

A MONOCLONAL ANTIBODY FRAMEWORK BINDING INTERFACE FOR MEDITOPES, MEDITOPE DELIVERY SYSTEMS AND METHODS FOR THEIR USE

PRIORITY CLAIM

[0001] This application claims the benefit of United States Provisional Application Serial Number 61/391,558 filed October 8, 2010, which is incorporated herein by reference in its entirety.

BACKGROUND

[0002] Cancers avoid immune surveillance by actively suppressing the immune system. One method envisioned for counteracting this immunosuppression is through vaccination using epitopes of antigens that are either uniquely expressed or over-expressed by the tumor cells. For example, monoclonal antibodies (mAbs) that block signaling pathways, sequester growth factor and/or induce an immune response have been successfully implemented in the clinic to treat cancer and other diseases. Due to their favorable properties and clinical success, mAbs have been and continue to be the subject of intense protein engineering efforts. These efforts have yielded bispecific mAbs for improved targeting; single chain Fab variable fragments (scFvs), diabodies, and minibodies for better tumor penetration and blood clearance; and modified Fcs (through mutation or glycosylation) to alter immunostimulation or improve pharmacokinetic/pharmacodynamic properties. Likewise, mAbs have been reengineered to permit the site-specific conjugation of small molecules for improved delivery (e.g., ThioMABs) or to irreversibly bind to their antigen (e.g., infinite affinity mAbs). MABs have also been developed to improve the circulation and presentation of bioactive peptides and other biologics (e.g., CovXbodies). Hetero-multimeric scFvs or scFvs or mAbs fused to avidin have also been developed for pre-targeted therapy and to improve the detection limits for tumor imaging.

[0003] Although mAbs can be effective and have some advantages over small molecule approaches, limitations such as adverse side effects due to off-target interactions or collateral damage due to long circulation times of radionuclide-

conjugated mAbs indicates that there remains considerable room to improve their efficacy, including improved targeting and synergy. Therefore, enhancement of antibody and small molecule therapeutic efficacy would be useful and desired in the treatment of cancer and other diseases.

SUMMARY

[0004] Antibody binding peptides C-QFDLSTRRLK-C (cQFD; SEQ ID NO:1) and C-QYNLSSRALK-C (cQYN; SEQ ID NO:2) were shown to have novel mAb binding properties. Specifically, cQFD and cQYN, which are also called “meditopes,” were shown to bind to a region of the Fab framework of the anti-EGFR mAb cetuximab and not to bind the complementarity determining regions (CDRs) that bind antigen. The binding region on the Fab framework is distinct from other framework-binding antigens, such as the superantigens Staphylococcal protein A (SpA) (Graille et al., 2000) and Peptostreptococcus magnus protein L (PpL) (Graille et al., 2001), and was previously unknown. Accordingly, a first embodiment is a framework binding interface comprising a framework region of a unique murine-human antibody or functional fragment thereof that binds a cyclic mediotope having the sequence CQFDLSTRRLKC (SEQ ID NO:1) or CQYNLSSRALKC (SEQ ID NO:2).

[0005] Characterization of the meditopes by surface plasmon resonance indicated that cQFD and cQYN bind to Fab with dissociation constants of between approximately 0.70 - 0.95 and 2-5 μ M, respectively. Point mutations designed to disrupt specific interactions further support the structural model. FACS analysis revealed that high concentrations of the cQFD mediotope (60 μ M) produced negligible differences in the ability of cetuximab to bind to MDA-MB-468 cells, which over-express the EGFR receptor. Thus, mediotope binding does not affect antigen binding. In addition, the meditopes were conjugated with a fluorescent group and shown to bind to MDA-MB-468 cells pretreated with cetuximab, but not to MDA-MB-468 cells pretreated with the murine anti-EGFR antibody, M425 (Figure 29). Collectively, these data define a mediotope binding interface within the Fab framework and demonstrate that the mediotope binding does not inhibit antigen binding (e.g., does not act as an allosteric regulator).

[0006] In another embodiment, mediotopes (e.g., cQYN or cQFD) or variants thereof having the novel binding properties described above may be used to add functionality to therapeutic monoclonal antibodies ("mAbs"). In a further embodiment, the mediotopes described herein may be exploited to affect the efficacy of therapeutic substances such as monoclonal antibodies and functional fragments thereof or other substances such as small molecules. In yet another embodiment, tags or detectable labels may be attached to the mediotopes for identification of certain types of cells or tissues for diagnostic or therapeutic use.

[0007] In a separate embodiment, a mediotope contains a cysteine that covalently binds to a cysteine in the Fab at the mediotope binding site. The mediotope is conjugated to any substance, molecule or compound, which may be therapeutic molecule, such as a small molecule diagnostic molecule, such as a marker. The "Cys mediotope" directs the conjugate to the IgG and binds via a covalent linkage.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Figure 1 shows mediotope peptides binding framework loops of cetuximab. Figure 1A: The complex of cetuximab Fab (light chain denoted by V_L and C_L, heavy chain denoted by V_H and C_H) and cyclic CQFDLSTRRLKC (depicted within the shaded area and labeled with the word "mediotope") (SEQ ID NO:1) indicates that the mediotope binds to an interface of the Fab framework, which is distinct from the CDR loops of cetuximab. Figure 1B shows the stick representation of the cQFD mediotope and Figure 1C shows the stick representation of the cQYN mediotope. The N- and C- terminal cysteines are solvent exposed and display high thermal factors.

[0009] Figure 2 shows certain embodiments of the cetuximab Fab binding interface. Cetuximab is a murine chimera and therefore has a mix of murine Ig variable domains and human constant Ig domains. Figure 2A shows the corresponding residues for the phage 'negative' selection, ch14.18, and the humanized trastuzumab that make contact with the mediotope. Figure 2B, top panel, shows a stereoview of Arg9 of the cQFD mediotope that occupies a distinct pocket encoded by the murine sequence of Cetuximab (foreground). Trastuzumab Fab (1N8Z.pdb; background) (Cho et al.,

2003) is superimposed. There is a salt bridge from Asp85 to the guanidinium group of the meditope Arg9 and the backbone amide of Leu10. Figure 2B, bottom panel, graphically represents the superposition of the Fab fragments indicating subtle effects due the F to Y in the meditope. Specifically, the hydrophobic groups, F/Y3 L5, and L10 are nearly identically positioned, but the hydroxyl group of Y5 in the cQYN meditope prevents R8 from interacting with the Q111 backbone, as observed in the cQFD meditope ("steric clash"). This rearrangement also results in a concomitant change in the backbone residues of the β -turn ("backbone rotation").

[0010] Figure 3 is two line graphs showing surface plasmon resonance (SPR) traces of cQFD and cQYN and the Fab fragment. The cetuximab Fab used for crystallographic studies was coupled to a CM5 chip at low densities. Traces at increasing concentrations of the cQFD (Figure 3A) and cQYN (Figure 3B) meditoes are shown. The series of traces are fit to single binding site model using a simple exponential (e.g., $\text{signal} = A \cdot \exp[k_{\text{on}} \cdot \text{time}]$). The residuals of the fit are shown below each.

[0011] Figure 4 illustrates that the present meditoes do not bind to the CDRs as was previously hypothesized. Figure 4A demonstrates a 2.0 Å crystal structure, wherein the meditope binds to middle 'hole' of the cetuximab Fab. The antigen, EGFR domain III, binds at the complementarity determining regions at a significant distance from the meditope binding site. Figure 4B shows gel results on the left-hand side and related size exclusion chromatography results on the right-hand side. Size exclusion experiments of the individual components, Fab, EGFR domain III, and SMT-cQFD meditope, as well as an admixture of all three, indicate the formation of a heterotrimeric complex and coelute. The non-reducing SDS-PAGE gel shows the fraction that eluted first, indicating the presence of all three components within the new peak (the left-most peak for "complex," shaded light gray) observed from the admixture. Figure 4C shows the results of a FACS analysis, indicating that the meditope binds to EGFR positive MD-MBA-468 cells only in the presence of cetuximab (arrows). The meditope alone or the meditope in the presence of M425, a murine EGFR antibody, does not bind. Figure 4D and 4E show results of surface plasmon resonance experiments using a sensor chip

coupled with a cetuximab scFv. The experiments indicate that saturation of the scFv could not be achieved at concentrations as high as 100 μ M of the cQFD meditope. The same experiments using the cetuximab Fab coupled sensor chip indicate full saturation. The dissociation constant from this experiment is 660 nM. Control SPR experiments show that the cetuximab scFv readily binds soluble EGFR domain III fragment, indicating that the CDR loops are functional.

[0012] Figure 5 is a graph of fluorescence intensity compared to cell count and shows fluorescently-labeled cetuximab binding to MDA-MB468 cells in the presence of cQFD. Cetuximab binds to MDA-MB468 cells without peptide, and in the presence of 6 μ M and 60 μ M peptide as well as the isotype control.

[0013] Figure 6 shows how meditope and EGFR bind to distinct sites. The top images show superposition of the cQFD-Fab complex and the EGFR-Fab complex (1YY8) in stereo. The bottom images show that residues 39-46 of the heavy chain are flexible and accommodate the meditope.

[0014] Figure 7 shows Fab framework binders. Superposition of Fabs bound to meditope, Protein A, and Protein L indicate that each binds to a unique site on the Fab.

[0015] Figure 8 illustrates one mechanism of action for enhancing tumor therapy. Overexpression of antigen (e.g., ErbB receptor family) on tumor cells binds to bivalent antibodies (left panel) and blocks receptor signaling, alters endocytosis and receptor recycling and/or elicits an immune response. The addition of a multivalent meditope tethers/cross-links the therapeutic mAb and can enhance its therapeutic potential (right). The right panel depicts the daisy-chain linkage expected from a trivalent meditope.

[0016] Figure 9 shows scFv-meditope linker. scFvs are created by fusing the light chain variable domain to the heavy chain variable domain (or vice versa) through a 12-20 amino acid linker (typically {GGGS}₃₋₅).

[0017] Figure 10 is a gel showing that the meditope selectively binds the murine cetuximab. Biotinylated cQFD peptide was added to avidin coupled beads, thoroughly washed, and equilibrated in PBS. Cetuximab was then added to the beads (lane 1),

washed (lanes 2-4), and then eluted (lane 5). The top band is the IgG heavy chain and bottom band is the IgG light chain.

[0018] Figure 11 is a depiction of the steric mask. The meditope can be fused to the N-terminus of the Fab light or heavy chain through a flexible linker containing a tumor associated protease site. An intramolecular interaction, as shown, would sterically occlude the antigen binding site.

[0019] Figure 12 shows the off-rate determination for Avidin-peptide mask on Cetuximab. The left panel shows that the binding kinetics of a biotinylated cQFD meditope was measured by SPR using immobilized cetuximab IgG. The boxed panel above the surface plasmon resonance traces depicts a cartoon of the monovalent meditope being passed over the bivalent IgG. As shown in the right panel, Avidin was saturated with biotinylated meditope and passed over the same immobilized cetuximab IgG. The off-rate of the multivalent meditope was reduced by at least 36 fold. (Note the time scales between the two experiments are different.) The boxed panel above the SPR traces depicts a “bivalent-bivalent interaction” between the tetravalent meditope and the bivalent IgG.

[0020] Figure 13 illustrates synthesis of dimeric and trimeric meditope according to some embodiments.

[0021] Figure 14 illustrates the characterization of a fluorescein isothiocyanate (FITC)-labeled meditope dimer 7. The left panel shows an HPLC trace of final bivalent meditope and the right panel shows its mass spectrum.

[0022] Figure 15 shows the nucleic acid sequence (SEQ ID NO:3) and the corresponding amino acid sequence (SEQ ID NO:4) for a meditope-Fc tethering agent according to some embodiments.

[0023] Figure 16 shows the structure of a bivalent meditope. The meditope is directly fused to the N-terminus of a peptide linker that is directly fused to the Fc Region of an IgG. The Fc is naturally homodimeric. Thus the Meditope-Fc construct is bivalent.

[0024] Figure 17 shows the results from an exemplary FACS analysis. MDA-MB-468 cells that over express EGFR receptor were pre-treated with 10 nM of cetuximab for 30 minutes, rinsed, and then treated with either the meditope-Fc construct or the monomeric meditope at four concentrations. The bottom trace is a negative control (no antibody). Next four traces show that a monomeric meditope binds to cells pre-treated with the cetuximab in a concentration dependent manner. The top four traces also show that the bivalent, meditope Fc binds to cells pre-treated with the cetuximab in a concentration dependent manner, but with higher affinity (e.g. shifted to the right). This is predicted and consistent with a multivalent interaction.

[0025] Figure 18 is an alternative linker, including a coiled coil, which may be used accordance with certain embodiments.

[0026] Figure 19: Fragment screening by NMR. Representative NMR spectra of a fragment pool before (red trace) and after (blue trace) cetuximab addition. Using this method, lead compounds have been identified and the binding site is being determined using diffraction studies.

