ANTI-VEGFR-3 ANTIBODY COMPOSITIONS

This invention is directed to antibodies that bind specifically to Vascular Endothelial Growth Factor Receptor-3 (VEGFR-3), particularly provided herein are amino acid and nucleic acid sequences of anti-VEGFR-3 antibodies, pharmaceutical compositions, and uses of said antibodies in methods of treating a medical condition mediated by VEGFR-3.

Endothelial cell specific growth factors and receptors are believed to be primarily responsible for the stimulation of endothelial cell growth, differentiation, as well as certain cellular functions. One widely studied family of growth factors comprises Vascular Endothelial Growth Factors (VEGFs).

VEGFR-3 is the only receptor tyrosine kinase (RTK) whose expression in normal adult tissues is largely restricted to the lymphatic endothelium. Nascent VEGF-C and VEGF-D specifically bind to VEGFR-3. Proteolytic cleavage of the N- and C-terminal regions of these proteins liberate mature VEGF-$C_{\Delta N\Delta C}$, and VEGF-$D_{\Delta N\Delta C}$, which acquire increased affinity for VEGFR-3. These ligands activate VEGFR-3 signaling and initiate lymphangiogenesis (i.e. the formation of new lymphatic vessels from pre-existing lymphatic vessels).

The pattern of expression of the ligands for VEGFR-3 suggests their involvement not only in the development and maintenance of the normal vascular system but also in tumor angiogenesis and lymphangiogenesis. Further, VEGFR-3 expression has been detected on blood capillaries within tumors. Thus monoclonal antibodies (mAbs) that inhibit the binding of VEGF-C and/or VEGF-D to VEGFR-3 have the potential to inhibit tumour angiogenesis.

In addition, blocking VEGFR-3 activity has been shown to inhibit VEGF-C – enhanced tumour lymphangiogenesis. In many types of cancer, the first site of metastasis is the lymph nodes and therefore blocking VEGFR-3 has the potential to inhibit tumour metastases.

Persaud, *et al.*, J. Cell Science *117*:2745-56 (2004), describes certain properties of a human anti-VEGFR-3 monoclonal antibody, but does not disclose the sequence of any such antibodies nor the epitopes that such antibodies may bind. There remains a need

therefore for high affinity anti-VEGFR-3 antibodies that bind novel epitopes within VEGFR-3 and which are able to block ligand binding and receptor activation. There further remains a need for anti-VEGFR-3 antibodies which are able to demonstrate anti-tumour efficacy against a variety of tumour types, without significant negative side effects.

The present invention provides an antibody, or antigen binding portion thereof, that binds to human VEGFR-3 wherein:

a) the binding of said antibody to human VEGFR-3 is reduced by at least 90% by singly mutating Pro-219 of human VEGFR-3 to Leu; and

b) the binding of said antibody to human VEGFR-3 is reduced by at least 50% by singly mutating Val-175 of human VEGFR-3 to Ala.

Preferably, the level of binding between the antibody, or antigen-binding fragment thereof, and the human or mutant VEGFR-3 is assayed by expressing the soluble extracellular domain of the human or mutant VEGFR-3 as a fusion protein with alkaline phosphatase and then determining the amount of each fusion protein that is able to bind to the antibody using an alkaline phosphatase chemiluminescence assay.

The invention further provides a pharmaceutical composition comprising an antibody, or antigen binding portion thereof, of the present invention together with a pharmaceutically acceptable carrier, diluent or excipient.

In addition, the invention provides a pharmaceutical composition comprising an antibody, or antigen binding portion thereof, of the present invention together with a pharmaceutically acceptable carrier, diluent or excipient and optionally contains at least one other therapeutic ingredient.

The invention also provides an antibody, or antigen binding portion thereof, of the invention for use as a medicament.

The invention additionally provides an antibody, or antigen binding portion thereof, of the invention for use in the treatment or prevention of ovarian cancer, human erythroleukaemia, head and neck cancer, breast cancer, renal cell carcinoma, pancreatic cancer, lung cancer, colon cancer and lymph node metastases.

The invention further provides a method of treating a cancer selected from the group consisting of ovarian cancer, human erythroleukaemia, head and neck cancer, breast cancer, renal cell carcinoma, pancreatic cancer, lung cancer, colon cancer and

lymph node metastases in a mammal, comprising administering to a mammal in need of such treatment an effective amount of an antibody, or antigen binding portion thereof, of the invention.

The invention additionally provides a use of an antibody, or antigen binding portion thereof, in the manufacture of a medicament for the treatment of a cancer selected from the group consisting of ovarian cancer, human erythroleukaemia, head and neck cancer, breast cancer, renal cell carcinoma, pancreatic cancer, lung cancer, colon cancer and lymph node metastases.

The invention also provides an antibody, or antigen binding portion thereof, of the invention in combination with a further anti-cancer agent selected from cisplatin, 5-fluorouracil, leucovorin, oxaliplatin and docetaxel for simultaneous, separate or sequential use in therapy.

The invention additionally provides a method of treating a cancer selected from the group consisting of ovarian cancer, human erythroleukaemia, head and neck cancer, breast cancer, renal cell carcinoma, pancreatic cancer, lung cancer, colon cancer and lymph node metastases in a mammal, comprising administering to a patient in need thereof a therapeutically effective combination of an antibody, or antigen binding portion thereof, of the invention and a further anti-cancer agent selected from cisplatin, 5-fluorouracil, leucovorin, oxaliplatin and docetaxel.

The antibodies of the present invention bind the second immunoglobulin (Ig)-like domain of a mammalian VEGFR-3. The second Ig-like domain of human VEGFR-3 corresponds to residues 138 to 226 of the full length receptor. *See*, Pajusola, *et. al.*, Cancer Res. *52*:5738-5743 (1992).

The term "second Ig-like domain of a mammalian/human/mouse VEGFR-3" (and variations thereof) is intended to encompass naturally occurring forms of the domain (*e.g.*, purified from a cell that expresses the domain under normal conditions) as well as recombinant versions, *e.g.*, encoded by naturally occurring or synthetic point mutants or truncated versions thereof.

The antibodies of the present invention bind an epitope in the second Ig-like domain of human VEGFR-3 wherein P219 is the dominant constituent of the epitope, V175 is a subordinate constituent of the epitope and L221 is a minor constituent of the epitope. (The numbering of these residues is consistent with the full-length human

VEGFR-3, as reported in Pajusola, *et. al.*, *supra*, and EMBL database, accession number X 68203.) This finding is based in part on the observation that including the mutations V175A or P219L or L221V (i.e. substituting the orthologous murine VEGFR-3 residues) in human VEGFR-3 abolishes or significantly reduces the binding of antibodies of the present invention to the mutant human VEGFR-3.

Moreover, the antibodies of the present invention that bind an epitope in human VEGFR-3 (wherein P219 is the dominant constituent of the epitope, V175 is a subordinate constituent of the epitope and L221 is a minor constituent of the epitope) are able to block the binding of the ligand VEGF-C to VEGFR-3 and thus neutralise the activity of the receptor. Accordingly, the present invention provides a novel, neutralising epitope on human VEGFR-3 that allows the production of novel neutralising antibodies to human VEGFR-3, which are able to block the binding of human VEGF-C to the receptor. The invention thus provides an epitope of human VEGFR-3 wherein P219 is the dominant constituent of the epitope, V175 is a subordinate constituent of the epitope and L221 is a minor constituent of the epitope.

The invention also provides an antibody, or antigen-binding portion thereof, that binds an epitope of human VEGFR-3 comprising the amino acid residues P219 and V175. Preferably the invention also provides an antibody, or antigen-binding portion therof, that binds an epitope of human VEGFR-3 comprising the amino acids P219, V175 and L221. Such an epitope is bound by antibodies of the present invention (e.g. Antibody 1) and therefore the invention also provides an antibody, or antigen-binding portion thereof that reacts with the same epitope of human VEGFR-3 as an antibody having a light chain comprising the amino acid sequence of SEQ ID NO: 15 and a heavy chain comprising the amino acid sequence of SEQ ID NO: 16. An antibody reacting with the same epitope of human VEGFR-3 as certain antibodies of the present invention (e.g. Antibody 1) would compete for binding to human VEGFR-3 and accordingly the invention also provides an antibody, or antigen-binding portion thereof that competes with an antibody having a light chain comprising the amino acid sequence of SEQ ID NO: 15 and a heavy chain comprising the amino acid sequence of SEQ ID NO: 16 for binding to human VEGFR-3.

Preferably, an antibody of the present invention also binds to a mutant mouse VEGFR-3 having the sequence shown in SEQ ID NO: 20 (which includes the mutation L219P) and a mutant mouse VEGFR-3 having the sequence shown in SEQ ID NO: 21

(which includes the mutation A175V) wherein the binding to the mutant mouse VEGFR-3 having the sequence shown in SEQ ID NO: 20 is increased by more than 50-fold when compared with the binding to wild type mouse VEGFR-3 (SEQ ID NO: 19) and the binding to the mutant mouse VEGFR-3 having the sequence shown in SEQ ID NO: 21 is increased by more than 10-fold when compared with the binding to wild type mouse VEGFR-3.

