FRIZZLED-BINDING AGENTS AND USES THEREOF

FIELD OF THE INVENTION

[0001] The field of this invention generally relates to antibodies and other agents that bind to human frizzled receptor(s), as well as to methods of using the antibodies or other agents for the treatment of diseases, such as cancer.

BACKGROUND OF THE INVENTION

[0002] Cancer is one of the leading causes of death in the developed world, with over one million people diagnosed with cancer and 500,000 deaths per year in the United States alone. Overall it is estimated that more than 1 in 3 people will develop some form of cancer during their lifetime. There are more than 200 different types of cancer, four of which—breast, lung, colorectal, and prostate—account for over half of all new cases (Jemal et al., 2003, *Cancer J. Clin.* 53:5-26).

[0003] The Wnt signaling pathway has been identified as a potential target for cancer therapy. The Wnt signaling pathway is one of several critical regulators of embryonic pattern formation, post-embryonic tissue maintenance, and stem cell biology. More specifically, Wnt signaling plays an important role in the generation of cell polarity and cell fate specification including self-renewal by stem cell populations. Unregulated activation of the Wnt pathway is associated with numerous human cancers where it can alter the developmental fate of tumor cells to maintain them in an undifferentiated and proliferative state. Thus carcinogenesis can proceed by usurping homeostatic mechanisms controlling normal development and tissue repair by stem cells (reviewed in Reya & Clevers, 2005, *Nature* 434:843; Beachy et al., 2004, *Nature* 432:324).

[0004] The Wnt signaling pathway was first elucidated in the Drosophila developmental mutant wingless (wg) and from the murine proto-oncogene int-1, now Wnt1 (Nusse & Varmus, 1982, *Cell* 31:99-109; Van Ooyen & Nusse, 1984, *Cell* 39:233-40; Cabrera et al., 1987, *Cell* 50:659-63; Rijsewijk et al., 1987, *Cell* 50:649-57). Wnt genes encode secreted lipid-modified glycoproteins of which 19 have been identified in mammals. These secreted ligands activate a receptor complex consisting of a Frizzled (Fzd) receptor family member and low-density lipoprotein (LDL) receptor-related protein 5 or 6 (LPR5/6). The Fzd receptors are seven transmembrane domain proteins of the G-protein coupled

receptor (GPCR) superfamily and contain a large extracellular N-terminal ligand binding domain with 10 conserved cysteines, known as a cysteine-rich domain (CRD) or Fri domain. There are ten human FZD receptors: FZD1-10. Different Fzd CRDs have different binding affinities for specific Wnts (Wu & Nusse, 2002, *J. Biol. Chem.* 277:41762-9), and Fzd receptors have been grouped into those that activate the canonical β-catenin pathway and those that activate non-canonical pathways described below (Miller et al., 1999, *Oncogene* 18:7860-72). To form the receptor complex that binds the FZD ligands, FZD receptors interact with LRP5/6, single pass transmembrane proteins with four extracellular EGF-like domains separated by six YWTD amino acid repeats (Johnson et al., 2004, *J. Bone Mineral Res.* 19:1749).

[0005] The canonical Wnt signaling pathway activated upon receptor binding is mediated by the cytoplasmic protein Dishevelled (Dsh) interacting directly with the Fzd receptor and results in the cytoplasmic stabilization and accumulation of β-catenin. In the absence of a Wnt signal, β-catenin is localized to a cytoplasmic destruction complex that includes the tumor suppressor proteins adenomatous polyposis coli (APC) and Axin. These proteins function as critical scaffolds to allow glycogen synthase kinase (GSK)-3β to bind and phosphorylate β-catenin, marking it for degradation via the ubiquitin/proteasome pathway. Activation of Dsh results in phophorylation of GSK3β and the dissociation of the destruction complex. Accumulated cytoplasmic β-catenin is then transported into the nucleus where it interacts with the DNA-binding proteins of the Tcf/Lef family to activate transcription.

[0006] In addition to the canonical signaling pathway, Wnt ligands also activate β-catenin-independent pathways (Veeman et al., 2003, *Dev. Cell* 5:367-77). Non-canonical Wnt signaling has been implicated in numerous processes but most convincingly in gastrulation movements via a mechanism similar to the Drosophila planar cell polarity (PCP) pathway. Other potential mechanisms of non-canonical Wnt signaling include calcium flux, JNK, and both small and heterotrimeric G-proteins. Antagonism is often observed between the canonical and non-canonical pathways, and some evidence indicates that non-canonical signaling can suppress cancer formation (Olson & Gibo, 1998, *Exp. Cell Res.* 241:134; Topol et al., 2003, *J. Cell Biol.* 162:899-908). Thus, in certain contexts, Fzd receptors act as negative regulators of the canonical Wnt signaling pathway. For example, FZD6 represses Wnt-3a-induced canonical signaling when co-expressed with FZD1 via the TAK1-NLK pathway (Golan et al., 2004, *JBC* 279:14879-88). Similarly, Fzd2 antagonized canonical

Wnt signaling in the presence of Wnt-5a via the TAK1-NLK MAPK cascade (Ishitani et al., 2003, *Mol. Cell. Biol.* 23:131-9).

[0007] The canonical Wnt signaling pathway also plays a central role in the maintenance of stem cell populations in the small intestine and colon, and the inappropriate activation of this pathway plays a prominent role in colorectal cancers (Reya & Clevers, 2005, *Nature* 434:843). The absorptive epithelium of the intestines is arranged into villi and crypts. Stem cells reside in the crypts and slowly divide to produce rapidly proliferating cells that give rise to all the differentiated cell populations that move up out of the crypts to occupy the intestinal villi. The Wnt signaling cascade plays a dominant role in controlling cell fates along the crypt-villi axis and is essential for the maintenance of the stem cell population. Disruption of Wnt signaling either by genetic loss of Tcf7/2 by homologous recombination (Korinek et al., 1998, *Nat. Genet.* 19:379) or overexpression of Dickkopf-1 (Dkk1), a potent secreted Wnt antagonist (Pinto et al., 2003, *Genes Dev.* 17:1709-13; Kuhnert et al., 2004, *Proc. Nat'l. Acad. Sci.* 101:266-71), results in depletion of intestinal stem cell populations.

[0008] Colorectal cancer is most commonly initiated by activating mutations in the Wnt signaling cascade. Approximately 5-10% of all colorectal cancers are hereditary with one of the main forms being familial adenomatous polyposis (FAP), an autosomal dominant disease in which about 80% of affected individuals contain a germline mutation in the adenomatous polyposis coli (APC) gene. Mutations have also been identified in other Wnt pathway components including Axin and β-catenin. Individual adenomas are clonal outgrowths of epithelial cell containing a second inactivated allele, and the large number of FAP adenomas inevitably results in the development of adenocarcinomas through addition mutations in oncogenes and/or tumor suppressor genes. Furthermore, activation of the Wnt signaling pathway, including gain-of-function mutations in APC and β-catenin, can induce hyperplastic development and tumor growth in mouse models (Oshima et al., 1997, *Cancer Res.* 57:1644-9; Harada et al., 1999, *EMBO J.* 18:5931-42).

[0009] A role for Wnt signaling in cancer was first uncovered with the identification of Wnt1 (originally int1) as an oncogene in mammary tumors transformed by the nearby insertion of a murine virus (Nusse & Varmus, 1982, *Cell* 31:99-109). Additional evidence for the role of Wnt signaling in breast cancer has since accumulated. For instance, transgenic overexpression of β-catenin in the mammary glands results in hyperplasias and adenocarcinomas (Imbert et al., 2001, *J. Cell Biol.* 153:555-68; Michaelson & Leder, 2001, *Oncogene* 20:5093-9) whereas loss of Wnt signaling disrupts normal mammary gland development (Tepera et al., 2003, *J. Cell Sci.* 116:1137-49; Hatsell et al., 2003, *J. Mammary*

Gland Biol. Neoplasia 8:145-58). More recently mammary stem cells have been shown to be activated by Wnt signaling (Liu et al., 2004, *Proc. Nat'l Acad. Sci.* 101:4158). In human breast cancer, β-catenin accumulation implicates activated Wnt signaling in over 50% of carcinomas, and though specific mutations have not been identified, upregulation of Frizzled receptor expression has been observed (Brennan & Brown, 2004, *J. Mammary Gland Neoplasia* 9:119-31; Malovanovic et al., 2004, *Int. J. Oncol.* 25:1337-42).

[0010] FZD10, FZD8, FZD7, FZD4, and FZD5 are five of ten identified human Wnt receptors. Fzd10 is co-expressed with Wnt7b in the lungs, and cell transfection studies have demonstrated that the Fzd10/LRP5 co-receptor activates the canonical Wnt signaling pathway in response to Wnt7b (Wang et al., 2005, *Mol. Cell Biol.* 25:5022-30). FZD10 mRNA is upregulated in numerous cancer cell lines, including cervical, gastric, and glioblastoma cell lines, and in primary cancers including approximately 40% of primary gastric cancers, colon cancers, and synovial sarcomas (Saitoh et al., 2002, *Int. J. Oncol.* 20:117-20; Terasaki et al., 2002, *Int. J. Mol. Med.* 9:107-12; Nagayama et al., 2005, *Oncogene* 1-12). FZD8 is upregulated in several human cancer cell lines, primary gastric cancers, and renal carcinomas (Saitoh et al., 2001, *Int. J. Oncol.* 18:991-96; Kirikoshi et al., 2001, *Int. J. Oncol.* 19:111-5; Janssens et al., 2004, *Tumor Biol.* 25:161-71). FZD7 is expressed throughout the gastrointestinal tract and is up-regulated in one out of six cases of human primary gastric cancer (Kirikoshi et al., 2001, *Int. J. Oncol.* 19:111-5). Expression of the FZD7 ectodomain by a colon cancer cell line induced morphological changes and decreased tumor growth in a xenograft model (Vincan et al., 2005, *Differentiation* 73:142-53). FZD5 plays an essential role in yolk sac and placental angiogenesis (Ishikawa et al., 2001, *Dev.* 128:25-33) and is upregulated in renal carcinomas in association with activation of Wnt/β-catenin signaling (Janssens et al., 2004, *Tumor Biology* 25:161-71). FZD4 is highly expressed in intestinal crypt epithelial cells and is one of several factors that display differential expression in normal versus neoplastic tissue (Gregorieff et al., 2005, *Gastroenterology* 129:626-38). The identification of FZD receptors as markers of cancer stem cells thus makes these proteins ideal targets for cancer therapeutics.

SUMMARY OF THE INVENTION

[0011] The present invention provides novel agents that bind to one or more human frizzled receptors (FZDs), including, but not limited to, antibodies or other agents that bind two or more human frizzled receptors, and methods of using the agents. The present

invention further provides novel polypeptides, such as antibodies that bind one or more human frizzled receptors, fragments of such antibodies, and other polypeptides related to such antibodies. In certain embodiments, the agent, antibodies, other polypeptides, or agents that bind a FZD, bind to a region of the FZD referred to herein as the Biological Binding Site (BBS) that the inventors have now for the first time identified as a target for inhibiting Wnt signaling and/or tumor growth. Antibodies and other polypeptides that comprise an antigen-binding site that binds more than one FZD are also provided. Polynucleotides comprising nucleic acid sequences encoding the polypeptides are also provided, as are vectors comprising the polynucleotides. Cells comprising the polypeptides and/or polynucleotides of the invention are further provided. Compositions (e.g., pharmaceutical compositions) comprising the novel FZD-binding agents or antibodies are also provided. In addition, methods of making and using the novel FZD-binding agents or antibodies are also provided, such as methods of using the novel FZD-binding agents or antibodies to inhibit tumor growth and/or treat cancer.

[0012] Thus, in one aspect, the invention provides an agent that specifically binds a human frizzled receptor. In certain embodiments, the agent inhibits the binding of a ligand (e.g., a Wnt) to the Biological Binding Site (BBS) of the human frizzled receptor. In certain embodiments, the agent binds to at least part of the Biological Binding Site (BBS) within the human frizzled receptor. In certain embodiments, the binding of the agent to the BBS results in an inhibition of Wnt signaling and/or tumor growth. In certain embodiments, the human frizzled receptor is FZD8 and the agent binds to at least a part of (a) a conformational epitope of FZD8 formed by amino acids 72(F), 74-75(PL), 78(I), 92(Y), 121-122(LM), and 129-132(WPDR (SEQ ID NO:70)); (b) a region of FZD8 consisting of the sequence QDEAGLEVHQFWPL (SEQ ID NO:67); and/or (c) a region of FZD8 consisting of the sequence QYGFA (SEQ ID NO:66). In certain embodiments, the human frizzled receptor is selected from the group consisting of FZD1, FZD2, FZD5, FZD7, or FZD8, and the agent binds to at least part of the sequence Q(DE/ED)AGLEVHQF(Y/W)PL (SEQ ID NO:24) within the human frizzled receptor. For instance, in certain embodiments, the human frizzled receptor is FZD8 and the agent binds to at least part of the sequence QDEAGLEVHQFWPL (SEQ ID NO:67) within FZD8. In certain embodiments, the agent binds to at least part of the sequence GLEVHQ (SEQ ID NO:25). In certain embodiments, the human frizzled receptor is FZD1, FZD2, FZD3, FZD4, FZD5, FZD6, FZD7, FZD9, or FZD10, and the agent binds to at least part of a region of the human frizzled receptor corresponding to the region of FZD8 consisting of QDEAGLEVHQFWPL (SEQ ID NO:67). In certain embodiments, the agent

binds to at least part of a sequence (K/Q)(F/Y)GF(Q/A) (SEQ ID NO:69) within FZD1, FZD2, FZD5, FZD7, and/or FZD8. For example, in certain embodiments, the human frizzled receptor is FZD8 and the agent binds to at least part of a sequence QYGFA (SEQ ID NO:66) within FZD8. In certain alternative embodiments, the human frizzled receptor is FZD1, FZD2, FZD3, FZD4, FZD5, FZD6, FZD7, FZD9, or FZD10, and the agent binds to at least part of a region of the human frizzled receptor corresponding to the region of FZD8 consisting of QYGFA (SEQ ID NO:66). In certain embodiments, the agent specifically binds to two or more, three or more, or four or more human frizzled receptors. In certain embodiments, the agent specifically binds to human frizzled receptors comprising FZD5 and FZD8.

[0013] In another aspect, the invention provides an agent that competes for specific binding to a human frizzled receptor with an antibody (e.g., in an *in vitro* competitive binding assay), wherein the antibody comprises a heavy chain variable region comprising SEQ ID NO:10 and a light chain variable region comprising SEQ ID NO:12 or SEQ ID NO:14. In certain embodiments, the antibody comprises a heavy chain variable region comprising SEQ ID NO:10 and a light chain variable region comprising SEQ ID NO:14. In certain embodiments, the agent competes for specific binding to two or more, three or more, or four or more human frizzled receptors. In certain embodiments, the agent competes for specific binding to FZD1, FZD2, FZD5, FZD7, or FZD8.

[0014] In another aspect, the invention provides an agent that competes for specific binding to a human FZD5 and/or FZD8 with an antibody that comprises a heavy chain variable region comprising SEQ ID NO:85 and a light chain variable region comprising SEQ ID NO:86.