[0027] Figure 20 illustrates steps to alter and/or enhance the binding affinity of a mAb for a meditope or compound binding at the meditope site using a directed random library. Specifically, a gene library where codons for mAb residues that line the meditope binding site are replaced with NNK (where N is any nucleotide and K is a Thymine or Guanosine) can be selected using FACS sorting (where the meditope and the antigen are labeled with distinct chromophores). The GPI linker ensures the selected mAb remains associated with the cell encoding the gene sequence. Sequencing the genes encoding the light can heavy chain from the selected cells will identify high affinity mAbs. The method can be repeated to select for higher affinity meditope or meditope analogs.

[0028] Figure 21 shows 3D surface representation of sequence differences. The dark grey regions in the top panel indicate amino acid differences between cetuximab and the fully human trastuzumab framework. Residues inside the box have been

mutated onto the trastuzumab framework. The CDR loops of trastuzumab have been identified (dark regions; bottom panel) and grafted onto the cetuximab framework.

[0029] Figure 22 illustrates that a mediotope-enabled trastuzumab binds to Mediotope-Fc. In the top graph, the mediotope binding site was created on trastuzumab, a fully human mAb that binds to the tumor antigen, Her2. FACS analysis shows that mediotope-enabled trastuzumab binds to SKBR3 cells that overexpresses Her2 (top two traces). In the bottom graph, the mediotope-Fc binds to mediotope-enabled trastuzumab (top two traces – peak shifted right), but not to wildtype trastuzumab (second from bottom) or to the negative control (bottom trace).

[0030] Figure 23A shows the nucleic acid (SEQ ID NO:5) sequence of a mediotope-enabled trastuzumab heavy chain sequence. Signal peptide sequence is shaded in grey. Figure 23B shows the amino acid (SEQ ID NO:6) sequence of a mediotope-enabled trastuzumab heavy chain sequence as compared to the wildtype (SEQ ID NO:7). Differences are highlighted in grey. After the amino acids shown in Figure 23B, there are no differences remaining to the human sequence of the heavy chain. Figure 23C shows the nucleic acid (SEQ ID NO:8) sequence of a mediotope-enabled trastuzumab light chain sequence. Signal peptide sequence is shaded in grey. Figure 23D shows the amino acid (SEQ ID NO:9) sequence of a mediotope-enabled trastuzumab light chain sequence as compared to the wildtype (SEQ ID NO:10). Differences are highlighted in grey.

[0031] Figure 24 shows Her2 CDR loops grafted on cetuximab framework binds to Mediotope-Fc. In Figure 24A, the Her2 CDR loops of trastuzumab were grafted onto cetuximab, which binds to the mediotope. FACS analysis shows that Her2-CDR grafted mediotope-enabled mAb binds to SKBR3 cells that overexpresses Her2 (top three traces at different concentrations). Figure 24B shows that the mediotope-Fc binds to Her2-CDR grafted, mediotope-enabled mAb (top three traces – peak shifted right in concentration dependent manner), but not to wildtype trastuzumab (second from bottom) or to the negative control (bottom trace).

[0032] Figure 25A shows nucleic acid (SEQ ID NO: 11) and amino acid (SEQ ID NO:12) sequences for the heavy chain of a Her2 CDR grafted, mediotope binding mAb heavy chain with restriction sites and secretion sequence. Figure 25B shows nucleic acid (SEQ ID NO: 13) and amino acid (SEQ ID NO:14) sequences for the light chain of a Her2 CDR grafted, mediotope binding mAb with restriction sites and secretion sequence. Underlined and shaded areas indicate changes used to enable mediotope binding. Additional changes to enhance or alter the specificity of the mediotope can be grafted in a similar manner.

[0033] Figure 26 illustrates examples of sequence and structural alignment of the IgG and IgE Fab domains indicates residues on the IgE near the mediotope binding site.

[0034] Figure 27 is a graph showing surface plasmon resonance (SPR) studies. The binding affinity of the different mediotopes to cetuximab (cQFD, cQYN, and cQYD) was determined at different pHs.

[0035] Figure 28 illustrates the results of an MTT assay comparing the efficacy of a bivalent mediotope-Fc to that of a monomeric mediotope. Figure 28A shows that only the mediotope-Fc, and not the monomeric mediotope, can inhibit cell growth when combined with cetuximab. Figure 28B shows that the mediotope-Fc enhances the cell-killing capacity of cetuximab.

[0036] Figure 29 illustrates that the mediotope binds to unique cetuximab framework, but not to human framework or other murine-chimera frameworks. The wildtype mediotope was conjugated to a CM5 chip for surface plasmon resonance studies and cetuximab (mediotope binding Fab), trastuzumab (fully human framework), and rituximab (murine-human chimeric framework) were tested concentrations 0.01, 0.05, 0.1, 0.5 and 1 uM. Only cetuximab bound to the mediotope-conjugated chip. Superposition of the molecular structure of trastuzumab (1N8Z; Cho et al. 2003) and rituximab (2OSL; Du et al. 2007) Fabs on to the mediotope bound cetuximab Fab structure further highlights the uniqueness of the framework. Moreover, this structural comparison gives a clear indication of which residues originating from the cetuximab

Fab contribute to mediotope binding and how they can be grafted onto other Fab framework regions.

DETAILED DESCRIPTION

[0037] An antibody delivery system that selectively delivers therapeutic or imaging agents to a target tissue, and methods for their use are provided herein. The antibody delivery system may include an antibody framework binding interface (“framework binding interface” or “binding interface”) bound to an antibody binding molecule (or “mediotope”) to form an antibody-mediotope complex. The antibody-mediotope complex may be further conjugated to one or more additional antibody-mediotope complexes, therapeutic agents, imaging agents or a combination thereof for use in methods described further below.

[0038] According to some embodiments, an antibody framework binding interface that can bind a mediotope is formed by a framework region, not by a complementarity determining region (CDR), of an antibody or functional fragment thereof. An “antibody or functional fragment thereof” as used herein refers to an immunoglobulin molecule that specifically binds to, or is immunologically reactive with a particular antigen or epitope, and includes both polyclonal and monoclonal antibodies. The term “antibody” includes genetically engineered or otherwise modified forms of immunoglobulins, such as intrabodies, peptibodies, chimeric antibodies, fully human antibodies, humanized antibodies, mediotope-enabled antibodies and heteroconjugate antibodies (e.g., bispecific antibodies, diabodies, triabodies, tetrabodies, tandem di-scFv, tandem tri-scFv). The term “functional antibody fragment” includes antigen binding fragments of antibodies including, but not limited to, fragment antigen binding (Fab) fragment, F(ab')₂ fragments, Fab' fragments, Fv fragments, recombinant IgG (rIgG) fragments, single chain variable fragments (scFv) and single domain antibodies (e.g., sdAb, sdFv, nanobody) fragments.

[0039] According to some embodiments, the binding interface may be exploited or optimized to enhance binding and imaging of antibodies or functional fragments thereof. In a separate embodiment, a mediotope may contain a cysteine residue that

binds to an engineered cysteine in the Fab at the mediotope binding site (e.g., ThioMAbs). The mediotope is thereby conjugated to any diagnostic and/or therapeutic substance, molecule or compound. For example, the substance may be a small molecule diagnostic molecule, such as a marker. The "Cys mediotope" directs the conjugate to the IgG and binds via a covalent linkage. Alternatively, the mediotope may be conjugated to the Fab to one or more unnatural amino acids that are incorporated into the mediotope binding site. Examples of linkages that may be made with unnatural amino acids include (i) stable hydrazone and oxime linkages by incorporation of p-acetylphenylalanine, m-acetylphenylalanine, p-(3-oxobutaboyl)-l-phenylalanine, and p-(2-amino-3-hydroxyethyl) phenylalanine, (ii) thiol reactive by incorporating phenylselenidylalanine, (iii) a UV crosslinker containing benzophenone by incorporating p-benzoyl-l-phenylalanine, (iv) amine reactive by incorporating p-isopropylthiocarbonyl-phenylalanine or p-ethylthiocarbonyl-phenylalanine, (v) azide alkyne Huisgen cycloaddition by incorporating p-propargyloxyphenylalanine or p-azidophenylalanine or any other suitable unnatural amino acid known in the art. In one embodiment, the mediotope may direct a reactive group to an unnatural amino acid incorporated into the Fab, such as p-acetylphenylalanine.

[0040] In addition, the mediotope framework binding interface can be grafted onto other mAbs to generate a mediotope-enabled mAb. Because the mediotope binding site can be grafted onto other mAbs, the binding interface represents a broadly useful platform technology that may be used not just with cetuximab for EGFR targeted conditions, but with any monoclonal antibody. The term "mediotope-enabled" antibody, monoclonal antibody or therapeutic antibody refers to any antibody that is able to bind a mediotope at its framework binding interface, including cetuximab. Thus, the platform may be expanded for use in treatment, diagnosis or imaging of any cancer, disease or other condition that may be treated or targeted using a therapeutic antibody, including, but not limited to, leukemia and lymphomas (which can be treated or imaged using, e.g., alemtuzumab, bectumumab, gemtuzumab, FBTA05, ibritumomab tiuzetan, ofatumumab, rituximab, tositumomab), breast cancer (which can be treated or imaged using, e.g., trastuzumab, adecatumumab, etrumaxomab) prostate cancer (which can be treated or imaged using, e.g., adecatumumab, capromab pendetide, etaracizumab),

colorectal cancer (which can be treated or imaged using, e.g., labetuzumab, panitumumab, altumumab pentetate, votumumab), gastrointestinal cancers (which can be treated or imaged using, e.g., arcitumumab, catumaxomab), ovarian cancer (which can be treated or imaged using, e.g., abagovomab, catumaxomab, etaracizumab, igovomab, oregovomab), lung cancer (which can be treated or imaged using, e.g., anatumumab mafenatox), pancreatic cancer (which can be treated or imaged using, e.g., clivatuzumab tetraxetan), renal cancer (which can be treated or imaged using, e.g., girentuximab), melanoma cancer (which can be treated or imaged using, etaracizumab, ipilimumab, TRBS07), glioma (which can be treated or imaged using, e.g., nimotuzumab), bone metastases (which can be treated or imaged using, e.g., denosumab), head and neck cancer (which can be treated or imaged using, e.g., zalutumumab), cardiovascular disease (which can be treated or imaged using, e.g., abciximab), autoimmune disorders (which can be treated or imaged using, e.g., adalimumab, infliximab), rheumatoid arthritis (which can be treated or imaged using, e.g., atlizumab, golimumab, infliximab), transplant rejection (which can be treated or imaged using, e.g., basiliximab, daclizumab, muromonab-CD3), Crohn's disease (which can be treated or imaged using, e.g., certolizumab, fontolizumab, natalizumab, infliximab, visilizumab), hemoglobinuria (which can be treated or imaged using, eculizumab), psoriasis (which can be treated or imaged using, e.g., efalizumab, infliximab, ustekinumab), multiple sclerosis (which can be treated or imaged using, e.g., natalizumab, ustekinumab), asthma (which can be treated or imaged using, e.g., benralizumab, mepolizumab, omalizumab), respiratory syncytial virus (RSV) (which can be treated or imaged using, e.g., palivizumab), macular degeneration (which can be treated or imaged using, e.g., ranibizumab), appendicitis (which can be treated or imaged using, e.g., fanolesomab) and any other condition that may be targeted or treated with an antibody. The above-listed antibodies and related diseases or disorders are examples only and do not limit the platform.

[0041] In one embodiment, cyclic antibody binding peptides C-QFDLSTRRLK-C (cQFD; SEQ ID NO:1) and C-QYNLSSRALK-C (cQYN; SEQ ID NO:2) can bind the antibody framework binding interface via a non-covalent binding interaction. This non-covalent nature of the binding interaction opens new alternative methods for modifying

the framework binding interface, the peptide, or both, expanding the possibilities for generating highly specific mediotope variants. In one embodiment, the cQFD and cQYN peptides bind to a framework region of the Fab region of cetuximab, and not to the CDR regions, as shown by diffraction and biophysical data as described below. This binding site is distinct from the binding sites of other framework-binding antigens such as the superantigens Staphylococcal protein A (SpA) and Peptostreptococcus magnus protein L (PpL) (Figure 7). In addition, protein A and Protein L will bind to IgGs present in the patient. Thus the interaction is specific.

[0042] X-ray crystallographic analysis has revealed that the peptide binds within the Fab cavity, as defined by the heavy and light chains (see Figures 1 and 4A), with a binding constant of ~700 nM. This interaction can be exploited to, among other things, improve the therapeutic efficacy of naked mAbs, enhance targeted delivery of imaging or therapeutic agents, and improve mAb-based imaging methods.

[0043] The cQFD and cQYN mediotopes bind to a chimeric framework binding region, such as that found in cetuximab. The term “mediotop” (a term combining medius + topos, Latin for middle and Greek for place), as used herein refers to an antibody binding peptide, such as the cQFD and cQYN peptides or variants thereof, that bind between the Fab light and heavy chains of an antibody. Other molecules may also bind between the Fab light and heavy chains of an antibody with a framework binding functionality similar to that of a mediotop. Such molecules may include, but are not limited to, small molecules, aptamers, nucleic acid molecules, peptibodies and any other substance able to bind the same binding interface as a mediotop. The framework binding interface described herein is distinct and distant from the CDR, which binds to the antigen epitope (Figure 4). Additionally, biochemical and cell-based assays have demonstrated that the cQFD and cQYN cyclic peptides can bind to murine chimeric cetuximab that is pre-bound to EGFR (Figure 4).