Preferably the level of binding between the antibody, or antigen-binding fragment thereof, and the wild type mouse or mutant mouse VEGFR-3 is assayed by expressing the soluble extracellular domain of the wild type mouse or mutant mouse VEGFR-3 as a fusion protein with alkaline phosphatase and then determining the amount of each fusion protein that is able to bind to the antibody using an alkaline phosphatase chemiluminescence assay.

Preferably, an antibody of the present invention, or antigen-binding portion thereof, has a high affinity for human VEGFR-3. For example, an antibody, or antigen-binding portion thereof, that has a K_d of between 1 x 10^{-9} M and 5.6 x 10^{-11} M for human VEGFR-3 as measured by surface plasmon resonance on a BIACORE® 2000 biosensor at 20°C. More preferably the antibody, or antigen-binding portion thereof, has a K_d of between 1 x 10^{-10} M and 5.6 x 10^{-11} M for human VEGFR-3 as measured by surface plasmon resonance on a BIACORE® 2000 biosensor at 20°C.

Preferably, the present invention provides an anti-VEGFR-3 antibody, or antigen-binding portion thereof, that inhibits the binding of human VEGF-$C_{\Delta N \Delta C}$ to human VEGFR-3 with an IC_{50} of between 2 nM and 1.3 nM.

Preferably, the present invention provides an anti-VEGFR-3 antibody, or antigen-binding portion thereof, that inhibits the VEGF-$C_{\Delta N \Delta C}$ stimulated mitogenic response with an IC_{50} of between 10 nM and 5 nM. More preferably the antibody, or antigen-binding portion thereof, inhibits the VEGF-$C_{\Delta N \Delta C}$ stimulated mitogenic response with an IC_{50} of between 8 nM and 5 nM, most preferably between 6 nM and 5 nM in an assay as described in Example 5.

Preferably, the present invention provides an antibody, or antigen-binding portion thereof, that binds human VEGFR-3 and which comprises a light chain variable region (LCVR) and a heavy chain variable region (HCVR), wherein the LCVR comprises

complementarity determining regions (CDRs) LCDR1, LCDR2, and LCDR3 and the HCVR comprises CDRs HCDR1, HCDR2 and HCDR3, wherein LCDR1 comprises the amino sequence of SEQ ID NO: 1, LCDR2 comprises the polypeptide of SEQ ID NO: 2, LCDR3 comprises the polypeptide of SEQ ID NO: 3, HCDR1 comprises the polypeptide of SEQ ID NO: 6, HCDR2 comprises the polypeptide of SEQ ID NO: 7 and HCDR3 comprises the polypeptide of SEQ ID NO: 8.

More preferably, the present invention provides an antibody, or antigen-binding portion thereof, that binds human VEGFR-3 and that comprises an LCVR polypeptide of SEQ ID NO: 5 and an HCVR polypeptide of SEQ ID NO: 10.

More preferably, the present invention provides an antibody, or antigen-binding portion thereof, that binds human VEGFR-3 and that comprises a light chain comprising the polypeptide of SEQ ID NO: 15 and a heavy chain comprising the polypeptide of SEQ ID NO: 16.

Still more preferably, the present invention provides an antibody, or antigen-binding portion thereof, that binds human VEGFR-3 and that comprises two light chains comprising the polypeptide of SEQ ID NO: 15 and two heavy chain comprising the polypeptide of SEQ ID NO: 16.

Preferably, the invention provides an antibody, or antigen-binding portion thereof that competes with an antibody of the invention for binding to human VEGFR-3.

Preferably, the invention provides an antibody, or antigen-binding portion thereof, that is a human antibody.

Preferably, the invention provides an antibody, or antigen-binding portion thereof, that is a human-engineered antibody.

Definitions

The term "antibody" as used herein is intended to refer to monoclonal antibodies which may be fully human antibodies or human engineered antibodies, as well as digestion fragments, specified portions and variants thereof, including antibody mimetics, portions of antibodies that mimic the structure and/or function of an antibody or specified fragment or portion thereof, including single chain antibodies and fragments thereof, that retain the ability to bind to the second Ig-like domain of human VEGFR-3. For example, antibody fragments capable of specifically binding the second Ig-like domain of human

VEGFR-3 embraced by the present invention include Fab fragments (*e.g.*, by papain digestion), a Facb fragment (*e.g.*, by plasmin digestion), $F(ab')_2$ fragments (*e.g.* by pepsin digestion) and disulphide-stabilised variable fragments (dsFv) or single chain variable fragments (scFv) generated by molecular biology techniques. Antibody fragments are also intended to include, *e.g.*, domain deleted antibodies, diabodies and triabodies that retain the ability to bind to the second Ig-like domain of human VEGFR-3.

Antibodies include immunoglobulin molecules comprising four polypeptide chains, two heavy (H) chains and two light (L) chains inter-connected by disulfide bonds. Each heavy chain is comprised of a heavy chain variable region (abbreviated herein as HCVR) and a heavy chain constant region. The heavy chain constant region contains three domains, CH1, CH2 and CH3. Each light chain is comprised of a light chain variable region (abbreviated herein as LCVR) and a light chain constant region. The light chains of antibodies from any vertebrate species can be assigned to one of two clearly distinct types, named kappa (κ) and lambda (λ), based on the amino acid sequences of their constant domains. The expression LCVR, as used herein, is intended to include both the variable regions from kappa-type light chains (Vκ) and the variable regions from lambda-type light chains (Vλ). The light chain constant region is comprised of one domain, CL. The HCVR and LCVR regions include regions of sequence hypervariability, termed complementarity determining regions (CDRs), interspersed with regions that are more conserved, termed framework regions (FR). Each HCVR and LCVR is composed of three CDRs and four FRs, arranged from amino-terminus to carboxy-terminus in the following order: FR1-CDR1-FR2-CDR2-FR3-CDR3-FR4. For purposes of the present invention, the LCVR CDRs are abbreviated LCDR1, LCDR2 and LCDR3, and the HCVR CDRs are abbreviated HCDR1, HCDR2 and HCDR3.

Depending on the amino acid sequence of the constant domain of their heavy chains, antibodies can be assigned to different classes. There are five major classes of intact antibodies: IgA, IgD, IgE, IgG, and IgM. Several of these may be further divided into subclasses (isotypes), *e.g.*, IgG1, IgG2, IgG3, IgG4, IgA, and IgA2. The heavy-chain constant domains that correspond to the different classes of antibodies are called alpha (α), delta (Δ), epsilon (ε), gamma (γ), and mu (μ), respectively. The subunit structures and three-dimensional configurations of different classes of immunoglobulins are well

known. The present invention includes antibodies that fall into any of the aforementioned classes or subclasses (isotypes).

As used herein, a "monoclonal antibody" refers to an antibody obtained from a population of substantially homogeneous antibodies, *e.g.*, the individual antibodies comprising the population are substantially identical except for possible naturally occurring mutations or minor post-translational variations that may be present. Monoclonal antibodies are highly specific, being directed against a single antigenic site (also known as determinant or epitope), which as taught herein are contained in the second Ig-like domain of a mammalian VEGFR-3. Furthermore, in contrast to conventional (polyclonal) antibody preparations which typically include different antibodies directed against different determinants, each monoclonal antibody is directed against a single determinant on the antigen. The modifier "monoclonal" indicates the character of the antibody as being obtained from a substantially homogeneous population of antibodies, and is not to be construed as requiring production of the antibody by any particular method.

As used herein, a "human antibody" refers to antibodies having variable and constant regions corresponding to human germline immunoglobulin sequences (as described in Kabat, *et al.*, (1991) *Sequences of Proteins of Immunological Interest*, 5th Edition, U.S. Department of Health and Human Services, NIH Publication No. 91-3242). The term "human antibody," as used herein, is not intended to include antibodies in which CDR sequences derived from the germline of another mammalian species, such as a mouse, have been grafted onto human framework sequences.

Modifications to the amino acid sequence of Antibody 1 as disclosed herein are included within the scope of the present invention, particularly in connection with improvements in the binding affinity and/or other biological properties of the antibodies. In this context, the term "human engineered antibody", as used herein, refers to additional antibodies that have similar functional properties to Antibody 1 (e.g. the ability to bind human VEGFR-3 at an epitope comprising P219 and V175) and which have framework regions that are substantially human or fully human surrounding CDRs that are derived from Antibody 1. Substantially human frameworks in the context of the present invention are those that have at least 80% sequence identity to the framework regions of Antibody 1. Preferably, such substantially human frameworks have at least about 85%, about 90%,

about 95%, or about 99% sequence identity to the framework regions of Antibody 1. Human germline sequences are described in WO 2007/044411. For example, germline light chain frameworks may be selected from the group consisting of: A11, A17, A18, A19, A20, A27, A30, LI, L1I, L12, L2, L5, L15, L6, L8, O12, O2, and O8 and germline heavy chain framework regions may be selected from the group consisting of: VH2-5, VH2-26, VH2-70, VH3-20, VH3-72, VHI-46, VH3-9, VH3-66, VH3-74, VH4-31, VH I -18, VH I -69, VH3-11, VH3-15, VH3-21, VH3-23, VH3-30, VH3-48, VH4-39, VH4-59, and VH5-5I.

