises:

- i) a HCVR domain comprising scFv CDRs scFv-HCDR1, scFv-HCDR2, and
15 scFv-HCDR3 consisting of the amino acid sequences GFSLTNYGVH (SEQ ID NO: 1), VIX₁SGGNTDYNTPF_{X₂}G (SEQ ID NO: 9), wherein X₁ is Y or W and X₂ is K or T, and ARALDYYDYDFAY (SEQ ID NO: 3), respectively; and
- ii) a LCVR domain comprising scFv CDRs scFv-LCDR1, scFv-LCDR2, and
20 scFv-LCDR3 consisting of the amino acid sequences RASYSIGTNIH (SEQ ID NO: 4), X₁YAX₂X₃SIS (SEQ ID NO: 10), wherein X₁ is R or Y, X₂ is K or S, and X₃ is E or R, and QQNNAWPTT (SEQ ID NO: 6), respectively .

In other embodiments of such an invention the scFv polypeptide that binds to EGFR comprises:

- 25 i) a HCVR domain comprising scFv CDRs scFv-HCDR1, scFv-HCDR2, and scFv-HCDR3 consisting of the amino acid sequences GFSLTNYGVH (SEQ ID NO: 1), VIYSGGNTDYNTPFKG (SEQ ID NO: 2), and ARALDYYDYDFAY (SEQ ID NO: 3), respectively; and
- ii) a LCVR domain comprising scFv CDRs scFv-LCDR1, scFv-LCDR2, and
30 scFv-LCDR3 consisting of the amino acid sequences RASYSIGTNIH (SEQ ID NO: 4), RYAKESIS (SEQ ID NO: 5), and QQNNAWPTT (SEQ ID NO: 6), respectively.

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In other embodiments of such an invention the scFv polypeptide that binds to EGFR comprises a HCVR domain comprising the amino acid sequence of SEQ ID NO: 17 and a LCVR domain comprising the amino acid sequence of SEQ ID NO: 18. In other embodiments of such an invention the scFv polypeptide that binds to EGFR comprises:

- 5 i) a HCVR domain comprising scFv CDRs scFv-HCDR1, scFv-HCDR2, and scFv-HCDR3 consisting of the amino acid sequences GFSLTNYGVH (SEQ ID NO: 1), VIYSGGNTDYNTPFKG (SEQ ID NO: 2), and ARALDYDYDFAY (SEQ ID NO: 3), respectively; and
- ii) a LCVR domain comprising scFv CDRs scFv-LCDR1, scFv-LCDR2, and
10 scFv-LCDR3 consisting of the amino acid sequences RASYSIGTNIH (SEQ ID NO: 4), RYAKESIS (SEQ ID NO: 5), and QQNNAWPTT (SEQ ID NO: 6), respectively, and wherein the C-terminus of the scFv polypeptide is fused via a peptide linker to the N-terminus of the MET antibody heavy chain.

In other embodiments of such an invention the multifunctional antibody comprises:

- 15 i) a heavy chain comprising the amino acid sequence of SEQ ID NO: 53; and
- ii) a light chain comprising the amino acid sequence of SEQ ID NO: 33.

An embodiment of the present invention is a multifunctional antibody comprising:

(a) an antibody that binds MET and comprises:

- 20 i) a heavy chain comprising heavy chain CDRs HCDR1, HCDR2, and HCDR3 consisting of the amino acid sequences of GYTFTDYMH (SEQ ID NO: 11), RVNPNRRGTTYNQKFEG (SEQ ID NO: 12), and ARANWLDY (SEQ ID NO: 13), respectively; and
- ii) a light chain comprising light chain CDRs LCDR1, LCDR2, and LCDR3 consisting of the amino acid sequences of SVSSSVSSIYLH (SEQ ID NO:
25 14), YSTSNLAS (SEQ ID NO: 15) and QVYSGYPLT (SEQ ID NO: 16), respectively; and

(b) a scFv polypeptide that binds to EGFR and comprises:

- 30 i) a HCVR domain comprising scFv CDRs scFv-HCDR1, scFv-HCDR2, and scFv-HCDR3 consisting of the amino acid sequences GFSLTNYGVH (SEQ ID NO: 1), VIX₁SGGNTDYNTPFX₂G (SEQ ID NO: 9), wherein X₁ is Y or W and X₂ is K or T, and ARALDYDYDFAY (SEQ ID NO: 3), respectively, and

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- ii) a LCVR domain comprising scFv CDRs scFv-LCDR1, scFv-LCDR2, and scFv-LCDR3 consisting of the amino acid sequences RASYSIGTNIH (SEQ ID NO: 4), X₁YAX₂X₃SIS (SEQ ID NO: 10), wherein X₁ is R or Y, X₂ is K or S, and X₃ is E or R, and QQNNAWPTT (SEQ ID NO: 6), respectively.

In other embodiments of such an invention the scFv polypeptide that binds to EGFR comprises:

- i) a HCVR domain comprising scFv CDRs scFv-HCDR1, scFv-HCDR2, and scFv-HCDR3 consisting of the amino acid sequences GFSLTNYGVH (SEQ ID NO: 1), VIWSGGNTDYNTPTTG (SEQ ID NO: 7), and ARALDYDYDFAY (SEQ ID NO: 3), respectively; and
- ii) a LCVR domain comprising scFv CDRs scFv-LCDR1, scFv-LCDR2, scFv-LCDR3 consisting of the amino acid sequences RASYSIGTNIH (SEQ ID NO: 4), YYASRSIS (SEQ ID NO: 8), and QQNNAWPTT (SEQ ID NO: 6), respectively.

In other embodiments of such an invention the scFv polypeptide that binds to EGFR comprises:

- i) a HCVR domain comprising scFv CDRs scFv-HCDR1, scFv-HCDR2, and scFv-HCDR3 consisting of the amino acid sequences GFSLTNYGVH (SEQ ID NO: 1), VIWSGGNTDYNTPTTG (SEQ ID NO: 7), and ARALDYDYDFAY (SEQ ID NO: 3), respectively; and
- ii) a LCVR domain comprising scFv CDRs scFv-LCDR1, scFv-LCDR2, scFv-LCDR3 consisting of the amino acid sequences RASYSIGTNIH (SEQ ID NO: 4), YYASRSIS (SEQ ID NO: 8), and QQNNAWPTT (SEQ ID NO: 6), respectively, and wherein the C-terminus of the scFv polypeptide is fused via a peptide linker to the N-terminus of the MET antibody heavy chain.

In other embodiments of such an invention the multifunctional antibody comprises:

- i) a heavy chain comprising the amino acid sequence of SEQ ID NO: 53; and
- ii) a light chain comprising the amino acid sequence of SEQ ID NO: 33.

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Another embodiment of the present invention is a multifunctional antibody comprising:

(a) an antibody that binds MET and comprises:

- 5 i) a first heavy chain and a second heavy chain wherein each of the heavy chains comprise heavy chain CDRs HCDR1, HCDR2, and HCDR3 consisting of the amino acid sequences of GYTFTDYMH (SEQ ID NO: 11), RVNPNRRGTTYNQKFEG (SEQ ID NO: 12), and ARANWLDY (SEQ ID NO: 13), respectively; and
- 10 ii) a first light chain and a second light chain wherein each of the light chains comprises light chain CDRs LCDR1, LCDR2, and LCDR3 consisting of the amino acid sequences of SVSSSVSSIYLH (SEQ ID NO: 14), YSTSNLAS (SEQ ID NO: 15) and QVYSGYPLT (SEQ ID NO: 16), respectively; and

(b) a first scFv polypeptide and a second scFv polypeptide wherein each of the scFv polypeptides binds to human EGFR and wherein each of the scFv polypeptides

15 comprises:

- 20 i) a HCVR domain comprising scFv CDRs scFv-HCDR1, scFv-HCDR2, and scFv-HCDR3 consisting of the amino acid sequences GFSLTNYGVH (SEQ ID NO: 1), VIX₁SGGNTDYNTPEX₂G (SEQ ID NO: 9), wherein X₁ is Y or W and X₂ is K or T, and ARALDYDYDFAY (SEQ ID NO: 3), respectively; and
- 25 ii) a LCVR domain comprising scFv CDRs scFv-LCDR1, scFv-LCDR2, and scFv-LCDR3 consisting of the amino acid sequences RASYSIGTNIH (SEQ ID NO: 4), X₁YAX₂X₃SIS (SEQ ID NO: 10), wherein X₁ is R or Y, X₂ is K or S, and X₃ is E or R, and QQNNAWPTT (SEQ ID NO: 6), respectively, and wherein the C-terminus of the first scFv polypeptide is fused via a peptide linker to the N-terminus of the first heavy chain and the C-terminus of the second scFv polypeptide is fused via a peptide linker to the N-terminus of the second heavy chain.

In various embodiments of such invention, the multifunctional antibody binds to an epitope

30 within the α -chain of MET at an amino acid sequence selected from the group consisting of:

- i) VVDTTYDDQL (SEQ ID NO: 39),

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- ii) ISCGSVNRGTCQRHVFPNHTADIQS (SEQ ID NO: 40),
- iii) ALGAKVLSSVKDRFINF (SEQ ID NO: 41), and
- iv) VRRLKETKDGFM (SEQ ID NO: 42).

In various embodiments of such invention, the multifunctional antibody may bind to an epitope within the α -chain of MET at an amino acid sequence i) VVDITYDDQL (SEQ ID NO: 39), ii) ISCGSVNRGTCQRHVFPNHTADIQS (SEQ ID NO: 40), iii) ALGAKVLSSVKDRFINF (SEQ ID NO: 41), and/or iv) VRRLKETKDGFM (SEQ ID NO: 42). In various embodiments of such invention, the multifunctional antibody may bind a conformational epitope characterized by the amino acids sequence DITYDD (SEQ ID NO: 43), HVFPNHTADIQS (SEQ ID NO: 44), FINF (SEQ ID NO: 45), and KETKDGFM (SEQ ID NO: 46), inclusive. In other embodiments of such an invention the multifunctional antibody comprises:

- i) a first heavy chain and a second heavy chain wherein both heavy chains comprise the amino acid sequence of SEQ ID NO: 53; and
- ii) a first light chain and a second light chain wherein both light chains comprise the amino acid sequence of SEQ ID NO: 33.

Furthermore, in various embodiments of such invention the multifunctional antibody induces HGF-independent and EGF-independent internalization and/or degradation of cell surface MET and EGFR, respectively.

Another embodiment of the present invention is a multifunctional antibody comprising:

(a) an antibody that binds MET and comprises:

- i) a first heavy chain and a second heavy chain wherein each of the heavy chains comprise heavy chain CDRs HCDR1, HCDR2, and HCDR3 consisting of the amino acid sequences of GYTFTDYMH (SEQ ID NO: 11), RVNPNRRGTTYNQKFEG (SEQ ID NO: 12), and ARANWLDY (SEQ ID NO: 13), respectively; and
- ii) a first light chain and a second light chain wherein each of the light chains comprises light chain CDRs LCDR1, LCDR2, and LCDR3 consisting of the amino acid sequences of SVSSSVSSIYHL (SEQ ID NO: 14), YSTSNLAS (SEQ ID NO: 15) and QVYSGYPLT (SEQ ID NO: 16), respectively; and

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(b) a first scFv polypeptide and a second scFv polypeptide wherein each of the scFv polypeptides binds to human EGFR and wherein each of the scFv polypeptides comprises:

- 5 i) a HCVR domain comprising scFv CDRs scFv-HCDR1, scFv-HCDR2, and scFv-HCDR3 consisting of the amino acid sequences GFSLTNYGVH (SEQ ID NO: 1), VIX₁SGGNTDYNTPF₂X₂G (SEQ ID NO: 9), wherein X₁ is Y or W and X₂ is K or T, and ARALDYDYDFAY (SEQ ID NO: 3), respectively; and
- 10 ii) a LCVR domain comprising scFv CDRs scFv-LCDR1, scFv-LCDR2, and scFv-LCDR3 consisting of the amino acid sequences RASYSIGTNIH (SEQ ID NO: 4), X₁YAX₂X₃SIS (SEQ ID NO: 10), wherein X₁ is R or Y, X₂ is K or S, and X₃ is E or R, and QQNNAWPTT (SEQ ID NO: 6), respectively, and wherein the C-terminus of the first scFv polypeptide is fused via a peptide linker to the N-terminus of the first heavy chain and the C-terminus of the
- 15 second scFv polypeptide is fused via a peptide linker to the N-terminus of the second heavy chain.

In other embodiments of such an invention each of the first and second scFv polypeptides that binds to EGFR comprises: i) a HCVR domain comprising scFv CDRs scFv-HCDR1, scFv-HCDR2, and scFv-HCDR3 consisting of the amino acid sequences GFSLTNYGVH (SEQ ID NO: 1), VIYSGGNTDYNTPFKG (SEQ ID NO: 2), and ARALDYDYDFAY (SEQ ID NO: 3), respectively; and ii) a LCVR domain comprising scFv CDRs scFv-LCDR1, scFv-LCDR2, and scFv-LCDR3 consisting of the amino acid sequences RASYSIGTNIH (SEQ ID NO: 4), RYAKESIS (SEQ ID NO: 5), and QQNNAWPTT (SEQ ID NO: 6), respectively. Alternatively, each of the first and second scFv

25 polypeptides that binds to EGFR comprises: i) a HCVR domain comprising scFv CDRs scFv-HCDR1, scFv-HCDR2, and scFv-HCDR3 consisting of the amino acid sequences GFSLTNYGVH (SEQ ID NO: 1), VIWSGGNTDYNTPF₂TG (SEQ ID NO: 7), and ARALDYDYDFAY (SEQ ID NO: 3), respectively; and ii) a LCVR domain comprising scFv CDRs scFv-LCDR1, scFv-LCDR2, and scFv-LCDR3 consisting of the amino acid

30 sequences RASYSIGTNIH (SEQ ID NO: 4), YYASRSIS (SEQ ID NO: 8), and QQNNAWPTT (SEQ ID NO: 6), respectively.

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Another embodiment of the present invention is a multifunctional antibody comprising:

(a) an antibody that binds MET and comprises:

- i) a first heavy chain and a second heavy chain wherein both of the heavy chains
5 comprise the amino acid sequence of SEQ ID NO: 53; and
- ii) a first light chain and a second light chain wherein both of the light chains
comprise the amino acid sequence of SEQ ID NO: 33; and

(b) a first scFv polypeptide and a second scFv polypeptide wherein both of the scFv polypeptides bind to EGFR and both of the scFv polypeptides comprise:

- 10 i) a HCVR domain comprising scFv CDRs scFv-HCDR1, scFv-HCDR2, and scFv-HCDR3 consisting of the amino acid sequences GFSLTNYGVH (SEQ ID NO: 1), VIX₁SGGNTDYNTPF_X₂G (SEQ ID NO: 9), wherein X₁ is Y or W and X₂ is K or T, and ARALDYDYDFAY (SEQ ID NO: 3), respectively; and
- 15 ii) a LCVR domain comprising scFv CDRs scFv-LCDR1, scFv-LCDR2, and scFv-LCDR3 consisting of the amino acid sequences RASYSIGTNIH (SEQ ID NO: 4), X₁YAX₂X₃SIS (SEQ ID NO: 10), wherein X₁ is R or Y, X₂ is K or S, and X₃ is E or R, and QQNNAWPTT (SEQ ID NO: 6), respectively, and wherein the C-terminus of the first scFv polypeptide is fused via a peptide
20 linker to the N-terminus of the first heavy chain and the C-terminus of the second scFv polypeptide is fused via a peptide linker to the N-terminus of the second heavy chain.

In other embodiments of such an invention the first and second scFv polypeptides comprise:

- i) a HCVR domain comprising scFv CDRs scFv-HCDR1, scFv-HCDR2, and scFv-
25 HCDR3 consisting of the amino acid sequences GFSLTNYGVH (SEQ ID NO: 1), VIYSGGNTDYNTPFKG (SEQ ID NO: 2), and ARALDYDYDFAY (SEQ ID NO: 3), respectively; and ii) a LCVR domain comprising scFv CDRs scFv-LCDR1, scFv-LCDR2, and scFv-LCDR3 consisting of the amino acid sequences RASYSIGTNIH (SEQ ID NO: 4), RYAKESIS (SEQ ID NO: 5), and QQNNAWPTT (SEQ ID NO: 6),
30 respectively. Alternatively, both scFv polypeptides comprise: i) a HCVR domain comprising scFv CDRs scFv-HCDR1, scFv-HCDR2, and scFv-HCDR3 consisting of the amino acid sequences GFSLTNYGVH (SEQ ID NO: 1), VIWSGGNTDYNTPF_TG (SEQ

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ID NO: 7), and ARALDYYDYDFAY (SEQ ID NO: 3), respectively; and ii) a LCVR domain comprising scFv CDRs scFv-LCDR1, scFv-LCDR2, and scFv-LCDR3 consisting of the amino acid sequences RASYSIGTNIH (SEQ ID NO: 4), YYASRSIS (SEQ ID NO: 8), and QQNNAWPTT (SEQ ID NO: 6), respectively.