[0015] In another aspect, the invention provides an agent that specifically binds to two or more human frizzled receptors. In certain embodiments, the two or more frizzled receptors comprise: (a) FZD1 and a second frizzled receptor selected from the group consisting of FZD2, FZD5, FZD7, and FZD8; (b) FZD2 and a second frizzled receptor selected from the group consisting of FZD5, FZD7, and FZD8; (c) FZD5 and FZD7; or (d) FZD7 and FZD8. In certain embodiments, the agent specifically binds three or more (i.e., 3, 4, or 5) human frizzled receptors, wherein the three or more human frizzled receptors comprise FZD1, FZD2, FZD5, FZD7, and/or FZD8. In certain embodiments, the three or more human receptors comprise FZD5 and FZD8. In certain embodiments, the three or more human frizzled receptors further comprise FZD3, FZD4, FZD6, FZD9, and/or FZD10.

[0016] In a further aspect, the invention provides a polypeptide that specifically binds a human frizzled receptor, wherein the polypeptide comprises a heavy chain variable region comprising: (a) a heavy chain CDR1 comprising GFTFSHYTLS (SEQ ID NO:1), or a variant thereof comprising 1, 2, 3, or 4 amino acid substitutions; (b) a heavy chain CDR2 comprising VISGDGSYTYYADSVKG (SEQ ID NO:2), or a variant thereof comprising 1, 2, 3, or 4 amino acid substitutions; and/or (c) a heavy chain CDR3 comprising NFIKYVFAN (SEQ ID NO:3), or a variant thereof comprising 1, 2, 3, or 4 amino acid substitutions. In certain embodiments, the polypeptide specifically binds FZD1, FZD2, FZD5, FZD7, and/or FZD8. In certain embodiments, the polypeptide specifically binds two or more human frizzled receptors including FZD5 and FZD8. In certain embodiments, the amino acid substitutions are conservative substitutions.

[0017] In an additional aspect, the invention provides a polypeptide that specifically binds a human frizzled receptor, wherein the polypeptide comprises a light chain variable region comprising: (a) a light chain CDR1 comprising SGDKLGKKYAS (SEQ ID NO:4) or SGDNIGSFYVH (SEQ ID NO:7), or a variant of SEQ ID NO:4 or SEQ ID NO:7 comprising 1, 2, 3, or 4 amino acid substitutions; (b) a light chain CDR2 comprising EKDNRPSG (SEQ ID NO:5) or DKSNRPSG (SEQ ID NO:8), or a variant of SEQ ID NO:5 or SEQ ID NO:8 comprising 1, 2, 3, or 4 amino acid substitutions; and/or (c) a light chain CDR3 comprising SSFAGNSLE (SEQ ID NO:6) or QSYANTLSL (SEQ ID NO:9), or a variant of SEQ ID NO:6 or SEQ ID NO:9 comprising 1, 2, 3, or 4 amino acid substitutions. In certain embodiments, the polypeptide specifically binds FZD1, FZD2, FZD5, FZD7, and/or FZD8. In certain embodiments, the polypeptide specifically binds two or more human frizzled receptors including FZD5 and FZD8. In certain embodiments, the amino acid substitutions are conservative substitutions.

[0018] In another aspect, the invention provides a polypeptide comprising: (a) a heavy chain CDR1 comprising GFTFSHYTLS (SEQ ID NO:1), a heavy chain CDR2 comprising VISGDGSYTYYADSVKG (SEQ ID NO:2), and a heavy chain CDR3 comprising NFIKYVFAN (SEQ ID NO:3); and/or (b) a light chain CDR1 comprising SGDKLGKKYAS (SEQ ID NO:4) or SGDNIGSFYVH (SEQ ID NO:7), a light chain CDR2 comprising EKDNRPSG (SEQ ID NO:5) or DKSNRPSG (SEQ ID NO:8), and a light chain CDR3 comprising SSFAGNSLE (SEQ ID NO:6) or QSYANTLSL (SEQ ID NO:9). In certain embodiments, the polypeptide specifically binds a human frizzled receptor. In certain embodiments, the polypeptide specifically binds two or more (e.g., at least FZD5 and FZD8), three or more, or four or more human frizzled receptors.

[0019] In a further aspect, the invention provides an antibody that specifically binds a human frizzled receptor selected from the group consisting of FZD1, FZD2, FZD5, FZD7, and FZD8, wherein the antibody comprises a heavy chain variable region comprising: (a) a heavy chain CDR1 comprising GFTFSHYTLS (SEQ ID NO:1), or a variant thereof comprising 1, 2, 3, or 4 amino acid substitutions; a heavy chain CDR2 comprising VISGDGSYTYYADSVKG (SEQ ID NO:2), or a variant thereof comprising 1, 2, 3, or 4 amino acid substitutions; and a heavy chain CDR3 comprising NFIKYVFAN (SEQ ID NO:3), or a variant thereof comprising 1, 2, 3, or 4 amino acid substitutions; and/or (b) a light chain CDR1 comprising SGDKLGKKYAS (SEQ ID NO:4), SGDNIGSFYVH (SEQ ID NO:7), or a variant of either SEQ ID NO:4 or SEQ ID NO:7 comprising 1, 2, 3, or 4 conservative amino acid substitutions; a light chain CDR2 comprising EKDNRPSG (SEQ ID NO:5), DKSNRPSG (SEQ ID NO:8), or a variant of either SEQ ID NO:5 or SEQ ID NO:8 comprising 1, 2, 3, or 4 conservative amino acid substitutions; and a light chain CDR3 comprising SSFAGNSLE (SEQ ID NO:6), QSYANTLSL (SEQ ID NO:9), or a variant of either SEQ ID NO:6 or SEQ ID NO:9 comprising 1, 2, 3, or 4 conservative amino acid substitutions. In certain embodiments, the antibody comprises (a) a heavy chain CDR1 comprising GFTFSHYTLS (SEQ ID NO:1), a heavy chain CDR2 comprising VISGDGSYTYYADSVKG (SEQ ID NO:2), and a heavy chain CDR3 comprising NFIKYVFAN (SEQ ID NO:3); and/or (b) a light chain CDR1 comprising SGDKLGKKYAS (SEQ ID NO:4) or SGDNIGSFYVH (SEQ ID NO:7), a light chain CDR2 comprising EKDNRPSG (SEQ ID NO:5) or DKSNRPSG (SEQ ID NO:8), and a light chain CDR3 comprising SSFAGNSLE (SEQ ID NO:6) or QSYANTLSL (SEQ ID NO:9). In certain embodiments, the antibody comprises (a) a heavy chain CDR1 comprising GFTFSHYTLS (SEQ ID NO:1), a heavy chain CDR2 comprising VISGDGSYTYYADSVKG (SEQ ID NO:2), and a heavy chain CDR3 comprising NFIKYVFAN (SEQ ID NO:3); and/or (b) a light chain CDR1 comprising SGDNIGSFYVH (SEQ ID NO:7), a light chain CDR2 comprising DKSNRPSG (SEQ ID NO:8), and a light chain CDR3 comprising QSYANTLSL (SEQ ID NO:9).

[0020] In another aspect, the invention provides a polypeptide comprising (a) a polypeptide having at least about 80% sequence identity to SEQ ID NO:10; and/or (b) a polypeptide having at least about 80% sequence identity to SEQ ID NO:12 or SEQ ID NO:14. In certain embodiments, the invention provides a polypeptide comprising (a) a polypeptide having at least about 80% sequence identity to SEQ ID NO:10; and/or (b) a polypeptide having at least about 80% sequence identity to SEQ ID NO:14. In certain

embodiments, the polypeptide specifically binds a human frizzled receptor. In certain embodiments, the polypeptide specifically binds two or more, three or more, or four or more human frizzled receptors. In certain embodiments, the human frizzled receptor(s) are selected from the group consisting of FZD1, FZD2, FZD5, FZD7, and FZD8.

[0021] In still another aspect, the invention provides an agent such as an antibody that specifically binds human FZD5 and/or FZD8, wherein the antibody comprises: (a) a heavy chain CDR1 comprising GFTFSSYYIT (SEQ ID NO:77), or a variant thereof comprising 1, 2, 3, or 4 conservative amino acid substitutions; a heavy chain CDR2 comprising TISYSSSNTYYADSVKG (SEQ ID NO:78), or a variant thereof comprising 1, 2, 3, or 4 conservative amino acid substitutions; and a heavy chain CDR3 comprising SIVFDY (SEQ ID NO:79), or a variant thereof comprising 1, 2, 3, or 4 conservative amino acid substitutions; and/or (b) a light chain CDR1 comprising SGDALGNRYVY (SEQ ID NO:80), or a variant thereof comprising 1, 2, 3, or 4 conservative amino acid substitutions; a light chain CDR2 comprising SG (SEQ ID NO:81), or a variant thereof comprising 1, 2, 3, or 4 conservative amino acid substitutions; and a light chain CDR3 comprising GSWDTRPYPKY (SEQ ID NO:82), or a variant thereof comprising 1, 2, 3, or 4 conservative amino acid substitutions. In certain embodiments, the antibody comprises: (a) a heavy chain CDR1 comprising GFTFSSYYIT (SEQ ID NO:77), a heavy chain CDR2 comprising TISYSSSNTYYADSVKG (SEQ ID NO:78), and a heavy chain CDR3 comprising SIVFDY (SEQ ID NO:79); and/or (b) a light chain CDR1 comprising SGDALGNRYVY (SEQ ID NO:80), a light chain CDR2 comprising SG (SEQ ID NO:81), and a light chain CDR3 comprising GSWDTRPYPKY (SEQ ID NO:82).

[0022] In an additional aspect, the invention provides a polypeptide that specifically binds FZD5 and/or FZD8, wherein said polypeptide comprises: (a) a polypeptide having at least about 80% identity to SEQ ID NO:85; and/or (b) a polypeptide having at least about 80% identity to SEQ ID NO: 86.

[0023] In a further aspect, the invention provides an agent that competes for specific binding to human FZD1, FZD2, FZD5, FZD7, and/or FZD8 with any one of the following IgG antibodies: 18R8, 18R5, 18R4605, and 18R4805.

[0024] In a still further aspect, the invention provides an agent that competes for specific binding to human FZD5 and/or FZD8 with the anti-FZD IgG antibody 44R24.

[0025] In certain embodiments of each of the aforementioned aspects, as well as other aspects described herein, the agent or polypeptide is an antibody. In certain alternative embodiments, the agent is not an antibody.

[0026] In certain embodiments of each of the aforementioned aspects, as well as other aspects described herein, the agent or polypeptide or antibody specifically binds to the extracellular domain (ECD) of the human frizzled receptor or receptors to which it binds. In certain embodiments of each of the aforementioned aspects, as well as other aspects described herein, the agent or polypeptide or antibody specifically binds to the Fri domain (Fri) of the human frizzled receptor or receptors to which it binds.

[0027] In certain embodiments of each of the aforementioned aspects, as well as other aspects described elsewhere herein, an individual antigen-binding site of the antibody or other polypeptide specifically binds (or is capable of binding) more than one human frizzled receptor.

[0028] In certain embodiments of each of the aforementioned aspects, as well as other aspects described herein, the agent or polypeptide or antibody inhibits binding of a ligand to the human frizzled receptor(s). In certain embodiments, the ligand is a Wnt.

[0029] In certain embodiments, of each of the aforementioned aspects, as well as other aspects described herein, the agent or polypeptide or antibody that binds to the FZD(s) is an antagonist of the FZD(s).

[0030] In certain embodiments of each of the aforementioned aspects, as well as other aspects described herein, the agent or polypeptide or antibody inhibits Wnt signaling. In certain embodiments, the Wnt signaling that is inhibited is canonical Wnt signaling. In some embodiments, the Wnt signaling that is inhibited by the FZD-binding agent is non-canonical Wnt signaling. In certain embodiments, the Wnt signaling is non-canonical Wnt signaling.

[0031] In certain embodiments of each of the aforementioned aspects, as well as other aspects described herein, the FZD-binding agent or polypeptide or antibody inhibits tumor growth.

[0032] The invention further provides the antibodies 18R8, 18R5, 18R4605, 44R24, and 18R4805, as well as fragments thereof.

[0033] The invention further provides compositions, such as pharmaceutical compositions, comprising a FZD-binding agent or antibody.

[0034] Methods of inhibiting Wnt signaling (e.g., canonical Wnt signaling) and/or inhibiting tumor growth in a subject comprising administering a therapeutically effective amount of the FZD-binding agent or polypeptide or antibody are provided.

[0035] Methods of reducing the tumorigenicity of a tumor that comprises cancer stem cells are also provided. In certain embodiments, the methods comprise administering a therapeutically effective amount of the FZD-binding agent or polypeptide or antibody to a

subject comprising the tumor. In certain embodiments, the frequency of cancer stem cells in the tumor is reduced by administration of the antibody. In certain embodiments, administration of the FZD-binding agent results in the differentiation of tumorigenic cells in the tumor to a non-tumorigenic state.

[0036] Also provided are methods of inducing cells in a tumor in a subject to differentiate, said methods comprising administering a therapeutically effective amount of the FZD-binding, agent, polypeptide, or antibody to the subject.

[0037] Methods of treating cancer in a subject, comprising administering a therapeutically effective amount of the FZD-binding agent, polypeptide, or antibody to the subject are further provided.

[0038] In addition, methods of reducing myofibroblast activation in the stroma of a solid tumor, comprising contacting the stroma with an effective amount of the FZD-binding agent, polypeptide, or antibody are also provided.

[0039] In certain embodiments, the methods comprising administration of the FZD-binding agent, polypeptide, or antibody further comprise administering a second anti-cancer agent (e.g., a chemotherapeutic agent) to the subject. In certain embodiments, the second agent is gemcitabine, irinotecan, or paclitaxel. In certain embodiments, the second agent is an angiogenesis inhibitor and/or an inhibitor of Notch signaling.

[0040] In another aspect, the invention provides a polypeptide comprising a sequence selected from the group consisting of SEQ ID NOs: 10-15. Polypeptides comprising a sequence selected from the group consisting of SEQ ID NOs: 85-86 are likewise provided. Polynucleotides comprising nucleic acid sequences encoding such polypeptides are also provided.

[0041] In a further aspect, the invention provides a polynucleotide comprising a sequence selected from the group consisting of SEQ ID NOs: 17-22. Polynucleotides comprising a sequence selected from the group consisting of SEQ ID NOs: 87-90, 92, and 94-95 are further provided.

[0042] In a still further aspect, the invention provides a polynucleotide that comprises a polynucleotide that hybridizes to a polynucleotide selected from the group consisting of SEQ ID NOs: 17, 19, 21, 87-90, 92, and 94-95, or a polynucleotide encoding a polypeptide selected from the group consisting of SEQ ID NOs: 10, 12, 14, and 85-86 under conditions of high stringency. In certain embodiments, the invention comprises a polynucleotide that hybridizes to a polynucleotide consisting of a sequence SEQ ID NOs: 17, 19, or 21, or a polynucleotide encoding SEQ ID NOs: 10, 12, or 14 under conditions of high stringency.

[0043] In certain embodiments of each of the aforementioned aspects, as well as other aspects described herein, the agent or polypeptide or antibody or polynucleotide is isolated. In certain embodiments, the agent or polypeptide or antibody or polynucleotide is substantially pure.

[0044] The present invention further provides a Wnt gene signature useful for the identification of tumors and/or patients likely to respond to treatment with a FZD-binding agent (e.g., an antagonist of a human frizzled receptor and/or an inhibitor of Wnt signaling) or other inhibitors of Wnt signaling. Methods of using the Wnt gene signature to select patients for treatment with a FZD-binding agent or other inhibitor of Wnt signaling are also provided. In certain embodiments, the methods involve the assessment of the level of one or more genes in the Wnt gene signature. Methods of screening drug candidates against tumors identified using the Wnt gene signature are also provided. Arrays, kits, and other compositions useful in the methods are also provided.