[0044] Cetuximab is a unique murine-human chimera and several interactions between the cQFD and cQYN mediotopes and the cetuximab Fab are specific to this murine-human chimeric IgG framework residues as determined by an atomic model

described herein. Further, the mediotopes fail to bind to human IgG framework (e.g., trastuzumab), indicating this interaction is specific for this murine-chimeric antibody, but not specific for other murine chimeras such as rituximab (Figure 29). This supports that the Cetuximab framework is highly specific. Superposition of multiple human and murine Fabs onto the cetuximab-cyclic peptide structure indicated that the key interactions between this peptide and murine-human chimeric Fab are absent in both human-only and murine-only IgG structures. Point mutations of key residues within the cyclic peptide reduced its binding affinity for the Fab, further confirming the high specificity and structural model (data not shown). Thus, the interaction appears to be specific to the central cavity of this specific murine-human chimera Fab and the selected mediotope. In contrast, PpL and SpA are not murine-specific. PpL binds to ~66% of murine and ~50% of human IgG Kappa light chains and SpA binds 12% of murine and 50% of human variable heavy chains (Graille et al., 2002).

[0045] Cetuximab is currently used for the treatment of EGFR-expressing metastatic colorectal cancer and head and neck cancers. Cetuximab recognizes a conformational epitope (e.g., folded EGFR domain III). A comparison of antibodies that recognize small molecule antigens, peptides and protein epitopes show that the interfaces tend to possess different features (Collis et al., 2003). Small molecules tend to be cradled in a small pocket; peptides fit into a linear groove; and proteins contact a large surface. Thus, the peptides that successfully recreate the protein-antibody interaction, as with cetuximab-EGFR, are generally those with the protein antigen having an unfolded domain with a large contacting surface area. For example, trastuzumab recognizes a protein antigen (conformational epitope), but makes contact primarily with a number of geometrically constrained loops (Du et al., 2007; Cho et al., 2003). This type of biological recognition is more compatible with peptide mimics.

[0046] The cQFD and cQYN mediotopes were originally identified as candidate peptides for binding the CDR region of cetuximab. Phage display libraries have been used to identify peptides that bind the complementarity determining regions (CDRs) of established therapeutic antibodies with the presumption that the peptides would mimic the antigenic epitope to artificially stimulate an immune response to that antigen

(Riemer et al., 2004; Riemer et al., 2005; Li et al., 2006). These peptide mimics, also referred to as mimotopes or anti-idiotypes, can be chemically synthesized, eliminating potential biological contamination and reducing cost. Vaccines based on this design, however, have resulted in partial responses, and are often followed by later recurrence of disease without loss of the immune response to tumor antigen (Sharav et al., 2007).

[0047] Because the cQFD and cQYN mediotopes bind the framework and not the CDR region, said mediotopes are not likely candidates for specific cetuximab-like antibody immunogens for use as a vaccine. Although Reimer et al. observed that sera collected from mice immunized with KLH-coupled mediotope produced antibodies that bound to A431 cells and block their proliferation (Riemer et al., 2005), the studies described herein show that multiple copies of the mediotopes coupled to adjuvant render the vaccine into a promiscuous crosslinker of murine IgGs (akin to a superantigen). In support of this embodiment, similar germ line or B-cell derived framework sequences were observed in the mouse light chain and both mouse and human heavy chains using BLAST. Thus, when tethered to an adjuvant, the mediotope peptides may function to activate the B-cell population with conserved framework regions and produce a generalized immune response as opposed to a specific immune response required for a vaccine. The reported ELISA competition assays do not indicate the specific binding site of EGFR nor the degree to which the polyclonal serum was specific for the cetuximab epitope on EGFR (e.g., the report did not indicate whether or not the serum-derived IgG could be blocked by unlabeled cetuximab). The diffraction and biochemical studies do not support using the cQYN or cQFD mediotopes as a vaccine in humans.

[0048] Additional mediotopes that may be used according to the embodiments described herein include any small peptide that binds to an antibody framework binding interface (i.e., between the Fab light and heavy chains) of cetuximab or any other therapeutic antibody. For example, in addition to the cyclic peptides cQFD and cQYN, some embodiments include one or more variants of cQFD and cQYN.

[0049] Structural and biophysical methods or modifications may be used in tandem with chemical synthesis to develop mediotope variants that have increased or

altered affinity (e.g., due to changes in pH, as discussed in the examples below) to cetuximab as compared to the unmodified meditopes, cQFD and cQYN. Furthermore, conjugation of an unmodified meditope or a variant meditope onto a multivalent tethering entity or scaffold may significantly improve the overall affinity and targeting of the multivalent meditope to a meditope-enabled mAb bound to tumor-associated antigen. Modifications to cQFD and cQYN meditopes that may be used to generate meditope variants with high affinity may include any method for modifying peptides known in the art.. Each amino acid position may be altered with an unnatural amino acid or chemically conjugated with a fragment.

[0050] In certain embodiments, one or more meditopes, meditope variants, multivalent meditope tethering agents or multivalent meditope variant tethering agents may be conjugated to one or more imaging agents, therapeutically effective agents or compounds in therapeutically effective amounts or both, such that the binding of the meditopes or variants thereof to one or more meditope-enabled antibody with the therapeutically effective compound may treat, prevent, diagnose or monitor a disease or condition. Such conjugation of a high affinity and/or multivalent meditope coupled to meditope-enabled mAbs provides a highly versatile platform technology that will significantly improve mAb based therapeutics and imaging methods to treat and detect disease (see Figure 8).

[0051] In some embodiments, the murine specific cQFD and cQYN meditopes or derivatives thereof may be used to tether two or more antibodies or functional fragments thereof. When used in a tethering method described below, the meditopes may be part of a multivalent tethering agent (also referred to as a “meditope scaffold” or “scaffold”) to enhance cancer or tumor therapy and imaging.

[0052] A multivalent tethering agent may include two or more cQFD and cQYN meditopes or any of the other novel meditope variants that are coupled through a long linker and biotin to streptavidin to create a multivalent meditope tethering entity. In one embodiment, the multivalent meditope tethering entity is a tetravalent meditope tethering agent. The tetrameric tethering entity is shown by surface plasmon resonance

to have enhanced binding to an IgG as compared to the monovalent peptide, which is consistent with a multivalent interaction. The tetravalent meditope also enhances the binding affinity of cetuximab in EGFR positive cells by FACS analysis.

[0053] Multivalent meditope scaffolds can be used to scaffold or “daisy-chain” meditope-enabled mAbs bound to tumor associated antigen to enhance ligand antagonism, alter receptor endocytosis, and/or improve an immune response through ADCC/CDC (Figure 8). Monoclonal antibodies (mAbs) encode two Fab domains coupled to a dimeric Fc. As such, these bivalent IgGs preferentially bind to cells that express antigen at high densities. It has been demonstrated that a second mAb that binds to a unique epitope on the same antigen can cluster the receptors and more effectively kill tumor cells. This clustering can be recapitulated through the use of multivalent meditoypes. The use of a multivalent meditope avoids necessity of identifying a second mAb and the associated and significant cost of its development thereof.

[0054] The specificity and binding of the meditoypes, meditope variants, multivalent meditope tethering agents and multivalent meditope variant tethering agents may be used to deliver therapeutic agents, diagnostic agents (e.g., imaging agents), or a combination of thereof for treatment, diagnosis or imaging a disease or condition when administered in combination with one or more meditope-enabled monoclonal antibodies. Thus, multivalent meditoypes can be used for pre-targeted therapy and imaging as described further below by administering a meditope-enabled monoclonal antibody before administering the meditoypes, meditope variants, multivalent meditope tethering agents or multivalent meditope variant tethering agents. Further, the use of multivalent meditoypes can enhance selectivity and improve tumor detection as has been demonstrated for engineered scFvs or chemically conjugated mAbs, but avoids potential immunogenicity inherent in these non-human constructs.

[0055] In some embodiments, a meditope administered in combination with a meditope enabled antibody, an antibody-meditope complex, a multivalent tethering agent administered in combination with a meditope enabled antibody, or a combination

thereof may be conjugated to one or more imaging agent. In one aspect, an imaging agent may include, but is not limited to a fluorescent, luminescent, or magnetic protein, peptide or derivatives thereof (e.g., genetically engineered variants). Fluorescent proteins that may be expressed by the mRNA component include green fluorescent protein (GFP), enhanced GFP (EGFP), red, blue, yellow, cyan, and sapphire fluorescent proteins, and reef coral fluorescent protein. Luminescent proteins that may be expressed by the mRNA component include luciferase, aequorin and derivatives thereof. Numerous fluorescent and luminescent dyes and proteins are known in the art (see, e.g., U.S. Patent Application Publication 2004/0067503; Valeur, B., "Molecular Fluorescence: Principles and Applications," John Wiley and Sons, 2002; Handbook of Fluorescent Probes and Research Products, Molecular Probes, 9.sup.th edition, 2002; and The Handbook--A Guide to Fluorescent Probes and Labeling Technologies, Invitrogen, 10th edition, available at the Invitrogen web site; both of which are hereby incorporated by reference as if fully set forth herein.)

[0056] In other aspects, the meditope administered in combination with a meditope enabled antibody, the antibody-meditope complex, the multivalent tethering agent administered in combination with a meditope enabled antibody, or a combination thereof may be further conjugated to or otherwise associated with a non-protein imaging agent or a delivery vehicle such as a nanoparticle, radioactive substances (e.g., radioisotopes, radionuclides, radiolabels or radiotracers), dyes, contrast agents, fluorescent compounds or molecules, bioluminescent compounds or molecules, enzymes and enhancing agents (e.g., paramagnetic ions). In addition, it should be noted that some nanoparticles, for example quantum dots and metal nanoparticles (described below) may also be suitable for use as an imaging agent or a therapeutic agent (e.g., using hyperthermal and photodynamic therapies as well as imaging agents through fluorescence and or MRI contrast).

[0057] Fluorescent and luminescent substances that may be used as an additional imaging agent in accordance with the embodiments of the disclosure include, but are not limited to, a variety of organic or inorganic small molecules commonly

referred to as "dyes," "labels," or "indicators." Examples include fluorescein, rhodamine, acridine dyes, Alexa dyes, and cyanine dyes.

[0058] Enzymes that may be used as an additional imaging agent in accordance with the embodiments of the disclosure include, but are not limited to, horseradish peroxidase, alkaline phosphatase, acid phosphatase, glucose oxidase, β -galactosidase, β -glucuronidase or β -lactamase. Such enzymes may be used in combination with a chromogen, a fluorogenic compound or a luminogenic compound to generate a detectable signal.

[0059] Radioactive substances that may be used as an additional imaging agent in accordance with the embodiments of the disclosure include, but are not limited to, ^{18}F , ^{32}P , ^{33}P , ^{45}Ti , ^{47}Sc , ^{52}Fe , ^{59}Fe , ^{62}Cu , ^{64}Cu , ^{67}Cu , ^{67}Ga , ^{68}Ga , ^{77}As , ^{86}Y , ^{90}Y , ^{89}Sr , ^{89}Zr , ^{94}Tc , ^{94}Tc , $^{99\text{m}}\text{Tc}$, ^{99}Mo , ^{105}Pd , ^{105}Rh , ^{111}Ag , ^{111}In , ^{123}I , ^{124}I , ^{125}I , ^{131}I , ^{142}Pr , ^{143}Pr , ^{149}Pm , ^{153}Sm , $^{154-158}\text{Gd}$, ^{161}Tb , ^{166}Dy , ^{166}Ho , ^{169}Er , ^{175}Lu , ^{177}Lu , ^{186}Re , ^{188}Re , ^{189}Re , ^{194}Ir , ^{198}Au , ^{199}Au , ^{211}At , ^{211}Pb , ^{212}Bi , ^{212}Pb , ^{213}Bi , ^{223}Ra and ^{225}Ac . Paramagnetic ions that may be used as an additional imaging agent in accordance with the embodiments of the disclosure include, but are not limited to, ions of transition and lanthanide metals (e.g. metals having atomic numbers of 21-29, 42, 43, 44, or 57-71). These metals include ions of Cr, V, Mn, Fe, Co, Ni, Cu, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu.

[0060] When the imaging agent is a radioactive metal or paramagnetic ion, the agent may be reacted with another long-tailed reagent having a long tail with one or more chelating groups attached to the long tail for binding these ions. The long tail may be a polymer such as a polylysine, polysaccharide, or other derivatized or derivatizable chain having pendant groups to which may be added for binding to the metals or ions. Examples of chelating groups that may be used according to the disclosure include, but are not limited to, ethylenediaminetetraacetic acid (EDTA), diethylenetriaminepentaacetic acid (DTPA), DOTA, NOTA, NETA, porphyrins, polyamines, crown ethers, bis-thiosemicarbazones, polyoximes, and like groups. The chelate is normally linked to the PSMA antibody or functional antibody fragment by a

group which enables the formation of a bond to the molecule with minimal loss of immunoreactivity and minimal aggregation and/or internal cross-linking. The same chelates, when complexed with non-radioactive metals, such as manganese, iron and gadolinium are useful for MRI, when used along with the antibodies and carriers described herein. Macrocyclic chelates such as NOTA, DOTA, and TETA are of use with a variety of metals and radiometals including, but not limited to, radionuclides of gallium, yttrium and copper, respectively. Other ring-type chelates such as macrocyclic polyethers, which are of interest for stably binding nuclides, such as ^{223}Ra for RAIT may be used. In certain embodiments, chelating moieties may be used to attach a PET imaging agent, such as an Al- ^{18}F complex, to a targeting molecule for use in PET analysis.