Human engineered antibodies derived from Antibody 1 may include deletions from and/or insertions into and/or substitutions of residues within the sequence of Antibody 1. However, the final construct must retain the desired functional characteristics of Antibody 1 (e.g. the ability to bind human VEGFR-3 at an epitope comprising P219 and V175).

Human engineered antibodies having similar functional properties to Antibody 1 can be generated using several different approaches, with each approach starting with Antibody 1 (i.e. an antibody having LCVR and HCVR sequences as shown in SEQ ID NO: 5 and SEQ ID NO: 10 respectively) as a template or parent antibody to make additional antibodies. In a first approach, the CDRs of Antibody 1 are grafted into a different human framework that has a high sequence identity with the framework regions of Antibody 1. The sequence identity of the new framework will generally be at least 80%, at least 85%, at least 90%, at least 95% or at least 99% identical with the corresponding framework in Antibody 1. This grafting may result in a reduction in binding affinity compared to Antibody 1. If this is the case, the framework can be back-mutated to the framework of Antibody 1 at certain positions based on specific criteria published by Queen *et al., Proc. Natl. Acad. Sci. USA* 88, 2869 (1991). The identification of residues to consider for back-mutation may be carried out as follows: When an amino acid falls under any of the following categories, the framework amino acid of the human germline sequence that is being used (acceptor framework) is replaced by a framework amino acid from the framework of Antibody 1 (donor framework):

(a) the amino acid in the human framework region of the acceptor framework is unusual for human frameworks at that position, whereas the corresponding amino acid in Antibody 1 is typical for human frameworks at that position;

(b) the position of the amino acid is immediately adjacent to one of the CDRs; or

(c) any side chain atom of a framework amino acid is within about 5-6 angstroms (centre-to-centre) of any atom of a CDR amino acid in a three dimensional immunoglobulin model.

When each of the amino acids in the human framework region of the acceptor framework and the corresponding amino acid in the Antibody 1 framework is unusual for human frameworks at that position, such an amino acid may be replaced by an amino acid typical for human frameworks at that position. These back-mutation criteria enable one to recover the activity of Antibody 1.

In a second approach, human engineered antibodies derived from Antibody 1 which retain the functional properties of Antibody 1, (e.g. the ability to bind human VEGFR-3 at an epitope comprising P219 and V175), can be generated by mutating the CDRs of Antibody 1 (either randomly or in a biased fashion to avoid degeneracy of the amino acid code) whilst retaining the framework regions of Antibody 1. Preferably, the mutations (deletions, insertions and/or substitutions) in the amino acid sequences of the CDRs of human engineered antibodies derived from Antibody 1 are limited to a maximum of three mutations, more preferably two mutations or most preferably a single mutation in the CDR sequences of the human engineered antibody when compared with the CDR sequences of Antibody 1. Where more than one mutation is present, the mutations may be distributed across the CDR sequences in a variety of different ways. For example, all of the mutations may occur in a single CDR sequence (e.g. LCDR1), each mutation may occur in a different CDR sequence or two mutations may be found in one CDR sequence and a third mutation found in another CDR sequence. This results in the creation of a combinatorial library of human engineered antibodies, wherein the CDR sequences are mutated at one or more positions as described above, whilst retaining the framework regions of Antibody 1. The library can be screened for additional variants that have similar or improved functional properties when compared with Antibody 1.

A further approach to generate human engineered antibodies derived from Antibody 1 (and which retain the functional properties of Antibody 1, e.g. the ability to bind human VEGFR-3 at an epitope comprising P219 and V175) is to combine the two approaches described above and make changes in both the frameworks and the CDRs. In

other words, after grafting the CDRs of Antibody 1 into a different framework, specific framework residues may be back-mutated in addition to making changes in the CDRs. The general principle of this methodology is described in Wu et al. (1999), *J. Mol. Biol.* 294: 151-162.

The amino acid changes also may alter post-translational processes of the human engineered antibodies, such as changing the number or position of glycosylation sites.

Substitution variants may be generated by substituting one or more hyper-variable region residues of Antibody 1. One such method for generating substitutional variants is known as affinity maturation using phage display. Several hypervariable region sites (e.g., 6-7 sites) are mutated to generate all possible amino substitutions at each site. The antibody variants thus generated are displayed in a monovalent fashion from filamentous phage particles as fusions to the gene III product of M13 packaged within each particle. The phage-displayed variants are then screened for their biological activity (e.g., binding affinity) as disclosed herein.

The assays disclosed herein can be used to screen human engineered antibodies derived from Antibody 1 to identify those antibodies having the *in vitro* and *in vivo* functions as disclosed herein.

The antibodies of the present invention may be isolated antibodies. An isolated antibody is substantially free of other cellular material and/or chemicals.

The term "epitope", as used herein, refers to a particular molecular region on the surface of an antigen capable of eliciting an immune response and of binding to the specific antibody produced by such a response. An epitope may be a linear epitope (i.e. composed of contiguous amino acid residues all contained within a single short stretch of sequence) or it may be a conformational epitope (i.e. composed of amino acid residues that are in disparate parts of the linear sequence of the antigen, but which are brought together to form the antibody binding site once the antigen assumes its appropriate secondary and tertiary structure). Typically, an epitope is constituted of a small number (e.g. 2 to 5) of key amino acid residues and disruption of those residues (e.g. by mutation to a different amino acid residue) results in a significant reduction or even complete abolition of the binding between the antigen and the epitope.

Antibodies or antigen-binding fragments thereof that "compete" with the molecules disclosed herein are those that bind human VEGFR-3 at site(s) that are

identical to, or overlapping with, the site(s) at which the present molecules bind. Competing human engineered antibodies or antigen-binding fragments thereof can be identified, for example, via an antibody competition assay. For example, a sample of purified or partially purified human VEGFR-3 is bound to a solid support. An antibody of the present invention and a test monoclonal antibody or antigen-binding fragment, with either the test or antibody of the present invention labelled, are then added. If the labelled antibody and the unlabeled antibody bind to separate and discrete sites on VEGFR-3, the labelled antibody will bind to the same level whether or not the suspected competing antibody is present. However, if the sites of interaction are identical or overlapping, the unlabeled antibody will compete, and the amount of labelled antibody bound to the antigen will be lowered. If the unlabelled antibody is present in excess, no labelled antibody will bind. For purposes of the present invention, competing human engineered antibodies or antigen-binding fragments thereof are those that decrease the binding of the present antibodies by about 50%, about 60%, about 70%, about 80%, about 85%, about 90%, about 95%, or about 99%. Details of procedures for carrying out such competition assays are well known in the art and can be found, for example, in Harlow and Lane (1988) *Antibodies, A Laboratory Manual*, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York, pages 567-569, ISBN 0-87969-314-2. Such assays can be made quantitative by using purified antibodies. A standard curve is established by titrating one antibody against itself, i.e., the same antibody is used for both the label and the competitor. The capacity of an unlabeled competing monoclonal antibody or antigen-binding fragment thereof to inhibit the binding of the labeled molecule to the plate is titrated. The results are plotted, and the concentrations necessary to achieve the desired degree of binding inhibition are compared.

Human VEGFR-3 exists in two forms, which are generated by mRNA transcripts of differing length. The longer transcript encodes a protein containing 65 extra amino acid residues at the C terminus when compared with the protein encoded by the shorter transcript, with the longer protein being the major form detected in tissues. The two variants are identical in their N-terminal extracellular domains. The term "human VEGFR-3", unless otherwise stated, refers to both variants of wild type human VEGFR-3 (i.e. SEQ ID NO: 17 and SEQ ID NO: 18) that are derived from the alternate mRNA transcripts.

The nucleic acid and corresponding amino acid sequences of the LCVR region of Antibody 1 are designated as SEQ ID NOS: 4 and 5 respectively.

The nucleic acid and corresponding amino acid sequences of the HCVR region of Antibody 1 are designated herein as SEQ ID NOS: 9 and 10 respectively.

The nucleic acid and corresponding amino acid sequences of the light chain of Antibody 1 are designated herein as SEQ ID NOS: 11 and 12 respectively. Amino acid residues 1-19 of SEQ ID NO: 12 constitute a secretory sequence useful in expression and extraction of the light chain from various mammalian host cell lines, but which is not present in the mature antibody. The amino acid sequence of the mature light chain of Antibody 1 is designated herein as SEQ ID NO: 15.

The nucleic acid and corresponding amino acid sequences of the heavy chain of Antibody 1 are designated as SEQ ID NOS: 13 and 14 respectively. As in the case of the sequence for the light chain, amino acid residues 1-19 of SEQ ID NO: 14 constitute a secretory sequence useful in expression and extraction of the heavy chain from various mammalian host cell lines, but which is not present in the mature antibody. The amino acid sequence of the mature heavy chain of Antibody 1 is designated herein as SEQ ID NO: 16.

Specificity of an antibody can be determined based on affinity and/or avidity. Affinity, represented by the equilibrium constant for the dissociation of an antigen with an antibody (K_d), measures the binding strength between an antigenic determinant and an antibody-binding site. Avidity is the measure of the strength of binding between an antibody with its antigen. Avidity is related to both the affinity between an epitope with its antigen binding site on the antibody, and the valence of the antibody, which refers to the number of antigen binding sites of a particular epitope. The lesser the value of the K_d, the stronger the binding strength between an antigenic determinant and the antibody binding site.