[0045] The present invention also provides methods of screening potential drug candidates or other agents. These methods include, but are not limited to, methods comprising comparing the levels of one or more differentiation markers in a first solid tumor that has been exposed to the agent relative to the levels of the one or more differentiation markers in a second solid tumor that has not been exposed to the agent. In certain embodiments, these methods include comprising (a) exposing a first solid tumor, but not a second solid tumor, to the agent; (b) assessing the levels of one or more differentiation markers in the first and second solid tumors; and (c) comparing the levels of the one or more differentiation markers in the first and second solid tumors.

[0046] Where aspects or embodiments of the invention are described in terms of a Markush group or other grouping of alternatives, the present invention encompasses not only the entire group listed as a whole, but each member of the group individually and all possible subgroups of the main group, but also the main group absent one or more of the group members. The present invention also envisages the explicit exclusion of one or more of any of the group members in the claimed invention.

BRIEF DESCRIPTIONS OF THE DRAWINGS

[0047] Figure 1. 18R8 binds multiple human frizzled receptors. FACS analysis demonstrated that 18R8 binds to FZD1, FZD2, FZD5, FZD7, and FZD8 sequences on transiently transfected HEK293 cells. FACS plots are shown for the binding of 18R8 to

HEK293 cells transfected with expression vectors encoding the indicated FZD and an expression vector for GFP. 18R8 binding is indicated by elevated staining within the co-transfected (GFP positive) cell population. FACS plots for FZD1, FZD2, FZD5, FZD7 and FZD8 are boxed with thick line to highlight the FZDs showing binding to 18R8.

[0048] Figure 2. Anti-FZD antibody 18R5 binds multiple human frizzled receptors on cells. FACS analysis demonstrated that 18R5, like 18R8, binds to FZD1, FZD2, FZD5, FZD7, and FZD8 sequences on cells. Antibodies 18R8 and 18R5 were incubated at a range of concentrations with the HEK293 cells overexpressing the indicated FZD and antibody binding was assessed by flow cytometry. While both 18R8 and 18R5 bind to FZD1, FZD2, FZD5, FZD7 and FZD8, 18R5 binds with greater affinity.

[0049] Figure 3. Luciferase reporter assays were carried out in STF293 cells that stably express 8xTCF promoter element linked to luciferase. Cells were treated with conditioned medium containing Wnt3A as well as a range of concentrations of 18R8 and 18R5 and then assayed 18 hours later using the Dual-Glo luciferase assay reporter system (Promega). The results demonstrate that both 18R8 and 18R5 inhibit Wnt signaling and that 18R5 binds with greater affinity than 18R8.

[0050] Figure 4. 18R8 blocks TCF signaling by multiple Wnts. Luciferase reporter assays were carried out in STF293 cells that stably express 8xTCF promoter element linked to luciferase. Various Wnt-overexpressing cells were generated by transfecting HEK293 cells (ATCC) with expression vectors encoding indicated Wnt proteins using Fugene 6 (Roche). STF293 cells were treated with 18R8 and added Wnts overexpressed HEK293 cells and assayed 18 hours later using the Dual-Glo luciferase assay reporter system.

[0051] Figure 5. 18R8 directly inhibits Wnt binding to FZD. Luciferase reporter assays were carried out in STF293 cells that stably express 8xTCF promoter element. A mixture containing Wnt3A conditioned medium, purified FZD8-Fc, and/or 18R8 were co-incubated as indicated for 2 hrs at 4°C with/without protein A sepharose beads. After the incubation, the protein A sepharose beads were removed and added to STF293 cells. The treated STF293 cells were assayed 18 hours later using the Dual-Glo luciferase assay reporter system. This experiment shows that in the absence of 18R8, Fzd8-Fc is able to inhibit the ability of Wnt3A to stimulate signaling, but that 18R8 is able to block the ability of FZD8 to bind Wnt3A, as evidenced by the restoration of signaling when the sepharose A beads are used to remove the FZD8-Fc (and 18R8) from the co-incubation.

[0052] Figure 6. FACS analysis of binding of 18R8 to mutant FZD8 compared to wild-type FZD8. To assess the epitope of 18R8 on FZD, epitope mapping studies were

performed. An expression construct that enabled the expression of the Fri domain of human FZD8 with an N-terminal FLAG tag, and a C-terminal CD4 transmembrane domain and intracellular domain was used in transient transfection studies together with an expression vector encoding GFP. Variants of this expression vector were also prepared which contained selected amino acid substitutions within the FZD8 sequence to encode the amino acids at the corresponding position within the Fri domain of other particular FZDs not bound by 18R8. The ability of 18R8 to bind to these variant FZD8 sequences was then assessed by flow cytometry. Certain positions including amino acids 66-71 and 126-127 of FZD8 were found to be required for 18R8 binding as indicated by reduced staining within the co-transfected (GFP positive) cell population. The region of the FACS plot showing binding of 18R8 to the cotransfected cell population is highlighted by a box and the box is shown in thick lines for those amino acid substitutions showing markedly reduced 18R8 binding.

[0053] Figure 7. 18R5 and 18R8 are shown to have a similar binding epitope on human FZD8. The ability of 18R5 to bind to a similar epitope as 18R8 was assessed by flow cytometry using a series of amino acid variants previous shown to disrupt binding of 18R8. Positions including amino acids 66-71 and 126-127 of FZD8 were found to be required for binding both 18R8 and 18R5 as indicated by reduced staining within the co-transfected (GFP positive) cell population. The region of the FACS plot showing binding of 18R8 to the cotransfected cell population is highlighted by a box and the box is shown in thick lines for those amino acid substitutions showing markedly reduced 18R8 and 18R5 binding.

[0054] Figure 8. Comparison of the amino acid sequences of portions of the Fri domain sequences of the human frizzled receptors. Sites with conserved residues are shaded in black; sites with similar amino acid residues are shaded in gray. The FZD epitope of 18R8 and 18R5 contains the regions denoted by underline and labeled as "top edge" and "bottom edge." The terms "top edge" and "bottom edge" reflect the recognition, based on examination of Fri domain crystal structure, that these regions flank a cleft on the surface of the FZD protein. This cleft contains multiple highly conserved residues. The amino acids that comprise this cleft are highlighted by carrot symbols above each corresponding position within the alignment. This region has not previously been ascribed specific function. The discovery of antibodies that bind to this region and the discovery that these antibodies inhibit Wnt binding and Wnt signaling as well as our recognition of the conserved nature of this cleft have enabled us to identify this region as a key functional aspect of the FZD proteins.

[0055] Figure 9. The Biological Binding Site (BBS) of FZD. Shown are images of the structure of a Fzd fri domain. The images are based on analysis of the previously

reported crystal structure of mouse FZD8 (Dann CE et al., *Nature* 412 (6842) 86-90, 2001) and analysis done using the software program Pymol. Shown in the upper left image is a surface view of the FZD Fri domain with the region of the Fzd protein comprising the biological binding site (BBS) that the inventors have discovered (encircled by a white oval). This is the region bound by the antibodies 18R8 and 18R5. This region contains structural elements we term the "top edge" the "bottom edge" and the "cleft." Each of these is highlighted in darker surface coloration in separate images at the bottom of the panel. The upper right image highlights in darker surface the residues that are conserved in nine or ten of the ten human Fzd family members and highlights the recognition that a distinct grouping of these residues occurs within the center of the "cleft" region flanked by the epitope that binds antibodies that inhibit Fzd function.

[0056] Figure 10. Prevention of Wnt-dependent tumor growth by anti-FZD mAb. NOD/SCID mice injected with 50,000 MMTV WNT1 tumor derived cells and tumor growth was monitored weekly until growth was detected, then tumor growth was measured twice a week. Ten mice with established tumors were treated with either 18R8 or a control antibody as a control. Tumor growth in animals treated with 18R8 was virtually eliminated compared to that observed in animals treated with control antibody.

[0057] Figure 11. Reduction of OMP-C28 xenograft tumor growth by combination treatment of 18R5 and irinotecan. NOD/SCID mice were injected with 10,000 OMP-C28 colon tumor cells, and on day 24, mice with tumors of average volume of 129 mm^3 were randomized and the indicated treatments were initiated. Tumor growth was monitored weekly. Tumor growth in animals treated with 18R5 was significantly reduced. Further, the combination of 18R5 and irinotecan was significantly reduced over treatment with either agent alone.

[0058] Figure 12. Reduction of OMP-PN4 xenograft tumor growth by combination treatment of 18R5 and gemcitabine. NOD/SCID mice injected with 50,000 OMP-PN4 pancreatic tumor cells and on day 38, mice with tumors of average volume of about 120 mm^3 were randomized, and the indicated treatments were initiated two days later. Tumor growth in animals treated with the combination of 18R5 and gemcitabine was significantly reduced over treatment with gemcitabine alone.

[0059] Figure 13. Heavy chain and light chain amino acid sequences for 18R8 and 18R5, including VH and VL sequences.

[0060] Figure 14. Nucleotide sequences encoding the heavy chain and VH sequences of 18R8 and 18R5.

[0061] Figure 15. Nucleotide sequences encoding the light chain and VL sequences of 18R8 and 18R5.

[0062] Figure 16. Amino acid sequence of FZD7 ECD Fc protein and nucleotide sequence encoding same.

[0063] Figure 17. Amino acid sequences of human FZD1 (SEQ ID NO:26), the extracellular domain (ECD) of FZD1 (SEQ ID NO:27, shown as underlined amino acids 1-321 of SEQ ID NO:26), and the Fri domain of FZD1 (SEQ ID NO:28).

[0064] Figure 18. Amino acid sequences of human FZD2 (SEQ ID NO:30), the extracellular domain (ECD) of FZD2 (SEQ ID NO:31, shown as underlined amino acids 1-250 of SEQ ID NO:30), and the Fri domain of FZD2 (SEQ ID NO:32).

[0065] Figure 19. Nucleotide sequence encoding human FZD1.

[0066] Figure 20. Nucleotide sequence encoding human FZD2.

[0067] Figure 21. Amino acid sequences of human FZD3 (SEQ ID NO:34), the extracellular domain (ECD) of FZD3 (SEQ ID NO:35, shown as underlined amino acids 1-204 of SEQ ID NO:34), and the Fri domain of FZD3 (SEQ ID NO:36).

[0068] Figure 22. Amino acid sequences of human FZD4 (SEQ ID NO:38), the extracellular domain (ECD) of FZD4 (SEQ ID NO:39, shown as underlined amino acids 1-224 of SEQ ID NO:38), and the Fri domain of FZD4 (SEQ ID NO:40).

[0069] Figure 23. Nucleotide sequence encoding human FZD3.

[0070] Figure 24. Nucleotide sequence encoding human FZD4.

[0071] Figure 25. Amino acid sequences of human FZD5 (SEQ ID NO:42), the extracellular domain (ECD) of FZD5 (SEQ ID NO:43, shown as underlined amino acids 1-233 of SEQ ID NO:42), and the Fri domain of FZD5 (SEQ ID NO:44).

[0072] Figure 26. Amino acid sequences of human FZD6 (SEQ ID NO:46), the extracellular domain (ECD) of FZD6 (SEQ ID NO:47, shown as underlined amino acids 1-207 of SEQ ID NO:46), and the Fri domain of FZD6 (SEQ ID NO:48).

[0073] Figure 27. Nucleotide sequence encoding human FZD5.

[0074] Figure 28. Nucleotide sequence encoding human FZD6.

[0075] Figure 29. Amino acid sequences of human FZD7 (SEQ ID NO:50), the extracellular domain (ECD) of FZD7 (SEQ ID NO:51, shown as underlined amino acids 1-255 of SEQ ID NO:50), and the Fri domain of FZD7 (SEQ ID NO:52).

[0076] Figure 30. Amino acid sequences of human FZD8 (SEQ ID NO:54), the extracellular domain (ECD) of FZD8 (SEQ ID NO:55, shown as underlined amino acids 1-277 of SEQ ID NO:54), and the Fri domain of FZD8 (SEQ ID NO:56).

[0077] Figure 31. Nucleotide sequence encoding human FZD7.

[0078] Figure 32. Nucleotide sequence encoding human FZD8.

[0079] Figure 33. Amino acid sequences of human FZD9 (SEQ ID NO:58), the extracellular domain (ECD) of FZD9 (SEQ ID NO:59, shown as underlined amino acids 1-230 of SEQ ID NO:58), and the Fri domain of FZD9 (SEQ ID NO:60).

[0080] Figure 34. Amino acid sequences of human FZD10 (SEQ ID NO:62), the extracellular domain (ECD) of FZD10 (SEQ ID NO:63, shown as underlined amino acids 1-227 of SEQ ID NO:62), and the Fri domain of FZD10 (SEQ ID NO:64).

[0081] Figure 35. Nucleotide sequence encoding human FZD9.

[0082] Figure 36. Nucleotide sequence encoding human FZD10.

[0083] Figure 37. Reduction of PE-13 breast tumor growth with combination treatment of 18R5 antibody and paclitaxel. NOD/SCID mice were injected with 10,000 PE-13 breast tumor cells and on day 22, mice with tumors of average volume of about 120 mm^3 were randomized. The mice were then treated with either a control antibody ("Control Ab"), 18R5 antibody ("Anti-FZD"), paclitaxel ("Taxol"), or a combination of 18R5 antibody plus paclitaxel ("Anti-FZD+Taxol"). Treatment with 18R5 antibody in combination with paclitaxel resulted in anti-tumor activity.

[0084] Figure 38. Breast tumor growth in individual animals treated with the combination of 18R5 antibody plus paclitaxel. Treatment with 18R5 antibody in combination with paclitaxel resulted in regression of established breast tumors.

[0085] Figure 39. Flow cytometry analysis of colorectal tumor cells following treatment with control antibody, 18R5 antibody, irinotecan, or both 18R5 antibody and irinotecan.

[0086] Figure 40. Tumor growth in mice following implantation of 30, 90, 270, or 810 tumor cells obtained from mice that had been treated for 41 days with either control antibody ("Control"), 18R5 antibody ("Anti-FZD"), gemcitabine ("Gemcitabine"), or the combination of 18R5 plus gemcitabine ("Combination").

[0087] Figure 41. Cancer stem cell (CSC) frequency in PN-4 pancreatic tumors following treatment with control antibody ("Control Ab"), 18R5 antibody alone ("Anti-FZD"), gemcitabine alone ("Gemcitabine"), or the combination of 18R5 antibody and gemcitabine ("Combination"), as determined by limiting dilution analysis.

[0088] Figure 42. Chromatogram gene expression in pancreatic tumor cells that have been treated with control antibody ("LZ-1"), 18R5 antibody alone ("18R5"), gemcitabine alone ("Gem"), or a combination of gemcitabine and 18R5 ("Combo").

[0089] Figure 43. Treatment with anti-FZD antibody 18R5 promotes differentiation of tumor cells into non-proliferative mucinous cells. NOD/SCID mice were injected with 50,000 OMP-PN13 pancreatic tumor cells and on day 23, mice with tumors of average volume of about 107 mm^3 were randomized, and treatment with control antibody or 18R5 was initiated four days later. After 20 days tumors were collected and sectioned. Tumor sections from 18R5 treated mice or control antibody treated mice were stained with alcian blue stain to reveal mucinous cells and by immunohistochemistry with antibody to ki67 to reveal proliferative cells. Exemplary mucinous cells and proliferative cells are highlighted by arrows.