5 In one embodiment the present invention provides, a multifunctional tetravalent antibody comprising:

(a) an antibody comprising two heavy chains and two light chains and capable of binding to an epitope within the α -chain of MET at an amino acid sequence selected from the group consisting of:

- 10 i) VVDTTYDDQL (SEQ ID NO: 39),
 ii) ISCGSVNRGTCQRHVFPNHTADIQS (SEQ ID NO: 40),
 iii) ALGAKVLSSVKDRFINF (SEQ ID NO: 41), and
 iv) VRRLKETKDGFM (SEQ ID NO: 42); and

(b) two scFv polypeptides capable of binding to EGFR comprising the heavy chain variable region of SEQ ID NO: 17 or SEQ ID NO: 19, and the light chain variable region of SEQ ID NO: 18 or SEQ ID NO: 20, wherein the multifunctional antibody induces internalization and/or degradation of cell surface MET and EGFR. In various embodiments of such invention, the multifunctional antibody may bind to an epitope within the α -chain of MET at an amino acid sequence i) VVDTTYDDQL (SEQ ID NO: 39), ii) ISCGSVNRGTCQRHVFPNHTADIQS (SEQ ID NO: 40), iii) ALGAKVLSSVKDRFINF (SEQ ID NO: 41), and/or iv) VRRLKETKDGFM (SEQ ID NO: 42). In various embodiments of such invention, the multifunctional antibody may bind a conformational epitope characterized by the amino acids sequence DTTYDD (SEQ ID NO: 43), HVFPNHTADIQS (SEQ ID NO: 44), FINF (SEQ ID NO: 45), and
 25 KETKDGFM (SEQ ID NO: 46), inclusive. Furthermore, in various embodiments of such invention the multifunctional antibody induces HGF-independent and EGF-independent internalization and/or degradation of cell surface MET and EGFR, respectively.

In one embodiment of the present invention, a multifunctional tetravalent antibody comprising: (a) two identical scFv polypeptides each capable of binding to EGFR; and (b)
 30 an antibody, or antigen-binding fragment thereof, that specifically binds to MET-ECD consisting of the amino acid sequence as in SEQ ID NO: 36, the antibody, or antigen-binding fragment thereof, comprising:

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light chain CDRs LCDR1, LCDR2, and LCDR3 consisting of the amino acid sequences SVSSSVSSIYLH (SEQ ID NO: 14), YSTSNLAS (SEQ ID NO: 15), and QVYSGYPLT (SEQ ID NO: 16), respectively, and

heavy chain CDRs HCDR1, HCDR2, and HCDR3 consisting of the amino acid sequences GYTFTDYMH (SEQ ID NO: 11), RVNPNRRGTTYNQKFEG (SEQ ID NO: 12), and ARANWLDY (SEQ ID NO: 13), respectively, is provided.

In one embodiment of the present invention, a multifunctional tetravalent antibody comprising: (a) two identical scFv polypeptides each capable of binding to EGFR; and (b) a MET antibody comprising two heavy chains and two light chains and capable of binding to MET wherein the two identical scFv polypeptides capable of binding to EGFR are C-terminally fused to the MET antibody via a peptide linker at the C-terminus of each heavy chain of said full-length antibody is provided. In some embodiments of the present invention, the heavy chain variable region of SEQ ID NO: 21, and the light chain variable region of SEQ ID NO: 22, which are both derived from the anti-MET Clone C8-H241 (which is described in detail in WO 2010/059654), can be used to form the antigen-binding sites of the MET antibody that specifically binds to MET.

By gene synthesis and recombinant molecular biology techniques, the HCVR of SEQ ID NO: 17 and the LCVR of SEQ ID NO: 18, or the HCVR of SEQ ID NO: 19 and the LCVR of SEQ ID NO: 20, are linked by a glycine-rich linker of the formula $(G_xS)_n$, $x=4$, $n=5$ to form a scFv that specifically binds to EGFR. The EGFR-binding scFv is then attached to the N- or C-terminus of the heavy chain of the anti-MET antibody C8-H241 (human IgG4 subtype) by another glycine-rich linker, creating multifunctional antibodies NH-YK (comprising an anti-EGFR YK_n-scFv and anti-Met HC fusion (i.e., SEQ ID NO: 27)), NH-H9 (comprising an anti-EGFR H9_n-scFv and anti-Met HC fusion (i.e., SEQ ID NO: 29)), YK (comprising an anti-Met HC and anti-EGFR YK-scFv fusion (i.e., SEQ ID NO: 31)), and H9 (comprising an anti-Met HC and anti-EGFR H9-scFv fusion (i.e., SEQ ID NO: 52)).

Another embodiment of the present invention is a multifunctional antibody that binds MET and EGFR comprising: (a) two first polypeptides wherein both of the first polypeptides comprise the amino acid sequence of SEQ ID NO: 25, SEQ ID NO: 26, SEQ ID NO: 27, SEQ ID NO: 29, SEQ ID NO: 31, SEQ ID NO: 52, or SEQ ID NO: 53;

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and (b) two second polypeptides wherein both of the second polypeptides comprise the amino acid sequence of SEQ ID NO: 33.

Another embodiment of the present invention is a pharmaceutical composition comprising a multifunctional antibody that binds MET and EGFR comprising: (a) two
5 first polypeptides wherein both of the first polypeptides comprise the amino acid sequence of SEQ ID NO: 25, SEQ ID NO: 26, SEQ ID NO: 27, SEQ ID NO: 29, SEQ ID NO: 31, SEQ ID NO: 52, or SEQ ID NO: 53; and (b) two second polypeptides wherein both of the second polypeptides comprise the amino acid sequence of SEQ ID NO: 33, and a pharmaceutically acceptable carrier, diluent, or excipient.

10 Another embodiment of the present invention is a method of treating cancer, comprising administering to a patient in need thereof an effective amount of a multifunctional antibody that binds MET and EGFR comprising: (a) two first polypeptides wherein both of the first polypeptides comprise the amino acid sequence of
15 SEQ ID NO: 25, SEQ ID NO: 26, SEQ ID NO: 27, SEQ ID NO: 29, SEQ ID NO: 31, SEQ ID NO: 52, or SEQ ID NO: 53; and (b) two second polypeptides wherein both of the second polypeptides comprise the amino acid sequence of SEQ ID NO: 33. In some embodiments of such an invention the cancer is NSCLC, SCLC, gastric cancer, colorectal cancer, cholangiocarcinoma, esophageal cancer, melanoma, uveal melanoma, renal cancer, liver cancer, bladder cancer, cervical cancer, or head and neck cancer. In some
20 embodiments of such an invention the cancer patient is a human. In other embodiments of such an invention the patient's tumor is characterized by comprising cells having one or more KRAS mutations. In other embodiments of the present invention provides a method of treating a cancer, including administering a pharmaceutically effective amount of one of the foregoing multifunctional antibodies, or a MET and EGFR binding fragment thereof, to a patient in need thereof wherein MET and/or EGFR are expressed by the
25 patient's tumor at a low, moderate, or high level and/or tumor or a tumor which is resistant, or has become resistant, to one or more anti-EGFR antibodies (e.g., cetuximab, panitumumab, etc.) and/or one or more small molecule inhibitors of EGFR (e.g., erlotinib), including, but not limited to, tumors harboring KRAS mutations. In various
30 embodiments of such an invention, the method of treating a cancer wherein MET and/or EGFR are expressed by the patient's tumor at a low, moderate, or high level and/or wherein the tumor is resistant, or has become resistant, to one or more anti-EGFR

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antibodies (e.g., cetuximab, panitumumab, etc.) and/or one or more small molecule inhibitors of EGFR (e.g., erlotinib), including, but not limited to, tumors harboring KRAS mutations may further comprise a step of identifying the patient in need of the treatment of the cancer, prior to the step of administering the multifunctional antibody, or a MET and EGFR binding fragment thereof, to the patient by measuring the levels of MET and EGFR expressed by the patient's tumor and/or assessing whether the patient's tumor comprises cells having one or more KRAS mutations.

Table 3 below depicts the SEQ ID NOs of the amino acid sequences of scFv and scFv fusions of the present invention.

10

Table 3

	YK-scFv	YK _n -scFv and anti-MET HCVR fusion	YK _n -scFv and anti-MET HC fusion	anti-MET HC and YK-scFv fusion
SEQ ID NO:	23	25	27	31
	H9-scFv	H9 _n -scFv and anti-MET HCVR fusion	H9 _n -scFv and anti-MET HC fusion	anti-MET HC and H9-scFv fusion
SEQ ID NO:	24	26	29	52

When used herein in reference to a scFv, including in Table 3 above, the subscript "n" indicates that the anti-EGFR YK scFv or the anti-EGFR H9 scFv is fused to the N-terminus of the MET antibody heavy chain.

15

A further embodiment of the present invention is a multifunctional antibody comprising two identical first polypeptides and two identical second polypeptides wherein the amino acid sequence of the first polypeptide is SEQ ID NO: 27 or SEQ ID NO: 29 and the amino acid sequence of the second polypeptide is SEQ ID NO: 33, wherein said multifunctional antibody binds to EGFR and MET. Furthermore, in various embodiments of such invention the multifunctional antibody induces HGF-independent and EGF-independent internalization and/or degradation of cell surface MET and EGFR, respectively.

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25

Standard molecular biology techniques are used to prepare the recombinant expression vector, transfect the host cells, select for transformants, isolated host cell lines producing a multifunctional antibody of the invention, culture these host cells and recover the antibody from the culture medium.

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The present invention is also directed to host cells that express a multifunctional antibody of the invention. A wide variety of host expression systems known in the art can be used to express an antibody of the present invention including prokaryotic (bacterial) and eukaryotic expression systems (such as yeast, baculovirus, plant, mammalian and other animal cells, transgenic animals, and hybridoma cells).

A multifunctional antibody of the invention can be prepared by recombinant expression of immunoglobulins in a host cell. To express an antibody recombinantly in a host cell, a host cell is transformed, transduced, infected or the like with one or more recombinant expression vectors carrying DNA fragments encoding the light chain and/or the scFv-heavy chain fusion of the multifunctional antibody. The heavy chain and the light chain may be expressed independently from different promoters to which they are operably linked in one vector or, alternatively, the heavy chain and the light chain may be expressed independently from different promoters to which they are operably linked in two vectors – one expressing the heavy chain and one expressing the light chain.

Optionally, the heavy chain and light chain may be expressed in different host cells. Preferably, the recombinant antibodies are secreted into the medium in which the host cells are cultured, from which the antibodies can be recovered or purified.

An isolated DNA encoding a HCVR region can be converted to a full-length heavy chain gene by operably linking the HCVR-encoding DNA to another DNA molecule encoding heavy chain constant regions. The sequences of human, as well as other mammalian, heavy chain constant region genes are known in the art. DNA fragments encompassing these regions can be obtained *e.g.*, by standard PCR amplification. The heavy chain constant region can be of any type, (*e.g.*, IgG, IgA, IgE, IgM or IgD), class (*e.g.*, IgG₁, IgG₂, IgG₃ and IgG₄) or subclass constant region and any allotypic variant thereof as described in Kabat (*supra*).

An isolated DNA encoding a LCVR region may be converted to a full-length light chain gene (as well as to a Fab light chain gene) by operably linking the LCVR-encoding DNA to another DNA molecule encoding a light chain constant region. The sequences of human, as well as other mammalian, light chain constant region genes are known in the art. DNA fragments encompassing these regions can be obtained by standard PCR amplification. The light chain constant region can be a kappa or lambda constant region.

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In addition to the antibody heavy and/or light chain gene(s), a recombinant expression vector of the invention carries regulatory sequences that control the expression of the antibody chain gene(s) in a host cell. The term “regulatory sequence” is intended to include promoters, enhancers and other expression control elements (*e.g.*,
5 polyadenylation signals), as needed, that control the transcription or translation of the antibody chain gene(s). The design of the expression vector, including the selection of regulatory sequences may depend on such factors as the choice of the host cell to be transformed, the level of expression of protein desired. Preferred regulatory sequences for mammalian host cell expression include viral elements that direct high levels of
10 protein expression in mammalian cells, such as promoters and/or enhancers derived from cytomegalovirus (CMV), Simian Virus 40 (SV40), adenovirus, (*e.g.*, the adenovirus major late promoter (AdMLP)) and/or polyoma virus.

Additionally, the recombinant expression vectors of the invention may carry additional sequences, such as sequences that regulate replication of the vector in host cells
15 (*e.g.*, origins of replication) and one or more selectable marker genes. The selectable marker gene facilitates selection of host cells into which the vector has been introduced. For example, typically the selectable marker gene confers resistance to drugs, such as G418, hygromycin, or methotrexate, on a host cell into which the vector has been introduced. Preferred selectable marker genes include the dihydrofolate reductase (*dhfr*)
20 gene (for use in *dhfr*-minus host cells with methotrexate selection/amplification), the *neo* gene (for G418 selection), and glutamine synthetase (GS) in a GS-negative cell line (such as NS0) for selection/amplification.

For expression of the light and/or heavy chains, the expression vector(s) encoding the heavy and/or light chains is introduced into a host cell by standard techniques *e.g.*,
25 electroporation, calcium phosphate precipitation, DEAE-dextran transfection, transduction, infection and the like. Although it is theoretically possible to express the antibodies of the invention in either prokaryotic or eukaryotic host cells, eukaryotic cells are preferred, and most preferably mammalian host cells, because such cells are more likely to assemble and secrete a properly folded and immunologically active antibody.
30 Preferred mammalian host cells for expressing the recombinant antibodies of the invention include Chinese Hamster Ovary (CHO cells) [including *dhfr* minus CHO cells, as described in Urlaub and Chasin, *Proc. Natl. Acad. Sci. USA* 77:4216-20, 1980, used

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with a DHFR selectable marker, *e.g.*, as described in Kaufman and Sharp, *J. Mol. Biol.* 159:601-21, 1982], NS0 myeloma cells, COS cells, and SP2/0 cells. When recombinant expression vectors encoding antibody genes are introduced into mammalian host cells, the antibodies are produced by culturing the host cells for a period of time sufficient to allow
5 for expression of the antibody in the host cells or, more preferably, secretion of the antibody into the culture medium in which the host cells are grown under appropriate conditions known in the art. Antibodies can be recovered from the host cell and/or the culture medium using standard purification methods.

Host cells can also be used to produce portions, or fragments, of intact antibodies,
10 *e.g.*, Fab fragments or scFv molecules by techniques that are conventional. For example, it may be desirable to transfect a host cell with DNA encoding either the light chain or the heavy chain of an antibody of this invention. Recombinant DNA technology may also be used to remove some or all the DNA encoding either or both of the light and heavy chains that is not necessary for binding to EGFR and MET. The molecules expressed from such
15 truncated DNA molecules are also encompassed by the antibodies of the invention.

The invention provides a host cell comprising a nucleic acid molecule of the present invention. Preferably, a host cell of the invention comprises one or more vectors or constructs comprising a nucleic acid molecule of the present invention. For example, a host cell of the invention is a cell into which a vector of the invention has been
20 introduced, said vector comprising a polynucleotide encoding a LCVR of an antibody of the invention and/or a polynucleotide encoding a HCVR of the invention. The invention also provides a host cell into which two vectors of the invention have been introduced; one comprising a polynucleotide encoding a LCVR of an antibody of the invention and one comprising a polynucleotide encoding a HCVR present in an antibody of the
25 invention and each operably linked to enhancer/promoter regulatory elements (*e.g.*, derived from SV40, CMV, adenovirus and the like, such as a CMV enhancer/AdMLP promoter regulatory element or an SV40 enhancer/AdMLP promoter regulatory element) to drive high levels of transcription of the genes.