The present invention also provides a polynucleotide that encodes a heavy chain of an antibody of the present invention (e.g. Antibody 1 – SEQ ID NO: 13), or polynucleotides that comprise any one of the VH regions or a portion thereof, or any one of the VH CDRs, including any variants thereof, of an antibody of the present invention (e.g. Antibody 1). The present invention also provides a polynucleotide that encodes a light chain of an antibody of the present invention (e.g. Antibody 1 – SEQ ID NO: 11), or

polynucleotides that comprise any one of the VL regions or a portion thereof, or any one of the VH CDRs, including any variants thereof, of an antibody of the present invention (e.g. Antibody 1).

The invention also includes expression vectors comprising any of the polynucleotides described herein. Exemplary vectors include plasmids, phagemids, cosmids, viruses and phage nucleic acids or other nucleic acid molecules that are capable of replication in a prokaryotic or eukaryotic host such as a cell, *e.g.*, a mammalian cell. Typical expression vectors contain transcription and translation terminators, initiation sequences, and promoters useful for regulation of the expression of the nucleic acid molecules of the invention. The vectors may also contain genetic expression cassettes containing an independent terminator sequence, sequences permitting replication of the vector in both eukaryotes and prokaryotes, *i.e.*, shuttle vectors and selection markers for both prokaryotic and eukaryotic systems. The vectors typically contain a marker to provide a phenotypic trait for selection of transformed hosts such as conferring resistance to antibiotics such as ampicillin or neomycin.

Suitable promoters include constitutive promoters and inducible promoters. Representative expression control sequences/promoters include the *lac* system, the *trp* system, the *tac* system, the *trc* system, major operator and promoter regions of phage lambda, the control region of *fd* coat protein, the glycolytic promoters of yeast, *e.g.*, the promoter for 3-phosphoglycerate kinase, the promoters of yeast acid phosphatase, *e.g.*, *Pho5*, the promoters of the yeast alpha mating factors, promoters derived from the human cytomegalovirus, metallothionine promoter, murine mammary tumor virus promoter, Rous sarcoma virus promoter, polyhedrin promoter and promoters derived from polyoma, adenovirus, retrovirus, and simian virus, *e.g.*, the early and late promoters of SV40.

The invention also includes non-human hosts such as cells containing a polynucleotide or a vector of the invention. By "host" it is meant a non-human multicellular organism or a “host cell”, which refers to a cell or population of cells into which a polynucleotide or vector of the invention is introduced. A host cell of the present invention may be a eukaryotic cell or cell line, such as a plant, animal, vertebrate, mammalian, rodent, mouse, primate, or human cell, or cell line. Suitable eukaryotic cells include yeast and other fungi, insect cells, plant cells, human cells, and animal cells, including mammalian cells, such as hybridoma lines, COS cells, NS0 cells and CHO

cells. By "a population of host cells," it is meant a group of cultured cells into which a polynucleotide or vector of the present invention can be introduced and expressed. Any host cells which will support expression from a polynucleotide or vector of the invention is intended.

A host of the present invention may also be prokaryotic. Suitable prokaryotic hosts include, for example, *E. coli*, such as *E. coli* SG-936, *E. coli* HB 101, *E. coli* W3110, *E. coli* X1776, *E. coli* X2282, *E. coli* DHI, and *E. coli* MRC1, *Pseudomonas*, *Bacillus*, such as *Bacillus subtilis*, and *Streptomyces*.

The invention also includes methods of producing an antibody of the present invention, which entails culturing a host cell expressing one or more polynucleotides encoding an antibody of the present invention, and recovering the antibody from the culture medium.

The antibodies of the present invention can be used as medicaments in human medicine, administered by a variety of routes. Most preferably, pharmaceutical compositions comprising the antibodies of the present invention are for parenteral administration. Such pharmaceutical compositions can be prepared by methods well known in the art (*See*, e.g., *Remington: The Science and Practice of Pharmacy*, 19th ed. (1995), A. Gennaro et al., Mack Publishing Co.) and comprise an antibody as disclosed herein, and a pharmaceutically acceptable carrier, diluent, or excipient.

As used herein, the terms “inhibit” or “neutralize” with respect to a bioactivity of an antibody of the invention means the ability to substantially antagonize, prohibit, prevent, restrain, slow, disrupt, eliminate, stop, reduce or reverse a bioactivity of human VEGFR-3, including, but not limited to, a human VEGFR-3 bioactivity as measured in Example 4 or 5 herein.

As used herein, the terms "treat" and "treatment" refer to therapeutic treatment, wherein the object is to prevent or slow down (lessen) an undesired physiological change associated with a disease or disorder. Beneficial or desired clinical results include alleviation of symptoms, diminishment of the extent of a disease or disorder, stabilization of a disease or disorder (*i.e.*, where the disease or disorder does not worsen), delay or slowing of the progression of a disease or disorder, amelioration or palliation of the disease or disorder, and remission (whether partial or total) of the disease or disorder, whether detectable or undetectable. "Treatment" can also mean prolonging survival as

compared to expected survival if not receiving treatment. Those in need of treatment include those already with the disease or disorder as well as those prone to having the disease or disorder.

The compositions of the invention may include a "therapeutically effective amount" of an antibody of the invention. A "therapeutically effective amount" refers to an amount effective, at dosages and for periods of time necessary, to achieve the desired therapeutic result. A therapeutically effective amount of the antibody may vary according to factors such as the disease state, age, sex, and weight of the individual, and the ability of the antibody or antibody portion to elicit a desired response in the individual. A therapeutically effective amount is also one in which any toxic or detrimental effects of the antibody or antibody portion are outweighed by the therapeutically beneficial effects.

Therapy may be "first-line", *i.e.*, as an initial treatment in patients who have had no prior anti-cancer treatments, either alone or in combination with other treatments; or "second-line", as a treatment in patients who have had one prior anti-cancer treatment regimen, either alone or in combination with other treatments; or as "third-line", "fourth-line", etc. treatments, either alone or in combination with other treatments.

Therapy may also be given to patients who have had previous treatments which have been partially successful but are intolerant to the particular treatment. Therapy may also be given as an adjuvant treatment, *i.e.*, to prevent reoccurrence of cancer in patients with no currently detectable disease or after surgical removal of tumor.

Cancers treated by the invention include primary tumors and secondary or metastatic tumors that have metastasized through the lymph system (including those metastasized from lung, breast, or prostate).

Cancers that may be treated include tumors that are not vascularized, or not yet substantially vascularized, as well as vascularized tumors. The cancers may be comprised of non-solid tumors (such as leukemias and lymphomas) or may be solid tumors.

Types of cancers to be treated with the antibodies of the invention include ovarian cancer, human erythroleukaemia, head and neck cancer, breast cancer, renal cell carcinoma, pancreatic cancer, lung cancer and colon cancer. Further, given the role of the VEGF-C/VEGFR-3 pathway in promoting lymphangiogenesis and given that, for most types of cancer, the first site of metastasis are lymph nodes, blocking the VEGF-C/VEGFR-3 pathway would be expected to inhibit lymph node metastases, e.g. from

breast, pancreatic, gastric or colorectal cancer (Roberts *et al.*, Cancer Res., 66(5), 2650-2657 (2006)).

The antibody may be administered alone (monotherapy), or in combination with one or more therapeutically effective agents or treatments (combination therapy). The other therapeutically effective agent may be conjugated to the antibody, incorporated into the same composition as the antibody, or may be administered as a separate composition. The other therapeutically effective agent or treatment may be administered prior to, during and/or after the administration of the antibody. The other therapeutically effective agent may be administered to augment the therapeutic effect of the antibody, or to diminish the negative side effects of the antibody.

The methods of treatment described herein can be used to treat any suitable mammal, including primates, such as monkeys and humans, horses, cows, cats, dogs, rabbits, and rodents such as rats and mice. In one embodiment, the mammal to be treated is human.

It will be seen by reference to the following examples that Antibody 1 binds an epitope on human VEGFR-3 comprising P219 as the dominant constituent of the epitope, V175 as a subordinate constituent of the epitope and L221 as a minor constituent of the epitope. Further it can be seen that Antibody 2 (a reference rat monoclonal antibody raised against murine VEGFR-3) binds an epitope on murine VEGFR-3 which comprises the residues L219 and V221. In addition, the examples also demonstrate that Antibody 1 has high affinity for human VEGFR-3 (56 pM), is able to block the binding of the ligand VEGF-C to VEGFR-3, is able to block the VEGF-C stimulated mitogenic response and is effective in *in vivo* xenograft models of ovarian cancer and HEL. Finally, it can also be seen that Antibody 2 is effective in xenograft models of head and neck cancer, breast cancer, lung cancer, RCC, pancreatic cancer and colon cancer.