[0090] Figure 44. Anti-FZD antibody 18R5, both alone and in combination with Taxol® (paclitaxel), inhibits OMP-LU24 xenograft tumor growth. Mice bearing OMP-LU24 human lung tumors were treated with either control antibody ("Control Ab"), anti-FZD 18R5 ("18R5"), Taxol® ("Taxol") or the combination of 18R5 plus Taxol® ("18R5+Taxol").

[0091] Figure 45. Anti-FZD antibody 18R5, both alone and in combination with Avastin® (bevacizumab), inhibits OMP-LU33 xenograft tumor growth. Mice bearing OMP-LU33 human lung tumors were treated with either control antibody (squares), Avastin® (triangles pointing up), anti-FZD 18R5 (triangles pointing down), or the combination of 18R5 plus Avastin® (circles).

[0092] Figure 46. The combination of anti-FZD antibody 18R5 with Herceptin® (trastuzumab) inhibits the growth of T3 xenograft tumor growth. Mice carrying T3 human breast tumors were treated with either control antibody (squares), anti-FZD 18R5 (triangles), Herceptin® (filled circles), or the combination of 18R5 plus Herceptin® (open circles).

[0093] Figure 47. 18R5 and 44R24 Fzd binding profiles. Dose-reponse curve representing the binding of each mAb to Fzd1, 2, 5, 7 and 8.

[0094] Figure 48. Inhibition of Wnt3a-induced reporter activity in STF cells by 18R5 and 44R24 (dose response curves).

[0095] Figure 49. Inhibition of basal level of axin2 gene expression by 18R5 and 44R24.

[0096] Figure 50. IHC detection of Muc16 in 18R5 and 44R24-treated OMP-PN13 tumors.

[0097] Figure 51. Inhibition of smooth muscle actin in 18R5-treated pancreatic tumor. A. ACTA2 gene expression levels as detected by microarray. B. SMA detection on control mAb (upper panel) and 18R5 (lower panel) –treated OMP-PN4 tumors.

[0098] Figure 52. Testing the tumorgenicity of 18R5-induced Muc16+ OMP-PN13 cells. A. FACS plot of lin-depleted OMP-PN13 tumor cells stained for Muc16. The 2 sorted populations are circled. B. Representative pictures of tumors resulting from the injection of Muc16- (upper panel) and Muc16+ (lower panel) cells. C. Tumor growth curves.

[0099] Figure 53. Inhibition of tumor recurrence by anti-FZD mAb 18R5 in PE13 breast tumor xenograft.

[00100] Figure 54. Reduction of breast cancer stem cell frequency by anti-FZD mAb18R5.

[00101] Figure 55. Inhibition of tumor recurrence by anti-FZD mAb 18R5 in PN4 pancreatic tumor xenograft.

[00102] Figure 56. Inhibition of tumor growth by anti-FZD mAb 44R24 in combination with gemcitabine in PN4 pancreatic tumor xenograft.

[00103] Figure 57. FACS analysis of binding of anti-FZD mAb 44R24 to mutant FZD8 relative to wild-type FZD8. The region of the FACS plot showing binding of 44R24 to the cotransfected cell population is highlighted by a box. The box for those amino acid substitutions showing markedly reduced 44R24 binding is marked with an arrow

[00104] Figure 58. Anti-Tumor activity of anti-FZD Antibodies 44R24 and 18R5 in C28 colon tumor xenografts.

[00105] Figure 59. Induction of cytokeratin 7 expression in C28 colon tumor xenografts treated with anti-FZD antibodies 44R24 or 18R5.

DETAILED DESCRIPTION OF THE INVENTION

[00106] The present invention provides novel agents, including, but not limited to polypeptides such as antibodies, that bind to one or more human frizzled receptors (FZDs). Related polypeptides and polynucleotides, compositions comprising the FZD-binding agents, and methods of making the FZD-binding agents are also provided. Methods of using the novel FZD-binding agents, such as methods of inhibiting tumor growth and/or treating cancer, are further provided.

[00107] The invention is based, in part, on the identification of a region within human frizzled receptors that is a suitable target for FZD-binding, anti-cancer agents. Two anti-FZD antibodies, 18R8 and 18R5, were found to specifically bind to FZD7, but also to cross-react with FZD1, FZD2, FZD5, and FZD8 (Examples 1 and 2, below). *In vitro* experiments with

the 18R8 antibody indicated that the antibody is capable of inhibiting Wnt signaling (Example 3, below) and inhibiting binding of Wnt ligands to FZD8 (Example 4, below). The 18R5 antibody has also been demonstrated to likewise be capable of inhibiting Wnt signaling in cell-based assays (Examples 3 and 20, below). *In vivo* experiments with the 18R5 antibody demonstrated that the antibody is capable of inhibiting tumor growth or recurrence (Examples 7, 17, and 23, below). The inventors have also shown the anti-FZD antibody 18R5 to be capable of reducing the frequency of cancer stem cells in tumors (Examples, 8 and 23, below) and inducing the differentiation and/or reducing the tumorigenicity of tumor cells (Examples 16, 21, 22, and 25, below). Epitope mapping experiments with these active 18R8 and 18R5 antibodies indicated that both of the antibodies bind to at least part of the sequence GLEVHQ (SEQ ID NO:25) and at least part of the sequence YGFA (SEQ ID NO:74) within FZD8 (Example 5, below). In light of the demonstrated biological activity of these two antibodies, the crystal structure of mouse Frizzled 8 (Dann et al., *Nature*, 412: 86-90 (2001)) was analyzed and an extracellular region of frizzled proteins comprising these sequences that had not previously been ascribed any specific function was identified for the first time as playing an important functional role in FZD biology and Wnt signaling (Example 6). This region of human frizzled receptors, designated the Biological Binding Site (BBS), is a suitable target for anti-cancer therapies.

[00108] In addition, a third antibody, 44R24, was found to specifically bind to human FZD5 and FZD8 (Example 19, below). This antibody has also been shown to be capable of inhibiting Wnt signaling in cell-based assays (Example 20, below) and of anti-tumor efficacy *in vivo* (Examples 23 and 25, below). Like treatment with the anti-FZD antibodies 18R8 and 18R5, treatment of a tumor with 44R24 resulted in increased levels of a differentiation marker in the tumor (Example 25, below). Epitope mapping has also shown that the epitope of the anti-FZD antibody 44R24 overlaps with that of the anti-FZD antibodies 18R8 and 18R5. More specifically, 44R24 has been shown to bind to at least part of the region YGFA (SEQ ID NO:74) in the BBS (Example 24, below).

I. Definitions

[00109] To facilitate an understanding of the present invention, a number of terms and phrases are defined below.

[00110] The term "antibody" means an immunoglobulin molecule that recognizes and specifically binds to a target, such as a protein, polypeptide, peptide, carbohydrate,

polynucleotide, lipid, or combinations of the foregoing through at least one antigen recognition site within the variable region of the immunoglobulin molecule. As used herein, the term "antibody" encompasses intact polyclonal antibodies, intact monoclonal antibodies, antibody fragments (such as Fab, Fab', F(ab')2, and Fv fragments), single chain Fv (scFv) mutants, multispecific antibodies such as bispecific antibodies generated from at least two intact antibodies, chimeric antibodies, humanized antibodies, human antibodies, fusion proteins comprising an antigen determination portion of an antibody, and any other modified immunoglobulin molecule comprising an antigen recognition site so long as the antibodies exhibit the desired biological activity. An antibody can be of any the five major classes of immunoglobulins: IgA, IgD, IgE, IgG, and IgM, or subclasses (isotypes) thereof (e.g. IgG1, IgG2, IgG3, IgG4, IgA1 and IgA2), based on the identity of their heavy-chain constant domains referred to as alpha, delta, epsilon, gamma, and mu, respectively. The different classes of immunoglobulins have different and well known subunit structures and three-dimensional configurations. Antibodies can be naked or conjugated to other molecules such as toxins, radioisotopes, etc.

[00111] The term "antibody fragment" refers to a portion of an intact antibody and refers to the antigenic determining variable regions of an intact antibody. Examples of antibody fragments include, but are not limited to Fab, Fab', F(ab')2, and Fv fragments, linear antibodies, single chain antibodies, and multispecific antibodies formed from antibody fragments.

[00112] A "monoclonal antibody" refers to a homogeneous antibody population involved in the highly specific recognition and binding of a single antigenic determinant, or epitope. This is in contrast to polyclonal antibodies that typically include different antibodies directed against different antigenic determinants. The term "monoclonal antibody" encompasses both intact and full-length monoclonal antibodies as well as antibody fragments (such as Fab, Fab', F(ab')2, Fv), single chain (scFv) mutants, fusion proteins comprising an antibody portion, and any other modified immunoglobulin molecule comprising an antigen recognition site. Furthermore, "monoclonal antibody" refers to such antibodies made in any number of manners including but not limited to by hybridoma, phage selection, recombinant expression, and transgenic animals.

[00113] The term "humanized antibody" refers to forms of non-human (e.g. murine) antibodies that are specific immunoglobulin chains, chimeric immunoglobulins, or fragments thereof that contain minimal non-human (e.g., murine) sequences. Typically, humanized antibodies are human immunoglobulins in which residues from the complementary

determining region (CDR) are replaced by residues from the CDR of a non-human species (e.g. mouse, rat, rabbit, hamster) that have the desired specificity, affinity, and capability (Jones et al., 1986, *Nature*, 321:522-525; Riechmann et al., 1988, *Nature*, 332:323-327; Verhoeyen et al., 1988, *Science*, 239:1534-1536). In some instances, the Fv framework region (FR) residues of a human immunoglobulin are replaced with the corresponding residues in an antibody from a non-human species that has the desired specificity, affinity, and capability. The humanized antibody can be further modified by the substitution of additional residues either in the Fv framework region and/or within the replaced non-human residues to refine and optimize antibody specificity, affinity, and/or capability. In general, the humanized antibody will comprise substantially all of at least one, and typically two or three, variable domains containing all or substantially all of the CDR regions that correspond to the non-human immunoglobulin whereas all or substantially all of the FR regions are those of a human immunoglobulin consensus sequence. The humanized antibody can also comprise at least a portion of an immunoglobulin constant region or domain (Fc), typically that of a human immunoglobulin. Examples of methods used to generate humanized antibodies are described in U.S. Pat. 5,225,539.

[00114] The term "human antibody" means an antibody produced by a human or an antibody having an amino acid sequence corresponding to an antibody produced by a human made using any technique known in the art. This definition of a human antibody includes intact or full-length antibodies, fragments thereof, and/or antibodies comprising at least one human heavy and/or light chain polypeptide such as, for example, an antibody comprising murine light chain and human heavy chain polypeptides.

[00115] The term "chimeric antibodies" refers to antibodies wherein the amino acid sequence of the immunoglobulin molecule is derived from two or more species. Typically, the variable region of both light and heavy chains corresponds to the variable region of antibodies derived from one species of mammals (e.g. mouse, rat, rabbit, etc) with the desired specificity, affinity, and capability while the constant regions are homologous to the sequences in antibodies derived from another (usually human) to avoid eliciting an immune response in that species.

[00116] The term "epitope" or "antigenic determinant" are used interchangeably herein and refer to that portion of an antigen capable of being recognized and specifically bound by a particular antibody. When the antigen is a polypeptide, epitopes can be formed both from contiguous amino acids and noncontiguous amino acids juxtaposed by tertiary folding of a protein. Epitopes formed from contiguous amino acids are typically retained upon protein

denaturing, whereas epitopes formed by tertiary folding are typically lost upon protein denaturing. An epitope typically includes at least 3, and more usually, at least 5 or 8-10 amino acids in a unique spatial conformation.

[00117] That an antibody "specifically binds" to an epitope or protein means that the antibody reacts or associates more frequently, more rapidly, with greater duration, with greater affinity, or with some combination of the above to an epitope or protein than with alternative substances, including unrelated proteins. In certain embodiments, "specifically binds" means, for instance, that an antibody binds to a protein with a K_D of about 0.1 mM or less, but more usually less than about 1 μM. In certain embodiments, "specifically binds" means that an antibody binds to a protein at times with a K_D of at least about 0.1 μM or less, and at other times at least about 0.01 μM or less. Because of the sequence identity between homologous proteins in different species, specific binding can include an antibody that recognizes a particular protein such as a frizzled receptor in more than one species. Likewise, because of homology between different FZD receptors (e.g., FZD5 and FZD8) in certain regions of the polypeptide sequences of the receptors, specific binding can include an antibody (or other polypeptide or agent) that recognizes more than one frizzled receptor. It is understood that an antibody or binding moiety that specifically binds to a first target may or may not specifically bind to a second target. As such, "specific binding" does not necessarily require (although it can include) exclusive binding, i.e. binding to a single target. Thus, an antibody may, in certain embodiments, specifically bind to more than one target (e.g., human FZD1, FZD2, FZD5, FZD7, and/or FZD8). In certain embodiments, the multiple targets may be bound by the same antigen-binding site on the antibody. For example, an antibody may, in certain instances, comprise two identical antigen-binding sites, each of which specifically binds two or more human frizzled receptors (e.g., human FZD1, FZD2, FZD5, FZD7, and/or FZD8). In certain alternative embodiments, an antibody may be bispecific and comprise at least two antigen-binding sites with differing specificities. By way of non-limiting example, a bispecific antibody may comprise one antigen-binding site that recognizes an epitope on one frizzled receptor, such as human FZD5, and further comprises a second, different antigen-binding site that recognizes a different epitope on a second frizzled receptor, such as human FZD8. Generally, but not necessarily, reference to binding means specific binding.

[00118] A polypeptide, antibody, polynucleotide, vector, cell, or composition which is "isolated" is a polypeptide, antibody, polynucleotide, vector, cell, or composition which is in a form not found in nature. Isolated polypeptides, antibodies, polynucleotides, vectors, cell or

compositions include those which have been purified to a degree that they are no longer in a form in which they are found in nature. In some embodiments, an antibody, polynucleotide, vector, cell, or composition which is isolated is substantially pure.

[00119] As used herein, "substantially pure" refers to material which is at least 50% pure (i.e., free from contaminants), more preferably at least 90% pure, more preferably at least 95% pure, more preferably at least 98% pure, more preferably at least 99% pure.

[00120] The terms "cancer" and "cancerous" refer to or describe the physiological condition in mammals in which a population of cells are characterized by unregulated cell growth. Examples of cancer include, but are not limited to, carcinoma, lymphoma, blastoma, sarcoma, and leukemia. More particular examples of such cancers include squamous cell cancer, small-cell lung cancer, non-small cell lung cancer, adenocarcinoma of the lung, squamous carcinoma of the lung, cancer of the peritoneum, hepatocellular cancer, gastrointestinal cancer, pancreatic cancer, glioblastoma, cervical cancer, ovarian cancer, liver cancer, bladder cancer, hepatoma, breast cancer, colon cancer, colorectal cancer, endometrial or uterine carcinoma, salivary gland carcinoma, kidney cancer, liver cancer, prostate cancer, vulval cancer, thyroid cancer, hepatic carcinoma and various types of head and neck cancers.

[00121] "Tumor" and "neoplasm" refer to any mass of tissue that result from excessive cell growth or proliferation, either benign (noncancerous) or malignant (cancerous) including pre-cancerous lesions.