Once expressed, the intact antibodies, individual light and heavy chains, or other
30 immunoglobulin forms of the present invention can be purified according to standard procedures of the art, including ammonium sulfate precipitation, ion exchange, affinity (*e.g.*, Protein A), reverse phase, hydrophobic interaction column chromatography,

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hydroxylapatite chromatography, gel electrophoresis, and the like. Substantially pure immunoglobulins of at least about 90%, about 92%, about 94% or about 96% homogeneity are preferred, and about 98% to about 99% or more homogeneity most preferred, for pharmaceutical uses. Once purified, partially or to homogeneity as desired, the sterile antibodies may then be used therapeutically, as directed herein.

The term "isolated polynucleotide" as used herein shall mean a polynucleotide of genomic, cDNA, or synthetic origin or some combination thereof, which by virtue of its origin the isolated polynucleotide (1) is not associated with all or a portion of a polynucleotide in which the isolated polynucleotide is found in nature, (2) is linked to a polynucleotide to which it is not linked in nature, or (3) does not occur in nature as part of a larger sequence.

An "isolated" multifunctional antibody is one that has been identified and separated and/or recovered from a component of its natural environment. Contaminant components of its natural environment are materials that would interfere with diagnostic or therapeutic uses for the antibody, and may include enzymes, hormones, and other proteinaceous or non-proteinaceous solutes. In preferred embodiments, an antibody will be purified (1) to greater than 95% by weight of antibody as determined by the Lowry method, and most preferably more than 99% by weight, (2) to a degree sufficient to obtain at least 15 residues of N-terminal or internal amino acid sequence by use of a spinning cup sequenator, or (3) to homogeneity by SDS-PAGE under reducing or nonreducing conditions using Coomassie blue, SimplyBlue™ SafeStain (Life Technologies) or, preferably, silver stain. Isolated antibody includes the antibody *in situ* within recombinant cells since at least one component of the antibody's natural environment will not be present.

As used herein, "substantially pure" or "substantially purified" means a compound or species that is the predominant species present (i.e., on a molar basis it is more abundant than any other individual species in the composition). In certain embodiments, a substantially purified composition is a composition wherein the species comprises at least about 50 percent (on a molar basis) of all macromolecular species present. In certain embodiments, a substantially pure composition will comprise more than about 80%, 85%, 90%, 95%, or 99% of all macromolecular species present in the composition. In certain embodiments, the species is purified to essential homogeneity (contaminant species

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cannot be detected in the composition by conventional detection methods) wherein the composition consists essentially of a single macromolecular species.

In another embodiment, the present invention provides an isolated polynucleotide that encodes the amino acid sequence selected from the group consisting of SEQ ID NOs:

5 27, 29, and 33.

In another embodiment, the present invention provides a recombinant expression vector comprising polynucleotide that encodes the amino acid sequence selected from the group consisting of SEQ ID NOs: 27, 29, and 33.

The invention also provides any one of the foregoing anti-MET/EGFR
10 multifunctional antibodies, or a MET and EGFR binding fragment thereof, for use in therapy.

The invention also provides any one of the foregoing anti-MET/EGFR multifunctional antibodies, or a MET and EGFR binding fragment thereof, for use in treating a cancer.

15 The invention also provides any one of the foregoing anti-MET/EGFR multifunctional antibodies, or a MET and EGFR binding fragment thereof, for use in treating a cancer wherein both MET and EGFR are expressed.

The invention also provides any one of the foregoing anti-MET/EGFR multifunctional antibodies, or a MET and EGFR binding fragment thereof, for use in
20 treating NSCLC, SCLC, gastric cancer, colorectal cancer, cholangiocarcinoma, esophageal cancer, melanoma, including, but not limited to, uveal melanoma, renal cancer, liver cancer, bladder cancer, cervical cancer, or head and neck cancer.

The invention also provides a method of treating a cancer, comprising administering to a human patient in need thereof an effective amount of any one of the
25 foregoing multifunctional antibodies, or a MET and EGFR binding fragment thereof.

The term “treating” (or “treat” or “treatment”) refers to slowing, interrupting, arresting, controlling, stopping, reducing, or reversing the progression or severity of a symptom, disorder, condition, or disease, but does not necessarily involve a total elimination of all disease-related symptoms, conditions, or disorders.

30 The term “cancer” (or “a cancer”) refers to proliferative diseases, such as lung cancer, non-small cell lung cancer (NSCLC), small cell lung cancer (SCLC), cancer of the head or neck, rectal cancer, cancer of the anal region, stomach cancer, gastric cancer,

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colon cancer, colorectal carcinoma (CRC), esophageal cancer, melanoma, including, but not limited to, uveal melanoma, liver cancer, cervical cancer, cancer of the bladder, cancer of the kidney or ureter, renal cell carcinoma, carcinoma of the renal pelvis, including refractory versions of any of the above cancers, or a combination of one or
5 more of the above cancers.

The phrase “effective amount” as used herein refers to an amount necessary (at dosages and for periods of time and for the means of administration) to achieve the desired therapeutic result. An effective amount of the multifunctional antibody may vary according to factors such as the disease state, age, gender, and weight of the individual,
10 and the ability of the antibody, or MET and EGFR binding fragment thereof, to elicit a desired response in the individual. An effective amount is also one in which any detrimental effect(s) of the antibody, or MET and EGFR binding fragment thereof, are outweighed by the therapeutically beneficial effects.

An effective amount is at least the minimal amount, but less than an overall
15 harmful amount, of an active agent which is necessary to impart therapeutic benefit to a subject. Stated another way, an effective amount or therapeutically effective amount of an antibody of the invention is an amount which in mammals, preferably humans, reduces the number of cancer cells; reduces the tumor size; inhibits (i.e., slow to some extent or stop) cancer cell infiltration into peripheral tissues organs; inhibit (i.e., slow to some
20 extent or stop) tumor metastasis; inhibits, to some extent, tumor growth; and/or relieves to some extent one or more of the symptoms associated with the cancer. An effective amount of an anti-MET/EGFR multifunctional antibody of the invention may be administered in a single dose or in multiple doses. Furthermore, an effective amount of an anti-MET/EGFR multifunctional antibody of the invention may be administered in
25 multiple doses of amounts that would be less than an effective amount if not administered more than once.

As is well known in the medical arts, dosages for any one subject depends upon many factors, including the patient’s size, body surface area, age, the particular compound to be administered, gender, time and route of administration, general health,
30 and other drugs being administered concurrently. Dose may further vary depending on the type and severity of the disease. A typical dose can be, for example, in the range of about 1 mg to about 100 mg; preferably, about 2 mg to about 100 mg; more preferably,

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about 5 mg to about 100 mg; even more preferably, about 5 mg to about 50 mg, even more preferably, about 5 mg to about 25 mg; even more preferably, about 5 mg to about 20 mg; even more preferably, about 5 mg to about 15 mg; however, doses below or above this exemplary range are envisioned, especially considering the aforementioned factors.

- 5 A daily parenteral dosage regimen can be from about 10 µg/kg to about 10 mg/kg. Progress may be monitored by periodic assessment, and the dose adjusted accordingly.

- In some embodiments of the present invention, a single dose of a multifunctional antibody of the present invention may be administered intravenously for treating a cancer in an adult patient. A typical single dose for intravenous administration can be, for
10 example, in the range of about 100 mg to about 1250 mg; preferably, about 200 mg to about 1250 mg; more preferably, about 500 mg to about 1250 mg; even more preferably, about 750 mg to about 1250 mg, even more preferably, about 800 mg to about 1250 mg; even more preferably, or most preferably about 800 mg to about 1000 mg; however, doses below or above this exemplary range are envisioned, especially considering the
15 aforementioned factors. Alternatively, a typical single dose for intravenous administration of a multifunctional antibody of the present invention can be, for example, from about 10 mg/kg to about 20 mg/kg body weight, more preferably about 12 mg/kg to about 15 mg/kg, or even more preferably about 12 mg/kg to about 13 mg/kg. Such doses can be administered intravenously once every week, once every two weeks, once every
20 three weeks, or once every month, for example. Progress may be monitored by periodic assessment, and the dose adjusted accordingly.

- These suggested amounts of antibody are subject to a great deal of therapeutic discretion. The key factor in selecting an appropriate dose and scheduling is the result obtained. Factors for consideration in this context include the particular disorder being
25 treated, the clinical condition of the individual patient, the cause of the disorder, the site of delivery of the antibody, the particular type of antibody, the method of administration, the scheduling of administration, and other factors known to medical practitioners.

- The anti-MET/EGFR multifunctional antibodies of the present invention can be used as medicaments in human medicine, administered by a variety of routes.
30 Accordingly, the invention also provides pharmaceutical compositions comprising any one of the foregoing multifunctional antibodies, or a MET and EGFR binding fragments thereof, and a pharmaceutically acceptable carrier, diluent, or excipient. Most preferably,

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such compositions are for parenteral administration. The term parenteral as used herein includes intravenous, intramuscular, subcutaneous, rectal, vaginal, or intraperitoneal administration. Parenteral delivery by intravenous or intraperitoneal or subcutaneous administration is preferred. Intravenous administration is most preferred. Suitable
5 vehicles for such administration are well known in the art.

The pharmaceutical composition typically must be sterile and stable under the conditions of manufacture and storage in the container provided, including *e.g.*, a sealed vial, syringe or other delivery device, *e.g.*, a pen. Therefore, pharmaceutical compositions may be sterile filtered, or otherwise made free of microbial contamination,
10 after making the formulation,.

An antibody of the invention may be administered to a human subject alone or with a pharmaceutically acceptable carrier and/or diluent in single or multiple doses. Such pharmaceutical compositions are designed to be appropriate for the selected mode of administration, and pharmaceutically acceptable diluents, carrier, and/or excipients
15 such as dispersing agents, buffers, surfactants, preservatives, solubilizing agents, isotonicity agents including but not limited to sodium chloride, stabilizing agents and the like are used as appropriate. Said compositions can be designed in accordance with conventional techniques disclosed in, *e.g.*, Remington, *The Science and Practice of Pharmacy*, 19th Edition, Gennaro, Ed., Mack Publishing Co., Easton, PA (1995) which
20 provides a compendium of formulation techniques as are generally known to practitioners. Suitable carriers for pharmaceutical compositions include any material which, when combined with an antibody of the invention, retains the molecule's activity and is non-reactive with the subject's immune system.

The following non-limiting examples illustrate various properties of the present
25 multifunctional antibodies.

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EXAMPLES

Reference Example 1

1.1. Expression and Purification of the multifunctional antibody NH-YK

- 5 The multifunctional antibody, NH-YK, can be expressed and purified essentially as follows. A glutamine synthetase (GS) expression vector containing the DNA of SEQ ID NO: 28 (encoding the first polypeptide having the amino acid sequence of SEQ ID NO: 27) and SEQ ID NO: 34 (encoding the light chain amino acid sequence of SEQ ID NO: 33) is used to transfect the Chinese hamster cell line, CHOK1SV (Lonza Biologics PLC,
- 10 Slough, United Kingdom) by electroporation. The expression vector encodes an SV Early (Simian Virus 40E) promoter and the gene for GS. Expression of GS allows for the biochemical synthesis of glutamine, an amino acid required by the CHOK1SV cells. Post-transfection, cells undergo bulk selection with 50 μ M L-methionine sulfoximine (MSX). The inhibition of GS by MSX is utilized to increase the stringency of selection.
- 15 Cells with integration of the expression vector cDNA into transcriptionally active regions of the host cell genome are selected against CHOK1SV wild type cells, which express an endogenous level of GS. Transfected pools are plated at low density to allow for close-to-clonal outgrowth of stable expressing cells. The masterwells may be screened for multifunctional antibody expression and then scaled up as needed in serum-free,
- 20 suspension cultures. Alternatively, bulk-selected transfectants may be subjected to single-cell cloning procedures such as Fluorescence-Activated Cell Sorting (FACS) or limited dilution and screened for multifunctional antibody expression. Once a suitable cell line is identified, it may be scaled up as needed in serum-free, suspension cultures. Clarified medium, into which the multifunctional antibody has been secreted, is applied to
- 25 a Protein A affinity column that has been equilibrated with a compatible buffer, such as phosphate buffered saline (pH 7.4) or Tris buffer (pH 7.4). The column is washed to remove nonspecific binding components. The bound multifunctional antibody is eluted, for example, by pH gradient (such as 0.1 M sodium phosphate buffer pH 6.8 to 0.1 M sodium citrate buffer pH 2.5-3.0). Multifunctional antibody fractions are detected and/or
- 30 collected, such as by absorbance cutting at 280 nm, SDS-PAGE or analytical size-exclusion. Soluble aggregate and multimers may be effectively removed by common techniques, including size exclusion, hydrophobic interaction, ion exchange, or

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hydroxyapatite chromatography. The multifunctional antibody may be concentrated and/or sterile filtered using common techniques. The purity of the multifunctional antibody after these chromatography steps is greater than 90%, preferably, greater than 98%. The multifunctional antibody may be immediately frozen at -70°C or stored at 4°C for several months.

1.2. Expression and Purification of the multifunctional antibodies, NH-H9

The multifunctional antibody, NH-H9, can be expressed and purified essentially as described above in Reference Example 1.1 except a glutamine synthetase (GS) expression vector containing the DNA of SEQ ID NO: 30 (encoding the first polypeptide having the amino acid sequence of SEQ ID NO: 29) and SEQ ID NO: 34 (encoding the light chain amino acid sequence of SEQ ID NO: 33) is used to transfect the Chinese hamster cell line, CHOK1SV (Lonza Biologics PLC, Slough, United Kingdom) by electroporation.

1.3. Expression and Purification of the multifunctional antibody, H9

The multifunctional antibody, H9, can be expressed and purified essentially as described above in Reference Example 1.1 except a glutamine synthetase (GS) expression vector containing a DNA encoding the first polypeptide having the amino acid sequence of SEQ ID NO: 52 and the DNA of SEQ ID NO: 34 (encoding the light chain amino acid sequence of SEQ ID NO: 33) is used to transfect the Chinese hamster cell line, CHOK1SV (Lonza Biologics PLC, Slough, United Kingdom) by electroporation.

1.4. Expression and Purification of the multifunctional antibody, YK

The multifunctional antibody, H9, can be expressed and purified essentially as described above in Reference Example 1.1 except a glutamine synthetase (GS) expression vector containing a DNA encoding the first polypeptide having the amino acid sequence of SEQ ID NO: 31 and the DNA of SEQ ID NO: 34 (encoding the light chain amino acid sequence of SEQ ID NO: 33) is used to transfect the Chinese hamster cell line, CHOK1SV (Lonza Biologics PLC, Slough, United Kingdom) by electroporation.

Example 1: Binding analysis of multifunctional antibodies to MET and EGFR

A surface plasmon resonance biosensor such as a BIAcore® 2000, BIAcore® 3000, or a BIAcore® T100 (Biacore Life Sciences Division, GE Healthcare, Piscataway, NJ) may be used to measure binding kinetics and affinity of antibodies such as the

5 antibodies disclosed herein according to methods known in the art. Except as noted, all reagents and materials can be purchased from BIAcore® AB (Uppsala, Sweden), and measurements may be performed at 25 °C. Briefly described, samples may be dissolved in HBS-EP buffer (150 mM sodium chloride, 3 mM EDTA, 0.005% (w/v) surfactant P-20, and 10 mM N-2-hydroxyethyl-piperazine-N'-2-ethanesulfonic acid (HEPES) at pH

10 7.4). A CM5 chip containing immobilized protein A (which may be generated using standard NHS-EDC amine coupling) on all four flow cells (Fc) may be used to employ a capture methodology. Antibody samples can be prepared at 1 mcg/mL by dilution into running buffer initially and then their capture may be tested at flow rate 10 µl/min for 30 seconds. Based on the amount captured, the antibody concentration can be adjusted

15 accordingly to target the capture amount between about 70 RU to 90 RU. MET-ECD or human EGFR-ECD may be prepared at final concentrations of 100, 50, 25, 12.5, 6.25, 3.13, 1.56, 0.78, 0.39 and 0 (blank) nM by dilution into running buffer. Each analysis cycle may consist of (1) capturing antibody samples on separate flow cells (Fc2, Fc3, and Fc4), (2) injection of 250 µL (300-sec) of MET-ECD or EGFR-ECD overall Fc at 50

20 µL/min, (3) return to buffer flow for 20 minutes to monitor dissociation phase, (4) regeneration of chip surfaces with a 25 µL (30-sec) injection of glycine, pH 1.5, (5) equilibration of chip surfaces with a 25 µL (30-sec) injection of HBS-EP+ buffer (i.e., HBS-EP buffer with 0.05% (w/v) surfactant P-20 instead of 0.005%). Data can be processed using standard double-referencing and fit to a 1:1 binding model using Biacore

25 T100 Evaluation software, version 2.0 or Biacore T200 Evaluation software, version 1.0, to determine the association rate (k_{on} , $M^{-1}s^{-1}$ units), dissociation rate (k_{off} , s^{-1} units), and R_{max} (RU units). The equilibrium dissociation constant (K_D) may be calculated as from the relationship $K_D = k_{off}/k_{on}$.