EXAMPLE 1

The antibodies of the present invention may be made and purified using various suitable methods that are well known in the art. For example an appropriate host cell, such as HEK 293 EBNA or CHO, is either transiently or stably transfected with an expression system for secreting antibodies using an optimal predetermined light chain to heavy chain vector ratio or a single vector system encoding both a light chain (e.g. SEQ

ID NO: 12 for Antibody 1) and a heavy chain (e.g. SEQ ID NO: 14 for Antibody 1). Clarified medium into which the antibody has been secreted is purified using any of many commonly-used techniques. For example, the medium may be conveniently applied to a Protein A or G Sepharose FF column that has been equilibrated with a compatible buffer, such as phosphate buffered saline (pH 7.4). The column is washed to remove nonspecific binding components. The bound antibody is eluted, for example, by pH gradient (such as 0.1 M sodium phosphate buffer pH 6.8 to 0.1 M sodium citrate buffer pH 2.5). Antibody fractions are detected, such as by SDS-PAGE, and then are pooled. Further purification is optional, depending on the intended use. The antibody may be concentrated and/or sterile filtered using common techniques. Soluble aggregate and multimers may be effectively removed by common techniques, including size exclusion, hydrophobic interaction, ion exchange, or hydroxyapatite chromatography. The purity of the antibody after these chromatography steps is greater than 99%. The product may be immediately frozen at -70°C or may be lyophilized. The CDR and variable region amino acid sequences (determined using the Kabat method) for Antibody 1 are provided below.

Table 1. Light Chain CDR Amino Acid Sequences

mAb	LCDR1	LCDR2	LCDR3
Antibody 1	RASQSISSSFLA (SEQ ID NO: 1)	AASTRAT (SEQ ID NO: 2)	QQYGRSLS (SEQ ID NO: 3)

Table 2. Heavy Chain CDR Amino Acid Sequences

mAb	HCDR1	HCDR2	HCDR3
Antibody 1	GNSATWN (SEQ ID NO: 6)	RTYYRSKWNHDYAESVKS (SEQ ID NO: 7)	GDSSSWYAFDY (SEQ ID NO: 8)

Table 3. LCVR, HCVR, Light chain & Heavy chain Amino Acid Sequences

mAb	LCVR	HCVR	**Light chain** (signal sequence at residues 1-19)	**Heavy chain** (signal sequence at residues 1-19)
Antibody 1	SEQ ID NO: 5	SEQ ID NO: 10	SEQ ID NO: 12	SEQ ID NO: 14

EXAMPLE 2

In the following example, experiments are described which lead to the elucidation of the epitope on the VEGFR-3 receptor to which Antibody 1 and Antibody 2 bind.

Production of VEGF-$C_{\Delta N\Delta C}$ and mouse and human sR3-AP. Recombinant mature human VEGF-$C_{\Delta N\Delta C}$ is generated as described in Pytowski, *et al.* (2005) J. Natl. Cancer Inst. *97(1)*:14-21. The full-length (i.e. Ig domains 1-7) soluble extracellular regions of human and mouse VEGFR-3 (sR3) are fused to cDNA encoding human alkaline phosphatase (AP) to generate the fusion protein sR3-AP (Persaud *et al.* (2004) J. Cell Science *117*:2745-56; Pytowski, *et al.* (2005) J. Natl. Cancer Inst. *97(1)*:14-21).

Production of mouse-human chimeric sR3-AP and site-directed mutants of sR3-AP. Chimeric mouse-human and human-mouse constructs of the 3 N-terminal immunoglobulin-like (Ig) domains of sR3-AP are prepared using overlapping PCR technique (Ho, *et al.* (1989), Gene 77:51-59) and are cloned into the AP expression vector (Persaud, *et al.*, *supra*; Pytowski, *et al.*, *supra*). Site-directed mutagenesis of sR3-AP constructs is performed using the QuickChange II XL Site-Directed Mutagenesis Kit per manufacturer's instructions (Stratagene). The presence of desired substitutions is verified by sequencing of both strands of the cDNA across the mutated region using the ABI Prism 3100 Genetic analyzer (Applied Biosystems) and the BigDye Terminator v3.1 Cycle Sequencing Kit (Applied Biosystems).

Expression of soluble VEGFR-3 proteins: The cDNA encoding extracellular regions of wild-type and mutated sR3-AP is transfected into FreeStyle™ 293 cells (Invitrogen, #R79007) cultured in suspension in a chemically-defined, protein-free FreeStyle™ 293 Expression Medium (Invitrogen, #12338026). In some cases, selected sR3-AP is purified using anti-AP antibody-affinity chromatography as previously described (Zhu, *et al.*, (1998) Cancer Res. *58*:3209-14) or by affinity chromatography with immobilized mAbs Antibody 1 and Antibody 2 described herein.

Normalization of sR3 proteins in conditioned medium (CM): CM is assayed for AP activity using the Great EscAPe™ SEAP Chemiluminescence kit 2.0 (Clontech, Mountain View, CA) using the Tropix TR7171 luminometer (Applied Biosystems, Foster City, CA). The CM is diluted in proportion to their AP activity in phosphate-buffered saline (PBS) containing 1% bovine serum albumin (PBS-BSA) and retested to verify the normalization by AP activity measurements and by Western blotting.

sR3-AP binding assays: One hundred (100) □l of normalized CM is transferred to 96-well microliter plates coated with either VEGF-$C_{\Delta N\Delta C}$, or the test antibody

(200ng/well). After 2 hr incubation, the plates are washed 5 times and bound sR3-AP is detected by chemiluminescence.

The binding specificity of Antibody 1 and a reference rat monoclonal antibody against mouse VEGFR-3 (designated 'Antibody 2') are tested by ELISA using the immobilized extracellular portions of mouse and human VEGFR-3 (Ig domains 1-7). Antibody 1 and Antibody 2 bind strongly and in a dose-dependent manner to human and mouse VEGFR-3 respectively. The human antibody Antibody 1 shows slight but reproducible cross-reactivity with mouse VEGFR-3 at concentrations exceeding 10 nM. In contrast, Antibody 2 fails to demonstrate any detectable binding to human VEGFR-3.

Epitopes of Antibody 1 and Antibody 2 are entirely contained within the second immunoglobulin-like (Ig) domain of VEGFR-3: The ligand-binding sites of all three members of VEGF receptor family are contained within the three N-terminal Ig domains of the extracellular domain. The species-specificity of Antibody 1 and Antibody 2 is utilized to ascertain which of the first three Ig domains contains the epitopes of these antibodies. DNA sequences encoding mouse and human Ig domains 1-3 are swapped in various combinations to form the following VEGFR-3 extracellular domain constructs: i) wild-type human; ii) wild-type mouse; iii) chimera 1 (human Ig1–human Ig2–mouse Ig3); chimera 2 (human Ig1–mouse Ig2–mouse Ig3); (iv) chimera 3 (mouse Ig1–human Ig2–mouse Ig3) and (v) chimera 4 (human Ig1–mouse Ig2–human Ig3). The constructs are expressed as fusion proteins with alkaline phosphatase (AP) Persaud, *et al.*, *supra*. The encoded proteins are isolated from conditioned media (CM) of transiently transfected cells and normalized to equal protein concentration and AP activity. Mouse and human sR3-AP bind human VEGF-$C_{\Delta N \Delta C}$ with similar affinity. Thus, the ability of the various sR3-AP chimeras to bind human VEGF-$C_{\Delta N \Delta C}$ is tested as a means to determine that correct protein folding is preserved in the chimeric receptors. The ability of Antibody 1 and Antibody 2 to bind to chimeric proteins 1 to 4 show that the epitopes of Antibody 1 and Antibody 2 are completely contained within the second Ig domain (Ig2) of human and mouse VEGFR-3 respectively. For example, Antibody 1 will not bind to chimera 2 or chimera 4, which contain the mouse VEGFR3 sequence at Ig domain 2.

Identification of amino acids of VEGFR-3 that constitute the epitopes of Antibody 1 and Antibody 2: The twelve (12) positions within the amino acid sequence of the

second Ig domain of VEGFR-3 that differ between the human and mouse proteins are identified. These positions along with the residues in the human and mouse proteins are shown in Table 4.

Table 4

Position	**153**	**167**	**175**	**177**	**184**	**192**	**194**	**199**	**214**	**219**	**221**
Human	A	V	V	W	V	L	S	H	D	P	L
Mouse	S	I	A	H	L	R	P	R	N	L	V

Site-directed mutagenesis is used to individually change each of the species-specific amino acids in the human and mouse sequence to the corresponding orthologue of the opposite species; each mutated protein is then expressed in the context of sR3-AP proteins encoding the first, second and third Ig domains. Epitope mapping is accomplished by two complementary approaches. In the first approach, the loss of binding of the human-specific Antibody 1 and the mouse-specific Antibody 2 to their respective human and mouse sR3-AP due to individual amino acid substitutions to the mouse or human orthologues is measured. In the second approach, the gain of binding of Antibody 1 and Antibody 2 to the sR3-AP of the opposite species mediated by individual amino acid substitutions to the mouse or human orthologues is measured. A residue is considered as a strong candidate to constitute a part of an epitope of an antibody if the mutations described above lead to loss of binding with the first approach and a gain of binding with the second approach. For all mutant proteins, the binding to VEGF-$C_{\Delta N \Delta C}$ is measured in parallel to check against gross changes in protein structure.