[00122] The terms "cancer stem cell," "tumor stem cell," or "solid tumor stem cell" are used interchangeably herein and refer to a population of cells from a solid tumor that: (1) have extensive proliferative capacity; 2) are capable of asymmetric cell division to generate one or more kinds of differentiated progeny with reduced proliferative or developmental potential; and (3) are capable of symmetric cell divisions for self-renewal or self-maintenance. These properties of "cancer stem cells," "tumor stem cells," or "solid tumor stem cells" confer on those cancer stem cells the ability to form palpable tumors upon serial transplantation into an immunocompromised mouse compared to the majority of tumor cells that fail to form tumors. Cancer stem cells undergo self-renewal versus differentiation in a chaotic manner to form tumors with abnormal cell types that can change over time as mutations occur.

[00123] The terms "cancer cell," "tumor cell," and grammatical equivalents refer to the total population of cells derived from a tumor or a pre-cancerous lesion, including both non-tumorigenic cells, which comprise the bulk of the tumor cell population, and tumorigenic stem cells (cancer stem cells). As used herein, the term "tumor cell" will be modified by the

term "non-tumorigenic" when referring solely to those tumor cells lacking the capacity to renew and differentiate to distinguish those tumor cells from cancer stem cells.

[00124] The term "tumorigenic" refers to the functional features of a solid tumor stem cell including the properties of self-renewal (giving rise to additional tumorigenic cancer stem cells) and proliferation to generate all other tumor cells (giving rise to differentiated and thus non-tumorigenic tumor cells) that allow solid tumor stem cells to form a tumor. These properties of self-renewal and proliferation to generate all other tumor cells confer on cancer stem cells the ability to form palpable tumors upon serial transplantation into an immunocompromised mouse compared to non-tumorigenic tumor cells, which are unable to form tumors upon serial transplantation. It has been observed that non-tumorigenic tumor cells may form a tumor upon primary transplantation into an immunocompromised mouse after obtaining the tumor cells from a solid tumor, but those non-tumorigenic tumor cells do not give rise to a tumor upon serial transplantation.

[00125] The term "subject" refers to any animal (e.g., a mammal), including, but not limited to humans, non-human primates, rodents, and the like, which is to be the recipient of a particular treatment. Typically, the terms "subject" and "patient" are used interchangeably herein in reference to a human subject.

[00126] "Pharmaceutically acceptable salt" refers to a salt of a compound that is pharmaceutically acceptable and that possesses the desired pharmacological activity of the parent compound.

[00127] "Pharmaceutically acceptable excipient, carrier or adjuvant" refers to an excipient, carrier or adjuvant that can be administered to a subject, together with at least one antibody of the present disclosure, and which does not destroy the pharmacological activity thereof and is nontoxic when administered in doses sufficient to deliver a therapeutic amount of the compound.

[00128] "Pharmaceutically acceptable vehicle" refers to a diluent, adjuvant, excipient, or carrier with which at least one antibody of the present disclosure is administered.

[00129] The term "therapeutically effective amount" refers to an amount of an antibody, polypeptide, polynucleotide, small organic molecule, or other drug effective to "treat" a disease or disorder in a subject or mammal. In the case of cancer, the therapeutically effective amount of the drug can reduce the number of cancer cells; reduce the tumor size; inhibit or stop cancer cell infiltration into peripheral organs including, for example, the spread of cancer into soft tissue and bone; inhibit and stop tumor metastasis; inhibit and stop tumor growth; relieve to some extent one or more of the symptoms associated with the

cancer; reduce morbidity and mortality; improve quality of life; decrease tumorigenicity, tumorgenic frequency, or tumorgenic capacity of a tumor; reduce the number or frequency of cancer stem cells in a tumor; differentiate tumorigenic cells to a non-tumorigenic state; or a combination of such effects. To the extent the drug prevents growth and/or kills existing cancer cells, it can be referred to as cytostatic and/or cytotoxic.

[00130] Terms such as "treating" or "treatment" or "to treat" or "alleviating" or "to alleviate" refer to both 1) therapeutic measures that cure, slow down, lessen symptoms of, and/or halt progression of a diagnosed pathologic condition or disorder and 2) prophylactic or preventative measures that prevent and/or slow the development of a targeted pathologic condition or disorder. Thus, those in need of treatment include those already with the disorder; those prone to have the disorder; and those in whom the disorder is to be prevented. In certain embodiments, a subject is successfully "treated" for cancer according to the methods of the present invention if the patient shows one or more of the following: a reduction in the number of or complete absence of cancer cells; a reduction in the tumor size; inhibition of or an absence of cancer cell infiltration into peripheral organs including, for example, the spread of cancer into soft tissue and bone; inhibition of or an absence of tumor metastasis; inhibition or an absence of tumor growth; relief of one or more symptoms associated with the specific cancer; reduced morbidity and mortality; improvement in quality of life; reduction in tumorigenicity, tumorgenic frequency, or tumorgenic capacity, of a tumor; reduction in the number or frequency of cancer stem cells in a tumor; differentiation of tumorigenic cells to a non-tumorigenic state; or some combination of effects.

[00131] "Polynucleotide," or "nucleic acid," as used interchangeably herein, refer to polymers of nucleotides of any length, and include DNA and RNA. The nucleotides can be deoxyribonucleotides, ribonucleotides, modified nucleotides or bases, and/or their analogs, or any substrate that can be incorporated into a polymer by DNA or RNA polymerase. A polynucleotide may comprise modified nucleotides, such as methylated nucleotides and their analogs. If present, modification to the nucleotide structure may be imparted before or after assembly of the polymer. The sequence of nucleotides may be interrupted by non-nucleotide components. A polynucleotide may be further modified after polymerization, such as by conjugation with a labeling component. Other types of modifications include, for example, "caps", substitution of one or more of the naturally occurring nucleotides with an analog, internucleotide modifications such as, for example, those with uncharged linkages (e.g., methyl phosphonates, phosphotriesters, phosphoamidates, cabamates, etc.) and with charged linkages (e.g., phosphorothioates, phosphorodithioates, etc.), those containing pendant

moieties, such as, for example, proteins (e.g., nucleases, toxins, antibodies, signal peptides, ply-L-lysine, etc.), those with intercalators (e.g., acridine, psoralen, etc.), those containing chelators (e.g., metals, radioactive metals, boron, oxidative metals, etc.), those containing alkylators, those with modified linkages (e.g., alpha anomeric nucleic acids, etc.), as well as unmodified forms of the polynucleotide(s). Further, any of the hydroxyl groups ordinarily present in the sugars may be replaced, for example, by phosphonate groups, phosphate groups, protected by standard protecting groups, or activated to prepare additional linkages to additional nucleotides, or may be conjugated to solid supports. The 5' and 3' terminal OH can be phosphorylated or substituted with amines or organic capping group moieties of from 1 to 20 carbon atoms. Other hydroxyls may also be derivatized to standard protecting groups. Polynucleotides can also contain analogous forms of ribose or deoxyribose sugars that are generally known in the art, including, for example, 2'-O-methyl-, 2'-O-allyl, 2'-fluoro- or 2'-azido-ribose, carbocyclic sugar analogs, .alpha.-anomeric sugars, epimeric sugars such as arabinose, xyloses or lyxoses, pyranose sugars, furanose sugars, sedoheptuloses, acyclic analogs and abasic nucleoside analogs such as methyl riboside. One or more phosphodiester linkages may be replaced by alternative linking groups. These alternative linking groups include, but are not limited to, embodiments wherein phosphate is replaced by P(O)S ("thioate"), P(S)S ("dithioate"), "(O)NR_2 ("amidate"), P(O)R, P(O)OR', CO or CH_2 ("formacetal"), in which each R or R' is independently H or substituted or unsubstituted alkyl (1-20 C) optionally containing an ether (--O--) linkage, aryl, alkenyl, cycloalkyl, cycloalkenyl or araldyl. Not all linkages in a polynucleotide need be identical. The preceding description applies to all polynucleotides referred to herein, including RNA and DNA.

[00132] A "variable region" of an antibody refers to the variable region of the antibody light chain or the variable region of the antibody heavy chain, either alone or in combination. The variable regions of the heavy and light chain each consist of four framework regions (FR) connected by three complementarity determining regions (CDRs) also known as hypervariable regions. The CDRs in each chain are held together in close proximity by the FRs and, with the CDRs from the other chain, contribute to the formation of the antigen-binding site of antibodies. There are at least two techniques for determining CDRs: (1) an approach based on cross-species sequence variability (i.e., Kabat et al. Sequences of Proteins of Immunological Interest, (5th ed., 1991, National Institutes of Health, Bethesda Md.)); and (2) an approach based on crystallographic studies of antigen-antibody complexes (Al-lazikani et al (1997) J. *Molec. Biol.* 273:927-948)). In addition, combinations of these two approaches are sometimes used in the art to determine CDRs.

[00133] The term "vector" means a construct, which is capable of delivering, and preferably expressing, one or more gene(s) or sequence(s) of interest in a host cell. Examples of vectors include, but are not limited to, viral vectors, naked DNA or RNA expression vectors, plasmid, cosmid or phage vectors, DNA or RNA expression vectors associated with cationic condensing agents, DNA or RNA expression vectors encapsulated in liposomes, and certain eukaryotic cells, such as producer cells..

[00134] The terms "polypeptide," "peptide," and "protein" are used interchangeably herein to refer to polymers of amino acids of any length. The polymer may be linear or branched, it may comprise modified amino acids, and it may be interrupted by non-amino acids. The terms also encompass an amino acid polymer that has been modified naturally or by intervention; for example, disulfide bond formation, glycosylation, lipidation, acetylation, phosphorylation, or any other manipulation or modification, such as conjugation with a labeling component. Also included within the definition are, for example, polypeptides containing one or more analogs of an amino acid (including, for example, unnatural amino acids, etc.), as well as other modifications known in the art. It is understood that, because the polypeptides of this invention are based upon antibodies, in certain embodiments, the polypeptides can occur as single chains or associated chains.

[00135] The terms "identical" or percent "identity" in the context of two or more nucleic acids or polypeptides, refer to two or more sequences or subsequences that are the same or have a specified percentage of nucleotides or amino acid residues that are the same, when compared and aligned (introducing gaps, if necessary) for maximum correspondence, not considering any conservative amino acid substitutions as part of the sequence identity. The percent identity may be measured using sequence comparison software or algorithms or by visual inspection. Various algorithms and software are known in the art that may be used to obtain alignments of amino acid or nucleotide sequences. One such non-limiting example of a sequence alignment algorithm is the algorithm described in Karlin et al, 1990, *Proc. Natl. Acad. Sci.*, 87:2264-2268, as modified in Karlin et al., 1993, *Proc. Natl. Acad. Sci.*, 90:5873-5877, and incorporated into the NBLAST and XBLAST programs (Altschul et al., 1991, *Nucleic Acids Res.*, 25:3389-3402). In certain embodiments, Gapped BLAST may be used as described in Altschul et al., 1997, *Nucleic Acids Res.* 25:3389-3402. BLAST-2, WU-BLAST-2 (Altschul et al., 1996, *Methods in Enzymology*, 266:460-480), ALIGN, ALIGN-2 (Genentech, South San Francisco, California) or Megalign (DNASTAR) are additional publicly available software programs that can be used to align sequences. In certain embodiments, the percent identity between two nucleotide sequences is determined

using the GAP program in GCG software (e.g., using a NWSgapdna.CMP matrix and a gap weight of 40, 50, 60, 70, or 90 and a length weight of 1, 2, 3, 4, 5, or 6). In certain alternative embodiments, the GAP program in the GCG software package, which incorporates the algorithm of Needleman and Wunsch (*J. Mol. Biol.* (48):444-453 (1970)) may be used to determine the percent identity between two amino acid sequences (e.g., using either a Blossum 62 matrix or a PAM250 matrix, and a gap weight of 16, 14, 12, 10, 8, 6, or 4 and a length weight of 1, 2, 3, 4, 5). Alternatively, in certain embodiments, the percent identity between nucleotide or amino acid sequences is determined using the algorithm of Myers and Miller (CABIOS, 4:11-17 (1989)). For example, the percent identity may be determined using the ALIGN program (version 2.0) and using a PAM120 with residue table, a gap length penalty of 12 and a gap penalty of 4. Appropriate parameters for maximal alignment by particular alignment software can be determined by one skilled in the art. In certain embodiments, the default parameters of the alignment software are used. In certain embodiments, the percentage identity "X" of a first amino acid sequence to a second sequence amino acid is calculated as 100 x (Y/Z), where Y is the number of amino acid residues scored as identical matches in the alignment of the first and second sequences (as aligned by visual inspection or a particular sequence alignment program) and Z is the total number of residues in the second sequence. If the length of a first sequence is longer than the second sequence, the percent identity of the first sequence to the second sequence will be longer than the percent identity of the second sequence to the first sequence.

[00136] As a non-limiting example, whether any particular polynucleotide has a certain percentage sequence identity (e.g., is at least 80% identical, at least 85% identical, at least 90% identical, and in some embodiments, at least 95%, 96%, 97%, 98%, or 99% identical) to a reference sequence can, in certain embodiments, be determined using the Bestfit program (Wisconsin Sequence Analysis Package, Version 8 for Unix, Genetics Computer Group, University Research Park, 575 Science Drive, Madison, WI 53711). Bestfit uses the local homology algorithm of Smith and Waterman, *Advances in Applied Mathematics* 2: 482 489 (1981), to find the best segment of homology between two sequences. When using Bestfit or any other sequence alignment program to determine whether a particular sequence is, for instance, 95% identical to a reference sequence according to the present invention, the parameters are set such that the percentage of identity is calculated over the full length of the reference nucleotide sequence and that gaps in homology of up to 5% of the total number of nucleotides in the reference sequence are allowed.

[00137] In some embodiments, two nucleic acids or polypeptides of the invention are substantially identical, meaning they have at least 70%, at least 75%, preferably at least 80%, more preferably at least 85%, more preferably at least 90%, and in some embodiments at least 95%, 96%, 97%, 98%, 99% nucleotide or amino acid residue identity, when compared and aligned for maximum correspondence, as measured using a sequence comparison algorithm or by visual inspection. Preferably, identity exists over a region of the sequences that is at least about 10, preferably about 20, more preferable about 40-60 residues in length or any integral value therebetween, preferably over a longer region than 60-80 residues, more preferably at least about 90-100 residues, and most preferably the sequences are substantially identical over the full length of the sequences being compared, such as the coding region of a nucleotide sequence for example.

[00138] A "conservative amino acid substitution" is one in which one amino acid residue is replaced with another amino acid residue having a similar side chain. Families of amino acid residues having similar side chains have been defined in the art, including basic side chains (e.g., lysine, arginine, histidine), acidic side chains (e.g., aspartic acid, glutamic acid), uncharged polar side chains (e.g., glycine, asparagine, glutamine, serine, threonine, tyrosine, cysteine), nonpolar side chains (e.g., alanine, valine, leucine, isoleucine, proline, phenylalanine, methionine, tryptophan), beta-branched side chains (e.g., threonine, valine, isoleucine) and aromatic side chains (e.g., tyrosine, phenylalanine, tryptophan, histidine). For example, substitution of a phenylalanine for a tyrosine is a conservative substitution. Preferably, conservative substitutions in the sequences of the polypeptides and antibodies of the invention do not abrogate the binding of the polypeptide or antibody containing the amino acid sequence, to the antigen(s), i.e., the one or more human frizzled receptors to which the polypeptide or antibody binds. Methods of identifying nucleotide and amino acid conservative substitutions which do not eliminate antigen binding are well- known in the art (see, e.g., Brummell et al., *Biochem.* 32: 1180-1 187 (1993); Kobayashi et al. *Protein Eng.* 12(10):879-884 (1999); and Burks et al. *Proc. Natl. Acad. Sci. USA* 94:.412-417 (1997)).