[0061] In some embodiments, a mediotope, an antibody-meditope complex, a multivalent tethering agent, or a combination thereof may be conjugated to one or more therapeutic agents.

[0062] A "therapeutic agent" as used herein is an atom, molecule, or compound that is useful in the treatment of cancer or other conditions described herein. Examples of therapeutic agents that may be conjugated to an antibody-meditope complex, a multivalent tethering agent, a multivalent tethering agent or a combination thereof include, but are not limited to, drugs, chemotherapeutic agents, therapeutic antibodies and antibody fragments, toxins, radioisotopes, enzymes (e.g., enzymes to cleave prodrugs to a cytotoxic agent at the site of the tumor), nucleases, hormones, immunomodulators, antisense oligonucleotides, RNAi molecules (e.g., siRNA or shRNA), chelators, boron compounds, photoactive agents and dyes. The therapeutic agent may also include a metal, metal alloy, intermetallic or core-shell nanoparticle bound to a chelator that acts as a radiosensitizer to render the targeted cells more sensitive to radiation therapy as compared to healthy cells. Further, the therapeutic agent may include paramagnetic nanoparticles for MRI contrast agents (e.g., magnetite or Fe_3O_4) and may be used with other types of therapies (e.g., photodynamic and hyperthermal therapies. And imaging (e.g., fluorescent imaging (Au and CdSe)).

[0063] Chemotherapeutic agents are often cytotoxic or cytostatic in nature and may include alkylating agents, antimetabolites, anti-tumor antibiotics, topoisomerase inhibitors, mitotic inhibitors hormone therapy, targeted therapeutics and immunotherapeutics. In some embodiments the chemotherapeutic agents that may be used as therapeutic agents in accordance with the embodiments of the disclosure include, but are not limited to, 13-cis-Retinoic Acid, 2-Chlorodeoxyadenosine, 5-Azacidine, 5-Fluorouracil, 6-Mercaptopurine, 6-Thioguanine, actinomycin-D, adriamycin, aldesleukin, alemtuzumab, alitretinoin, all-transretinoic acid, alpha interferon, altretamine, amethopterin, amifostine, anagrelide, anastrozole, arabinosylcytosine, arsenic trioxide, amsacrine, aminocamptothecin, aminoglutethimide, asparaginase, azacytidine, bacillus calmette-guerin (BCG), bendamustine, bevacizumab, bexarotene, bicalutamide, bortezomib, bleomycin, busulfan, calcium leucovorin, ciprofloxacin, capecitabine, canertinib, carboplatin, carmustine, cetuximab, chlorambucil, cisplatin, cladribine, cortisone, cyclophosphamide, cytarabine, darbepoetin alfa, dasatinib, daunomycin, decitabine, denileukin diftitox, dexamethasone, dexasone, dexrazoxane, dactinomycin, daunorubicin, decarbazine, docetaxel, doxorubicin, doxifluridine, eniluracil, epirubicin, epoetin alfa, erlotinib, everolimus, exemestane, estramustine, etoposide, filgrastim, fluoxymesterone, fulvestrant, flavopiridol, floxuridine, fludarabine, fluorouracil, flutamide, gefitinib, gemcitabine, gemtuzumab ozogamicin, goserelin, granulocyte - colony stimulating factor, granulocyte macrophage-colony stimulating factor, hexamethylmelamine, hydrocortisone hydroxyurea, ibritumomab, interferon alpha, interleukin - 2, interleukin-11, isotretinoin, ixabepilone, idarubicin, imatinib mesylate, ifosfamide, irinotecan, lapatinib, lenalidomide, letrozole, leucovorin, leuprolide, liposomal Ara-C, lomustine, mechlorethamine, megestrol, melphalan, mercaptopurine, mesna, methotrexate, methylprednisolone, mitomycin C, mitotane, mitoxantrone, nelarabine, nilutamide, octreotide, oprelvekin, oxaliplatin, paclitaxel, pamidronate, pemetrexed, panitumumab, PEG Interferon, pegaspargase, pegfilgrastim, PEG-L-asparaginase, pentostatin, plicamycin, prednisolone, prednisone, procarbazine, raloxifene, rituximab, romiplostim, raltrexed, sapacitabine, sargramostim, satraplatin, sorafenib, sunitinib, semustine, streptozocin, tamoxifen, tegafur, tegafur-uracil, temsirolimus, temozolamide, teniposide, thalidomide,

thioguanine, thiotepa, topotecan, toremifene, tositumomab, trastuzumab, tretinoin, trinitrexate, alrubicin, vincristine, vinblastine, vindestine, vinorelbine, vorinostat, or zoledronic acid.

[0064] Therapeutic antibodies and functional fragments thereof, that may be used as therapeutic agents in accordance with the embodiments of the disclosure include, but are not limited to, alemtuzumab, bevacizumab, cetuximab, edrecolomab, gemtuzumab, ibritumomab tiuxetan, panitumumab, rituximab, tositumomab, and trastuzumab and other antibodies associated with specific diseases listed herein.

[0065] Toxins that may be used as therapeutic agents in accordance with the embodiments of the disclosure include, but are not limited to, ricin, abrin, ribonuclease (RNase), DNase I, Staphylococcal enterotoxin-A, pokeweed antiviral protein, gelonin, diphtheria toxin, Pseudomonas exotoxin, and Pseudomonas endotoxin.

[0066] Radioisotopes that may be used as therapeutic agents in accordance with the embodiments of the disclosure include, but are not limited to, ^{32}P , ^{89}Sr , ^{90}Y , $^{99\text{m}}\text{Tc}$, ^{99}Mo , ^{131}I , ^{153}Sm , ^{177}Lu , ^{186}Re , ^{213}Bi , ^{223}Ra and ^{225}Ac .

[0067] The meditope-mAb technology allows for a system that may be used to generate an antibody-meditope complex that may be further conjugated to one or more meditope-enabled antibody, a therapeutic agent, an imaging agent or a combination thereof. Thus, a set of meditope or high affinity meditope variants, each conjugated to a unique cytotoxic or imaging agent, would allow for the co-administration of a desired meditope conjugate and meditope-enabled mAb for treatment. The meditope conjugates are an improvement over the current antibody-drug conjugates, which have drawbacks such as a reduced specificity due to chemical modification or release of payload.

[0068] This platform technology has a broad impact on the mAb delivery field and provides useful methods for the treatment and diagnosis of EGFR-positive cancers including colorectal and squamous cell carcinoma head and neck cancers where cetuximab is indicated. Additionally, grafting the framework binding interface onto other

therapeutic antibody, allows for the platform technology to be utilized in methods for the treatment and diagnosis of several other cancers, diseases and other conditions as described above.

[0069] A method for enhancing the binding affinity of a therapeutic antibody or functional fragment thereof is provided herein. Such a method may include administering to a subject a therapeutically effective amount of a pharmaceutical composition via any suitable route of administration. The pharmaceutical composition may include a meditope or meditope variant in combination with a meditope enabled antibody, a multivalent meditope or meditope variant tethering entity in combination with a meditope enabled antibody, a meditope-enabled therapeutic antibody or functional fragment thereof, a pharmaceutically acceptable carrier, and any combination thereof. The enhanced binding affinity of the multivalent meditope may be attributed to the multivalent cross-linking of IgGs bound to the cell surface. Crosslinking IgGs (through parental murine 425 antibody or using anti-IgG IgM) significantly affects signaling, receptor endocytosis and recycling, and cell death. Thus, multivalent peptides may act synergistically with a therapeutic monoclonal antibody to enhance its therapeutic efficacy.

[0070] In some embodiments, the meditope, alone or as part of the tethering entity, may contain a cysteine or other suitable alkylating agent that binds to a Fab cysteine at the binding site, thus creating a cysteine-cysteine interaction. Alternatively, the meditope may bind to the Fab at an unnatural amino acid (e.g., p-acetylphenylalanine). The Cys meditope is conjugated to any substance and directs the conjugate to the IgG.

[0071] An antibody-meditope complex may also be used in a method for directing treatment to a particular type of cell or population of cells in a disease or condition that can be targeted by a therapeutic antibody. Such a method of treatment may include administering a therapeutically effective amount of a pharmaceutical composition to a subject having the disease or condition via any suitable route of administration. The pharmaceutical composition may include a meditope or meditope variant in combination

with a meditope enabled antibody, a multivalent meditope or meditope variant tethering entity in combination with a meditope enabled antibody, a meditope-enabled therapeutic antibody or functional fragment thereof.

[0072] In other embodiments, a method for imaging tumors or other tissues is provided. In such methods, an unmodified therapeutic antibody may be administered to target a tumor or other tissue that overexpress the corresponding antigen.

Subsequently, a multivalent meditope tethering entity that is labeled with an imaging agent is administered via any suitable route of administration and will bind the therapeutic antibodies that are bound to the target tumor or tissue. See Figure 8.

Examples of imaging agents include but are not limited to radiolabels (e.g., ^3H , ^{14}C , ^{35}S , ^{90}Y , $^{99\text{m}}\text{Tc}$, ^{125}I , ^{131}I , ^{177}Lu , ^{166}Ho , and ^{153}Sm), metal or magnetic labels (e.g., gold, iron, gadolinium), biotin, chelating agents (e.g., 1,4,7,10-tetraazacyclododecane-N,N', N'',N'''-tetraacetic acid ("DOTA")) or any agent described above. In one embodiment, the imaging agent used with the method described herein is DOTA.

[0073] There are several advantages over known methods to the imaging or treatment methods described above. First, the bivalent character of a therapeutic monoclonal antibody IgG enhances the selectivity to the tumor. As discussed further below, this enhanced selectivity is lost with the use of scFvs and other minibodies and cannot be made up through enhanced affinity. Second, the mass of the labeled multivalent meditope tethering entity will be below the renal threshold for filtering (less than 60 kD, may be as low as ~10 kD), allowing it to be easily filtered out of the body. In contrast, direct labeling of a therapeutic antibody IgG with an imaging agent or other therapeutic agent is typically avoided because it will circulate for extended periods in the body. Thus, imaging of tumors or other diseased organs is often accomplished using less selective scFvs.

[0074] In further embodiments, the cQFD and cQYN meditoes or variants thereof may be used to join two or more therapeutic molecules to form a pharmaceutical compound that may be administered, as part of a pharmaceutical composition, in a therapeutically effective amount to a subject for treatment of cancer, autoimmune

disease or other conditions. The two or more therapeutic molecules may include, but are not limited to, functional antibody fragments (e.g., F(ab')₂ or Fab fragments), peptides or other small molecules that can target tumor or disease-specific receptors such as those described above. The therapeutic molecules may be two or more of the same therapeutic molecule or alternatively, may be two or more different molecules that target the same tumor or diseased tissue.

[0075] In some embodiments, the pharmaceutical compound may include the use of proprietary antibody, or portion thereof, such as a CovX-BodyTM. For example, the mediotopes may be used as a linker to join two or more therapeutic molecules to a binding interface or binding site of a specially designed CovX antibody. A small molecule, peptide or scFv that is associated with a mediotope that acts as a CovX-specific linker is recognized by its framework binding interface, which is the active binding site of the CovX antibody. When these components are combined, the resulting bivalent CovX-BodyTM possesses the biologic actions of the small molecule, peptide or scFv while also retaining an extended half-life of the antibody.

[0076] In addition to the benefits described above with respect to therapeutic monoclonal antibodies, mediotopes used as linkers to tether or bind to therapeutic molecules can be synthesized and are more cost effective to produce than monoclonal antibodies. For example, although a number of preclinical/clinical trials are investigating the co-administration of two monoclonal antibodies, the costs of producing and marketing such a therapeutic is likely to be prohibitive.

[0077] The scFv (single chain Fab variable fragment) format of the cetuximab Fab binds to the EGFR domain III with a substantially lower affinity than the Fab itself, which is similar to other scFvs of clinical interest. This is attributed, at least in part, to absence of the Fab constant domain that directly affects the orientation, conformational fluctuations of the Fv domains, and possibly, to poor linker design.

[0078] Therefore, in some embodiments, a method for improving the stability and affinity of the scFvs is provided. The method comprises incorporating the peptide

meditope in the scFv linker, to stabilize the scFv. This will help to enforce the proper orientation of the variable domains and thus enhance the affinity (Fig. 9).

[0079] The embodiments described above can be applied to human or humanized antibodies (e.g., trastuzumab) by replacing one or more of the human framework residues (i.e. generating one or more point mutations) with their corresponding murine residues. The human residues that are replaced by corresponding murine residues are found within the central Fab cavity of the human framework and are therefore not exposed to the immune system (e.g., they should not be antigenic). In addition, antigenicity prediction algorithms may be further used to indicate that the human sequence with the point mutations should not be antigenic.