The binding experiments are carried out in triplicate and the results are calculated as the average and standard deviation of the three separate experiments. Of the 12 substitutions examined in the Ig2 domain of human sR3-AP, only one (V184L) leads to complete loss of binding to both VEGF-$C_{\Delta N \Delta C}$ and Antibody 1. This change is thus considered as disturbing the overall structure of the human sR3-AP. The substitution V175A leads to approximately 50% loss of binding to both VEGF-C and to Antibody 1. The substitution P219L results in approximately 75% loss in binding to VEGF-C and nearly complete (~95%) loss of binding to Antibody 1. Change of L221 to V does not affect binding of human sR3-AP to VEGF-C but reduces binding to Antibody 1 by about

55%. The remaining substitutions do not lead to a substantial loss of binding to either VEGF-C or Antibody 1.

When individual mouse to human mutations in the mouse sR3-AP are examined for increased binding to the human specific Antibody 1, a significant increase above binding to wild-type mouse sR3-AP is observed for the substitutions A175V (~12-fold) and L219P (~60-fold). None of the other substitutions lead to a significant increase of binding above background.

The criteria are thus set for considering an amino acid to comprise an epitope for Antibody 1 wherein human to mouse orthologue substitution in human sR3-AP would significantly reduce binding to Antibody 1 while reducing (but NOT abolishing) or leaving unaffected the binding to VEGF-$C_{\Delta N \Delta C}$. In addition, for an amino acid to comprise an epitope for Antibody 1, mouse to human orthologue substitution in mouse sR3-AP would lead to significant binding to Antibody 1. For Antibody 1, these criteria are satisfied by V175 and P219 of human sR3-AP. V184 is excluded because a substitution in human sR3-AP to the mouse orthologue abolishes both binding to VEGF-$C_{\Delta N \Delta C}$ and to Antibody 1 while the corresponding substitution in mouse sR3-AP to the human orthologue at this position does not lead to binding to Antibody 1. Changing leucine 221 in human sR3-AP to the corresponding murine valine reduces binding to Antibody 1 by 55%. However, the corresponding substitution in mouse sR3-AP to the human orthologue at this position does not lead to binding to Antibody 1. Therefore L221 may make a minor contribution to the epitope of Antibody 1 but does not meet all the criteria established above.

To study the role of the residue at position 221 further, the P219L and L221V mutations in human sR3-AP are combined into a single construct. The binding of the double mutant to Antibody 1 is essentially abolished as compared to the single P219L mutant that retains 5% of binding to human sR3-AP.

Taken together, these results identify P219 as the dominant and V175 as a subordinate constituent of the epitope of Antibody 1 on human VEGFR-3 and raise the possibility that L221 is also a minor component of the epitope.

An examination is then made as to which residues of Ig domain 2 of the mouse VEGFR-3 constitute the epitope of Antibody 2 using a similar method. Again, the binding experiments are carried out in triplicate and the results are calculated as the

average and standard deviation of the three separate experiments. Of the twelve individual substitutions that change the mouse amino acid into the corresponding human amino acid, four substitutions (H177W, P194S, R199H and N214D) significantly reduce binding of mouse sR3-AP to both VEGF-C and Antibody 2. Interestingly, mutations at positions 219 and 221 (L219P and V221L) reduce binding to Antibody 2 but not to VEGF-C. The corresponding human to mouse mutations in human VEGFR-3 at positions 219 and 221 (P219L and L221V) permit the binding of Antibody 2 to the human sR3-AP at levels, respectively approximately 55-fold and 10-fold, greater than the binding of Antibody 2 to the wild type human sequence. It is also demonstrated that the binding of the mouse mutant proteins containing the human orthologue amino acid at positions 219 and 221 to VEGF-$C_{\Delta N \Delta C}$ increases slightly or is unaffected while the binding of these mutant proteins to Antibody 2 is either abolished (219) or reduced by about 85% (221).

The criteria set for considering an amino acid to comprise an epitope for Antibody 2 is that human orthologue substitution in mouse sR3-AP would significantly reduce binding to Antibody 2 while reducing (but NOT abolishing) or leaving unaffected the binding to VEGF-$C_{\Delta N \Delta C}$. In addition, for an amino acid to comprise an epitope for Antibody 2, human to mouse orthologue substitution in human sR3-AP would lead to significant binding to Antibody 2. For Antibody 2, these criteria are satisfied by P219 and L221 of the mouse sR3-AP.

Another method to express the data is to calculate the percentage of maximal binding of Antibody 2 to wild type mouse sR3-AP that is reconstituted by each of the individual human to mouse orthologue mutations within the human sR3-AP sequence. This demonstrates that individually substituting P219L and L221V within the sequence of human sR3-AP results in the reconstitution of about 5% and 1% respectively of the maximal binding to Antibody 2 seen with wild type mouse sR3-AP. It is therefore concluded that L219 and V221 are constituents of the epitope of Antibody 2.

It can be seen that Antibody 1 and Antibody 2 bind highly similar epitopes in human VEGFR-3 and mouse VEGFR-3 respectively, with the residue at position 219 being the key residue in each case. The data in the following examples demonstrate that both Antibody 1 and Antibody 2 are neutralising antibodies which are able to block the activity of their respective antigens as well as inhibit tumour growth in *in vivo* xenograft

models. Such data provides further evidence to demonstrate that the novel epitope in the Ig2 domain of VEGFR-3 identified herein provides the key advantageous feature of being a neutralising epitope. Antibodies binding to said epitope are thus able to block ligand binding, VEGFR-3 signalling and inhibit tumour growth *in vivo*.

EXAMPLE 3: Affinity (K_d) Measurements for anti-VEGFR-3 antibodies

The binding kinetics of the Antibody 1 are measured by surface plasmon resonance on the BIACORE® 2000 biosensor (BIACORE®, Piscataway, NY) at 20°C. Soluble extracellular domain of human VEGFR-3 (sR3-AP) is immobilized on a sensor chip and Antibody 1 is injected over the surface of the sensor at concentrations between 0.8 and 6.25 nM. Sensograms are evaluated using the BIA Evaluation 3.2 program to determine the on rates (ka) and the off rates (kd). The dissociation constant (K_d) is calculated from the ka and kd rates using the equation: K_d = ka/kd. BIAcore kinetic analysis yields a K_d of 56 pM for the binding of Antibody 1 to immobilized sR3-AP. Thus, Antibody 1 has an extremely high affinity for human VEGFR-3 wherein said affinity is nearly 2 orders of magnitude greater than that of sR3-AP for VEGF- $C_{\Delta N \Delta C}$.

EXAMPLE 4: Blockade of VEGF-C binding to VEGFR-3 by anti-VEGFR-3 antibodies

To measure the ability of VEGFR-3 antibodies to block VEGF-C binding to human VEGFR-3, a competitive VEGF-C blocking assay is utilized. Antibodies or soluble phage particles at a concentration of 0.001 μg/ml to 5 μg/ml are mixed with 50 ng of sR3-AP, incubated at room temperature for 1 hour and transferred to 96-well microtiter plates coated with VEGF- $C_{\Delta N \Delta C}$ (200 ng/well). After an additional 2 hours, the plates are washed five times and p-nitrophenyl phosphate (Sigma) is added to quantify the bound sR3-AP molecules at OD_{405nm}. The IC_{50}, i.e. the concentration of Fab or IgG required for 50% inhibition of sR3-AP binding to VEGF- $C_{\Delta N \Delta C}$, is calculated. The Fab and IgG forms of Antibody 1 strongly block the binding of sR3-AP to immobilized VEGF-$C_{\Delta N \Delta C}$ with an IC_{50} of 2 and 1.3 nM, respectively. By contrast, a control antibody which targets the human IGF receptor and is obtained from the same phage library is inactive.

EXAMPLE 5: Inhibition of VEGF- $C_{\Delta N \Delta C}$ -stimulated mitogenic response by Antibody 1

In order to test the ability of Antibody 1 to inhibit signal transduction mediated by VEGFR-3, a NIH-3T3 cell line is prepared that expresses a chimeric form of VEGFR-3 which fuses the extracellular domain of human VEGFR-3 with the transmembrane and cytoplasmic domains of human cFMS. No endogenous expression of VEGFR-3 by the parental cells is detected, and localization of the chimeric receptor on the plasma membrane is shown by FACS analysis. VEGFR-3-FMS cells (5×10^3 cells/well) are plated onto 96-well tissue culture plates (Wallac, Gaithersburg, MD) in 200 ml of serum free medium and incubated at 37°C for 72 hours. Antibody up to 20 nM is added and pre-incubated at 37°C for 1 hour, after which VEGF- $C_{\Delta N \Delta C}$ is added to a final concentration of 20 ng/ml. After 18 hours of incubation, 0.25 mCi of tritiated thymidine ([^{3}H]-TdR) (Amersham) is added to each well and incubated for an additional 4 hours. The cells are placed on ice, washed once with serum containing medium, incubated for 10 minutes at 4°C with 10% TCA, and solubilized in 25 ml of 2% SDS. Incorporated radioactivity is determined on a scintillation counter (Wallac, Model 1450 Microbeta Scintillation Counter). The incorporation of [^{3}H]-TdR by the NIH-3T3 cells that express VEGFR-3-cFMS is stimulated by at least threefold by the addition of VEGF- $C_{\Delta N \Delta C}$. The mitogenic response is specifically blocked in a dose-dependent manner by Antibody 1, with an IC_{50} value of 5 nM.