[00139] As used in the present disclosure and claims, the singular forms "a," "an," and "the" include plural forms unless the context clearly dictates otherwise.

[00140] It is understood that wherever embodiments are described herein with the language "comprising," otherwise analogous embodiments described in terms of "consisting of" and/or "consisting essentially of" are also provided.

[00141] The term "and/or" as used in a phrase such as "A and/or B" herein is intended to include both "A and B," "A or B," "A," and "B." Likewise, the term "and/or" as used in a

phrase such as "A, B, and/or C" is intended to encompass each of the following embodiments: A, B, and C; A, B, or C; A or C; A or B; B or C; A and C; A and B; B and C; A (alone); B (alone); and C (alone).

[00142] "Conditions of high stringency," may be identified by those that: (1) employ low ionic strength and high temperature for washing, for example 0.015 M sodium chloride/0.0015 M sodium citrate/0.1% sodium dodecyl sulfate at 50°C; (2) employ during hybridization a denaturing agent, such as formamide, for example, 50% (v/v) formamide with 0.1% bovine serum albumin/0.1% Ficoll/0.1% polyvinylpyrrolidone/50 mM sodium phosphate buffer at pH 6.5 with 750 mM sodium chloride, 75 mM sodium citrate at 42°C; or (3) employ 50% formamide, 5xSSC (0.75 M NaCl, 0.075 M sodium citrate), 50 mM sodium phosphate (pH 6.8), 0.1% sodium pyrophosphate, 5x Denhardt's solution, sonicated salmon sperm DNA (50 μg/ml), 0.1% SDS, and 10% dextran sulfate at 42°C, with washes at 42°C. in 0.2xSSC (sodium chloride/sodium citrate) and 50% formamide at 55°C, followed by a high-stringency wash consisting of 0.1xSSC containing EDTA at 55°C.

II. FZD-binding agents

[00143] The present invention provides agents that specifically bind one or more human frizzled receptors (FZDs). These agents are referred to herein as "FZD-binding agents." In certain embodiments, the agents specifically bind two, three, four, five, six, seven, eight, nine, or ten frizzled receptors. The human frizzled receptor or receptors bound by the agent may be selected from the group consisting of FZD1, FZD2, FZD3, FZD4, FZD5, FZD6, FZD7, FZD8, FZD9, and FZD10. In certain embodiments, the one or more human frizzled receptors comprise FZD1, FZD2, FZD5, FZD7, and/or FZD8. In certain embodiments, the one or more human frizzled receptors comprise FZD7. In certain embodiments, the one or more human frizzled receptors comprise FZD5 and/or FZD8. In certain embodiments, the agent specifically binds FZD1, FZD2, FZD5, FZD7, and FZD8. The full-length amino acid (aa) and nucleotide (nt) sequences for FZD1-10 are known in the art and also provided herein as SEQ ID NO:26 (FZD1 aa), SEQ ID NO:30 (FZD2 aa), SEQ ID NO:34 (FZD3 aa), SEQ ID NO:38 (FZD4 aa), SEQ ID NO:42 (FZD5 aa), SEQ ID NO:46 (FZD6 aa), SEQ ID NO:50 (FZD7 aa), SEQ ID NO:54 (FZD8 aa), SEQ ID NO:58 (FZD9 aa), SEQ ID NO:62 (FZD10 aa), SEQ ID NO:29 (FZD1 nt), SEQ ID NO:33 (FZD2 nt), SEQ ID NO:37 (FZD3 nt), SEQ ID NO:41 (FZD4 nt), SEQ ID NO:45 (FZD5 nt), SEQ ID NO:49

(FZD6 nt), SEQ ID NO:53 (FZD7 nt), SEQ ID NO:57 (FZD8 nt), SEQ ID NO:61 (FZD9 nt), and SEQ ID NO:65 (FZD10 nt).

[00144] In certain embodiments, the antibody or other polypeptide or agent described herein specifically binds FZD7. In certain embodiments, that antibody, polypeptide, or agent may further specifically bind or cross-react with one or more additional human frizzled receptors.

[00145] In certain embodiments, the antibody or other polypeptide or agent described herein specifically binds FZD5. In certain embodiments, that antibody, polypeptide, or agent may further specifically bind or cross-react with one or more additional human frizzled receptors.

[00146] In certain embodiments, the agent specifically binds to two or more human frizzled receptors. In certain embodiments, the two or more human frizzled receptors are selected from the group consisting of FZD2, FZD5, FZD7, and FZD8. In certain embodiments, the two or more frizzled receptors comprise FZD1 and a second frizzled receptor selected from the group consisting of FZD2, FZD5, FZD7, and FZD8. In certain embodiments, the two or more frizzled receptors comprise FZD2 and a second frizzled receptor selected from the group consisting of FZD1, FZD5, FZD7, and FZD8. In certain embodiments, the two or more frizzled receptors comprise FZD5 and a second frizzled receptor selected from the group consisting of FZD1, FZD2, FZD7, and FZD8. In certain embodiments, the two or more frizzled receptors comprise both FZD5 and FZD8. In certain embodiments, the two or more frizzled receptors comprise FZD7 and a second frizzled receptor selected from the group consisting of FZD1, FZD2, FZD5, and FZD8.

[00147] In certain embodiments, the agent specifically binds to three or more human frizzled receptors. In certain embodiments, the three or more human frizzled receptors comprise three or more frizzled receptors selected from the group consisting of FZD1, FZD2, FZD5, FZD7, and FZD8. In certain embodiments, the agent further specifically binds to one or more additional human frizzled receptors.

[00148] In certain embodiments, the agent or antibody specifically binds to the extracellular domain (ECD) within the one or more human frizzled receptors to which it binds. Sequences of the extracellular domain of each of the human frizzled receptors are known in the art and are also provided as SEQ ID NO:27 (FZD1 ECD), SEQ ID NO:31 (FZD2 ECD), SEQ ID NO:35 (FZD3 ECD), SEQ ID NO:39 (FZD4 ECD), SEQ ID NO:43 (FZD5 ECD), SEQ ID NO:47 (FZD6 ECD), SEQ ID NO:51 (FZD7 ECD), SEQ ID NO:55 (FZD8 ECD), SEQ ID NO:59 (FZD9 ECD), and SEQ ID NO:63 (FZD10 ECD).

[00149] In certain embodiments, the agent or antibody specifically binds to the Fri domain (FRI) (also known as the cysteine-rich domain (CRD)) within the human frizzled receptor(s) to which it binds. Sequences of the Fri domain of each of the human frizzled receptors are known in the art and are also provided as SEQ ID NO:28 (FZD1 FRI), SEQ ID NO:32 (FZD2 FRI), SEQ ID NO:36 (FZD3 FRI), SEQ ID NO:40 (FZD4 FRI), SEQ ID NO:44 (FZD5 FRI), SEQ ID NO:48 (FZD6 FRI), SEQ ID NO:52 (FZD7 FRI), SEQ ID NO:56 (FZD8 FRI), SEQ ID NO:60 (FZD9 FRI), and SEQ ID NO:64 (FZD10 FRI).

[00150] In certain embodiments, an individual antigen-binding site of a FZD-binding antibody or polypeptide described herein is capable of binding (or binds) the one, two, three, four, or five (or more) human frizzled receptors. In certain embodiments, an individual antigen-binding site of the FZD-binding antibody or polypeptide is capable of specifically binding one, two, three, four, or five human frizzled receptors selected from the group consisting of FZD1, FZD2, FZD5, FZD7, and FZD8. In certain embodiments, an individual binding site of the antibody or polypeptide specifically binds to at least FZD5 and FZD8.

[00151] In certain embodiments, the FZD-binding agent or antibody binds to one or more (for example, two or more, three or more, or four or more) human frizzled receptors with a dissociation constant (K_D) of about 1 μM or less, about 100 nM or less, about 40 nM or less, about 20 nM or less, or about 10 nM or less. For example, in certain embodiments, a FZD-binding agent or antibody described herein that binds to more than one FZD, binds to those FZDs with a K_D of about 100 nM or less, about 20 nM or less, or about 10 nM or less. In certain embodiments, the FZD-binding agent or antibody binds to each of one or more (e.g., 1, 2, 3, 4, or 5) of the following FZDs with a dissociation constant of about 40 nM or less: FZD1, FZD2, FZD5, FZD7, and FZD8. In certain embodiments, the FZD-binding agent or antibody binds to each of one or more of the following FZDs with a dissociation constant of about 10 nM or less: FZD1, FZD2, FZD5, FZD7, and FZD8. In certain embodiments, the FZD-binding agent or antibody binds to each of the following FZDs with a dissociation constant of about 10 nM or less: FZD1, FZD2, FZD5, FZD7, and FZD8. In certain embodiments, the dissociation constant of the agent or antibody to a particular FZD is the dissociation constant determined using an FZD-Fc fusion protein comprising the FZD extracellular domain or Fri domain immobilized on a Biacore chip.

[00152] In certain embodiments, the FZD-binding agent or antibody binds to one or more (for example, two or more, three or more, or four or more) human frizzled receptors with an EC_{50} of about 1 μM or less, about 100 nM or less, about 40 nM or less, about 20 nM or less, about 10 nM or less, or about 1 nM or less. For example, in certain embodiments, a

FZD-binding agent or antibody described herein that binds to more than one FZD has an EC_{50} of about 40 nM or less, about 20 nM or less, or about 10 nM or less, with respect to those FZDs. In certain embodiments, the FZD-binding agent or antibody has an EC_{50} of about 20 nM or less with respect to one or more (e.g., 1, 2, 3, 4, or 5) of the following FZDs: FZD1, FZD2, FZD5, FZD7, and FZD8. In certain embodiments, the FZD-binding agent or antibody has an EC_{50} of about 10 nM or less with respect to one or more (e.g., 1, 2, 3, 4, or 5) of the following FZDs: FZD1, FZD2, FZD5, FZD7, and FZD8. In certain embodiments, the FZD-binding agent or antibody has an EC50 of about 40 nM or less or 20 nM or less with respect to binding of FZD5 and/or FZD8.

[00153] In certain embodiments, the FZD-binding agent (e.g., antibody) binds to the same epitope as or binds to an epitope that overlaps with the epitope of an antibody comprising a heavy chain variable region comprising SEQ ID NO:10 and a light chain variable region comprising SEQ ID NO:12 or SEQ ID NO:14 (e.g., the 18R5 or 18R8 IgG antibody). In certain embodiments, the FZD-binding agent or antibody binds to the same epitope as or binds to an epitope that overlaps with the epitope of an antibody comprising a heavy chain comprising the sequence of SEQ ID NO:11 and a light chain comprising the sequence of SEQ ID NO:13 or SEQ ID NO:15. In certain embodiments, the FZD-binding agent binds to the same epitope as or binds to an epitope that overlaps with the epitope of an antibody comprising a heavy chain variable region comprising SEQ ID NO:85 and a light chain variable region comprising SEQ ID NO:86 (e.g., the 44R24 IgG antibody).

[00154] In certain embodiments, the FZD-binding agent competes for specific binding to a human frizzled receptor with an antibody in a competitive binding assay, wherein the antibody comprises a heavy chain variable region comprising SEQ ID NO:10 and a light chain variable region comprising SEQ ID NO:12 or SEQ ID NO:14. In certain embodiments, the FZD-binding agent competes for specific binding to a human frizzled receptor with an antibody comprising a heavy chain comprising the sequence of SEQ ID NO:11 and a light chain comprising the sequence of SEQ ID NO:13 or SEQ ID NO:15. In certain embodiments, the antibody with which the agent competes for specific binding to the human frizzled receptor is an 18R5 IgG antibody. In certain alternative embodiments, the antibody is an 18R8 IgG antibody.

[00155] In certain embodiments, the FZD-binding agent competes for specific binding to a human frizzled receptor with an antibody in a competitive binding assay, wherein the antibody comprises a heavy chain variable region comprising SEQ ID NO:85 and a light chain variable region comprising SEQ ID NO:86.

[00156] In certain embodiments, the FZD-binding agent or antibody binds to at least part of a region of a human frizzled receptor designated by the inventors as the Biological Binding Site (BBS) (Figure 9, Example 6). In human FZD8 (SEQ ID NO:54), the BBS consists of the following: (a) a conformational epitope consisting of amino acids 72(F), 74-75(PL), 78(I), 92(Y), 121-122(LM), and 129-132(WPDR (SEQ ID NO:70)) (the "cleft" of the BBS shown in Figures 8 and 9); (b) a region of FZD8 consisting of the sequence GLEVHQ (SEQ ID NO:25) (the "top edge" of the BBS shown in Figures 8 and 9); and (c) a region of FZD8 consisting of the sequence YGFA (SEQ ID NO:74) (the "bottom edge" of the BBS shown in Figures 8 and 9). The corresponding residues of the BBS on FZD1-7, FZD9, and FZD10 are identified in Table 1, below, and Figure 8. In certain embodiments, an agent that blocks binding of a ligand (e.g., a Wnt) to the FZD inhibits the binding of the ligand to the BBS. It is understood that in certain embodiments, the agents which bind to at least part of the BBS may also bind one or more regions elsewhere (i.e., outside of the BBS) on the human frizzled receptor. In other words, in certain embodiments, the epitope to which the FZD-binding agent or antibody binds is a region within the extracellular domain of the FZD receptor that overlaps with the BBS, but is not entirely contained within the BBS. In certain alternative embodiments, the epitope to which the FZD-binding agent or antibody binds is entirely contained within the BBS (i.e., the BBS comprises the entire epitope to which the FZD binding antibody or other agent binds).

Table 1. Biological Binding Sites (BBS) of FZD Receptors

Human Frizzled Receptor (aa sequence)	Amino acid residues forming the Biological Binding Site (BBS)
FZD1 (SEQ ID NO:26)	147-153 (GLEVHQF) , 155-156(PL), 159(V), 173(Y), 201-202(LM), 205-212(FGFQWPDT)
FZD2 (SEQ ID NO:30)	70-76(GLEVHQF), 78-79(PL), 82(V), 96(Y), 124-125(LM), 128-135 (FGFQWPER)
FZD3 (SEQ ID NO:34)	59-65(ALAMEPF), 67-68(PM), 71(L), 85(Y), 113-114(LM), 117-124 (FGVPWPED)
FZD4 (SEQ ID NO:38)	79-85(ELQLTTF), 87-88(PL), 91(Y), 105(Y), 134-135(VL), 138-145(FGFAWPES)
FZD5	64-70(GLEVHQF), 72-73(PL), 76(I) 90(Y), 119-120(LM), 123-

(SEQ ID NO:42)	130(YGFAWPER)
FZD6 (SEQ ID NO:46)	55-61(AVEMEHF), 63-64(PL), 67(L), 81(F), 109-110(LI), 113-120(FGIRWPEE)
FZD7 (SEQ ID NO:50)	80-86(GLEVHQF), 88-89(PL), 92(V), 106(Y), 134-135(LM), 138-145(FGFQWPER)
FZD8 (SEQ ID NO:54)	66-72(GLEVHQF), 74-75(PL), 78(I), 92(Y), 121-122(LM), and 125-132(YGFAWPDR)
FZD9 (SEQ ID NO:58)	70-76(AAELAEF), 78-79(PL), 82(Y), 96(Y), 125-126(IM), 129-136(FNFGWPDS)
FZD10 (SEQ ID NO:62)	65-71(AIQLHEF), 73-74(PL), 77(Y), 91(Y), 120-121(IM), 124-131(FNFKWPDS)

[00157] Without being bound by theory, the BBS is believed to comprise a possible ligand binding site, such as a binding site for Wnt. On FZD8, this possible ligand binding site comprises the conformational epitope formed by amino acids 72(F), 74-75(PL), 78(I), 92(Y), 121-122(LM), and 129-132(WPDR (SEQ ID NO:70)) (the "cleft" of the BBS shown in Figures 8 and 9). The corresponding residues of the possible ligand binding site on FZD1-7, FZD9, and FZD10 are shown in the alignment of sequences in Figure 8. In certain embodiments, an agent that blocks binding of a ligand (e.g, a Wnt) to the BBS inhibits the binding of the ligand to this conformational epitope. It is understood that in certain embodiments, the agents which bind to at least a part of this ligand binding site may also bind to a region elsewhere (e.g., outside of the BBS) on the human frizzled receptor. In certain alternative embodiments, the agent does not bind to any portion of the FZD outside of the conformational epitope.