[0080] In some embodiments, the one or more human framework residues that are replaced by the corresponding murine residues may be selected from light chain framework residues 10, 39-43, 83, 85, 100 and 104 (Kabat numbers) and/or heavy chain framework residue numbers 40, 89 and 111 (Kabat numbers) (see Figure 2). In one embodiment, the one or more human framework residues that are replaced by the corresponding murine residues are light chain framework residues including, but not limited to, 40, 41, 83 and 85. Specifically, in one embodiment, light chain framework Pro40 is replaced with Thr (P40T) or Ser (P40S), light chain framework Gly41 is replaced with Asn (G41N), light chain framework residue Phe83 is replaced with Ile (F83I) or Val (F83V) and light chain framework residue Thr85 is replaced with Asp (T85D) or Asn (T85N). This mediotope-site grafting (or "murinization" or "mousification") of this Fab cavity within human monoclonal antibodies can be used to create a unique handle for mediotope binding and used with the technology previously disclosed. In addition, additional point mutations may be engineered by generating a pharmacophore binding model to further enhance the affinity of the mediotope.

[0081] The embodiments described herein identify and characterize a novel interface within the Fab framework, and demonstrates that it does not perturb the binding of Fab to the antigen or act as an allosteric antagonist of EGFR binding. In

addition, the two peptide mediotopes do not bind to the cetuximab CDRs, and thus do not mimic the antigen (EGFR).

[0082] A "therapeutically effective amount," "therapeutically effective concentration" or "therapeutically effective dose" is the amount of a compound that produces a desired therapeutic effect in a subject, such as preventing or treating a target condition, alleviating symptoms associated with the condition, producing a desired physiological effect, or allowing imaging or diagnosis of a condition that leads to treatment of the disease or condition. The precise therapeutically effective amount is the amount of the composition that will yield the most effective results in terms of efficacy of treatment in a given subject. This amount will vary depending upon a variety of factors, including but not limited to the characteristics of the therapeutic compound (including activity, pharmacokinetics, pharmacodynamics, and bioavailability), the physiological condition of the subject (including age, sex, disease type and stage, general physical condition, responsiveness to a given dosage, and type of medication), the nature of the pharmaceutically acceptable carrier or carriers in the formulation, and the route of administration. One skilled in the clinical and pharmacological arts will be able to determine a therapeutically effective amount through routine experimentation, namely by monitoring a subject's response to administration of a compound and adjusting the dosage accordingly. For additional guidance, see Remington: The Science and Practice of Pharmacy 21st Edition, Univ. of Sciences in Philadelphia (USIP), Lippincott Williams & Wilkins, Philadelphia, PA, 2005.

[0083] A "pharmaceutically acceptable carrier" refers to a pharmaceutically acceptable material, composition, or vehicle that is involved in carrying or transporting a compound of interest from one tissue, organ, or portion of the body to another tissue, organ, or portion of the body. For example, the carrier may be a liquid or solid filler, diluent, excipient, solvent, or encapsulating material, or some combination thereof. Each component of the carrier must be "pharmaceutically acceptable" in that it must be compatible with the other ingredients of the formulation. It also must be suitable for contact with any tissue, organ, or portion of the body that it may encounter, meaning

that it must not carry a risk of toxicity, irritation, allergic response, immunogenicity, or any other complication that excessively outweighs its therapeutic benefits.

[0084] A "route of administration" may refer to any administration pathway known in the art, including but not limited to aerosol, enteral, nasal, ophthalmic, oral, parenteral, rectal, transdermal, or vaginal. "Transdermal" administration may be accomplished using a topical cream or ointment or by means of a transdermal patch. "Parenteral" refers to a route of administration that is generally associated with injection, including infraorbital, infusion, intraarterial, intracapsular, intracardiac, intradermal, intramuscular, intraperitoneal, intrapulmonary, intraspinal, intrasternal, intrathecal, intrauterine, intravenous, subarachnoid, subcapsular, subcutaneous, transmucosal, or transtracheal.

[0085] "In combination" or "in combination with," as used herein, means in the course of treating the same disease or condition in the a subject using two or more agents, drugs, treatment regimens, treatment modalities or a combination thereof (e.g., an antibody in combination with a meditope or a multivalent tethering agent), in any order. This includes simultaneous administration (or "coadministration"), administration of a first agent prior to or after administration of a second agent, as well as in a temporally spaced order of up to several days apart. Such combination treatment may also include more than a single administration of any one or more of the agents, drugs, treatment regimens or treatment modalities. Further, the administration of the two or more agents, drugs, treatment regimens, treatment modalities or a combination thereof may be by the same or different routes of administration.

[0086] A "therapeutic antibody" may refer to any antibody or functional fragment thereof that is used to treat cancer, autoimmune diseases, transplant rejection, cardiovascular disease or other diseases or conditions such as those described herein. Examples of therapeutic antibodies that may be used according to the embodiments described herein include, but are not limited to murine antibodies, murinized or humanized chimera antibodies or human antibodies including, but not limited to, Erbitux (cetuximab), ReoPro (abciximab), Simulect (basiliximab), Remicade (infliximab);

Orthoclone OKT3 (muromonab-CD3); Rituxan (rituximab), Bexxar (tositumomab) Humira (adalimumab), Campath (alemtuzumab), Simulect (basiliximab), Avastin (bevacizumab), Cimzia (certolizumab pegol), Zenapax (daclizumab), Soliris (eculizumab), Raptiva (efalizumab), Mylotarg (gemtuzumab), Zevalin (ibritumomab tiuxetan), Tysabri (natalizumab), Xolair (omalizumab), Synagis (palivizumab), Vectibix (panitumumab), Lucentis (ranibizumab), and Herceptin (trastuzumab).

[0087] "Treating" or "treatment" of a condition may refer to preventing the condition, slowing the onset or rate of development of the condition, reducing the risk of developing the condition, preventing or delaying the development of symptoms associated with the condition, reducing or ending symptoms associated with the condition, generating a complete or partial regression of the condition, or some combination thereof.

[0088] In one embodiment, a method of screening for novel mediotopes or small molecules with framework binding functionality similar to that of a mediotope is provided herein. Such a method may include, but is not limited to, steps of contacting a library of putative mediotopes or small molecules with a mediotope-enabled antibody; determining whether the putative mediotopes or small molecules bind the mediotope-enabled antibody at a framework binding interface; identifying one or more candidate mediotopes or a small molecules with framework binding functionality similar to that of a mediotope; determining binding affinity of the one or more candidates; and identifying one or more of the candidates as a mediotope or small molecule with framework binding functionality similar to that of a mediotope when the binding dissociation constant is at least 0.70 μM . Additionally, methods of screening for novel framework binding interfaces are also provided, and are described further in the examples below

[0089] Having described the invention with reference to the embodiments and illustrative examples, those in the art may appreciate modifications to the invention as described and illustrated that do not depart from the spirit and scope of the invention as disclosed in the specification. The examples are set forth to aid in understanding the invention but are not intended to, and should not be construed to limit its scope in any way. The examples do not include detailed descriptions of conventional methods.

Such methods are well known to those of ordinary skill in the art and are described in numerous publications. Further, all references cited above and in the examples below are hereby incorporated by reference in their entirety, as if fully set forth herein.

EXAMPLE 1: DETERMINATION OF CRYSTAL STRUCTURES

Materials and Methods

[0090] *Reagents.* The antigen binding fragment [F(ab)'] (or "Fab") of cetuximab was obtained by digestion of the IgG with immobilized papain (Pierce), followed by reverse purification with protein A and size exclusion chromatography (SEC) on a Superdex 75 column (GE Healthcare). The single chain binding fragment (scFvC225) of cetuximab was synthesized with a twenty amino acid linker between the light chain and heavy chain. ScFvC225 and soluble epidermal growth factor receptor domain III (sEGFRdIII) were expressed in Sf9 cells and purified as previously described (Donaldson et al., 2009).

[0091] Meditopes CQFDLSTRRLKC (cQFD; SEQ ID NO:1) and CQYNLSSRALKC (cQYN; SEQ ID NO:2), isolated from a phage display as previously described (Riemer et al. 2005), were synthesized, oxidized and purified at the City of Hope Synthetic and Polymer Chemistry Core Facility.

[0092] *Crystallization and Diffraction Data.* The Fab fragment of cetuximab (5 mg/mL) was mixed with individual meditopes at a 1:10 molar ratio and screened using the Qiagen JCSG Core Suites (IIV) at 20 °C. Co-crystals that diffracted beyond 2.2 Å were grown in 100 mM sodium phosphate/citrate, pH 4.5, 2.5 M sodium/potassium phosphate and 1.6 % w/v mesoerythritol. The crystals were wicked through 14% w/v mesoerythritol and flash frozen in liquid nitrogen. Crystallization trials and initial screening studies were carried out in the X-ray facility at the City of Hope. Diffraction data were collected at the Stanford Synchrotron Radiation Lab, beam lines 9.1 and 11.1. The initial phases were determined by molecular replacement using the program Phaser (McCoy et al., 2007) with the unliganded structure of cetuximab (pdb:1YY8 – chains A and B) (Li et al., 2005). Two Fabs were placed in the asymmetric unit with a

Matthews Coefficient of 3.26 and solvent content of 62.4%. The Z scores (standard deviation of the solution over the mean) were 27 and 25 for the rotational search and 38 and 71 for the translational search. A third Fab fragment could not be placed (three Fabs in the asymmetric unit cell produces a reasonable Matthews coefficient of 2.18 at 43% solvent). The mediotopes were built into the density manually through multiple iterations using Coot (Emsley et al., 2004) and Phenix (Adams et al., 2002).

Crystallization and structure determination

[0093] To identify the binding site of the mediotopes on cetuximab, the Fab fragment was generated and purified, mixed with the cQFD mediotope at a 1:10 ratio and commercial factorials were used to screen for crystal formation. Crystals formed after 1 to 3 days at 20 °C. Initial diffraction analysis of these crystals indicated that the unit cell was similar to the cetuximab Fab already deposited in the Protein Data Bank (1YY8.pdb) (Li et al., 2005), and the crystal packing (e.g., the CDRs were excluded) suggested the peptide was not present at the CDR loops. Nonetheless, the structure was solved by molecular replacement and the experimental maps were examined to identify unmodeled electron density consistent with the mediotope. The initial Fo-Fc map clearly indicated an area in the middle of the Fab fragment as a potential binding site (Fig 1). After an initial round of refinement using the Fab model only, a continuous stretch of unmodeled density consistent with the mediotope was observed. The mediotope was built into the density and the R and RFree dropped accordingly. Water molecules were added during refinement using Phenix (Adams et al., 2002). The diffraction data and refinement statistics are given in Table 3 below.

Experimental and Refinement Statistics for Co-Crystal Structures

	cQFD	cQYN
Data collection		
Space group	P2 ₁ 2 ₁ 2 ₁	P2 ₁ 2 ₁ 2 ₁
Cell dimensions		
a, b, c (Å)	64.29, 82.53, 211.7	64.16, 82.52, 211.9
α, β, γ (°)	90.00, 90.00, 90.00	90.00, 90.00, 90.00
Resolution (Å)	20 - 2.24 (2.3-2.24)	30 - 2.20 (2.26-2.20)
R_{merge}	0.078 (0.50)	0.067 (0.26)
$I / \sigma(I)$	17 (3.1)	25.5 (6.0)
Completeness (%)		
$I / \sigma > 0$	91.6 (74.4)	97.0 (92.8)
$I / \sigma > -3$	97.4 (83.3)	99.9 (100)
Redundancy	4.2 (3.2)	7.9 (8.2)
Refinement		
Resolution (Å)	19 - 2.24	20.6-2.20
No. reflections*	53791	58047
$R_{\text{work}} / R_{\text{free}}$	18.4/23.4	18.6/23.0
No. atoms		
Protein	6602	6529
Mimotope	200	188
Water	556	539
B-factors		
Protein		
Fab	31.4	31.2
Mimotope	49.7	62.6
Water	37.1	37.1
r.m.s.d.		
Bond lengths (Å)	0.003	0.007
Bond angles (°)	0.710	1.07
Ramachandran		
favoured / allowed / disallowed	96.7/0.2/0.1	98.0/2.0/0.0

*Values in parentheses are for highest-resolution shell with $I/\sigma(F) > 0$.

$F/\sigma(F) > 1.99$ for and > 1.36 for cQFD or cQYN co-crystals, respectively.

[0094] Based on these observations and as a point of comparison, crystals were produced of the cetuximab Fab bound to the second mediotope identified by phage display, cQYN. As before, clear unmodeled electron density was observed in the center of the Fab. Using the first structure, the differences in sequences were modeled accordingly and multiple rounds of refinement were carried out. Representative electron density maps of both mediotopes are shown in Fig. 1 B and C.

EXAMPLE 2: MEDITOPES ARE SPECIFIC TO A MURINE FRAMEWORK REGION OF CETUXIMAB FAB

Materials and Methods

[0095] In addition to those described in Example 1 above, the following materials and methods were used.

[0096] *Meditopes and point mutations.* As described above, CQFDLSTRRLKC (cQFD; SEQ ID NO:1) and CQYNLSSRALKC (cQYN; SEQ ID NO:2), were synthesized, oxidized and purified at the City of Hope Synthetic and Polymer Chemistry Core Facility. Alanine point mutations in the cQFD meditope were generated at residues 3 (Phe3 to Ala), 5 (Leu5 to Ala), 8 (Arg8 to Ala) and 10 (Leu10 to Ala) and were produced bacterially by encoding the peptides at the C-terminus of SMT3 (Mossessova et al., 2000). Before surface plasmon resonance (SPR) analysis, ubiquitin-like protease (Ulp1) was added to the samples to release the peptides.