Four anti-MET/EGFR multifunctional antibodies of the present invention were

30 tested to determine their binding kinetics and binding affinity to MET-ECD and EGFR-ECD essentially as described above and the results are summarized in Tables 4 and 5

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below. The antibodies NH-YK, NH-H9, H9, and YK bind both MET-ECD (Table 4) and EGFR-ECD (Table 5) with high binding affinity (K_D).

Table 4: Binding Kinetics and Affinity of multifunctional antibodies to MET-ECD

Multifunctional Antibodies	k_{on} $M^{-1}s^{-1} (10^4)$	k_{off} $s^{-1} (10^{-5})$	K_D (nM)
NH-YK	7.5	6.3	0.84
NH-H9	10.5	7.9	0.75
H9	9.5	10.9	1.15
YK	12.6	3.3	0.26

Table 5: Binding Kinetics and Affinity of multifunctional antibodies to EGFR-ECD

Multifunctional Antibodies	k_{on} $M^{-1}s^{-1} (10^6)$	k_{off} $s^{-1} (10^{-4})$	K_D (nM)
NH-YK	4.0	7.5	0.19
NH-H9	1.8	1.8	0.10
H9	0.57	1.8	0.32
YK	1.3	5.7	0.44

10 Example 2: Binding of NH-YK to both cell surface MET and EGFR

The NSCLC cell line H441 (ATCC, Manassas, VA; catalog #HTB-174) expresses both MET and EGFR on the surface. H441 cells (6×10^6) may be plated onto 100 mm poly-D-lysine coated tissue culture dishes and incubated 2 days at 37 °C, 5% CO₂. Then the cells can be treated with 100 nM control IgG4, a combination of 100 nM cetuximab and 100 nM anti-MET antibody, or 100 nM NH-YK for 20 minutes at 4 °C. The cells can be washed with ice-cold DPBS and lysed using CHAPS lysis buffer with HALT protease and phosphatase inhibitors (Thermo Scientific, Rockford, IL). Immunoprecipitations (IP) can be performed on 600 µg of each cell lysate sample using anti-MET agarose or anti-EGFR sepharose and incubated overnight at 4 °C. The resin may be washed and the bound protein eluted from the resin, then loaded onto 4-20% SDS-PAGE and blotted onto nitrocellulose membranes for Western blot. The membranes may be probed for total MET or total EGFR.

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Immunoprecipitation experiments performed essentially as described above, demonstrate that MET and EGFR co-immunoprecipitate after treatment with the anti-MET/EGFR multifunctional antibody NH-YK, but not after treatment with either the anti-MET antibody, cetuximab, or even a combination of anti-MET antibody and cetuximab.

5 These data indicate that NH-YK can bind to both MET and EGFR (data not shown).

Example 3: Multifunctional antibodies NH-YK and NH-H9 exhibit enhanced avidity binding to cell-surface MET

10 The NSCLC cancer cell line HCC827 has high levels of MET expression. Briefly, HCC827 cells may be removed from a cell culture flask using enzyme-free dissociation buffer and added at approximately 5×10^5 cells per well in a 96-well plate. Then the cells may be treated with dose titrations of unlabeled antibodies (starting at 500 nM) in combination with 5 nM Alexa488-labeled anti-MET antibody for 1 hour at 4 °C in

15 order to determine the ability of the unlabeled antibodies to compete for binding to cell surface MET with labeled anti-MET antibody. Finally, binding of labeled anti-MET antibody may be detected by FACS.

As demonstrated by assays performed essentially as described in this Example, the anti-MET/EGFR multifunctional antibodies NH-YK and NH-H9 have demonstrably

20 higher avidity binding than their parental anti-MET antibody (Table 6).

Table 6: ANTI-MET/EGFR multifunctional antibodies have increased avidity binding to HCC827 cells

Antibody conc., (nM)	anti-EGFR Ab MFI	anti-MET Ab MFI	NH-YK MFI	NH-H9 MFI	HGF (ng/mL)
500.00	65.01	3.03	3.05	3.08	25.11
100.00	65.05	4.92	3.49	4.06	43.73
20.00	65.95	13.50	4.88	7.43	53.44
4.00	64.30	35.60	10.03	18.27	57.41
0.80	64.97	51.77	27.35	41.01	57.62
0.16	64.96	59.25	47.81	54.91	60.22
0.03	65.76	59.04	55.62	60.31	61.44

MFI = mean fluorescence intensity as indicated by competition with Alexa 488- labeled anti-MET Ab

Example 4: Anti-MET/EGFR multifunctional antibodies NH-YK and NH-H9 exhibit better activity than cetuximab does for internalization and degradation of cell surface EGFR

5 **Part A:** The NSCLC cell line H441 expresses moderate levels of both MET and EGFR on its cell surface. Anti-MET/EGFR multifunctional antibodies may be tested for their capability of depleting cell surface MET and EGFR from H441 cells. Briefly, 1.5×10^5 cells in 2 mL culture medium may be plated per well in 6 well plates and incubated overnight at 37 °C, 5% CO₂. Antibodies NH-YK, NH-H9 or control antibodies can be
10 added at 50 nM to H441 cells. After overnight treatment, the cells may be removed from wells with enzyme-free dissociation buffer, washed, and then stained with labeled EGFR or MET antibodies (that recognize different epitope from multifunctional antibodies or control antibody treatments) for 1 hour. Cells are washed and measured for labeled antibody staining by FACS.

15 To assess the ability of the anti-MET/EGFR multifunctional antibodies NH-YK and NH-H9 to promote the degradation of MET and EGFR *in vivo*, assays were performed essentially as described in part A of this Example. The results from these studies demonstrate that the anti-MET/EGFR multifunctional antibodies NH-YK and NH-H9 are capable of depleting cell surface MET from H441 cells similarly to its
20 parental anti-MET antibody. Surprisingly, though, the anti-MET/EGFR multifunctional antibodies NH-YK and NH-H9 triggered significant EGFR degradation whereas cetuximab or the combination of anti-MET antibody and cetuximab did not (Table 7).

Part B: The NSCLC cell line H1993 expresses a high level of MET and a moderate level of EGFR; the gastric cancer cell line MKN45 expresses a high level of
25 MET and a low level of EGFR; the NSCLC cell line H441 expresses moderate levels of both MET and EGFR on its cell surface. Briefly, 5×10^5 cells in 2 mL culture medium may be plated per well in 6 well plates and incubated overnight at 37 °C, 5% CO₂. The anti-MET/EGFR multi-functional antibodies NH-YK, NH-H9 or control antibodies may be added to the cells at 100 nM. After overnight treatment, the cells can be lysed and
30 $15 \mu\text{g}$ of each sample may be run on 4-12% BisTris gels and then blotted onto PVDF membranes. Membranes may be probed by western blotting for total EGFR, total MET, and GAPDH.

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To assess the ability of the anti-MET/EGFR multifunctional antibodies NH-YK and NH-H9 to promote the degradation of MET and EGFR *in vitro*, assays were performed essentially as described in part B of this Example. The results from these studies demonstrate that the antibodies NH-YK and NH-H9 degrade MET from H1993, MKN45, and H441 cells similarly to the parental anti-MET antibody. However, surprisingly, the anti-MET/EGFR multifunctional antibodies NH-YK and NH-H9 trigger significant degradation of EGFR whereas cetuximab or a combination of the parental anti-MET antibody and cetuximab did not (Fig. 1).

10 **Table 7. Anti-MET/EGFR multifunctional antibodies have increased internalization activity for EGFR on H441 cells**

Antibody conc., (50 nM)	AVG of MFI	hIgG4, AVG of MFI	% cell surface MET remaining	Std. Err
hIgG4	77.40	77.40	100.00	0.08
cetuximab	76.20		98.45	1.69
anti-MET Ab	47.44		61.30	0.32
anti-MET Ab +				
cetuximab	50.41		65.13	0.10
NH-H9	48.84		63.10	0.07
NH-YK	44.89		57.99	2.71
			% cell surface EGFR remaining	
hIgG4	56.29	56.29	100.00	2.09
cetuximab	47.25		83.95	0.71
anti-MET Ab	58.80		104.47	1.42
anti-MET Ab +				
cetuximab	50.08		88.98	0.85
NH-H9	17.93		31.86	0.34
NH-YK	17.87		31.74	0.51

MFI = mean fluorescence intensity; AVG = average; Std. Err = Standard Error

Example 5: Anti-MET/EGFR multifunctional antibodies NH-YK and NH-H9 block both MET and EGFR activation

Part A: NSCLC cancer cell line H596 has been shown to be resistant to the growth inhibitory effects of EGFR inhibitors in the presence of HGF. Thus, this cell line can be used to determine if antibodies can inhibit the proliferation of H596 cells in the presence of HGF. Briefly described, 3×10^3 cells/well in 100 μ L culture medium may be plated in 96 well plates and incubated overnight at 37 °C, 5% CO₂. The anti-MET/EGFR multifunctional antibodies NH-YK and NH-H9 or control antibodies may be diluted 1:3 in serum-free culture medium starting from 100 nM (final) and added in combination with 50 ng/mL HGF (final) in 50 μ L as 4x concentrations to the H596 cells. At the end of an additional 6 days of cell growth, plates may be equilibrated to room temperature for 30 minutes and 100 μ L/well of CellTiter-Glo® reagent (Promega Corp., Fitchburg, WI) can be added. Cell viability can be determined by measuring luminescence.

Assays performed essentially as described in this Example demonstrate that the anti-MET/EGFR multifunctional antibodies NH-YK and NH-H9 inhibit *in vitro* proliferation of H596 stimulated with HGF better than cetuximab or a combination of the parental anti-MET antibody and cetuximab.

Table 8: Anti-MET/EGFR multifunctional antibodies exhibit superior activity than the combination of individual antibodies in inhibition of H596 proliferation in the presence of HGF

Anti-body conc. (nM)	hIgG4		cetuximab		anti-MET Ab	
	AVG	Std. Err	AVG	Std. Err	AVG	Std. Err
100	132.3	1.1	129.2	4.0	108.6	3.1
33.3	130.9	0.7	127.4	1.8	112.8	1.4
11.1	138.6	1.9	132.6	0.2	121.0	3.1
3.7	137.0	1.6	129.7	2.7	121.4	1.8
1.2	138.5	2.5	132.0	4.7	128.2	0.0
0.4	138.9	0.9	128.6	2.4	129.8	1.8
0.0	100.0	0.6				

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Anti-body conc. (nM)	anti-MET Ab + cetuximab		NH-YK		NH-H9	
	AVG	Std. Err	AVG	Std. Err	AVG	Std. Err
100	98.1	3.1	101.5	0.4	101.6	0.6
33.3	108.0	1.2	101.3	1.7	101.8	1.0
11.1	116.1	2.6	107.1	3.0	104.8	0.8
3.7	116.7	1.6	103.9	1.2	102.6	1.9
1.2	125.0	0.6	108.1	1.3	101.9	1.0
0.4	131.8	1.5	113.4	0.9	106.7	3.1
0.0						

Antibody only, (100 nM)	AVG	Std. Err
hIgG4	102.51	1.06
cetuximab	91.35	0.71
anti-MET Ab	92.33	0.98
anti-MET Ab + cetuximab	94.03	0.07
NH-YK	94.10	0.38
NH-H9	91.55	0.75
HGF, 50 ng/mL	136.66	0.48

Abbreviations: AVG = average % of cell viability; Std. Err = Standard Error

Part B: Other tumor cell lines may also be used to determine if anti-MET/EGFR multifunctional antibodies have superior activity than the combination of two individual antibodies in inhibiting the proliferation of tumor cells *in vitro* assays. For example, colon cancer cell line GEO has been shown to be driven by EGFR ligand autocrine activation despite having a medium level of MET expression. The lung cancer cell line H1666 has EGFR gene amplification and its proliferation has been shown to be driven by EGFR activation. Both NSCLC cell lines H1993 and EBC-1 express a high level of MET, due to MET gene amplification, and a moderate level of EGFR.

Assays performed essentially as described in this Example demonstrate that the anti-MET/EGFR multifunctional antibodies NH-YK and NH-H9 inhibit *in vitro* proliferation of the colon cancer cell line GEO better than cetuximab and, surprisingly, even more potently than the combination of their parental anti-MET antibody and cetuximab (Table 9).

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Table 9: Anti-MET/EGFR multifunctional antibodies exhibit superior activity than the combination of individual antibodies in inhibiting proliferation of GEO

Antibody (nM)	hIgG4		cetuximab		anti-MET Ab	
	AVG	Std. Err	AVG	Std. Err	AVG	Std. Err
100	102.64	0.54	46.39	1.55	101.71	0.39
33.33	102.43	0.33	50.06	0.55	101.48	0.66
11.11	102.43	0.11	57.67	1.27	102.82	0.66
3.70	102.22	1.12	67.23	0.68	103.03	0.58
1.23	103.80	0.45	73.63	2.71	103.42	0.55
0.41	102.56	1.08	77.70	2.46	103.42	0.22
0.14	103.30	1.66	89.99	5.56	104.67	0.33
0.05	103.00	1.40	100.83	0.80	105.67	0.41
0.02	103.42	1.11	101.64	0.93	103.90	1.28
0.00	100.00	0.33				
Antibody (nM)	anti-MET Ab + cetuximab		NH-YK		NH-H9	
	AVG	Std. Err	AVG	Std. Err	AVG	Std. Err
100	57.93	0.52	46.15	1.67	42.65	0.96
33.33	61.99	2.02	45.05	1.03	41.33	1.31
11.11	69.07	2.36	44.44	0.57	43.99	0.44
3.70	76.49	1.58	47.99	0.79	45.52	1.05
1.23	77.92	0.99	47.09	0.76	44.21	1.11
0.41	92.10	4.98	51.33	0.80	47.07	0.65
0.14	103.72	1.57	61.90	1.74	59.98	1.30
0.05	104.32	0.41	77.54	1.87	76.05	1.52
0.02	104.90	0.55	103.62	2.22	102.97	1.04
0.00						

Abbreviations: AVG = average % of cell viability; Std. Err = Standard Error

5

Similarly, the results shown in Table 10 demonstrate that the anti-MET/EGFR multifunctional antibodies NH-YK, NH-H9, and H9 each inhibits H1666 proliferation better than cetuximab and more potently than the combination of the parent anti-MET antibody and cetuximab.

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Table 10: Anti-MET/EGFR multifunctional antibodies exhibit superior activity than the combination of individual antibodies in the inhibition of H1666 proliferation

Antibody conc., (nM)	hIgG4		cetuximab		anti-MET Ab	
	AVG	Std. Err	AVG	Std. Err	AVG	Std. Err
100	94.45	0.92	30.60	0.36	101.25	1.63
33.33	103.42	2.64	35.13	1.17	102.15	2.90
11.11	104.25	2.50	41.65	0.63	105.58	2.99
3.70	100.34	0.46	49.31	1.96	106.48	1.57
1.23	101.46	2.01	56.26	0.47	103.49	1.48
0.41	103.94	1.53	68.71	1.40	105.72	1.99
0.14	104.85	2.46	84.94	3.16	101.01	1.33
0.05	104.24	1.46	97.56	1.50	105.35	2.11
0.02	108.89	2.07	102.80	1.80	104.50	2.24
0.00	100.00	0.47				

5

Anti-body conc., (nM)	Anti-MET Ab + cetuximab		NH-YK		NH-H9		H9	
	AVG	Std. Err	AVG	Std. Err	AVG	Std. Err	AVG	Std. Err
100	36.78	0.73	26.36	0.14	23.11	0.27	28.02	0.25
33.33	42.61	0.66	27.94	0.39	24.12	0.29	31.22	1.43
11.11	48.24	0.59	31.92	0.18	26.58	0.40	34.67	0.66
3.70	53.18	1.57	36.86	0.61	31.64	0.52	41.65	0.14
1.23	63.92	1.76	45.62	0.96	38.65	0.75	49.45	0.40
0.41	70.46	0.34	65.52	2.92	52.90	0.75	58.90	1.11
0.14	81.73	1.58	87.22	3.16	77.78	2.82	79.34	2.48
0.05	96.94	1.74	105.13	3.84	100.45	2.88	96.50	1.02
0.02	103.30	1.02	106.30	2.88	104.51	1.19	99.45	2.59
0.00								

Abbreviations: AVG = average % of cell viability; Std. Err = Standard Error

Similarly, the results shown in Table 11 demonstrate that the anti-MET/EGFR multifunctional antibodies NH-YK and NH-H9 each inhibit H1993 (Table 11) and EBC-1 (Table 12) proliferation as well as or better than the combination of their parental anti-MET antibody and cetuximab.