[00158] In certain embodiments, the agent binds to at least part of the sequence QDEAGLEVHQFWPL (SEQ ID NO:67) within the human frizzled receptor if the human frizzled receptor is FZD8, or the corresponding sequence if the human frizzled receptor is FZD1-7, FZD9, or FZD10. This region on the FZDs comprises the "top edge" of the BBS identified in Figures 8 and 9. The sequences corresponding to the epitope QDEAGLEVHQFWPL (SEQ ID NO:67) of FZD8 in the various frizzled receptors are identified in Table 2, below, and are also apparent from the alignment in Figure 8. In certain embodiments, the agent specifically binds to a human frizzled receptor selected from the group consisting of FZD1, FZD2, FZD5, FZD7, and FZD8, and the agent binds to at least

part of the sequence Q(DE/ED)AGLEVHQF(Y/W)PL (SEQ ID NO:24) within the human frizzled receptor. In certain embodiments, the agent specifically binds to at least part of the sequence AGLEVHQF (SEQ ID NO:68) within the human frizzled receptor(s) FZD1, FZD2, FZD5, FZD7, and/or FZD8. In certain embodiments, the agent binds to at least part of a sequence in FZD3, FZD4, FZD6, FZD9, and/or FZD10 that corresponds to the sequence AGLEVHQF (SEQ ID NO:68) in FZD8. In certain embodiments, the agent specifically binds to at least part of the sequence GLEVHQ (SEQ ID NO: 25) within the human frizzled receptor(s) FZD1, FZD2, FZD5, FZD7, and/or FZD8. This sequence is the "top edge" of the BBS shown in Figure 9. In certain embodiments, the agent binds to at least part of the sequence in FZD3, FZD4, FZD6, FZD9, and/or FZD10 that corresponds to the sequence GLEVHQ (SEQ ID NO: 25) in FZD8. Sequences which correspond to the sequence GLEVHQ (SEQ ID NO: 25) of FZD8 are underlined in the second and third columns of Table 2 below and are apparent from the sequence alignment in Figure 8. In certain embodiments, an agent that binds to at least part of SEQ ID NO:67 or 68 in FZD8, or to a corresponding epitope in another FZD, inhibits binding of a ligand (e.g., a Wnt) to the FZD (e.g., to the BBS of the FZD). In certain embodiments, the agents which bind to the above indicated regions may also bind to additional regions elsewhere (i.e., outside of the above-specified regions) on the human frizzled receptor.

Table 2. Corresponding regions on human frizzled receptors

FZD (aa seq)	aa corresponding to aa 62-75 (QDEAGLEVHQFWPL; SEQ ID NO:67) of FZD8 (SEQ ID NO:54)[a]	aa corresponding to aa 65-72 (AGLEVHQF; SEQ ID NO:68) of FZD8 (SEQ ID NO:54)[a]	aa corresponding to aa 124-128 (QYGFA; SEQ ID NO:66) of FZD8 (SEQ ID NO:54)[b]
FZD1 (SEQ ID NO:26)	143-156 (QEDAGLEVHQFYPL)	146-153 (AGLEVHQF)	204-208 (KFGFQ)
FZD2 (SEQ ID NO:30)	66-79 (QEDAGLEVHQFYPL)	69-76 (AGLEVHQF)	127-131 (KFGFQ)
FZD3 (SEQ ID NO:34)	55-68 (QQTAALAMEPFHPM)	58-65 (AALAMEPF)	116-120 (MFGVP)
FZD4	75-88	78-85 (AELQLTTF)	137-141 (EFGFA)

(SEQ ID NO:38)	(QTDAELQLTTFTPL)		
FZD5 (SEQ ID NO:42)	60-73 (QDEAGLEVHQFWPL)	63-70 (AGLEVHQF)	122-126 (QYGFA)
FZD6 (SEQ ID NO:46)	51-64 (QSIAAVEMEHFLPL)	54-61 (AAVEMEHF)	112-116 (TFGIR)
FZD7 (SEQ ID NO:50)	76-89 (QEDAGLEVHQFYPL)	79-86 (AGLEVHQF)	137-141 (KFGFQ)
FZD9 (SEQ ID NO:58)	66-79 (QGEAAAELAEFAPL)	69-76 (AAAELAEF)	128-132 (QFNFG)
FZD10 (SEQ ID NO:62)	61-74 (QREAAIQLHEFAPL)	64-71(AAIQLHEF)	123-127 (QFNFK)

(a): Sequences corresponding to aa 66-71 GLEVHQ (SEQ ID NO: 25) of FZD8 (SEQ ID NO:54) are underlined.

(b): Sequences corresponding to aa 125-128 YGFA (SEQ ID NO:74) of FZD8 (SEQ ID NO:54) are underlined.

[00159] In certain embodiments, the FZD-binding agent binds to at least part of a region consisting of the sequence QYGFA (SEQ ID NO:66) if the human frizzled receptor is FZD8, which comprises the "bottom edge" of the BBS, or the corresponding sequence if the human frizzled receptor is FZD1-7, FZD9, or FZD10. The sequences corresponding to the region QYGFA (SEQ ID NO:66) in the various frizzled receptors are identified in Figure 8 and Table 2 above. In certain embodiments, the FZD-binding agent binds to at least part of a region consisting of the sequence YGFA (SEQ ID NO:74), the "bottom edge" of the BBS, if the human frizzled receptor is FZD8, or the corresponding sequence if the human frizzled receptor is FZD1-7, FZD9, or FZD10. The sequences corresponding to the region YGFA (SEQ ID NO:74) in the various frizzled receptors are identified in Figure 8 and underlined in the fourth column of Table 2 above. In certain embodiments, an agent that binds to at least part of SEQ ID NO:66 or SEQ ID NO:74 in FZD8, or to its corresponding sequence in another FZD, inhibits binding of a ligand (e.g., a Wnt) to the FZD (e.g., the BBS of the FZD). In certain embodiments, the agents which bind to this region may also bind to one or more amino acid residues elsewhere (i.e., outside of this region) on the human frizzled receptor.

[00160] In certain embodiments, FZD-binding agent binds at least part of the region forming the "top edge" of the BBS, as well as at least a part of the region forming the "bottom edge" of the BBS. In certain embodiments, the FZD-binding agent that binds to at least part of Q(DE/ED)AGLEVHQF(Y/W)PL (SEQ ID NO:24) within FZD1, FZD2, FZD5,

FZD7, and/or FZD8, QDEAGLEVHQFWPL (SEQ ID NO:67) within FZD8, AGLEVHQF (SEQ ID NO:68) within FZD8, and/or GLEVHQ (SEQ ID NO:25) within FZD8, and/or a sequence corresponding to any of these sequences in a different human frizzled receptor (as defined in Table 2, above) further binds to at least part of QYGFA (SEQ ID NO:66) within FZD8 or YGFA (SEQ ID NO:74) within FZD8, and/or a sequence corresponding to one of these sequences within FZD1-7, FZD9, or FZD10 (as defined in Table 2, above). In certain embodiments, the FZD binding agent binds to at least part of the sequence GLEVHQ (SEQ ID NO:25) within FZD8, as well as to at least part of the sequence YGFA (SEQ ID NO:74) within FZD8. In certain embodiments, the FZD-binding agent binds to at least part of a region of FZD1-7, FZD9, or FZD10 corresponding to the sequence GLEVHQ (SEQ ID NO:25) in FZD8, as well as to at least part of a region of FZD1-7, FZD9, or FZD10 corresponding to the sequence YGFA (SEQ ID NO:74) in FZD8. In certain embodiments, the FZD-binding agent that binds to the indicated sequences also binds to one or more sequences elsewhere within the human frizzled receptor(s) to which it binds. In other words, in certain embodiments, the epitope to which the FZD-binding agent or antibody binds is a region within the FZD extracellular domain that overlaps only partially with the above-indicated sequences. In certain alternative embodiments, the entire epitope to which the FZD-binding agent binds is entirely contained within the above-indicated sequences.

[00161] In certain embodiments, the agent is a polypeptide. In certain embodiments, the agent or polypeptide is an antibody. In certain embodiments, the antibody is an IgG1 antibody or an IgG2 antibody. In certain embodiments, the antibody is a monoclonal antibody. In certain embodiments, the antibody is a human antibody or a humanized antibody. In certain embodiments, the antibody is an antibody fragment.

[00162] The antibodies or other agents of the present invention can be assayed for specific binding by any method known in the art. The immunoassays which can be used include, but are not limited to, competitive and non-competitive assay systems using techniques such as BIAcore analysis, FACS analysis, immunofluorescence, immunocytochemistry, Western blots, radioimmunoassays, ELISA, "sandwich" immunoassays, immunoprecipitation assays, precipitation reactions, gel diffusion precipitin reactions, immunodiffusion assays, agglutination assays, complement-fixation assays, immunoradiometric assays, fluorescent immunoassays, and protein A immunoassays. Such assays are routine and well known in the art (see, e.g., Ausubel et al, eds, 1994, Current Protocols in Molecular Biology, Vol. 1, John Wiley & Sons, Inc., New York, which is incorporated by reference herein in its entirety).

[00163] For example, the specific binding of an antibody to a human frizzled receptor may be determined using ELISA. An ELISA assay comprises preparing antigen, coating wells of a 96 well microtiter plate with antigen, adding the FZD-binding antibody or other FZD-binding agent conjugated to a detectable compound such as an enzymatic substrate (e.g. horseradish peroxidase or alkaline phosphatase) to the well, incubating for a period of time and detecting the presence of the antigen. In some embodiments, the FZD-binding antibody or agent is not conjugated to a detectable compound, but instead a second conjugated antibody that recognizes the FZD-binding antibody or agent is added to the well. In some embodiments, instead of coating the well with the antigen, the FZD-binding antibody or agent can be coated to the well and a second antibody conjugated to a detectable compound can be added following the addition of the antigen to the coated well. One of skill in the art would be knowledgeable as to the parameters that can be modified to increase the signal detected as well as other variations of ELISAs known in the art (see e.g. Ausubel et al, eds, 1994, Current Protocols in Molecular Biology, Vol. 1, John Wiley & Sons, Inc., New York at 11.2.1).

[00164] The binding affinity of an antibody or other agent to a human frizzled receptor and the off-rate of an antibody-antigen interaction can be determined by competitive binding assays. One example of a competitive binding assay is a radioimmunoassay comprising the incubation of labeled antigen (e.g. ^{3}H or ^{125}I), or fragment or variant thereof, with the antibody of interest in the presence of increasing amounts of unlabeled antigen followed by the detection of the antibody bound to the labeled antigen. The affinity of the antibody against a frizzled receptor and the binding off-rates can be determined from the data by scatchard plot analysis. In some embodiments, BIAcore kinetic analysis is used to determine the binding on and off rates of antibodies or agents that bind one or more human frizzled receptors. BIAcore kinetic analysis comprises analyzing the binding and dissociation of antibodies from chips with immobilized FZD antigens on their surface.

[00165] In certain embodiments, the agent (e.g., antibody) is an antagonist of at least one human frizzled receptor (i.e., 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10 FZDs) bound by the agent. In certain embodiments, the agent inhibits at least about 10%, at least about 20%, at least about 30%, at least about 50%, at least about 75%, at least about 90%, or about 100% of one or more activity of the bound human frizzled receptor.

[00166] In certain embodiments, the FZD-binding agent inhibits binding of a ligand to the at least one human frizzled receptor. In certain embodiments, the FZD-binding agent inhibits binding of a ligand to the Biological Binding site (BBS) of the human frizzled

receptor. In certain embodiments, the ligand is a human Wnt protein. Nineteen human Wnt proteins have been identified: WNT1, WNT2, WNT2B/13, WNT3, WNT3A, WNT4, WNT5A, WNT5B, WNT6, WNT7A, WNT7B, WNT8A, WNT8B, WNT9A (previously WNT14), WNT9B (previously WNT15), WNT10A, WNT10B, WNT11, and WNT16. In certain embodiments, the agent inhibits binding of WNT3A to FZD8. In certain embodiments, the inhibition of binding of a particular ligand to a particular human frizzled protein provided by the FZD-binding agent is at least about 10%, at least about 25%, at least about 50%, at least about 75%, at least about 90%, or at least about 95%. In certain embodiments, an agent that inhibits binding of a ligand such as a Wnt to a FZD, further inhibits Wnt signaling (e.g., inhibits canonical Wnt signaling).

[00167] In certain embodiments, the FZD-binding agent inhibits Wnt signaling. It is understood that a FZD-binding agent that inhibits Wnt signaling may, in certain embodiments, inhibit signaling by one or more Wnts, but not necessarily by all Wnts. In certain alternative embodiments, signaling by all human Wnts may be inhibited. In certain embodiments, signaling by one or more Wnts selected from the group consisting of WNT1, WNT2, WNT2B/13, WNT3, WNT3A, WNT4, WNT5A, WNT5B, WNT6, WNT7A, WNT7B, WNT8A, WNT8B, WNT9A (previously WNT14), WNT9B (previously WNT15), WNT10A, WNT10B, WNT11, and WNT16 is inhibited. In certain embodiments, the Wnt signaling that is inhibited is signaling by WNT1, WNT2, WNT3, WNT3A, WNT7a, WNT7b, and/or WNT10B. In certain embodiments, the agent inhibits signaling by (at least) WNT1, WNT3A, WNT7b, and WNT10B. In particular embodiments, the agent inhibits signaling by (at least) WNT3A. In certain embodiments, the inhibition of signaling by a Wnt provided by the FZD-binding agent is a reduction in the level of signaling by the Wnt of least about 10%, at least about 25%, at least about 50%, at least about 75%, at least about 90%, or at least about 95%. In certain embodiments, the Wnt signaling that is inhibited is canonical Wnt signaling.