EXAMPLE 6: Anti-VEGFR-3 monoclonal antibodies in a human ovarian carcinoma cell line subcutaneous xenograft model

In this experiment, anti-VEGFR3 monoclonal antibodies Antibody 1 and Antibody 2 are used alone or in combination on xenografts of human ovarian carcinoma cell line OVCAR-8 (NCI-60, Developmental Therapeutics Program, NCI/NIH) in immunodeficient SCID mice. OVCAR-8 is one of very few human carcinoma cell lines that express human VEGFR-3. The expectation in this experiment is that Antibody 2 will block angiogenesis and lymphangiogenesis in the mouse stroma of the growing tumor while having no effect on the tumor. In contrast, Antibody 1 is expected to only act on the human carcinoma cells.

OVCAR-8 cells are injected s.c. into the left flank of 75 female athymic mice at 1 x 10^7 cells/mouse. When tumors reach ~180mm^3, 13 days after cell implantation, the mice are randomized and divided into five treatment groups (n = 12): USP saline control, 0.5ml/dose; Rat IgG at 40mg/kg; Antibody 1 at 40mg/kg; Antibody 2 at 40mg/kg and Antibody 1 at 40mg/kg + Antibody 2 at 40mg/kg. Anti-VEGFR-3 mAbs and controls are given i.p. on a Mon-Wed-Fri schedule. Tumor measurements are recorded twice weekly. The T/C% is calculated for each treatment group as the ratio of the relative tumor volume of each treatment group versus the relative tumor volume of the saline control group. RM ANOVA through Day 41 is used to compare tumor growth among the treatment groups.

Antibody 2 significantly inhibits the growth of OVCAR-8 tumors with a T/C% of 71% (P = 0.0299). Antibody 1 has a trend toward efficacy in this model (T/C% was 74%) but the degree of tumor inhibition does not reach significance (P > 0.05). This may be due to the wide range of tumor volumes at Day 41 in this group (335-1504mm^3) that may have prevented this group from reaching statistical significance.

The combination of Antibody 1 and Antibody 2 together enhances the tumor inhibitory effect of Antibody 2 (T/C% was 47% and the combination effect reaches significance compared to either antibody alone ($P \leq 0.0358$)).

Antibody 2 significantly inhibits the growth of OVCAR-8 tumors while Antibody 1 appears to be efficacious in this model without reaching statistical significance. However, since the combination of the two monoclonal antibodies significantly inhibits OVCAR-8 tumor growth compared to Antibody 2 monotherapy, it is concluded that Antibody 1 demonstrated therapeutic efficacy in this experiment. Accordingly, the antibodies of the present invention demonstrate anti-tumour efficacy in an *in vivo* model of ovarian cancer.

EXAMPLE 7: Anti-VEGFR-3 mAb Antibody 1 in the human erythroleukemia (HEL) cell subcutaneous xenograft model

In the following example, a significant anti-tumor effect is measured for Antibody 1 in the human erythroleukemic (HEL) cell subcutaneous xenograft model.

Nu/nu mice (female, 7-8 weeks) housed 5-6 per cage are injected subcutaneously with 5 x10^6 HEL cells/mouse. When tumors reach approximately 400 mm^3, mice are randomized by tumor volume into one of four treatment groups (n=11/group):

1) USP saline, 10 ml/kg,

2) Antibody 1, 60 mg/kg (loading dose of 150 mg/kg on Day 1)

3) Antibody 1, 20 mg/kg (loading dose of 50 mg/kg on Day 1)

4) Antibody 1, 6 mg/kg (loading dose of 15 mg/kg on Day 1)

Antibody 1 is prepared in USP saline. Treatments are administered i.p., twice a week, at 10 ml dosing solution/kg of body weight. The first dose, the loading dose, is administered on Day 1, followed by the maintenance dose administered twice a week for the duration of the study. Tumor volumes are measured twice a week. Body weights are recorded at least twice a week for the duration of the study. The T/C% is calculated for each treatment group on Day 18 as the ratio of the relative tumor volume of each treatment group versus the relative tumor volume of the saline control group (Table 5). Tumor growth and body weight change in the treatment groups are compared by Repeated Measures ANOVA.

Treatment with Antibody 1 results in a dose dependent inhibition of HEL tumor growth, with 60 mg/kg Antibody 1 significantly inhibiting tumor growth ($p=0.0031$). There is no effect on body weight with Antibody 1 treatment in this study (Table 5). Accordingly, the antibodies of the present invention demonstrate anti-tumor efficacy in an *in vivo* model of HEL, while resulting in minimal adverse side effects in that model.

Table 5

	T/C% on Day 18	**RM ANOVA for Tumor Volume**	**Final Mean % Body Weight Change**	**RM ANOVA for Body Weight**
Saline Control			6.6	
Antibody 1 60 mg/kg	52.5	0.0031	4.6	0.21
Antibody 1 20 mg/kg	69.6	0.13	3.2	0.20
Antibody 1 6 mg/kg	81.9	0.39	4.6	0.41

EXAMPLE 8: Anti-VEGFR-3 mAb Antibody 2 in combination with cisplatin in the CAL27 squamous cell carcinoma xenograft model

In order to test for activity of anti-VEGFR-3 antibodies in head and neck cancer, the CAL27 xenograft model is used. CAL27 cell suspension, at 1 x 10^7 cells/mouse, is injected s.c. into the left flank of 60 female athymic mice. When tumors reach ~180mm^3, eight days after cell implantation, the mice are randomized and divided into four treatment groups (n = 12): 1.) USP saline control, 0.5 ml i.p., 3 days per week 2.) Antibody 2 at 40 mg/kg, 3 days per week 3.) cisplatin at 7 mg/kg, q7d 4.) Antibody 2 at 40 mg/kg, 3 days per week + cisplatin at 7 mg/kg, q7d.

Tumor measurements are recorded twice weekly; RM ANOVA through Day 61 is used to compare tumor growth among the treatment groups. Chi Squared tests are used to test for statistical significance in the number of tumor regressions among the treatment groups.

Monotherapy using Antibody 2 or cisplatin significantly inhibits the growth of CAL27 tumors compared to the USP saline control ($P \leq 0.0077$). The T/C% values are 55% and 39% for Antibody 2 and for cisplatin, respectively. Combination therapy with both Antibody 2 and cisplatin results in significant inhibition of tumor growth when compared to monotherapy ($P \leq 0.0322$). The effect of combination therapy is greater-than-additive as determined by the Fractional Product Method. Accordingly, an anti-VEGFR-3 antibody binding to an epitope in the Ig2 domain of VEGFR-3 demonstrates anti-tumor efficacy in an *in vivo* model of head and neck cancer either as a monotherapy or in combination with cisplatin.

EXAMPLE 9: Anti-VEGFR-3 mAb Antibody 2 in combination with 5-Fluorouracil / Leucovorin in an MDA-MB-231 breast cancer xenograft model

In order to test for activity of anti-VEGFR-3 antibodies in breast cancer, the MDA-MB-231 xenograft model is used. NIH nu/nu athymic mice (female 8 weeks) are injected subcutaneously in the mammary fat pad with 6 x 10^6 MDA-MB-231 cells in 0.4ml (1:1 w/matrigel). When tumors reach approximately 300 mm^3, mice are randomized by tumor size into the following treatment groups (n=12): 1) USP saline 10 µl/g, 3 times per week 2) 40 mg/kg Antibody 2, 3 times per week 3) 125 mg/kg 5FU (5-Fluorouracil) + 62 mg/kg LV (Leucovorin), once per week 4) Antibody 2 at 40 mg/kg, 3

times per week + 5FU/LV at 125 mg/kg and 62 mg/kg, respectively, once per week. All agents are prepared the day of treatment and administered i.p. Cytotoxic treatment is started one day prior to the start of antibody treatment.

A comparison of the tumor volumes from the saline control group versus the tumor volumes of the treated mice shows significant tumor growth inhibition with Antibody 2 or Antibody 2 + 5FU/LV administration (see Table 6). While the effects of the combination of Antibody 2 + 5-FU/LV are not greater than that of the monotherapies, there is a trend for increased antitumor effects for the combination. Accordingly, an anti-VEGFR-3 antibody binding to an epitope in the Ig2 domain of VEGFR-3 demonstrates anti-tumor efficacy in an *in vivo* model of breast cancer (compared to saline control) either as a monotherapy or in combination with 5FU/LV.

Table 6

	Tumor Volumes	
	[1]*p*- value	T/C%
Antibody 2 v. USP saline	p=0.04	49
5FU/LV v. USP saline	p=0.17	52
Antibody 2 + 5FU/LV v. USP saline	p<0.01	28
Antibody 2 v. Antibody 2 + 5FU/LV	p=0.09	57
5FU/LV v. Antibody 2 + 5FU/LV	p=0.09	54

[1] *RM ANOVA through Day 34*

EXAMPLE 10: Anti-VEGFR-3 mAb Antibody 2 alone and in combination with Docetaxel in a NCI-H292 Lung cancer xenograft model

In order to test for activity of anti-VEGFR-3 antibodies in lung cancer, the NCI-H292 xenograft model is used. Nu/nu mice (female, 7-8 weeks of age) are injected subcutaneously with 2 x 10^6 NCI-H292 cells/mouse. When tumors reach approximately 300 mm^3, mice are randomized by tumor size into the following treatment groups (n=15): 1) USP saline at 10 µl/g, 3 times per week, i.p., starting on day 2. 2) Antibody 2 at 40 mg/kg, 3 times per week, i.p., starting day 2. 3) Docetaxel at 12 mg/kg, q7d, starting day 1. 4) Docetaxel at 12 mg/kg, q7d, starting day 1 plus Antibody 2 at 40 mg/kg, 3 times per week, starting day 2.