[0097] *Characterization of the meditope-Fab interface.* Affinity analysis by SPR was performed as previously described (Donaldson et al., 2009; Li et al., 2005). Briefly, scFvC225 or FabC225 was immobilized on a CM5 chip using amine chemistry. Peptide or sEGFRdIII affinities were assessed by equilibrium methods at 20 °C and fit to the equation $RU = \{R_{max} * [L]\} / \{[L] * K_d\} + R_{offset}$. SEC was performed using a Superdex 200 10/30 column (GE Healthcare). The proteins were mixed, incubated at room temperature for 20 min and applied to the column at 4 °C.

[0098] The MDA-MB-468 cell line was used to test cetuximab binding in the presence of peptide meditope. Labeled cetuximab (AF488, Invitrogen) was added for 20 min with or without 60 µM cQFD peptide at 4 °C. Labeled MOPS-21 was used as an isotope control. Cell fluorescence was determined using a FACS Calibur instrument (BD Biosciences).

Analysis of meditope/Fab interface

[0099] The interface of the binding site between the mediotope and the Fab identified herein is formed by all four domains of the IgG (e.g., the variable and constant domains of the heavy and light chains). Using the PISA server, the buried surface area at the cQFD or cQYN mediotope-Fab interface was $904 (\pm 28) \text{ \AA}^2$ and $787 (\pm 42) \text{ \AA}^2$, respectively, and equally distributed between the light and heavy chains. Figures 2 and 4 show the residues and the loops from the Fab that contacts the mediotope.

[00100] Both mediotopes make multiple hydrogen bonds and hydrophobic contacts with the cetuximab Fab. Figure 2A shows the subtle differences between the residues of the central cavity binding interface of the cetuximab Fab (murine chimera IgG), the humanized monoclonal IgG used as an isotype control in the phage display experiments (ch14.18) and the humanized trastuzumab Fab. Superposition of the humanized trastuzumab Fab on the cetuximab Fab indicated that Arg9 of the cQFD mediotope binds to a unique cavity created by the mouse variable light chain. Specifically, Asp85, Ile83 and Thr40 of the mouse variable light chain are important with respect to binding to the Arg9 residue of the cQFD mediotope (Fig. 2B). Asp85 in the murine framework makes a salt bridge to the guanidinium group of Arg9 of the cQFD mediotope ($d_{NE \cdots OD1} = 2.8 \text{ \AA}$ & $d_{NH1/2 \cdots OD2} = 3.0 \text{ \AA}$). The carboxyl group of Asp85 also makes a hydrogen bond to the backbone amide of Leu10 of the cQFD mediotope ($d_{OD2 \cdots HN} = 2.7 \text{ \AA}$). The hydroxyl group of Thr40 from the light chain also makes a hydrogen bond to guanidinium group of the mediotope Arg9 ($d_{OG1 \cdots NH1} = 3.1 \text{ \AA}$). The phenyl ring in Phe83 and the pyrrolidine ring of Pro40 in the human Fab sterically occlude the side chain of Arg9.

[00101] Although the selection of the Arg9 side chain in the cQFD mediotope maps to the differences between the murine and human Fab sequences, it was also noted that the cQYN mediotope encodes an alanine at the same position as Arg9 in the cQFD mediotope, and thus could potentially bind to the human Fab. To discern why the cQYN mediotope was selected despite pretreating the phage library with the hu14.18 antibody, differences between the cQFD and cQYN mediotopes and their interaction with the cetuximab Fab were determined. Superposition of the C α atoms of the heavy and light Fab chains from the cQFD and cQYN structures show that the hydrophobic side chains

of residues Phe/Tyr3, Leu5 and Leu10 from each meditope are positioned nearly identically (Fig. 2B). However, the backbone traces of the cQFD and cQYN peptides deviate significantly. Specifically, the Arg8 side chain structure of the cQFD meditope is extended and makes a strong backbone hydrogen bond to the backbone carbonyl of Gln111 of the Fab heavy chain ($\text{dNH} \cdots \text{O}=\text{C} = 2.8 \text{ \AA}$). The hydroxyl group of Tyr3 in the cQYN peptide, however, sterically interferes with the Arg8 side chain (Fig. 2B) and blocks the interaction between Arg8 of the cQYN meditope and Asn111 of the heavy chain. Consistent with this observation, both Arg8 side chains in the cQYN complex are poorly defined in the electron density map and takes on at least two different rotamers. (There are two Fab-meditope complexes in the asymmetric unit.) Concomitant with this change, a shift in the backbone hydrogen bond pattern was observed. The amide carbonyl of Thr7 in the cQFD meditope makes a hydrogen bond to the amide Asn41 in the cetuximab Fab light chain ($\text{dNH} \cdots \text{OC} = 2.7 \text{ \AA}$). This hydrogen bond shifts to the carbonyl of the Arg8 backbone in the amide of backbone of Asn41 in the cQYN peptide ($\text{dC}=\text{O} \cdots \text{HN} = 3.0 \text{ \AA}$).

[00102] Collectively, the differences between the cQFD and cQYN (e.g., loss of a salt bridge between R8 and the heavy chain Fab) and sequence differences in the Fab light chain where Arg9 in cQFD binds (e.g., the loss of the hydrogen bond between Asp85 and the amide of Leu10 for either meditope) indicate that the meditoes selected to bind to the murine chimera have substantially weaker interactions with human Fab frameworks and were removed in the washes during the selection.

Meditopes do not induce large conformational changes in the Fab

[00103] Based on the location of the meditope-Fab interface, it was determined whether the meditoes perturbed the relative orientation of the IgG domains to the unligated and/or ligated structure. First, the light and heavy chains within the asymmetric unit cell of both meditope complexes were compared and then each chain was compared to the unligated and EGFR-ligated structures. The variable domains of the light chains bound to either meditope were essentially identical to the unliganded structure of cetuximab (r.m.s.d. average: cQFD, $0.231 \pm 0.014 \text{ \AA}$, cQYN, $0.18 \pm 0.01 \text{ \AA}$).

However, the variable domains of the heavy chain showed significantly higher divergence (r.m.s.d. average: cQFD, 0.85 ± 0.01 Å, cQYN, 0.88 ± 0.01 Å). It is noted that this divergence stems primarily from the position of framework loop 2 (residues 39-46), since deleting the residues in this loop and recalculating the r.m.s.d. produced a much lower value: cQFD, 0.18 ± 0.01 Å; cQYN, 0.31 ± 0.01 Å (Fig. 6). In addition, this loop is also displaced in the Fab C225-EGFR co-crystal structure, and its relative B-factor value suggests that it is flexible (Fig. 6). Finally, the presence of the mediotope does not result in significant changes to the CDR structure relative to the EGFR bound or unbound structure. Although the backbone of Tyr101 in the heavy chain CDR loop 3 of the EGFR liganded structure is flipped as compared to the Fab structure bound to either mediotope, this flip is also observed in the unliganded cetuximab Fab structure (Li et al., 2005).

Contribution of mediotope residues to interface

[00104] Based on the structure of the cQFD mediotope-Fab complex, as well as the sequence similarity of cQYN to cQFD, several point mutations in the cQFD mediotope were generated (Phe3→Ala, Leu5→Ala, Arg8→Ala and Leu10→Ala) to characterize the role of these residues to the overall binding affinity of the mediotope. To assess binding affinity, the Fab fragment was coupled to a CM5 chip using standard amine chemistry. Next, the affinity of the synthetic cQFD and cQYN mediotopes to the cetuximab Fab was measured. The cQFD mediotope bound to the Fab with an affinity of 950 ± 30 nM whereas the cQYN mediotope bound with an affinity of 3.5 ± 0.1 μM (n=3). The binding kinetics were also measured (Fig. 3). The association constants, modeled as a bimolecular interaction, were $4.2 (\pm 0.1) \times 10^4$ M⁻¹s⁻¹ and $1.8 (\pm 0.1) \times 10^4$ M⁻¹s⁻¹ for cQFD and cQYN, respectively. The dissociation constants were $2.5 (\pm 0.1) \times 10^{-2}$ s⁻¹ and $8.6 (\pm 0.1) \times 10^{-2}$ s⁻¹ for cQFD and cQYN, respectively. The K_D values based on these measurements, 430 (± 30) nM for cQFD and 3.5 (± 0.1) μM for cQYN, are in close agreement with the equilibrium measurements.

[00105] Next, the affinity of each mutated cQFD mediotope was measured. The point mutation and wildtype cQFD mediotopes were generated as C-terminal fusions to

SMT3 and cleaved with Ulp1 before the analysis. The biologically-produced, wildtype cQFD meditope bound with an affinity of 770 nM, similar to the synthetically-produced cQFD, whereas the mutations Phe3→Ala, Leu5→Ala and Arg8→Ala significantly reduced the affinity for the Fab (Table 4, below). In particular, the Arg8→Ala mutation resulted in a 140-fold loss in binding affinity.

Dissociation constants of cQFD mimotope mutants

Ligand	K_D (μ M)	$\Delta\Delta G$ (kcal/mol)
WT	0.77	-
F3A	34	2.3
L5A	57	2.6
R8A	141	3.1
L10A	2.2	0.63

[00106] Finally, the Fab of trastuzumab, a humanized therapeutic monoclonal antibody, was coupled to a CM5 chip to characterize the affinity of the cQFD and cQYN meditoes to a human framework. Equilibrium measurements revealed that the dissociation constants for either meditope exceed 150 μ M.

EXAMPLE 3: CETUXIMAB FAB BINDS MEDITOPES AND EGFR SIMULTANEOUSLY

Materials and Methods

[00107] In addition to those described in Examples 1 and 2 above, the following materials and methods were used.

[00108] *Reagents.* The single chain binding fragment (scFvC225) of cetuximab was synthesized with a twenty amino acid linker between the light chain and heavy chain. ScFvC225 and soluble epidermal growth factor receptor domain III (sEGFRdIII)

were expressed in Sf9 cells and purified as previously described (Donaldson et al., 2009).

[00109] *Meditopes and point mutations.* As described above, CQFDLSTRRLKC (cQFD; SEQ ID NO:1) and CQYNLSSRALKC (cQYN; SEQ ID NO:2), were synthesized, oxidized and purified at the City of Hope Synthetic and Polymer Chemistry Core Facility. Alanine point mutations in the cQFD meditope were generated at residues 3 (Phe3 to Ala), 5 (Leu5 to Ala), 8 (Arg8 to Ala) and 10 (Leu10 to Ala) and were produced bacterially by encoding the peptides at the C-terminus of SMT3 (Mossessova et al., 2000). Before surface plasmon resonance (SPR) analysis, ubiquitin-like protease (Ulp1) was added to the samples to release the peptides.

Simultaneous binding of EGFR and meditope to Fab

[00110] The diffraction data conflict with the hypothesis that these peptides are effective as vaccines. Specifically, the atomic model shows that the meditoes do not directly bind to the CDRs, and thus do not mimic an antigen epitope. However, serum collected from mice inoculated with the cQYN meditope blocked cell proliferation (Riemer et al., 2005). Therefore, to test whether or not the meditope occludes antigen binding, the cetuximab Fab was incubated with EGFR-domain III and cQFD and applied to an analytic SEC column. A peak at 13.9 mL was observed, and non-reducing SDS-PAGE of the peak showed the presence of all three components (Fig. 4B). The individual components eluted at 15.2 mL (Fab C225), 15.6 mL (sEGFRdIII) and 16.3 mL (SMT-CQFDLSTRRLKC; SEQ ID NO:1).

[00111] In addition, it was determined whether or not the meditope could bind to the scFv of cetuximab. In the scFv, the CDR loops remain intact, but the Fab variable domains are directly connected through a short peptide linker, eliminating the Fab constant domains. In other words, the meditope binding pocket is eliminated in the scFv, while the CDRs are minimally affected. SPR demonstrated that EGFR domain III and the cQFD meditope bound to cetuximab Fab tethered to a CM5 chip (See Fig. 4B). In addition, EGFR domain III bound with a minimal affinity loss to the scFv tethered to a second CM5 chip. However, relative to Fab binding, the cQFD meditope did not

saturate the scFv at concentrations as high as 100 μ M of meditope. This indicates minimal, if any, affinity of the meditope for the CDRs, consistent with the crystallographic studies.

Meditope does not affect cetuximab binding to EGFR-expressing cells

[00112] Although the Fab could bind to the meditope and EGFR domain III simultaneously, it was determined whether the meditope could affect cetuximab binding to EGFR-expressing cells as a full IgG. To test this, FACS analysis was used to follow the binding of the IgG, as a function of meditope concentration, to MDA MB-468 cells, which overexpress EGFR. Cells were incubated with cetuximab in the presence of increasing cQFD meditope concentrations. Even with meditope concentrations greater than 60 μ M, no significant changes in cetuximab binding to the cells were observed (Fig. 5). This observation is consistent with the SEC studies described above, and indicates that the meditope does not act as an allosteric regulator of antigen binding.