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Table 11: Anti-MET/EGFR multifunctional antibodies exhibit superior activity than the combination of individual antibodies in inhibition of H1993 proliferation

Antibody conc., (nM)	hIgG4		cetuximab		anti-MET Ab	
	AVG	Std. Err	AVG	Std. Err	AVG	Std. Err
100	98.68	2.39	95.77	1.07	53.17	1.11
33.33	101.50	1.91	102.27	2.01	51.66	0.75
11.11	102.77	1.47	101.18	1.95	52.92	0.41
3.70	102.53	1.41	100.52	1.08	57.39	1.31
1.23	99.73	0.63	98.61	0.28	84.82	0.93
0.41	103.23	0.02	97.18	1.78	98.80	1.71
0.14	103.29	0.33	99.45	2.35	99.69	0.98
0.05	102.09	1.01	96.62	1.79	100.67	2.36
0.02	100.28	1.18	97.48	2.79	99.77	0.56
0.00	100.00	0.63				

Antibody conc., (nM)	Anti-MET Ab + cetuximab		NH-YK		NH-H9	
	AVG	Std. Err	AVG	Std. Err	AVG	Std. Err
100	47.47	0.76	40.83	0.57	36.90	0.97
33.33	47.95	0.76	42.08	1.18	38.38	0.30
11.11	49.33	0.74	44.42	1.37	40.71	0.97
3.70	53.12	2.03	51.21	0.96	44.22	0.82
1.23	75.00	1.04	84.69	1.33	75.02	0.82
0.41	96.13	2.16	94.11	0.79	94.40	0.45
0.14	99.82	1.74	96.67	1.70	99.09	1.20
0.05	100.80	1.78	98.77	1.20	100.26	0.99
0.02	100.84	0.76	99.43	0.19	100.60	1.43
0.00						

5 Abbreviations: AVG = average % of cell viability; Std. Err = Standard Error

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Table 12: Anti-MET/EGFR multifunctional antibodies exhibit superior activity than the combination of individual antibodies in inhibition of EBC-1 proliferation

Antibody conc., (nM)	hIgG4		cetuximab		anti-MET Ab	
	AVG	Std. Err	AVG	Std. Err	AVG	Std. Err
100	105.35	1.61	107.55	1.27	43.38	0.14
33.33	102.82	0.74	105.74	1.31	38.11	0.57
11.11	102.08	0.63	105.58	0.98	37.24	0.55
3.70	103.72	1.19	106.17	1.48	35.75	0.87
1.23	103.53	2.28	106.03	0.80	38.84	0.44
0.41	103.48	0.72	105.02	1.70	80.23	1.47
0.14	100.42	1.09	103.51	0.57	99.04	1.21
0.05	100.00	1.96	100.73	0.95	102.58	0.54
0.02	102.36	0.92	102.02	1.88	102.25	0.77
0.00	100.00	0.38				

Antibody conc., (nM)	anti-MET Ab + cetuximab		NH-YK		NH- H9	
	AVG	Std. Err	AVG	Std. Err	AVG	Std. Err
100	40.73	0.80	34.95	0.22	22.34	0.27
33.33	36.25	1.20	30.65	0.19	21.30	0.42
11.11	34.08	0.42	30.15	0.47	21.15	0.58
3.70	33.54	0.80	33.04	0.90	22.43	0.37
1.23	35.60	0.50	46.98	1.11	24.23	0.43
0.41	73.46	0.64	91.82	0.83	79.44	0.82
0.14	101.37	1.06	97.62	1.29	97.02	1.89
0.05	102.92	0.80	102.14	1.96	100.50	1.21
0.02	101.88	1.16	101.86	1.82	101.03	0.65
0.00						

5 Abbreviations: AVG = average % of cell viability; Std. Err = Standard Error

Example 6: Anti-MET/EGFR multifunctional antibodies NH-YK and NH-H9 induce apoptosis

10 The gastric cancer cell line MKN45 can be used to assay apoptosis induced by antibodies. Briefly, 3×10^3 cells/well in 80 μ L culture medium may be plated in 96 well plates and incubated overnight at 37 °C, 5% CO₂. CellEvent™ reagent (Life Technologies, Carlsbad, CA) may be diluted in cell culture medium and added at 10 μ L per well. NH-YK, NH-H9 or control antibodies were added as 10x concentrations at

15 10 μ L to MKN45 cells for final concentrations of 100 nM. The caspase-3/7 positive cells

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may be measured in real-time by INCUCYTE™ Kinetic Imaging System (Essen Bioscience, Ann Arbor, MI) with 3 hours intervals at 37 °C, 5% CO₂ for a total of 120 hours.

As determined by performance of assays essentially as described in this Example, the anti-MET/EGFR multifunctional antibodies NH-YK and NH-H9 each induce greater apoptosis *in vitro* in MKN45 than a combination of the parental MET Ab and cetuximab (Table 13). In addition, in assays performed essentially as described in this Example, NH-YK induces MKN45 apoptosis to a greater extent than the combination of one-armed 5D5 and erlotinib (data not shown).

Table 13: MKN45 Apoptosis assay

Antibody conc., (100 nM)	24 hr		48 hr		72 hr	
	AVG	Std. Err	AVG	Std. Err	AVG	Std. Err
untreated	100.00	2.92	100.00	10.14	100.00	13.83
hIgG4	83.60	8.92	106.20	3.55	111.25	13.78
cetuximab	73.56	4.69	121.70	26.26	102.24	10.34
Anti-MET Ab	100.35	7.27	222.81	28.70	275.40	21.16
Anti-MET Ab + cetuximab	126.73	22.78	235.60	29.73	292.40	23.35
NH-YK	114.20	9.96	291.31	19.04	393.83	43.63
NH-H9	94.60	10.59	243.82	35.58	361.13	9.04

Antibody conc., (100 nM)	96 hr		120 hr	
	AVG	Std. Err	AVG	Std. Err
untreated	100.00	13.48	100.00	7.55
hIgG4	91.24	10.61	108.28	12.02
cetuximab	107.11	3.56	127.04	14.16
Anti-MET Ab	286.63	32.84	353.84	30.08
Anti-MET Ab + cetuximab	326.83	32.56	386.84	19.08
NH-YK	446.24	28.10	557.79	32.44
NH-H9	434.42	2.87	515.31	13.63

Abbreviations: AVG = average % increase of cell apoptosis;
Std. Err = Standard Error

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Example 7: Anti-MET/EGFR multifunctional antibody NH-YK restores erlotinib sensitivity of tumor cells in the presence of HGF.

The NSCLC cancer cell line HCC827 has EGFR gene amplification and high MET expression. HCC827 cells are sensitive to erlotinib treatment, but become resistant to erlotinib treatment in the presence of HGF. Briefly, 3×10^3 cells/well in 100 μ L culture medium may be plated in 96 well plates and incubated overnight at 37 °C, 5% CO₂. NH-YK or control antibodies (hIgG4) can be added to cells for 1 hour followed by addition of erlotinib and/or HGF for final concentrations of 50 nM antibody, 50 ng/mL HGF, and 1 μ M erlotinib. At the end of an additional 3 days of cell growth at 37 °C under 95% relative humidity and 5% (v/v) CO₂, plates may be equilibrated to room temperature for 30 minutes and 100 μ L/well of CellTiter-Glo® reagent (Promega Corp.) added. The plates may be shaken for two minutes on an orbital shaker to mix contents and then left to incubate at room temperature for 10 minutes to stabilize the luminescent signal. Cell viability may be determined by measuring luminescence.

As determined by performance of assays essentially as described in this Example, the antibody NH-YK is able to restore erlotinib sensitivity of HCC827 cells *in vitro* in the presence of HGF better than the parental anti-MET antibody in combination with cetuximab (Table 14).

Table 14: Anti-MET/EGFR multifunctional antibody NH-YK has superior activity than a combination of individual antibodies in restoring HCC827 sensitivity to erlotinib in the presence of HGF

Antibody conc., (50 nM)	untreated	Erlotinib, 1 μ M	Erlotinib + H 50 ng/mL	Erlotinib + H + hIgG4
AVG	101.27	17.98	80.00	85.14
Std. Err	2.26	0.20	3.95	1.39

Antibody conc., (50 nM)	Erlotinib + H + cetuximab	Erlotinib + H + anti-MET Ab	Erlotinib + H + anti-METAb + cetuximab	Erlotinib + H + NH-YK
AVG	102.76	46.35	61.33	27.25
Std. Err	0.86	0.65	1.59	1.01

Abbreviations: AVG = average % of cell viability; Std. Err = Standard Error; H=HGF

Example 8: Anti-MET/EGFR multifunctional antibody, NH-YK, restores B-Raf inhibitor, PLX4032, sensitivity of HT-29 cells treated with HGF and EGF

The colon cancer cell line HT-29 has a B-Raf mutation and is sensitive to the B-Raf inhibitor PLX4032. HT-29 cells become resistant to PLX4032 or pan-Raf inhibitor treatment upon HGF and EGF stimulation. Anti-MET/EGFR multifunctional antibodies may be tested for their ability to restore PLX4032 inhibitor sensitivity of HT-29 cells treated with HGF and EGF. Briefly, 3×10^3 cells/well in 100 μ L culture medium may be plated in 96 well plates and incubated overnight at 37 °C, 5% CO₂. Antibody NH-YK, PLX4032, HGF, EGF, positive controls, and negative controls were diluted in serum-free culture medium and added to HT-29 cells in 50 μ L as 4x concentrations. The final concentrations of reagents may be: 50 nM for antibodies, 50 ng/mL for HGF and EGF, and 1:5 dilutions of PLX4032 starting at 1 μ M. At the end of an additional 5 days of cell growth, plates may be equilibrated to room temperature for 30 minutes and 100 μ L per well of CellTiter-Glo® reagent (Promega Corp.) may be added. Cell viability can be determined by measuring luminescence.

As determined by performance of assays essentially as described in this Example antibody NH-YK is able to restore PLX4032 sensitivity of HT-29 cells treated with HGF and EGF (Table 15). In addition, antibody NH-YK is superior to the combination of the parental anti-MET antibody and cetuximab in restoring lapatinib (i.e., a EGFR/HER-2 inhibitor) sensitivity in FaDu cells (Table 16).

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Table 15: Antibody NH-YK has superior activity than the combination of individual antibodies in restoring HT-29 sensitivity to B-Raf inhibitor PLX4032 in the presence of HGF and EGF

PLX conc., (nM)	PLX		PLX + H + E		PLX + H + E + hIgG4		PLX + H + E + cetuximab	
	AVG	Std. Err	AVG	Std. Err	AVG	Std. Err	AVG	Std. Err
1000	33.67	0.19	104.02	0.58	108.76	0.64	103.80	2.43
200.00	56.66	0.36	120.67	1.65	124.38	4.18	121.05	1.36
40.00	83.14	0.18	122.51	1.39	124.52	1.61	123.21	1.19
8.00	97.63	1.05	120.42	0.51	125.81	0.31	124.51	0.44
1.60	99.92	0.94	117.09	1.98	116.77	2.15	127.26	0.76
0.32	101.11	1.13	113.02	1.57	120.78	1.56	125.35	2.78
0.00	100.00	1.01						

5

PLX conc., (nM)	PLX + H + E + anti-MET Ab		PLX + H + E + anti-MET Ab + cetuximab		PLX + H + E + NH-YK	
	AVG	Std. Err	AVG	Std. Err	AVG	Std. Err
1000	110.65	2.28	97.86	1.41	39.98	0.89
200.00	120.52	1.18	116.73	1.20	59.53	0.94
40.00	122.38	0.19	121.34	0.65	85.59	1.03
8.00	123.57	1.94	122.98	0.70	98.74	0.86
1.60	126.02	0.86	125.28	0.50	100.39	0.11
0.32	123.46	3.30	124.17	0.31	101.93	1.59
0.00						

Abbreviations: PLX = PLX4032; AVG = average % of cell viability;
Std. Err = Standard Error; H = HGF (50 ng/mL); E = EGF (50 ng/mL)
All antibodies at 50 nM

Table 16: Anti-MET/EGFR multifunctional antibodies NH-YK and NH-H9 have superior activity than the combination of individual antibodies in restoring FaDu sensitivity to lapatinib in the presence of HGF

lapatinib, μ M	% of cell viability						
	lapatinib alone	lapatinib + H	lapatinib + H + cetuximab	lapatinib + H + anti-MET	lapatinib + H + anti-MET + cetuximab	lapatinib + H + NH-H9	lapatinib + H + NH-YK
0	95.99	154.12	139.07	130.33	98.43	59.67	60.33
0.001	99.49	154.06	151.14	128.70	98.47	64.58	62.16
0.003	101.04	165.69	155.31	158.30	111.36	63.61	56.71
0.01	95.77	157.19	146.42	143.19	107.71	53.75	53.64

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0.03	68.82	150.88	140.30	127.18	92.73	53.60	53.56
0.1	45.42	142.78	131.75	102.62	73.76	42.42	48.89
0.3	32.49	131.23	120.62	79.03	64.03	38.82	45.47
1	26.85	112.89	104.69	60.76	57.14	33.93	37.68
3	18.52	15.06	12.15	15.37	10.44	20.42	29.46
10	17.07	9.65	6.54	9.05	7.41	20.85	17.59

H= HGF (50 ng/ml); all antibodies at 50 nM

lapatinib, μM	% of cell viability						
	lapatinib alone	lapatinib + E	lapatinib + E + cetuximab	lapatinib + E + anti- MET	lapatinib + E + cetuximab + anti- MET	lapatinib + E + NH-H9	lapatinib + E + NH-YK
0	102.84	145.35	136.60	144.82	120.07	90.91	110.53
0.001	109.28	149.73	145.86	155.81	132.52	106.86	118.84
0.003	108.81	170.83	156.56	163.50	146.05	108.79	115.48
0.01	78.67	158.71	149.86	147.32	154.82	90.88	109.72
0.03	69.43	160.76	150.95	148.64	122.95	65.99	102.30
0.1	45.64	152.45	101.10	143.07	101.54	42.00	62.87
0.3	32.47	161.37	47.58	137.03	56.25	33.46	40.24
1	26.27	141.20	31.90	128.06	36.16	29.66	27.80
3	18.99	37.11	21.17	18.19	23.48	18.10	19.41
10	19.62	21.39	17.61	15.87	22.55	14.88	7.06

E=EGF (50 ng/ml); all antibodies at 50 nM

5 Example 9: Degradation of MET and EGFR in mouse xenograft models

The ability of anti-MET/EGFR multifunctional antibodies to promote the degradation of MET and EGFR *in vivo* may be assessed in mice bearing H441 (NSCLC) and MKN45 (gastric carcinoma) xenograft tumors according to methods well-known in the art.

Administration of the antibody NH-YK at two different dose levels (10 and 27 mg/kg) induced degradation of MET at comparable levels to the combination of the parental anti-MET antibody and cetuximab (both dosed at 20 mg/kg) 48 hours post-dosing in H441 xenografts. In contrast, the combination of the parental anti-MET antibody and cetuximab (both dosed at 20 mg/kg) failed to induce EGFR degradation when compared to PBS-treated control animals in the same xenograft model. Surprisingly, the administration of antibody NH-YK triggered significant EGFR degradation when compared to either PBS-treated or the parental anti-MET antibody and

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cetuximab-treated (both dosed at 20 mg/kg) mice. Similarly, in animals bearing MKN45 gastric xenografts, antibody NH-YK promoted equivalent degradation of MET but surprisingly much greater degradation of EGFR when compared to the combination of the parental anti-MET antibody and cetuximab (both dosed at 20 mg/kg).