Tumor volumes are measured approximately twice a week and body weights are recorded at least twice a week for the duration of the study. At sacrifice, mice are

euthanized by CO_2 asphyxiation. The T/C% is calculated for each treatment group as the ratio of the relative tumor volume in the experimental groups versus the control group. Tumor growth and body weights are compared to the control group by repeated measures ANOVA through Day 26.

Treatment with Antibody 2 and Docetaxel significantly inhibits NCI-H292 tumor growth with T/C% values of 74% and 49%, respectively. Combination therapy of Antibody 2 and Docetaxel significantly increases antitumor efficacy compared to either monotherapy with a T/C% of 24%. Accordingly, an anti-VEGFR-3 antibody binding to an epitope in the Ig2 domain of VEGFR-3 demonstrates anti-tumor efficacy in a further *in vivo* model of lung cancer either as a monotherapy ($p=<0.0001$) or in combination with Docetaxel ($p=<0.0001$).

EXAMPLE 11: Anti-VEGFR-3 mAb Antibody 2 in a Subcutaneous SK-RC-29 Human Renal Cell Carcinoma (RCC) Xenograft Model

In order to test for activity of anti-VEGFR-3 antibodies in RCC, the SK-RC-29 Human Renal Cell Carcinoma xenograft model is used. Female athymic nu/nu mice (n = 12 per group) are implanted s.c. with 2 x 10^6 SK-RC-29 RCC cells per mouse. The cells are injected as a mixture in 1:1 Matrigel® basement membrane (Vt = 0.4 ml). When tumors reach 200 - 250 mm^3, mice are randomized into groups and i.p. dosing is initiated with control group receiving USP Saline (500 □l/injection) and Antibody 2 group receiving 60 mg/kg for the first dose and 40 mg/kg on all subsequent doses. Tumor volume measurements are recorded twice weekly, for 43 days. Representative tumor samples (n = 4 per treatment group) were taken at day 48 (end of the study) for histological analysis. To determine the significance of anti-tumor effects between treatment groups, statistical analysis was performed using Repeated Measures (RM) ANOVA. Weight loss due to antibody toxicity did not occur in any of the treatment groups as measured day 47. In fact, the weight of the mice treated with antibody increased by approximately 5.5 % over the course of the study.

To assess anti-tumor efficacy and calculate T/C % values, all treatment groups are compared to control mice up to day 32. Antibody 2 yields a T/C % of 62% ($p=0.012$); this demonstrates inhibition of the growth of renal cell carcinoma in a subcutaneous xenograft model with minimal adverse side effects.

EXAMPLE 12: Anti-VEGFR-3 mAb Antibody 2 in BxPC-3 Pancreatic Carcinoma Xenografts

In order to test for activity of anti-VEGFR-3 antibodies in pancreatic carcinoma, the BxPC-3 Pancreatic Carcinoma Xenograft model is used. Female athymic nu/nu mice (n = 36) are injected s.c. with 2 x 10^6 BxPC-3 human pancreatic cells/mouse mixed in 1:1 Matrigel. When tumors reach ~350mm^3, the animals are separated into three treatment groups (n = 10): 1) USP saline. 2) mAb Antibody 2 at 10mg/kg. 3) mAb Antibody 2 at 40mg/kg. All treatments are administered i.p. three times per week at 0.1ml/10g body weight. Tumor volume measurements are recorded twice weekly, for six weeks.

Antibody 2 treatment inhibits growth of BxPC-3 tumors in a dose-dependent manner. At the end of the study on Day 40, the T/C values are 75% (p=0.042) and 56% (p=0.002) for the 10mg/kg and 40mg/kg dose groups, respectively.

EXAMPLE 13: Anti-VEGFR-3 mAb Antibody 2 in Combination with Oxaliplatin on HT-29 Colon Xenografts

In order to test for activity of anti-VEGFR-3 antibodies in colon cancer, the HT-29 Colon xenograft model is used. HT-29 cell suspension, at 5 x 10^6/mouse, is injected s.c. into the left flank of 60 female athymic mice. When tumors reach ~180mm^3, eight days after cell implantation, the mice are randomized and divided into four treatment groups (n = 12): 1) USP saline control, 0.5ml i.p., three times per week. 2) Antibody 2 at 40mg/kg, three times per week. 3) oxaliplatin at 12mg/kg, q7d. 4) Antibody 2 at 40mg/kg, three times per week + oxaliplatin at 12mg/kg, q7d.

Tumor measurements are recorded twice weekly; RM ANOVA is used to compare tumor growth among the treatment groups. Antibody 2 alone does not significantly inhibit the growth of HT-29 tumors; the antibody has a trend for efficacy with a T/C% of 80%. Combination therapy with both Antibody 2 and oxaliplatin significantly inhibits the growth of HT-29 tumors compared to control or to either monotherapy ($P \leq 0.0280$) with a T/C% of 47%. Accordingly, an anti-VEGFR-3 antibody binding to an epitope in the Ig2 domain of VEGFR-3 demonstrates anti-tumor efficacy in an *in vivo* model of colon cancer when used in combination with oxaliplatin.

WE CLAIM:

1. An antibody or antigen binding portion thereof that specifically binds to human VEGFR-3 comprising a LCDR1 of SEQ ID NO 2, a LCDR2 of SEQ ID NO 2, a LCDR3 of SEQ ID NO 3, a HCDR1 of SEQ ID NO 6, a HCDR2 of SEQ ID NO 7 and a HCDR3 of SEQ ID NO 8.

2. The antibody or antigen binding portion thereof of claim 1, comprising a light chain variable region of SEQ ID NO: 5 and a heavy chain variable region of SEQ ID NO: 10.

3. The antibody or antigen binding portion thereof of claim 1 or 2, wherein the antibody comprises a light chain of SEQ ID NO: 15 and a heavy chain of SEQ ID NO: 16.

4. The antibody or antigen binding portion thereof of claim 3, wherein the antibody comprises two light chains of SEQ ID NO: 15 and two heavy chains of SEQ ID NO: 16.

5. An antibody or antigen binding portion thereof of any of claims 1-4 wherein:

a) the binding of said antibody to human VEGFR-3 is reduced by at least 90% by singly mutating Pro-219 of human VEGFR-3 to Leu; and

b) the binding of said antibody to human VEGFR-3 is reduced by at least 50% by singly mutating Val-175 of human VEGFR-3 to Ala.

6. The antibody or antigen binding portion thereof of any of claims 1-4 wherein the binding of said antibody to human VEGFR-3 is reduced by at least 50% by singly mutating Leu-221 of human VEGFR-3 to Val.

7. The antibody or antigen binding portion thereof of any of claims 1-4 that also binds to a mutant mouse VEGFR-3 of SEQ ID NO. 20 and a mutant mouse

VEGFR-3 of SEQ ID NO. 21, wherein the binding to the mutant mouse VEGFR-3 of SEQ ID NO. 20 is increased by more than 50-fold when compared with the binding to wild type mouse VEGFR-3 (SEQ ID NO. 19) and the binding to the mutant mouse VEGFR-3 of SEQ ID NO. 21 is increased by more than 10-fold when compared with the binding to wild type mouse VEGFR-3.

8. The antibody or antigen binding portion thereof of any one of claims 1 to 4 wherein the antibody has a K_d of 1 x 10^{-9} M to 5.6 x 10^{-11} M for human VEGFR-3 as measured by surface plasmon resonance on a BIACORE® 2000 biosensor at 20°C.

9. The antibody or antigen binding portion thereof of any one of claims 1 to 4, wherein the antibody inhibits the binding of human VEGF-$C_{\Delta N \Delta C}$ (SEQ ID NO: 22) to human VEGFR-3 with an IC_{50} of 2 nM to 1.3 nM.

10. The antibody, or antigen binding portion thereof, of any one of claims 1 to 4, wherein the antibody inhibits the VEGF-$C_{\Delta N \Delta C}$ stimulated mitogenic response with an IC_{50} of 10 nM to 5 nM.

11. A pharmaceutical composition comprising the antibody or antigen binding portion thereof of any one of claims 1 to 10 together with a pharmaceutically acceptable carrier, diluent or excipient.

12. A pharmaceutical composition as claimed in claim 11 wherein said composition optionally contains at least one other therapeutic ingredient.

13. The antibody or antigen binding portion thereof of any one of claims 1 to 10 for use as a medicament.

14. The antibody or antigen binding portion thereof of any one of claims 1 to 10 for use in the treatment of ovarian cancer, human erythroleukaemia, head and neck

cancer, breast cancer, renal cell carcinoma, pancreatic cancer, lung cancer, colon cancer and lymph node metastases.

15. The antibody or antigen binding portion thereof of any one of claims 1 to 7 in combination with a further anti-cancer agent selected from cisplatin, 5-fluorouracil, leucovorin, oxaliplatin and docetaxel for simultaneous, separate or sequential use in therapy.