[00113] Simultaneous binding to the Fab of EGFR domain III and the meditope is shown at concentrations significantly above the K_D of the meditope. Like the cQFD and cQYN meditoes, superantigens SpA and PpL, bind to the Fab framework region and do not affect antigen binding (Graille et al., 2000; Graille et al., 2001; Graille et al., 2002; Young et al., 1984).

[00114] In addition, the meditope chemical coupled to a solid support can be used to purify the murine chimera cetuximab, which represents a novel method to purify murine chimera IgGs as well as meditope-grafted gGs. See Figure 10. There are several of advantages to this purification approach. First, the meditope is easily synthesized and can be readily added to common solid supports (including magnetic beads). Second, the affinity of the meditoes is easily modulated by point mutations, which enables the fine-tuning of the purification procedure and avoids harsh conditions such as low pH that is commonly used to elute antibodies. Finally, as described herein, the meditoes can be made bivalent or multivalent (such as those described in Example 4 below) and used to extract intact murine or mousified human IgGs. The use of a peptide would also have additional advantages over current purification methods that

use Protein A or Protein L, including the high cost associated with the production of Protein A or Protein L, limited life cycle and, potential introduction extraneous biological material such as bacterial pathogens.

Steric Mask

[00115] The mediotope can be tethered to the N-terminus of either the light chain or heavy chain N-terminus of a murine chimera or mousified human mAb through a flexible linker (Figure 11). The N-termini of mAb IgGs are juxtaposed to the antigen binding site and the extension from the N-termini through the flexible linker will sterically interfere with antigen binding. By encoding a tumor specific protease site (e.g., MMP9, MMP14, prostate-specific antigen (PSA) serine protease or other suitable site) in the linker, the steric constraint of intramolecular 'masked' IgG construct will be severed at the tumor site and permit antibody binding. This design principle would avoid binding of the intramolecularly 'masked' IgG to healthy tissues and avoid adverse side effects due to off-target binding. The off-rate determination for Avidin-peptide mask on Cetuximab is shown in Figure 12. This figure shows that a multivalent mediotope binds with higher affinity than a monovalent mediotope, but does not mask.

EXAMPLE 4: GENERATION OF MULTIVALENT MEDIOTOPES

[00116] Combinations of monoclonal antibodies (mAbs) that recognize unique epitopes on the same antigen (e.g., EGFR) have been shown to enhance cell death and inhibit tumor growth. While the precise mechanism of this enhanced cell death remains debated (immunological response versus receptor down regulation versus enhanced ligand antagonism), previous studies indicate that both Mabs should be multivalent (e.g., full IgG or F(ab)₂) to achieve enhanced cell death. As such, a multivalent mediotope may be substituted as a second antibody as shown below. Therefore, the mediotopes describe herein may be tethered to a scaffold to create a multivalent mediotope for enhanced selectivity and binding affinity.

[00117] Specificity and affinity are often achieved through multivalency. This can be expressed as $\Delta G_{\text{Total}} = \Delta G_1 + \Delta G_2 - \Delta G_{\text{linker}}$ for a bivalent ligand, which is equivalent

to $K_{\text{Total}} = K_1 * K_2 / K_{\text{linker}}$. In the case where the linker makes no contribution to the free energy ($K_{\text{linker}} \sim 1$), the apparent affinity of the bivalent ligand for the bivalent target is the product of the monomeric binding constants. Thus, significant gains in affinity can be achieved (e.g., for a meditope with $K_D = 1 \mu\text{M}$, the affinity of a 'theoretical' bivalent meditope is 1 pM. Such gains, however, are rarely seen, primarily due to the geometry of the bivalent/trivalent/multivalent receptor. The geometry of the receptor places strict constraints on the linker, but it also ensures specificity, which is an important goal for targeted delivery.

[00118] To address the receptor constraints on the linker, the unmodified or optimized meditoes may be coupled to a multivalent scaffold. To accomplish this, the linker is optimized. Because tumor cells have high antigen density, a multivalent meditope should "latch-on" to adjacent IgGs to form a "daisy-chain"-like array (Figure 8). While an intramolecular association of a bivalent meditope and IgG is possible, the C2 symmetry of the IgG would place severe geometrical constraints on the linker for such an interaction. A trivalent or higher valency scaffold ensures that more than one antibody would be "daisy chained". By including a third meditope arm, the lifetime of the initial encounter of a trivalent meditope to antigen-bound antibody will increase. This, in turn, will increase the probability that an additional arm will bind to a neighboring antigen-bound antibody, thus stabilizing the overall complex.

Scaffold synthesis

[00119] Synthesis of a FITC-labeled bivalent meditope was developed based on "Click" chemistry using (compound **2**) (Figure 13). The use of templates **4** and **5** (Figure 13) allows for the formation of both bi- and trivalent meditoes, respectively. This synthesis represents an exciting advance since the present discovery describes the chemistry developed for the preparation of multivalent meditoes and allows focus on investigating differing length polyethylene glycol (PEG) (and other) linkers for optimal binding. The synthetic approach is also amenable to DOTA incorporation for radionuclide imaging. For example, a 30 Å PEG bifunctional arm has been incorporated in the synthesis of a FITC-labeled divalent meditope, namely compound **13** (Figure 13).

The distance between the CDR regions within an IgG is ~130 Å. Therefore, the length of the PEG linker may be systematically varied to ensure this approach is optimal. End-to-end distances of commercially available PEGs extend to 90 Å (Pierce), which would exceed the IgG distance.

Multivalent Characterization

[00120] Each multivalent mediotope is characterized by SPR and ITC to ensure that conjugation to the multivalent scaffold does not affect the mediotope-IgG interaction. These measurements, however, are limited in their effectiveness in determining multivalency since the IgG is not bound to the surface of a tumor. Instead, FACS analysis and cell viability assays may be used to quantify the effect of the multivalent mediotope directly on cells that overexpress EGFR.

[00121] For FACS analysis, cell lines that overexpress EGFR (MDA-MB-468 and A431) are incubated with cetuximab at various concentrations (1 nM to 100 nM). Next, cetuximab-treated cells are incubated with the labeled multivalent mediotope (Figure 17; Mediotope-Fc) at increasing concentrations (0.1 nM to 1 µM) and analyze the binding characteristics using a CyAn FACS sorter. A shift at far lower concentrations than observed for the monovalent mediotope (Figure 17) and/or an increase in percentage of cells that shift may be observed. To further confirm the additive effects expected for the multivalent mediotope, the non-labeled, monovalent mediotope may be used to compete with the labeled multivalent mediotope for the antigen-bound cetuximab.

[00122] The efficacy of the multivalent mediotope at enhancing cetuximab-mediated cell death using cell viability assays may also be measured. Briefly, MDA-MB-468 and A431 cell lines are plated and treated with varying concentrations of cetuximab and multivalent mediotopes. As a control, a monovalent mediotope is used, which produces similar results as cetuximab alone. MTT, 3-(4,5-Dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide, may be used to quantify the number of viable cells. For multivalent mediotopes that demonstrate activity, Western blot analysis may be performed to follow the phosphorylation status of EGFR as well as AKT and MAP which are part of the EGFR signaling pathway. These data are then compared with data from

cetuximab-only treated cells and cells treated with tyrosine kinase inhibitors (AG1478). Collectively, this should cause an increase in cell death as a function of multivalent meditope concentration.

MTT assay

[00123] The effect of the monomeric meditope or the bivalent meditope-Fc on inducing cell death in conjunction with cetuximab was investigated using an MTT assay. 4000 MDA-MB-468 cells were placed in each well of a 96 well plate in 80µl of medium. 10µl of 1µM cetuximab is added along with 10µl of 0.1, 1 or 10µM of meditope or meditope-Fc to a final concentration of 0.1µM cetuximab and 0.01, 0.1 and 1µM meditope or meditope-Fc. Each component was also added alone with PBS as control. After a 48-hour incubation, 10µl of MTT reagent was added and let incubate for another 4 hours. The culture supernatant was then removed, 100µl of MTT crystal dissolving reagent was added, and the plate was read at 630nm. Meditope or meditope-Fc alone did not alter cell growth significantly, but only meditope-Fc and not the monomeric meditope could inhibit cell growth together with cetuximab (Figure 28A).

[00124] To show that a multivalent meditope has efficacy in enhancing cell killing akin to the effect of a second anti-EGFR antibody in addition to cetuximab, the effect of tumor cell growth inhibition by either cetuximab with medito-Fc or cetuximab with M425 was compared. 4000 MDA-MB-468 cells were placed in each well of a 96 well plate in 80µl of medium. 10µl of 1µM cetuximab is added along with 10µl of either 2, 4 or 8µM of meditope-Fc or M425 to a final concentration of 0.1µM cetuximab and either 0.2, 0.4 or 0.8 µM meditope-Fc or M425. Cetuximab added along with PBS was used as control. After a 48-hour incubation, 10µl of MTT reagent was added and let incubate for another 4 hours. The culture supernatant was then removed, 100µl of MTT crystal dissolving reagent was added, and the plate was read at 630nm. Meditope-Fc could be seen enhancing the cell-killing capacity of cetuximab, although not as yet potent as M425 (Figure 28B).

[00125] As an alternate approach, different scaffolds and linkers may be used to generate high affinity multivalent mediotopes. For example, DNA may be used as a scaffold for the mediotopes to create a more rigid scaffold.

[00126] The mediotope (wildtype) was fused to the N-terminus of the Fc region of an IgG through a flexible peptide linker ("mediotope-Fc") (Figure 15; SEQ ID NO:3-4). The sequence and structure of the mediotope-Fc are shown in Figures 15 and 16, respectively. The use of the Fc region to 'dimerize' ligands is been well established (<http://www.ncbi.nlm.nih.gov/pubmed/18215087>). In this example, a linker 17 amino acids long consisting of glycine and serines was chosen, but a linker of any suitable length may be used. To demonstrate enhanced binding due to multivalency, 0.5×10^6 MDA-MB-468 cells were labeled with 10 nM Cetuximab for 30 min at room temperature, washed, then incubated with 0.1, 0.3, 1 and 3 μM of bivalent Mediotope-Fc or monomeric Mediotope for 30 min, room temperature, washed and analyzed by FACS. As shown in Figure 17, FACS analysis indicates that the mediotope-Fc, corrected for the stoichiometry, binds cells pre-treated with cetuximab with significantly higher affinity. Furthermore, we demonstrate that this interaction is specific to the mediotope-enabled mAb (cetuximab). This data indicates that the mediotope-Fc combined with a mediotope enabled mAb is synergistic and can be substituted for a second antibody.

[00127] Different scaffolds of biological and chemical origin may also be used to achieve multivalency. This includes, but is not limited to, constructing a bivalent or trivalent scaffold, using streptavidin or collagen (<http://ip.com/patapp/EP2065402A1>), streptavidin as a tetravalent scaffold, unique scaffolds (<http://www.sciencedirect.com/science/article/pii/S0022283611000283>), Origami DNA (<http://www.nature.com/nnano/journal/v4/n4/abs/nnano.2009.5.html>) and the like. A chemical scaffold may also be created using molecules including, but not limited to, DNA (single strand, duplex, Holliday junctions, aptamers and the like), RNA (single strand, hairpin, stem loop, aptamers and the like), PNA (peptide nucleic acids), DNA/PNA duplexes and triplexes for rigidity, nanoparticles (directly coupled or coupled through organic polymers such as PEG), organic polymers that can form duplexes with themselves and/or with DNA or PNA. For example, in Figure 13, a trivalent mediotope

was successfully synthesized. Figure 14 illustrates the characterization of a fluorescein isothiocyanate (FITC)-labeled meditope dimer 7.

[00128] In addition, the composition of and the distance between the Fc and meditope can be systematically explored to optimize affinity and specificity. In one embodiment, each natural or unnatural residue can be substituted at any position within the linker for optimization. In addition, a linker between 2 to 100 or more residues is possible (e.g., can be generated by current and future DNA synthesizers and inserted between the meditope and the Fc regions. The linker may also be 'rigidified' to limit the radius of gyration and to enhance the affinity and specificity of the Fc-meditope. For example, a coiled coil domain may be placed between the meditope and the Fc (Figure 18). Alternatively, inert protein domains (e.g., immunoglobulin folds) may be substituted for the linker. Multiple immunoglobulin folds can be placed between the meditope and the Fc domain. In certain embodiments, the composition of the linker is of human origin to mitigate potential antigenicity.

EXAMPLE 5: MODIFICATION OF THE MEDITOPE POCKET

[00129] The residues lining the meditope site can be systematically or randomly altered (degenerate libraries and selection) to enhance and/or change the specificity of the meditope or meditope analogs (see, for example, Sheedy et al. 2007 and Akamatsu et al. 2007, hereby incorporated herein by reference, for methods of making alterations). These positions can be substituted with non-natural, unnatural amino acids or both, in order to improve the affinity of the meditope interaction. Recently, the incorporation of a non-natural amino acid in an antibody to generate a bi-specific antibody was described (Hutchins et al. 2001).