5

Example 10: Inhibition of tumor growth in mouse xenograft models for NSCLC (H1993, H441, EBC-1) and gastric cancer

Female athymic nude mice age 6- to 7-weeks old are available commercially,
10 including from Harlan Laboratories (Indianapolis, IN). The mice are allowed to acclimate for one week and fed ad libitum on a normal low fat (4.5%) diet, which may be continued for the duration of the study. Tumor cells are available for purchase from ATCC and may be cultured in cell culture media such as RPMI 1640 (Life Technologies) with L-glutamine, 25 mM HEPES supplemented with 10% FBS and 1 mM Na Pyruvate.
15 Cells may be detached, washed with serum free medium and then resuspended at a final concentration of 50×10^6 cells/mL in serum free RPMI 1640. Tumor cells, approximately 5×10^6 may be injected subcutaneously in the rear flank of subject mice in a 1:1 mixture of serum free growth medium and Matrigel (Becton Dickinson, Bedford, MA). Tumor and body weight measurements are performed twice weekly. Prior to
20 treatment, mice can be randomized based on tumor size using a randomization algorithm. Treatments may be started when the average tumor volume reaches 100 mm^3 . The randomized mice were separated into different groups and dosed with antibodies through tail vein injection once a week.

All test or control antibodies are prepared in phosphate Buffered Saline (PBS)
25 prior to dose. Tumor size may be determined by caliper measurements. Tumor volume (mm^3) may be estimated from the formula $A^2 \times B \times 0.536$, where A is the smaller and B is the larger of perpendicular diameters. Tumor volume data can be transformed to a log scale to equalize variance across time and treatment groups. Log volume data can be analyzed with two-way repeated measures ANOVA by time and treatment using SAS
30 PROC MIXED software (SAS Institutes Inc, Cary, NC). Treatment groups are compared with the specified control group at each time point.

Part A: Immunodeficient mice bearing H1993 NSCLC xenografts were generated as described above in this Example and treated with either vehicle control, the

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antibody NH-YK, or the combination of the parental MET antibody plus cetuximab once a week for 5 consecutive weeks. The combination of the parental MET antibody and cetuximab (both dosed at 20 mg/kg) resulted in a percentage of the average treated-tumor-volume divided by the average vehicle-control-tumor-volume (T/C%) value of 86.1% while an equimolar dose of antibody NH-YK (27 mg/kg) resulted in a significantly greater decrease in tumor volume (T/C% of 28.5%, $p < 0.001$) (Fig. 2). When tested in H441 xenografts, the antibody NH-YK also showed superior efficacy when compared to either the vehicle control or the combination of the parental MET antibody and cetuximab (Fig. 3).

Part B: In an EBC-1 NSCLC xenograft model, treatment (10 mpk) with the antibody NH-YK resulted in T/C% of 32.9% ($p < 0.001$) (Fig. 4).

Part C: Gastric cancer cell line MKN45 has a high level of MET gene amplification and is very sensitive to MET inhibitors. In a MKN45 gastric xenograft model, the antibody NH-YK showed comparable anti-tumor efficacy to the combination of the parental MET antibody and cetuximab (T/C% = 17.4%, $p < 0.001$ and 18.6%, $p < 0.001$, respectively) (Fig. 5).

Part D: In the H1993 NSCLC xenograft model, immunodeficient mice bearing xenografts were treated with either vehicle control, the anti-MET/EGFR multifunctional antibody H9 (4 and 27 mg/kg), anti-MET alone (3 and 20 mg/kg), cetuximab (3 and 20 mg/kg) or the combination of anti-MET plus cetuximab (3 mg/kg and 20 mg/kg of each antibody) once a week for five consecutive weeks. The anti-MET/EGFR multifunctional antibody H9 at 27 mg/kg resulted in significant greater antitumor efficacy than any other treatment ($p < 0.001$) (Fig. 6).

When tested in H441 xenografts, the antibody H9 also showed superior efficacy when compared to individual treatments or the combination of the parental MET antibody and cetuximab (Fig. 7).

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Example 11: Inhibition of tumor growth in patient-derived xenograft (PDX) models for colorectal cancer

Patient-derived colorectal carcinoma samples may be procured and tumor fragments derived from an individual patient can be implanted in a single immune-compromised mouse and allowed to grow until it reaches an approximate volume of 100-200 mm³. The antibody NH-YK at 27 mg/kg or vehicle control may be administered once a week for 3-4 consecutive weeks. Tumors may be measured via electronic caliper twice a week. Body weight can also be assessed regularly. The vehicle control group may be treated with phosphate buffered saline (PBS) administered through intraperitoneal (i.p.) injection on a once weekly schedule for four cycles. Tumor volume may be calculated using the formula: $A^2 \times B \times 0.536$, where A is the smaller and B is the larger of perpendicular diameters.

Colorectal carcinoma tumor samples from two patients were individually implanted into two different immunocompromised mice essentially as described above in this Example 11. As shown in Tables 17 and 18, weekly administration of the antibody NH-YK significantly reduced the volume of each of the PDX tumors when compared to vehicle-treated animals harboring PDX tumors.

Table 17

Absolute Tumor Volume (mm ³) of PDX (from Patient #1)	Day 0	Day 25
Vehicle	192.1	1186.1
NH-YK	195.2	23.6

Table 18

Absolute Tumor Volume (mm ³) of PDX (from Patient #2)	Day 0	Day 21
Vehicle	248.4	1141.1
NH-YK	207.8	46.2

Example 12: Inhibition of tumor growth in patient-derived xenograft (PDX) models for Squamous Cell Carcinoma of the Head and Neck (SCCHN)

Patient-derived squamous cell carcinoma of the head and neck (SCCHN) samples may be procured and tumor fragments derived from an individual patient can be implanted in a single immune-compromised mouse and allowed to grow until it reaches

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an approximate volume of 100-200 mm³. The antibody NH-YK at 27 mg/kg or vehicle control may be administered twice a week for 4 consecutive weeks. Tumors may be measured via electronic caliper twice a week. Body weight can also be assessed regularly. The vehicle control group may be treated with PBS administered through i.p.

- 5 injection on a once weekly schedule for four cycles and 20% PEG 400/80% [20% captisol in distilled de-ionized water] administered through oral gavage (p.o.) on a once daily schedule for 28 cycles. Tumor volume may be calculated using the formula: Tumor Volume (mm³) = width² x length x 0.52.

- 10 Squamous cell carcinoma of the head and neck tumor samples from two patients were individually implanted into two different immunocompromised mice essentially as described above in this Example 12. As shown in Table 19, twice weekly administration of the antibody NH-YK significantly reduced the volume of the PDX tumor when compared to a vehicle-treated animal harboring a PDX tumor.

Table 19

Absolute Tumor Volume (mm ³) of PDX (from Patient #1)	Day 0	Day 46
Vehicle	200	1221 ± 236 (SEM)
NH-YK	200	222 ± 121 (SEM)

- 15 The standard error of the mean (SEM)

Example 13: Inhibition of tumor growth in mouse xenograft model for erlotinib-resistant NSCLC (erlotinib-resistant HCC-827)

- 20 Female athymic nude mice age 6- to 7-weeks old are available commercially, including from Harlan Laboratories. The mice are allowed to acclimate for one week and fed ad libitum on a normal low fat (4.5%) diet, which may be continued for the duration of the study. HCC-827 tumor cells are available for purchase from ATCC and may be cultured in cell culture media such as RPMI 1640 with L-glutamine, 25 mM HEPES
- 25 supplemented with 10% FBS and 1 mM Na Pyruvate. Cells may be detached, washed with serum free medium and then resuspended at a final concentration of 50 x 10⁶ cells/mL in serum free RPMI 1640. Viable tumor cells, approximately 5 x 10⁶, may be subcutaneously implanted in the rear flank of female athymic nude mice in a 1:1 mixture of serum free growth medium and Matrigel. Once tumors are established, the
- 30 mice may be treated with daily doses of 25 mg/kg erlotinib until resistant tumors start to

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regrow, even in the presence of erlotinib. Once resistant tumors reach a mean volume of approximately 1000 mm³, they may be excised, divided into 50 mm³ fragments and reimplanted into subject female athmic nude mice. In order to monitor regrowth, tumor and body weight measurements may be performed twice weekly. Once the average tumor

5 volume reached 100 mm³, animals were randomized using a randomization algorithm and divided into treatment groups. Antibodies were diluted in PBS and administered via tail vein injection once a week. In order to assure tumors are erlotinib resistant, animals in the control group received PBS vehicle and 25 mg/kg erlotinib. Tumor volume (mm³) was determined via electronic calipers and may be estimated from the formula $A^2 \times B \times$

10 0.536, where A is the smaller and B is the larger of perpendicular diameters.

Immunodeficient mice bearing erlotinib-resistant HCC-827 NSCLC xenografts were generated as described above in this Example and treated with either (A) the vehicle plus 25 mg/kg erlotinib (i.e., control group), (B) the combination of 25 mg/kg erlotinib and 27 mg/kg antibody NH-YK, (C) the combination of 25 mg/kg erlotinib and 20 mg/kg

15 cetuximab, (D) the combination of the parental MET antibody dosed at 20 mg/kg and 25 mg/kg erlotinib, or (E) the combination of the parental MET antibody dosed at 20 mg/kg, cetuximab dosed at 20 mg/kg, and 25 mg/kg erlotinib. The combination of antibody NH-YK and erlotinib (i.e., treatment group (B)) resulted in a significant reduction in absolute tumor volume after the same or longer period of time as compared to all of the other

20 treatment groups (Table 20). Thus, tumor growth in mice carrying erlotinib-resistant tumors is significantly reduced upon treatment with the antibody NH-YK in combination with erlotinib, particularly when compared to animals treated with erlotinib combined with PBS vehicle, cetuximab, or the parental MET antibody. The antibody NH-YK in combination with erlotinib (B) also showed superior antitumor efficacy when compared

25 to the combination of erlotinib, cetuximab and the parental MET antibody (E).

Table 20

Treatment Group	Day of Final Measurement	Absolute Tumor Volume (mm ³)
A	110	2587
B	152	304
C	126	2312
D	126	1706
E	152	1172

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WE CLAIM:

1. A multifunctional antibody comprising:
 - (a) an antibody that binds MET and comprises:
 - 5 i) a heavy chain comprising heavy chain CDRs HCDR1, HCDR2, and HCDR3 consisting of the amino acid sequences of GYTFTDYMH (SEQ ID NO: 11), RVNPNRRGTTYNQKFEG (SEQ ID NO: 12), and ARANWLDY (SEQ ID NO: 13), respectively; and
 - 10 ii) a light chain comprising light chain CDRs LCDR1, LCDR2, and LCDR3 consisting of the amino acid sequences of SVSSSVSSIYLH (SEQ ID NO: 14), YSTSNLAS (SEQ ID NO: 15) and QVYSGYPLT (SEQ ID NO: 16), respectively; and
 - (b) a scFv polypeptide that binds to EGFR and comprises:
 - 15 i) a HCVR domain comprising scFv CDRs scFv-HCDR1, scFv-HCDR2, and scFv-HCDR3 consisting of the amino acid sequences GFSLTNYGVH (SEQ ID NO: 1), VIX₁SGGNTDYNTPF_{X₂}G (SEQ ID NO: 9), wherein X₁ is Y or W and X₂ is K or T, and ARALDYDYDFAY (SEQ ID NO: 3), respectively; and
 - 20 ii) a LCVR domain comprising scFv CDRs scFv-LCDR1, scFv-LCDR2, and scFv-LCDR3 consisting of the amino acid sequences RASYSIGTNIH (SEQ ID NO: 4), X₁YAX₂X₃SIS (SEQ ID NO: 10), wherein X₁ is R or Y, X₂ is K or S, and X₃ is E or R, and QQNNAWPTT (SEQ ID NO: 6), respectively.
- 25 2. The multifunctional antibody according to claim 1 wherein the scFv that binds to EGFR comprises:
 - i) a HCVR domain comprising scFv CDRs scFv-HCDR1, scFv-HCDR2, and scFv-HCDR3 consisting of the amino acid sequences
 - 30 GFSLTNYGVH (SEQ ID NO: 1), VIYSGGNTDYNTPFKG (SEQ ID NO: 2), and ARALDYDYDFAY (SEQ ID NO: 3), respectively; and

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- ii) a LCVR domain comprising scFv CDRs scFv-LCDR1, scFv-LCDR2, and scFv-LCDR3 consisting of the amino acid sequences RASYSIGTNIH (SEQ ID NO: 4), RYAKESIS (SEQ ID NO: 5), and QQNNAWPTT (SEQ ID NO: 6), respectively.

5

3. The multifunctional antibody according to claim 1 or 2 wherein the scFv polypeptide comprises:

- (a) a HCVR domain comprising the amino acid sequence of SEQ ID NO: 17;
and

10

- (b) a LCVR domain comprising the amino acid sequence of SEQ ID NO: 18.

4. The multifunctional antibody according to any one of claims 1 to 3, wherein the heavy chain comprises the amino acid sequence of SEQ ID NO: 53 and the light chain comprises the amino acid sequence of SEQ ID NO: 33.

15

5. The multifunctional antibody according to any one of claims 1 to 3, wherein the C-terminus of the scFv polypeptide is fused via a peptide linker to the N-terminus of the MET antibody heavy chain.

20

6. The multifunctional antibody according to any one of claims 1 to 5, which comprises the amino acid sequence of SEQ ID NO: 25.

7. The multifunctional antibody according to any one of claims 1 to 6, wherein the heavy chain comprises the amino acid sequence of SEQ ID NO: 27 and the light chain comprises the amino acid sequence of SEQ ID NO: 33.

25

8. The multifunctional antibody according to any one of the claims 1 to 7 wherein the antibody that binds MET comprises:

- (a) a first heavy chain and a second heavy chain wherein each of the heavy chains comprises heavy chain CDRs HCDR1, HCDR2, and HCDR3 consisting of the amino acid sequences of GYTFTDYMH (SEQ ID NO:

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11), RVNPNRRGTTYNQKFEG (SEQ ID NO: 12), and ARANWLDY (SEQ ID NO: 13), respectively; and

(b) a first light chain and a second light chain wherein each of the light chains comprises light chain CDRs LCDR1, LCDR2, and LCDR3 consisting of the amino acid sequences of SVSSSVSSIYLH (SEQ ID NO: 14), YSTSNLAS (SEQ ID NO: 15) and QVYSGYPLT (SEQ ID NO: 16), respectively.

9. The multifunctional antibody according to claim 8 wherein the first scFv polypeptide and the second scFv polypeptide each comprises:

i) a HCVR domain comprising scFv CDRs scFv-HCDR1, scFv-HCDR2, and scFv-HCDR3 consisting of the amino acid sequences GFSLTNYGVH (SEQ ID NO: 1), VIYSGGNTDYNTPFKG (SEQ ID NO: 2), and ARALDYDYDFAY (SEQ ID NO: 3),

respectively; and

ii) a LCVR domain comprising scFv CDRs scFv-LCDR1, scFv-LCDR2, and scFv-LCDR3 consisting of the amino acid sequences RASYSIGTNIH (SEQ ID NO: 4), RYAKESIS (SEQ ID NO: 5), and QQNNAWPTT (SEQ ID NO: 6).

10. The multifunctional antibody according to claim 9 wherein the first scFv polypeptide and the second scFv polypeptide each comprises:

(a) a HCVR domain comprising the amino acid sequence of SEQ ID NO: 17; and

(b) a LCVR domain comprising the amino acid sequence of SEQ ID NO: 18.

11. The multifunctional antibody according to claim 10, wherein the first and the second scFv polypeptides each comprises the amino acid sequence of SEQ ID NO: 23.

12. The multifunctional antibody according to claim 11 wherein the antibody that binds to MET comprises:

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- 5
- i) a first heavy chain and a second heavy chain wherein each of the heavy chains comprises the amino acid sequence of SEQ ID NO: 53; and
 - ii) a first light chain and a second light chain wherein each of the light chains comprises the amino acid sequence of SEQ ID NO: 33.

10 13. The multifunctional antibody according to claim 12 wherein the C-terminus of the first scFv polypeptide is fused via a peptide linker to the N-terminus of the first heavy chain and the C-terminus of the second scFv polypeptide is fused via a peptide linker to the N-terminus of the second heavy chain.

15 14. The multifunctional antibody according to claim 13 comprising two first polypeptides and two second polypeptides wherein the amino acid sequence of both first polypeptides is SEQ ID NO: 27 and the amino acid sequence of both second polypeptides is SEQ ID NO: 33.

20 15. The multifunctional antibody according to any one of claims 1 to 14 wherein the multifunctional antibody induces internalization and/or degradation of cell surface MET and EGFR.