[00130] Residues making contact with the meditope/line the cavity (within 8 Å of any atom of the bound meditope -cQFD) that can be systematically or randomly changed to improve the meditope affinity through hydrogen bonding, ionic, electrostatic or steric interaction include one or more light chain residues (e.g., P8, V9, I10, S14, E17, Q38, R39, T40, N41, G42, S43, P44, D82, I83, A84, D85, Y86, Y87, G99, A100, G101, T102, K103, L104, E105, K107, R142, S162, V163, T164, E165, Q166, D167,

S168, or Y173 of the light chain; or Q6, P9, R38, Q39, S40, P41, G42, K43, G44, L45, S87, D89, T90, A91, I92, Y93, Y94, W109, G110, Q111, G112, T113, L114, V115, T116, Y151, E154, P155, V156, T171, F172, P173, A174, V175, Y182, S183, or L184 of the heavy chain) or a combination thereof. In addition, other residues in the meditope binding region may be mutated to allow a meditope group to hydrate it and bind with high affinity. For example, the Tyr87 of the light chain residue, the Tyr94 of the heavy chain residue, or both, may be used to form a hydrate with an aldehyde or boron containing compound originating from a meditope analog.

[00131] *Evolution of meditope site.* It was demonstrated that the meditope does not affect antigen binding and thus can be used to deliver drugs, daisy chain/crosslink other antibodies or other methods for increasing efficiency and efficacy of a therapeutic antibody. The composition of the meditope binding site can be altered such that it can bind to current meditope with higher affinity, different meditope analogs or small molecules such as DOTA (for radioactive delivery). Each residue lining the meditope binding site can be systematically altered, produced and characterized. However, the number of mutations is staggering ($>20^6$ combinations, potentially $>20^{16}$ combinations). To more efficiently identify mutations in the Fab that enable binding to the meditope, a library of IgGs may be generated at the DNA level such that each amino acid has been substituted at a given site. The most useful combination can be selected, characterized in detail and used for additional modifications.

[00132] One method to do this is to create a DNA library using degenerate oligos at sites of interest (e.g., Ile90, Thr92, Leu114 and Thr116 of the heavy chain and Lys103 and Glu165 light chain) to encode all 20 naturally occurring amino acids at these sites. In addition, a GPI domain may be added to the C-terminus of the IgG heavy chain. The library may be transfected using standard methods and unique IgGs will be allowed to express. To ensure that the antigen binding is not affected, cells that bind to a fluorescently labeled antigen (e.g., Her2, EGFR, IGFR, CLTA-4, etc) may be sorted by FACs (Figure 20). Cells that are bound to the antigen are then selected for binding to a specific meditope, meditope analog, or other molecule of interest (e.g., DOTA). Once the cells are sorted, PCR is used to identify the resulting mutations that

enable or enhance meditope/analog/small molecule binding. This can be repeated multiple times to 'evolve/optimize' the binding.

EXAMPLE 6: GENERATION OF MEDITOPE-ENABLED ANTIBODIES

[00133] In certain embodiments, the meditope binding site can be created on pre-existing and all future monoclonal antibodies including IgG1-4 (Lambda and Kappa isoforms), IgEs, IgA1, IgA2, IgDs and IgMs via mutation of residues of other IgGs, such as human, murine, or chicken.

[00134] The framework that binds to the meditope is unique as the Fab variable regions (Fvs) are murine and the Fab constant regions (CH1) are human. Moreover, the maturation of this Fab produced a combination of residues within each IgG domain that are not found in murine or human chimeric IgGs (based on a sequence alignment of known IgGs). To show this, it was demonstrated that the original meditope does not bind to fully human or fully murine serum IgGs. As such, the meditope binding site may be mapped (or engineered or mutated) onto any framework, including human IgGs to enable meditope binding. The antigen specificity of the current meditope enabled monoclonal antibody may be altered through CDR grafting of preexisting monoclonal antibodies (Figure 21).

[00135] The sequence differences between a human framework sequence and the cetuximab framework were mapped onto the crystal structure of cetuximab Fab. Residues in the human framework (trastuzumab – 1N8Z.pdb) that line the meditope site were mutated to corresponding residues in cetuximab. The heavy and light chains were synthesized using standard methods, subcloned into a standard vector for mammalian expression, the mutated IgG was purified using standard methods and characterized for Her2 and meditope binding. Figures 23A and 23C show the nucleic acid sequences of the heavy chain (SEQ ID NO:5) and the light chain (SEQ ID NO:8), respectively; and Figures 23B and 23D show the corresponding amino acid sequences of the light chain (SEQ ID NO:6) and heavy chain (SEQ ID NO:9) as compared to the wildtype sequences (SEQ ID NO:7 and SEQ ID NO:10) of the meditope-enabled trastuzumab.

[00136] To characterize antigen binding, wildtype trastuzumab and meditope enabled trastuzumab were labeled with Alexa 647 using standard protocols. Likewise, the meditope-Fc was labeled with Alexa488 using the same protocols. To show that the meditope-Fc binds to the meditope-enabled trastuzumab and not to the wildtype trastuzumab, SKBR3 cells (0.5×10^6) which over express Her2 were incubated with labeled wild trastuzumab or the meditope-enabled meditope for 30 minutes. Unbound antibody was washed and the cells were incubated with the meditope-Fc construct for 30 minutes. Antibody binding and meditope binding were analyzed by FACS analysis. As an important component of the “meditope-grafting,” the FACS data demonstrates that meditope-enabled trastuzumab binds to Her2 expressed on the SKBR3 cells (e.g., the meditope site can be grafted onto an antibody without loss of antigen specificity) (Figure 22A). The FACS data also demonstrates that the meditope-Fc binds to the meditope-enabled trastuzumab, but not to wildtype trastuzumab (Figure 22B).

[00137] It is noted that the production of the meditope-enabled trastuzumab must be optimized to afford more material for rigorous quantitative characterization, which may account for the apparent reduced affinity (e.g., uncertainty in the final concentration of the meditope-enabled trastuzumab and its labeling with Alexa 647). Likewise, we note that there are standard methods to optimize antigen binding as well as meditope binding (see optimization of meditope binding site). Regardless, the data shows unequivocally that meditope-enabled trastuzumab binds to Her2 overexpressing SKBR3 cells and that cells pretreated with the meditope-enabled Trastuzumab binds to the meditope.

[00138] *Her2 CDR-grafted, meditope-enabled antibody.* CDR grafting is now standard practice to produce humanized monoclonal antibodies. The meditope binding site is unique to the cetuximab framework (and not to human, murine or other murine-human chimerics – e.g., rituximab). Another embodiment demonstrates that the CDR loops of other antibodies may be grafted on to the cetuximab framework to provide meditope binding by grafting the CDR loops of trastuzumab onto the cetuximab framework. While the ‘boundaries’ of the CDR loops of mAbs have been clearly defined by sequence homology structural methods in general, we superimposed the crystal structure of trastuzumab onto cetuximab and examined the position of each residue to

address potential differences outside of the CDR loops that may have a secondary effect on the conformation of the CDR loops. The resulting amino acid sequences of the light and heavy chains (e.g., trastuzumab CDR loops on cetuximab) were translated into DNA sequences and the genes encoding each were synthesized. The genes were then subcloned in frame into the remaining IgG DNA sequence, confirmed by DNA sequencing and placed in individual expression vectors. The resulting expression vectors were transformed into NS0 cells for co-expression of the heavy and light chains. As the expressed full-length CDR-grafted IgG was secreted, the supernatant was clarified by centrifugation, concentrated, and passed over a protein A column. The IgG was eluted using a low pH solution and immediately neutralized. SDS-PAGE (poly acrylamide gel electrophoresis) of the full-length CDR-grafted IgG under reducing conditions indicated two protein bands with apparent masses consistent with the light and heavy chain. The position of the bands migrated at similar positions compared to wildtype cetuximab.

[00139] To characterize antigen binding, wildtype trastuzumab and the trastuzumab CDR-grafted, mediotope-enabled mAb were labeled with Alexa 647 using standard protocols. As before, the mediotope-Fc was labeled with Alexa488 using the same protocols. To show that the mediotope-Fc binds to the trastuzumab CDR-grafted, mediotope-enabled mAb and not to the wildtype trastuzumab, SKBR3 cells (0.5×10^6) which over-express Her2 were incubated with labeled wild trastuzumab or the mediotope-enabled mediotope for 30 minutes. Unbound antibody was washed and the cells were incubated with the mediotope-Fc construct for 30 minutes. Antibody binding and mediotope binding were analyzed by FACS analysis. As an important component of the "CDR-grafting", the FACS data demonstrates that the trastuzumab CDR-grafted, mediotope-enabled mAb binds to Her2 expressed on the SKBR3 cells (e.g., the CDR loops can be grafted onto cetuximab framework region and bind to Her2) (Figure 24A). The FACS data also demonstrates that the mediotope-Fc binds to the trastuzumab CDR-grafted, mediotope-enabled mAb, but not to wildtype trastuzumab (Figure 24B).

[00140] It is noted that the production of the mediotope-enabled trastuzumab must be optimized to afford more material for rigorous/quantitative characterization, which

may account for the apparent reduced affinity (e.g., uncertainty in the final concentration of the meditope-enabled trastuzumab and its labeling with Alexa 647). There are art-known methods to optimize antigen binding, which may be applied to meditope binding. The data shows unequivocally that meditope-enabled trastuzumab binds to Her2 overexpressing SKBR3 cells and that cells pretreated with the meditope-enabled trastuzumab binds to the meditope. A Her2 CDR grafted, meditope binding mAb Sequence is shown in Figures 25A (heavy chain; SEQ ID NOS:11-12) and Figure 25B (light chain; SEQ ID NOS:13-14).

[00141] This approach may be used for any antibody including IgA, IgE, IgD, and IgM and from any organism that produces antibodies including but not limited to chicken, murine, rat, bovine, primates, and goat. As an example, the sequence and structural alignment of the IgG and an IgE 'Fab' domains indicates residues on the IgE near the meditope binding site (Figure 26).

EXAMPLE 7: MEDITOPE BINDING AFFINITY AS A FUNCTION OF pH

[00142] The composition of the meditope can be altered to affect the binding affinity as a function of pH. As shown in Figure 27, the binding affinity of three different meditope variants was measured as a function of buffer pH. The QYD meditope variant shows a marked decrease in affinity at lower pH. Substitution of the asparatate to asparagine in the QYN variant produces a flat pH dependence. Likewise, the affinity of the QFD variant is slightly greater at higher pHs. Collectively, these experiments indicate that the affinity of the meditope-MAb interaction can be tailored to pH.

[00143] Therefore, in some embodiments, modification of meditope variants (or "analogs") for the specific release at low pHs (e.g., in lysosomes for drug delivery) is provided; and modification of meditopes so that they bind with higher affinity in a hypoxic environment (e.g., tumor stroma pH is often lower than normal tissues).

[00144] The foregoing examples and methods of the invention are illustrative only and are not intended to be limiting of the invention in any way. Those of ordinary skill in

the art will recognize that various modifications of the foregoing are within the intended scope of the invention.

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All references below and cited in the specification above are hereby incorporated by reference in their entirety, as if fully set forth herein.

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CLAIMS

1. A method of purifying a monoclonal antibody or antigen-binding fragment thereof, comprising
contacting a solution containing the monoclonal antibody or antigen-binding fragment thereof with a peptide coupled to a solid support, such that a mediotope binding interface of the monoclonal antibody or fragment thereof binds to the peptide, and isolating the antibody or fragment, thereby purifying the antibody or fragment,
wherein the monoclonal antibody is cetuximab and
wherein the peptide comprises an amino acid sequence selected from the group consisting of SEQ ID NOs: 1, 2, 5, 6, 7, 8, 21, 22, 26, 32, and 33.

2. The method of claim 1, wherein the peptide comprises the amino acid sequence of SEQ ID NO: 7 or 8.

3. The method of claim 1, wherein the peptide comprises an amino acid sequence selected from the group consisting of SEQ ID NOs: 1, 5, 6, and 22.

4. The method of claim 1, wherein the peptide comprises an amino acid sequence selected from the group consisting of SEQ ID NOs: 1, 5, 7, 8, 22, and 26.

5. The method of claim 1, wherein the peptide comprises the amino acid sequence selected from the group consisting of SEQ ID NOs: 5, 6, 7, 8, 21, 22, 26, 32, and 33.

6. The method of claim 1, wherein the peptide comprises the amino acid sequence of SEQ ID NO: 32.

7. A method of purifying a monoclonal antibody or antigen-binding fragment thereof, comprising:
contacting a solution containing the monoclonal antibody or antigen-binding fragment thereof with a peptide coupled to a solid support, such that a mediotope binding

interface of the monoclonal antibody or fragment thereof binds the peptide, and isolating the antibody or fragment, thereby purifying the antibody or fragment,

wherein the monoclonal antibody is cetuximab, and

wherein the peptide comprises the sequence of SEQ ID NO: 32.

8. A method of purifying a monoclonal antibody or antigen-binding fragment thereof, comprising

contacting a solution containing the monoclonal antibody or antigen-binding fragment thereof with a peptide coupled to a solid support, such that a mediotope binding interface of the monoclonal antibody or fragment thereof binds to the peptide, and isolating the antibody or fragment, thereby purifying the antibody or fragment,

wherein the monoclonal antibody is cetuximab, and

wherein the peptide comprises an amino acid sequence selected from the group consisting of SEQ ID NOs: 5, 6, 7, 8, 21, 22, 26, 32, and 33.