16. The multifunctional antibody according to claim 1 wherein the scFv that binds to EGFR comprises:

- 25
- i) a HCVR domain comprising scFv CDRs scFv-HCDR1, scFv-HCDR2, and scFv-HCDR3 consisting of the amino acid sequences GFSLTNYGVH (SEQ ID NO: 1), VIWSGGNTDYNTPTG (SEQ ID NO: 7), and ARALDYYDYDFAY (SEQ ID NO: 3), respectively; and
 - 30 ii) a LCVR domain comprising scFv CDRs scFv-LCDR1, scFv-LCDR2, scFv-LCDR3 consisting of the amino acid sequences RASYSIGTNIH (SEQ ID NO: 4), YYASRSIS (SEQ ID NO: 8), and QQNNAWPTT (SEQ ID NO: 6), respectively.

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17. The multifunctional antibody according to claim 16 wherein the scFv polypeptide comprises:
- (a) a HCVR domain comprising the amino acid sequence of SEQ ID NO: 19;
and
 - 5 (b) a LCVR domain comprising the amino acid sequence of SEQ ID NO: 20.
18. The multifunctional antibody according to any one of claims 16 to 17, wherein the antibody that binds MET comprises:
- i) a heavy chain comprising the amino acid sequence of SEQ ID NO:
10 53; and
 - ii) a light chain comprising the amino acid sequence of SEQ ID NO:
33.
19. The multifunctional antibody according to any one of claims 16 to 18, wherein the
15 C-terminus of the scFv polypeptide is fused via a peptide linker to the N-terminus of the MET antibody heavy chain.
20. The multifunctional antibody according to any one of claims 16 to 19 which
20 comprises the amino acid sequence of SEQ ID NO: 26.
21. The multifunctional antibody according to any one of claims 16 to 20, comprising:
- i) the amino acid sequence of SEQ ID NO: 29; and
 - ii) the amino acid sequence of SEQ ID NO: 33.
22. The multifunctional antibody according to claim 21 wherein the antibody that
25 binds MET comprises:
- (a) a first heavy chain and a second heavy chain wherein both heavy chains
comprise heavy chain CDRs HCDR1, HCDR2, and HCDR3 consisting of
the amino acid sequences of GYTFTDYMH (SEQ ID NO: 11),
30 RVNPNRRGTTYNQKFEG (SEQ ID NO: 12), and ARANWLDY (SEQ
ID NO: 13), respectively; and

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(b) a first light chain and a second light chain wherein both light chains comprise light chain CDRs LCDR1, LCDR2, and LCDR3 consisting of the amino acid sequences of SVSSSVSSIYLH (SEQ ID NO: 14), YSTSNLAS (SEQ ID NO: 15) and QVYSGYPLT (SEQ ID NO: 16), respectively.

23. The multifunctional antibody according to claim 22 wherein the first scFv polypeptide and the second scFv polypeptide each comprises:

- i) a HCVR domain comprising scFv CDRs scFv-HCDR1, scFv-HCDR2, and scFv-HCDR3 consisting of the amino acid sequences GFSLTNYGVH (SEQ ID NO: 1), VIWSGGNTDYNTPTFG (SEQ ID NO: 7), and ARALDYDYDFAY (SEQ ID NO: 3), respectively; and
- ii) a LCVR domain comprising scFv CDRs scFv-LCDR1, scFv-LCDR2, scFv-LCDR3 consisting of the amino acid sequences RASYSIGTNIH (SEQ ID NO: 4), YYASRSIS (SEQ ID NO: 8), and QQNNAWPTT (SEQ ID NO: 6), respectively.

24. The multifunctional antibody according to claim 23 wherein the first scFv polypeptide and the second scFv polypeptide each comprises:

- i) a HCVR domain comprising the amino acid sequence of SEQ ID NO: 19; and
- ii) a LCVR domain comprising the amino acid sequence of SEQ ID NO: 20.

25. The multifunctional antibody according to claim 24, wherein the first and the second scFv polypeptides each comprise the amino acid sequence of SEQ ID NO: 24.

26. The multifunctional antibody according to claim 25 wherein the antibody that binds to MET comprises:

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- i) a first heavy chain and a second heavy chain wherein both heavy chains comprise the amino acid sequence of SEQ ID NO: 53; and
- ii) a first light chain and a second light chain wherein both light chains comprises the amino acid sequence of SEQ ID NO:33.

5

27. The multifunctional antibody according to claim 26 wherein the C-terminus of the first scFv polypeptide is fused via a peptide linker to the N-terminus of the first heavy chain and the C-terminus of the second scFv polypeptide is fused via a peptide linker to the N-terminus of the second heavy chain.

10

28. The multifunctional antibody according to claim 27 comprising two first polypeptides and two second polypeptides wherein the amino acid sequence of both first polypeptides is SEQ ID NO: 29 and the amino acid sequence of both second polypeptides is SEQ ID NO: 33.

15

29. A pharmaceutical composition, comprising the multifunctional antibody, or a MET and EGFR binding fragment thereof, according to any one of claims 1 to 28, and a pharmaceutically acceptable carrier, diluent, or excipient.

20

30. The multifunctional antibody, or a MET and EGFR binding fragment thereof, according to any one of claims 1 to 28, for use in therapy.

31. The multifunctional antibody, or a MET and EGFR binding fragment thereof, according to any one of claims 1 to 28, for use in treating a cancer.

25

32. The multifunctional antibody, or a MET and EGFR binding fragment thereof, according to any one of claims 1 to 28, for use in treating NSCLC, SCLC, gastric cancer, colorectal cancer, cholangiocarcinoma, esophageal cancer, melanoma, uveal melanoma, renal cancer, liver cancer, bladder cancer, cervical cancer, or head and neck cancer.

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33. The multifunctional antibody, or a MET and EGFR binding fragment thereof,
according to any one of claims 1 to 28, for use in treating NSCLC, SCLC, gastric
cancer, colorectal cancer, cholangiocarcinoma, esophageal cancer, melanoma,
uveal melanoma, renal cancer, liver cancer, bladder cancer, cervical cancer, or head
5 and neck cancer wherein the cancer is characterized by comprising cells having one
or more KRAS mutations.
34. A method of treating cancer, comprising administering to a patient in need thereof
an effective amount of the multifunctional antibody, or a MET and EGFR binding
10 fragment thereof, according to any one of claims 1 to 28.
35. The method of claim 34 wherein the cancer is NSCLC, SCLC, gastric cancer,
colorectal cancer, cholangiocarcinoma, esophageal cancer, melanoma, uveal
melanoma, renal cancer, liver cancer, bladder cancer, cervical cancer, or head and
15 neck cancer in a human.
36. The method according to claim 34 or 35 wherein said tumor is characterized by
comprising cells having one or more KRAS mutations.
- 20 37. A DNA molecule comprising a polynucleotide encoding a polypeptide having the
amino acid sequence of SEQ ID NO: 27.
38. A DNA molecule comprising a polynucleotide encoding a polypeptide having the
amino acid sequence of SEQ ID NO: 23.
25
39. A DNA molecule comprising:
(a) a polynucleotide encoding a polypeptide having the amino acid sequence
of SEQ ID NO: 27; and
(b) a polynucleotide encoding a polypeptide having the amino acid sequence
30 of SEQ ID NO: 33.

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40. A mammalian cell transformed with the DNA molecule according to any one of claims 37 to 39, which cell is capable of expressing a multifunctional antibody comprising a first polypeptide having an amino acid sequence of SEQ ID NO: 27 and a second polypeptide having an amino acid sequence of SEQ ID NO: 33.

5

41. The mammalian cell of claim 40, wherein the mammalian cell is CHO.

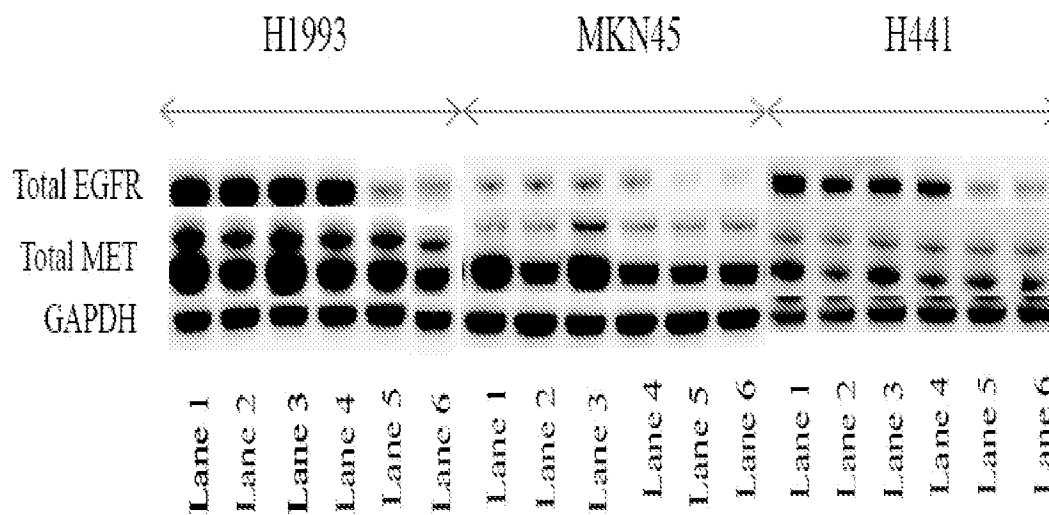
42. A process for producing a multifunctional antibody comprising a first polypeptide whose amino acid sequence is SEQ ID NO: 27 and a second polypeptide whose amino acid sequence is SEQ ID NO: 33, comprising: (1) cultivating the mammalian cell of claim 40 or 41 under conditions such that the multifunctional antibody is expressed, and (2) recovering the expressed multifunctional antibody.

10

43. A multifunctional antibody that binds MET and EGFR produced by the process of claim 42.

15

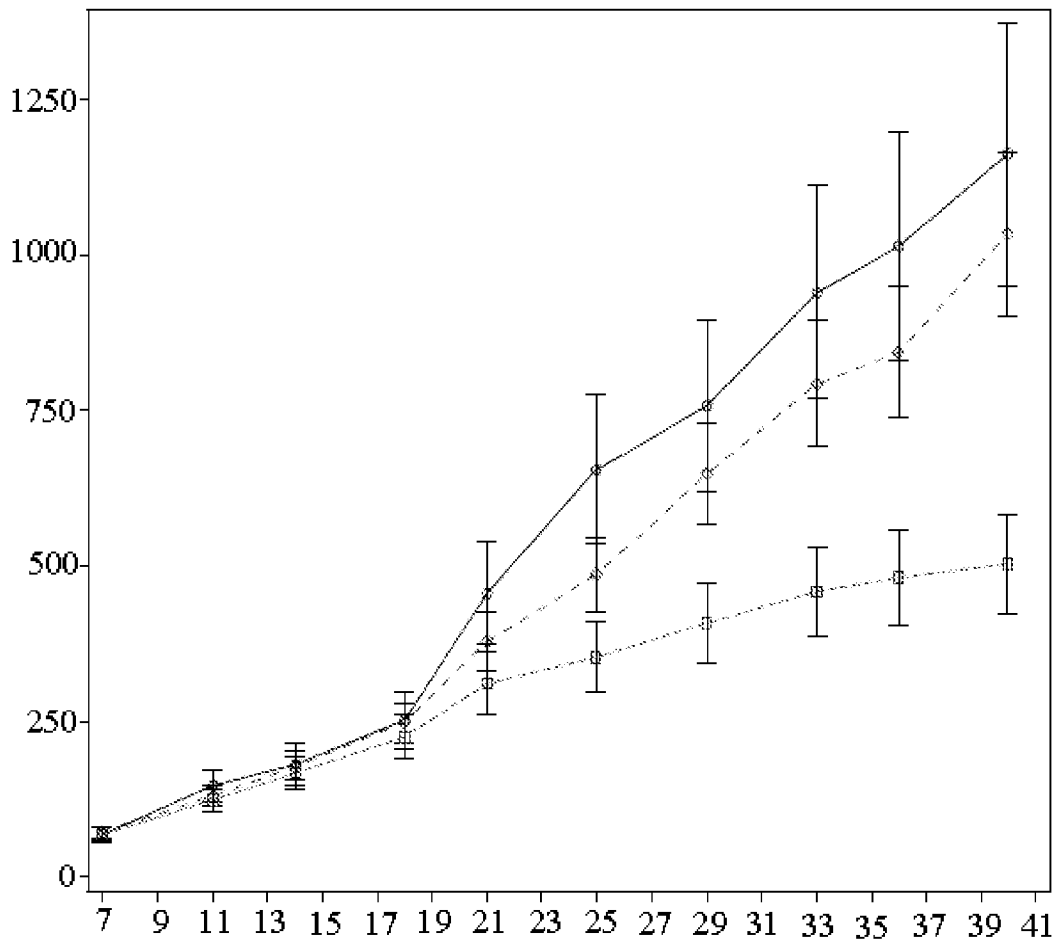
1/7

Fig. 1

Lane 1: hIgG4; Lane 2: anti-MET Ab; Lane 3: cetuximab;

Lane 4 anti-MET Ab + cetuximab; Lane 5: NH-YK; Lane 6: NH-H9

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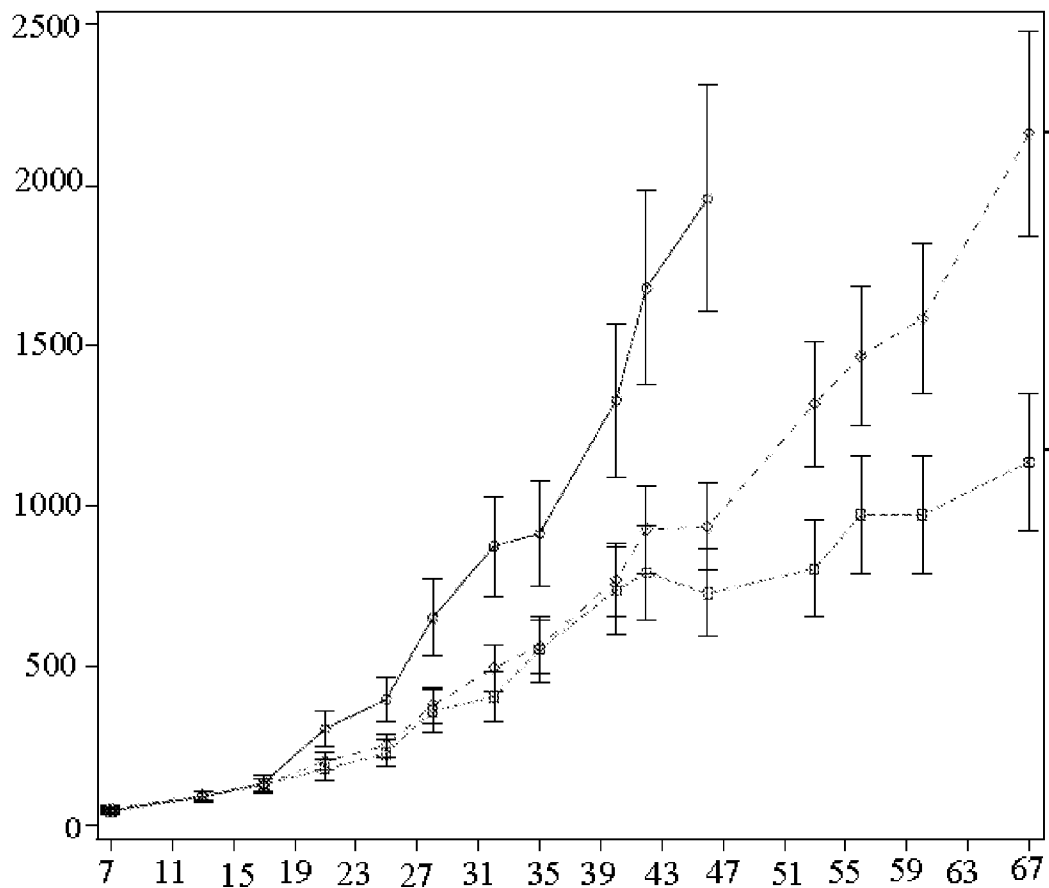
Fig. 2

Y-axis of graph = Tumor Volume (mm³), Mean $\pm$ Standard Error
X-axis of graph = Days Post Implantation

Key:

- Vehicle control
- - - - - 20 mpk cetuximab + 20 mpk anti-MET Ab
- 27 mpk NH-YK

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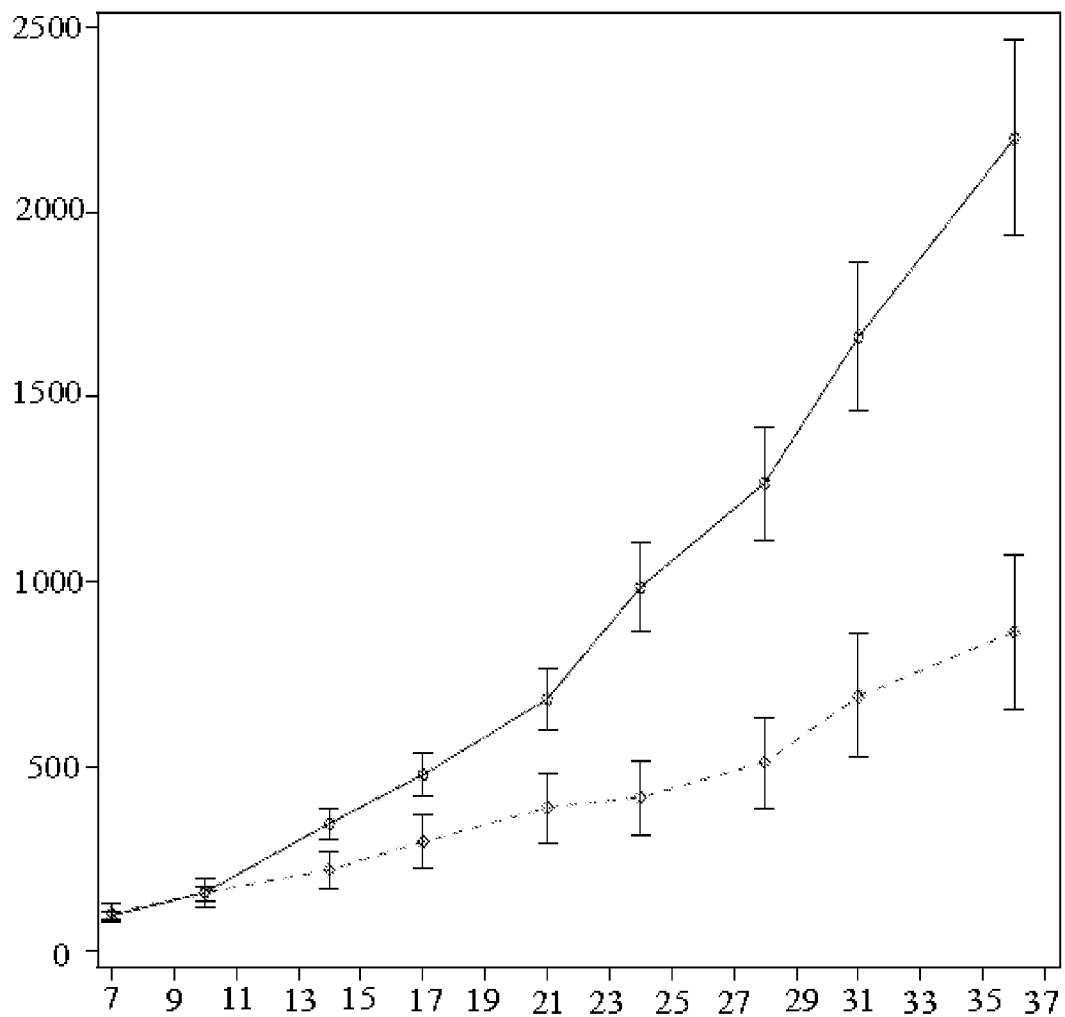
Fig. 3

Y-axis of graph = Tumor Volume (mm^3), Mean $\pm$ Standard Error
X-axis of graph = Days Post Implantation

Key:

- Vehicle control
- - - - - 20 mpk cetuximab + 20 mpk anti-MET Ab
- 27 mpk NH-YK

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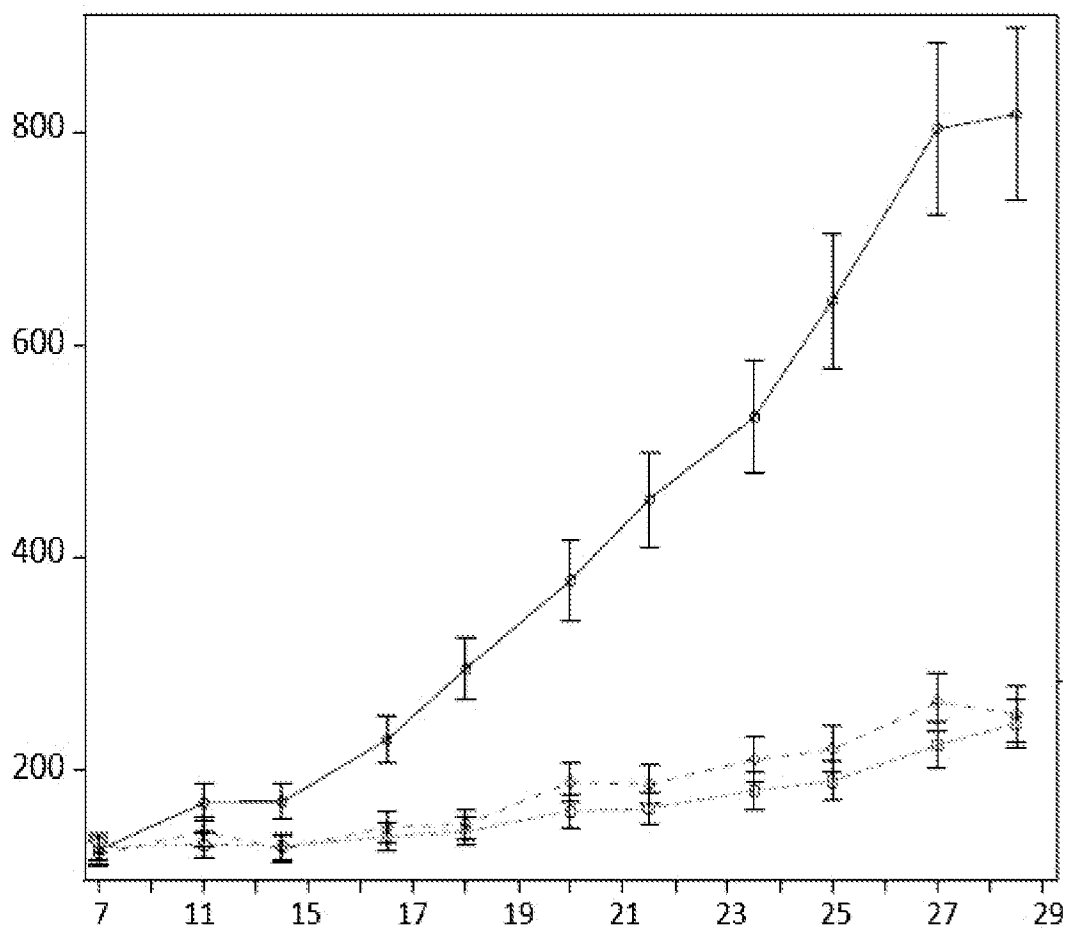
Fig. 4

Y-axis of graph = Tumor Volume (mm³), Mean $\pm$ Standard Error
X-axis of graph = Days Post Implantation

Key:

———— Vehicle control
----- 10 mpk NH-YK

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Fig. 5

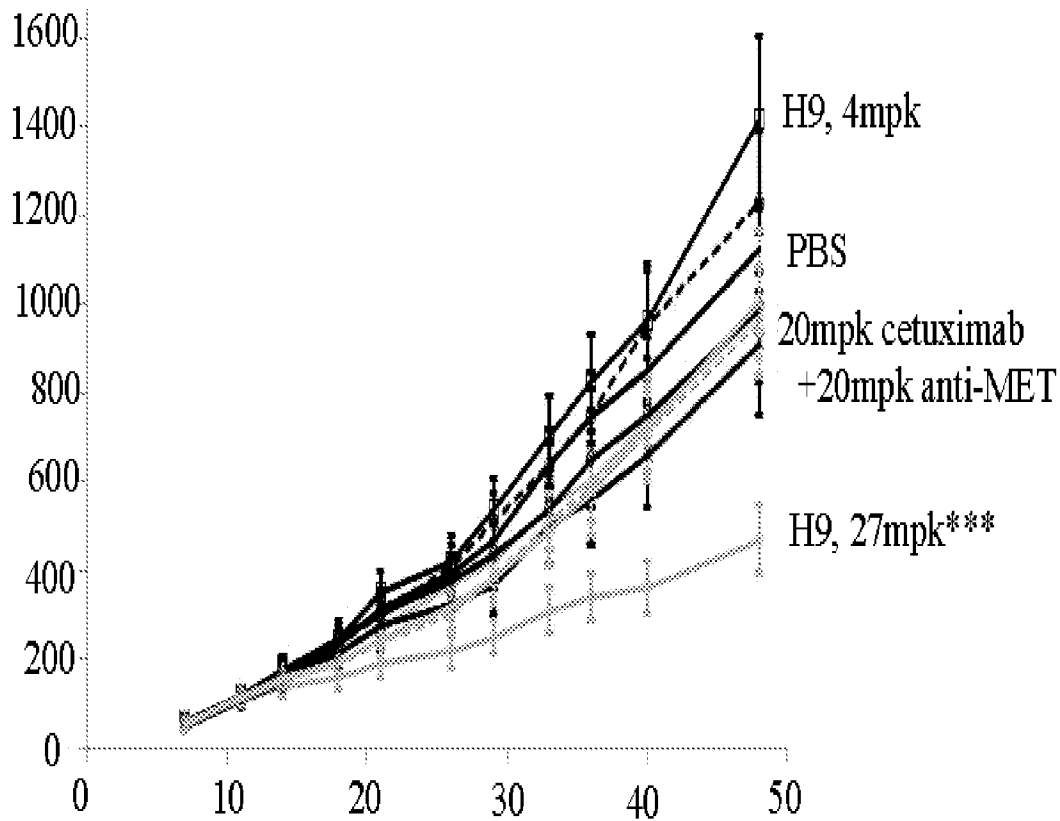
Y-axis of graph = Tumor Volume (mm^3), Mean $\pm$ Standard Error
X-axis of graph = Days Post Implantation

Key:

- vehicle control
- - - - - 20 mpk cetuximab + 20 mpk anti-MET Ab
- 27 mpk NH-YK

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Fig. 6

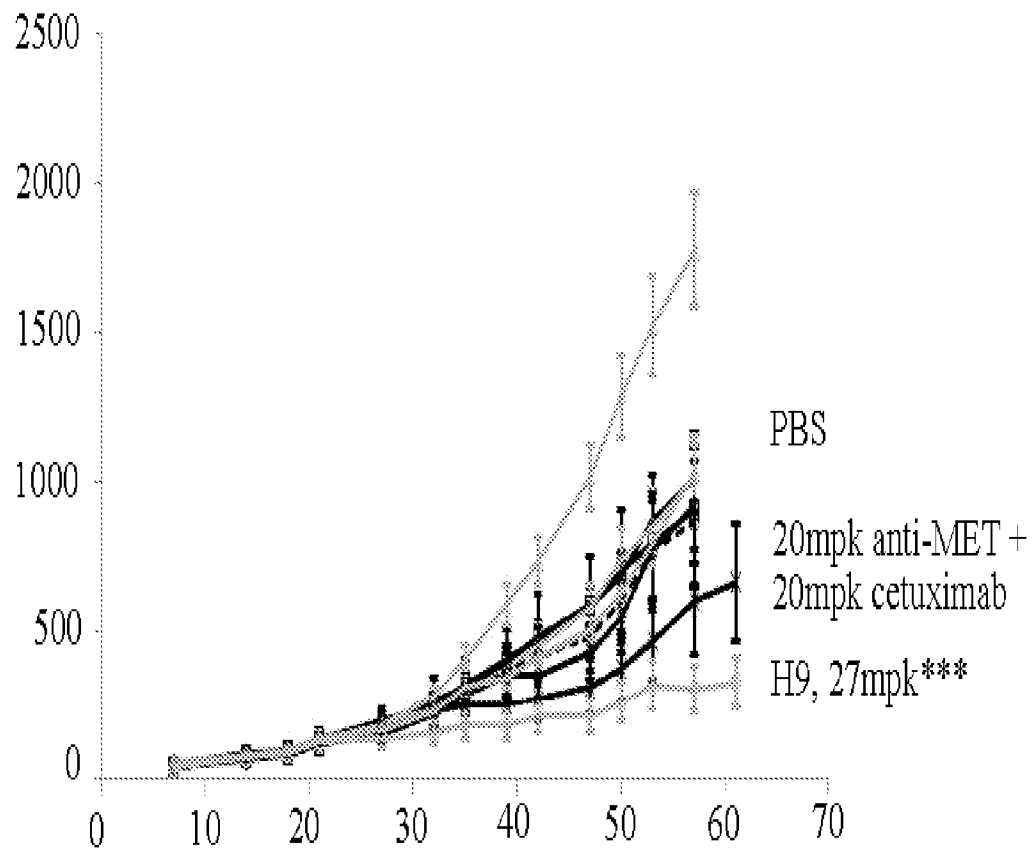


Y-axis of graph = Tumor Volume (mm³), Mean $\pm$ St. Err., Method = (LogVol,SP)
 X-axis of graph = Days Post Implantation

Key:

- PBS, 0.2 ml, IV, q7d x 5
- H9, 4 mg/kg, IV, q7d x 5
- ◇— H9, 27 mg/kg, IV, q7d x 5
- ◇— anti-MET, 3 mg/kg, IV, q7d x 5
- ◇— cetuximab, 3 mg/kg, IV, q7d x 5
- ◇— <n cetuximab, 3 mg/kg, IV, q7d x 5
- ◇— anti-MET, 3 mg/kg, IV, q7d x 5 / cetuximab, 3 mg/kg, IV, q7d x 5
- ◇— anti-MET, 20 mg/kg, IV, q7d x 5
- ◇— cetuximab, 20 mg/kg, IV, q7d x 5
- ◇— <n cetuximab, 20 mg/kg, IV, q7d x 5
- ◇— anti-MET, 20 mg/kg, IV, q7d x 5 / cetuximab, 20 mg/kg, IV, q7d x 5

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Fig. 7

Y-axis of graph = Tumor Volume (mm³), Mean $\pm$ St. Err., Method = (LogVol,SP)
 X-axis of graph = Days Post Implantation

5

Key:

- PBS, 0.2 ml, IV, q7d x 5
- anti-MET, 0.6 mg/kg, IV, q7d x 5 / cetuximab, 0.6 mg/kg, IV, q7d x 5
- anti-MET, 3 mg/kg, IV, q7d x 5
- ◇— cetuximab, 3 mg/kg, IV, q7d x 5
- ▲— anti-MET, 3 mg/kg, IV, q7d x 5 / cetuximab, 3 mg/kg, IV, q7d x 5
- ◆— anti-MET, 3 mg/kg, IV, q7d x 5 / cetuximab, 3 mg/kg, IV, q7d x 5
- anti-MET, 20 mg/kg, IV, q7d x 5 / cetuximab, 20 mg/kg, IV, q7d x 5
- *— H9, 0.8 mg/kg, IV, q7d x 5
- H9, 4 mg/kg, IV, q7d x 5
- △— H9, 27 mg/kg, IV, q7d x 5

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2014/070850

A. CLASSIFICATION OF SUBJECT MATTER

INV. C07K16/28 C07K16/30 C07K16/46 A61K39/395 A61P35/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C07K A61K A61P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, BIOSIS, EMBASE, WPI Data, Sequence Search

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	R CASTOLDI ET AL: "A novel bispecific EGFR/Met antibody blocks tumor-promoting phenotypic effects induced by resistance to EGFR inhibition and has potent antitumor activity", ONCOGENE, vol. 32, no. 50, 1 July 2013 (2013-07-01), pages 5593-5601, XP055129019, ISSN: 0950-9232, DOI: 10.1038/onc.2013.245	1,4-6, 15,29-38
A	whole document, especially the Abstract; page 5594, right-hand column, second paragraph; Figure 6 ----- -/--	2,3, 7-14, 16-28, 39-43



Further documents are listed in the continuation of Box C.



See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

23 March 2015

Date of mailing of the international search report

01/04/2015

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INTERNATIONAL SEARCH REPORT

International application No

PCT/US2014/070850

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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X	WO 2010/115551 A1 (ROCHE GLYCART AG [CH]; BOSSENMAIER BIRGIT [DE]; BRINKMANN ULRICH [DE];) 14 October 2010 (2010-10-14) cited in the application	1,4-6, 15,29-38
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A	----- WO 2013/134743 A1 (HALOZYME INC [US]) 12 September 2013 (2013-09-12) Examples 1, 2, 15; SEQ ID NOs 29, 1135-1159, 288-468 -----	1-43

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2014/070850

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