[00168] In vivo and in vitro assays for determining whether a FZD-binding agent (or candidate FZD-binding agent) inhibits Wnt signaling are known in the art. For example, cell-based, luciferase reporter assays utilizing a TCF/Luc reporter vector containing multiple copies of the TCF-binding domain upstream of a firefly luciferase reporter gene may be used to measure canonical Wnt signaling levels in vitro (Gazit et al., 1999, Oncogene 18; 5959-66). The level of Wnt signaling in the presence of one or more Wnts (e.g., Wnt(s) expressed by transfected cells or provided by Wnt-conditioned media) with the FZD-binding agent present is compared to the level of signaling without the FZD-binding agent present. Non-

limiting, specific examples of the use of such a luciferase reporter assay to assess inhibition of canonical Wnt signaling are provided in Examples 3 and 11, below. In addition to the TCF/luc reporter assay, the effect of a FZD-binding agent (or candidate agent) on canonical Wnt signaling may be measured in vitro or in vivo by measuring the effect of the agent on the level of expression of beta-catenin regulated genes, such as c-myc (He et al., Science, 281:1509-12 (1998)), cyclin D1 (Tetsu et al., Nature, 398:422-6 (1999)) and/or fibronectin (Gradl et al. Mol. Cell Biol., 19:5576-87 (1999)). In certain embodiments, the effect of an agent on Wnt signaling may also be assessed by measuring the effect of the agent on the phosphorylation state of Dishevelled-1, Dishevelled-2, Dishevelled-3, LRP5, LRP6, and/or beta-catenin. In still further embodiments, the effect of a FZD-binding agent on Wnt signaling is determined by assessing the impact of the FZD-binding agent on the expression level of one or more genes in a Wnt signature.

[00169] In certain embodiments, the FZD-binding agents have one or more of the following effects: inhibit proliferation of tumor cells, reduce the tumorigenicity of a tumor by reducing the frequency of cancer stem cells in the tumor, inhibit tumor growth, increase survival, trigger cell death of tumor cells, differentiate tumorigenic cells to a non-tumorigenic state, or prevent metastasis of tumor cells.

[00170] In certain embodiments, antibodies or other agents that specifically bind one or more human frizzled receptors trigger cell death via a conjugated toxin, chemotherapeutic agent, radioisotope, or other such agent. For example, in certain embodiments, an antibody to a human frizzled antibody is conjugated to a toxin that is activated in tumor cells expressing the FZD by protein internalization. In certain alternative embodiments, the agent or antibody is not conjugated to a toxin, chemotherapeutic agent, or radioisotope.

[00171] In certain embodiments, the FZD-binding agents are capable of inhibiting tumor growth. In certain embodiments, the FZD-binding agents are capable of inhibiting tumor growth in vivo (e.g., in a xenograft mouse model and/or in a human having cancer).

[00172] In certain embodiments, the FZD-binding agents are capable of reducing the tumorigenicity of a tumor. In certain embodiments, the agent or antibody is capable of reducing the tumorigenicity of a tumor comprising cancer stem cells in an animal model, such as a mouse xenograft model. In certain embodiments, the number or frequency of cancer stem cells in a tumor is reduced by at least about two-fold, about three-fold, about five-fold, about ten-fold, about 50-fold, about 100-fold, or about 1000-fold. In certain embodiments, the reduction in the number or frequency of cancer stem cells is determined by limiting dilution assay using an animal model. An example of a limiting dilution assay used

to test the efficacy of an anti-FZD antibody is provided in Example 8, below. Additional examples and guidance regarding the use of limiting dilution assays to determine a reduction in the number or frequency of cancer stem cells in a tumor can be found, e.g., in International Publication Number WO 2008/042236, U.S. Patent Application Publication No. 2008/0064049, and U.S. Patent Application Publication No. 2008/0178305, each of which is incorporated by reference herein in its entirety.

[00173] In certain embodiments, antibodies to human frizzled receptors mediate cell death of a cell expressing the FZD protein via antibody-dependent cellular cytotoxicity (ADCC). ADCC involves cell lysis by effector cells that recognize the Fc portion of an antibody. Many lymphocytes, monocytes, tissue macrophages, granulocytes and eosinophiles, for example, have Fc receptors and can mediate cytolysis (Dillman, 1994, J. Clin. Oncol. 12:1497).

[00174] In certain embodiments, antibodies to one or more FZDs trigger cell death of a cell expressing the FZD protein(s) by activating complement-dependent cytotoxicity (CDC). CDC involves binding of serum complement to the Fc portion of an antibody and subsequent activation of the complement protein cascade, resulting in cell membrane damage and eventual cell death. Biological activity of antibodies is known to be determined, to a large extent, by the constant domains or Fc region of the antibody molecule (Uananue and Benacerraf, Textbook of Immunology, 2nd Edition, Williams & Wilkins, p. 218 (1984)). Antibodies of different classes and subclasses differ in this respect, as do antibodies of the same subclass but from different species. Of human antibodies, IgM is the most efficient class of antibodies to bind complement, followed by IgG1, IgG3, and IgG2 whereas IgG4 appears quite deficient in activating the complement cascade (Dillman, 1994, J. Clin. Oncol. 12:1497; Jefferis et al., 1998, Immunol. Rev. 163:59-76). According to the present invention, antibodies of those classes having the desired biological activity are prepared.

[00175] The ability of any particular antibody against one or more FZDs to mediate lysis of the target cell by complement activation and/or ADCC can be assayed. The cells of interest are grown and labeled *in vitro*; the antibody is added to the cell culture in combination with either serum complement or immune cells which can be activated by the antigen antibody complexes. Cytolysis of the target cells is detected, for example, by the release of label from the lysed cells. In fact, antibodies can be screened using the patient's own serum as a source of complement and/or immune cells. The antibody that is capable of activating complement or mediating ADCC in the in vitro test can then be used therapeutically in that particular patient.

[00176] The invention provides polypeptides, including, but not limited to, antibodies that specifically bind to one or more human frizzled receptors, that comprise one, two, three, four, five and/or six of the CDRs of 18R5 and/or 18R8 (see Table 4 of Example 1 below) with up to four (i.e., 0, 1, 2, 3, or 4) conservative amino acid substitutions per CDR. Thus, the invention provides polypeptides, including, but not limited to, antibodies that specifically bind to one or more human frizzled receptors that comprise one, two, three, four, five and/or six of the CDRs of 18R5 and/or 18R8. In certain embodiments, the polypeptides comprise the heavy chain CDR3 of 18R8 and/or the light chain CDR3 of 18R5 or 18R8. In certain embodiments, the heavy chain CDR(s) are contained within a heavy chain variable region and/or the light chain CDR(s) are contained within a light chain variable region.

[00177] For example, the invention provides a polypeptide (e.g., an antibody) that specifically binds a human frizzled receptor, wherein the polypeptide comprises a heavy chain variable region comprising: (a) a heavy chain CDR1 comprising GFTFSHYTLS (SEQ ID NO:1), or a variant thereof comprising 1, 2, 3, or 4 amino acid substitutions; (b) a heavy chain CDR2 comprising VISGDGSYTYYADSVKG (SEQ ID NO:2), or a variant thereof comprising 1, 2, 3, or 4 amino acid substitutions; and/or (c) a heavy chain CDR3 comprising NFIKYVFAN (SEQ ID NO:3), or a variant thereof comprising 1, 2, 3, or 4 amino acid substitutions. In certain embodiments, the polypeptide further comprises a light chain variable region comprising: (a) a light chain CDR1 comprising SGDKLGKKYAS (SEQ ID NO:4) or SGDNIGSFYVH (SEQ ID NO:7), or a variant of SEQ ID NO:4 or SEQ ID NO:7 comprising 1, 2, 3, or 4 amino acid substitutions; (b) a light chain CDR2 comprising EKDNRPSG (SEQ ID NO:5) or DKSNRPSG (SEQ ID NO:8), or a variant of SEQ ID NO:5 or SEQ ID NO:8 comprising 1, 2, 3, or 4 amino acid substitutions; and/or (c) a light chain CDR3 comprising SSFAGNSLE (SEQ ID NO:6) or QSYANTLSL (SEQ ID NO:9), or a variant of SEQ ID NO:6 or SEQ ID NO:9 comprising 1, 2, 3, or 4 amino acid substitutions. In certain embodiments, the amino acid substitutions are conservative substitutions.

[00178] Thus, the invention provides polypeptides or antibodies that comprise a heavy chain CDR1 comprising GFTFSHYTLS (SEQ ID NO:1), a heavy chain CDR2 comprising VISGDGSYTYYADSVKG (SEQ ID NO:2), and/or a heavy chain CDR3 comprising NFIKYVFAN (SEQ ID NO:3). In certain embodiments, the light chain CDR(s) are contained within a variable region of an antibody heavy chain. In certain embodiments, the polypeptide or antibody comprising the one or more of heavy chain CDRs specifically binds one or more human frizzled receptors. In certain embodiments, the CDR(s) have been modified with 1, 2, 3, or 4 conservative amino acid substitutions. In certain embodiments,

each of the heavy chain CDR(s) has been modified by no more than 1-2 conservative amino acid substitutions.

[00179] The invention also provides an antibody that specifically binds a human frizzled receptor, wherein the antibody comprises a heavy chain variable region comprising: (a) a heavy chain CDR1 comprising GFTFSHYTLS (SEQ ID NO:1), or a variant thereof comprising 1, 2, 3, or 4 amino acid substitutions; (b) a heavy chain CDR2 comprising VISGDGSYTYYADSVKG (SEQ ID NO:2), or a variant thereof comprising 1, 2, 3, or 4 amino acid substitutions; and (c) a heavy chain CDR3 comprising NFIKYVFAN (SEQ ID NO:3), or a variant thereof comprising 1, 2, 3, or 4 amino acid substitutions. In certain embodiments, the antibody further comprises a light chain variable region comprising: (a) a light chain CDR1 comprising SGDKLGKKYAS (SEQ ID NO:4) or SGDNIGSFYVH (SEQ ID NO:7), or a variant of SEQ ID NO:4 or SEQ ID NO:7 comprising 1, 2, 3, or 4 amino acid substitutions; (b) a light chain CDR2 comprising EKDNRPSG (SEQ ID NO:5) or DKSNRPSG (SEQ ID NO:8), or a variant of SEQ ID NO:5 or SEQ ID NO:8 comprising 1, 2, 3, or 4 amino acid substitutions; and (c) a light chain CDR3 comprising SSFAGNSLE (SEQ ID NO:6) or QSYANTLSL (SEQ ID NO:9), or a variant of SEQ ID NO:6 or SEQ ID NO:9 comprising 1, 2, 3, or 4 amino acid substitutions. In some alternative embodiments, the antibody instead further comprises a light chain variable region comprising: (a) a light chain CDR1 comprising SGDKLGKKYAS (SEQ ID NO:4) or SGDNIGSFYVH (SEQ ID NO:7); (b) a light chain CDR2 comprising EKDNRPSG (SEQ ID NO:5) or DKSNRPSG (SEQ ID NO:8); and (c) a light chain CDR3 comprising SSFAGNSLE (SEQ ID NO:6) or QSYANTLSL (SEQ ID NO:9). In certain embodiments, the antibody specifically binds FZD1, FZD2, FZD5, FZD7, and/or FZD8. In certain embodiments, the antibody specifically binds two or more human frizzled receptors including FZD5 and FZD8. In certain embodiments, the amino acid substitutions are conservative substitutions.

[00180] The invention further provides a polypeptide (e.g., an antibody) that specifically binds a human frizzled receptor, wherein the polypeptide comprises a light chain variable region comprising: (a) a light chain CDR1 comprising SGDKLGKKYAS (SEQ ID NO:4) or SGDNIGSFYVH (SEQ ID NO:7), or a variant of SEQ ID NO:4 or SEQ ID NO:7 comprising 1, 2, 3, or 4 amino acid substitutions; (b) a light chain CDR2 comprising EKDNRPSG (SEQ ID NO:5) or DKSNRPSG (SEQ ID NO:8), or a variant of SEQ ID NO:5 or SEQ ID NO:8 comprising 1, 2, 3, or 4 amino acid substitutions; and/or (c) a light chain CDR3 comprising SSFAGNSLE (SEQ ID NO:6) or QSYANTLSL (SEQ ID NO:9), or a

variant of SEQ ID NO:6 or SEQ ID NO:9 comprising 1, 2, 3, or 4 amino acid substitutions. In certain embodiments, the amino acid substitutions are conservative substitutions.

[00181] Also provided are polypeptides or antibodies that comprise (a) a light chain CDR1 comprising the sequence SGD(K/N)(L/I)G(K/S)(K/F)Y(A/V)(S/H) (SEQ ID NO:71) or the sequence of SEQ ID NO:71 with up to four (i.e., 0, 1, 2, 3, or 4) conservative amino acid substitutions, (b) a light chain CDR2 comprising the sequence (E/D)K(D/S)NRPSG (SEQ ID NO:72) or the sequence of SEQ ID NO:72 with up to four conservative amino acid substitutions, and/or (c) a light chain CDR3 comprising the sequence (S/Q)S(F/Y)A(G/N)(N/T)(no aa/L)SL(E/no aa) (where "no aa/L" indicates either L or no amino acid and "E/no aa" indicates either E or no amino acid; SEQ NO:73) or the sequence of SEQ ID NO:73 with up to four conservative amino acid substitutions.

[00182] The invention also provides polypeptides or antibodies that comprise a light chain CDR1 comprising SGDKLGKKYAS (SEQ ID NO:4) or SGDNIGSFYVH (SEQ ID NO:7), a light chain CDR2 comprising EKDNRPSG (SEQ ID NO:5) or DKSNRPSG (SEQ ID NO:8), and/or a light chain CDR3 comprising SSFAGNSLE (SEQ ID NO:6) or QSYANTLSL (SEQ ID NO:9). In certain embodiments, the polypeptide or antibody comprises a light chain CDR1 comprising SGDNIGSFYVH (SEQ ID NO:7), a light chain CDR2 comprising DKSNRPSG (SEQ ID NO:8), and a light chain CDR3 comprising QSYANTLSL (SEQ ID NO:9). In certain alternative embodiments, the polypeptide or antibody comprises a light chain CDR1 comprising SGDKLGKKYAS (SEQ ID NO:4), a light chain CDR2 comprising EKDNRPSG (SEQ ID NO:5), and a light chain CDR3 comprising SSFAGNSLE (SEQ ID NO:6). In certain embodiments, the light chain CDR(s) are contained within a variable region of an antibody light chain. In certain embodiments, the polypeptide or antibody specifically binds one or more human frizzled receptors. In certain embodiments, the polypeptide or antibody comprising the one or more of light chain CDRs specifically binds one or more human frizzled receptors. In certain embodiments, the CDR(s) have been modified with 1, 2, 3, or 4 conservative modifications. In certain embodiments, each of the light chain CDR(s) has been modified by no more than 1-2 conservative amino acid substitutions.

[00183] In certain embodiments, the antibody comprises (a) a heavy chain CDR1 comprising GFTFSHYTLS (SEQ ID NO:1), a heavy chain CDR2 comprising VISGDGSYTYYADSVKG (SEQ ID NO:2), and a heavy chain CDR3 comprising NFIKYVFAN (SEQ ID NO:3); and/or (b) a light chain CDR1 comprising SGDKLGKKYAS (SEQ ID NO:4) or SGDNIGSFYVH (SEQ ID NO:7), a light chain CDR2 comprising

EKDNRPSG (SEQ ID NO:5) or DKSNRPSG (SEQ ID NO:8), and a light chain CDR3 comprising SSFAGNSLE (SEQ ID NO:6) or QSYANTLSL (SEQ ID NO:9). In certain embodiments, the antibody comprises (a) a heavy chain CDR1 comprising GFTFSHYTLS (SEQ ID NO:1), a heavy chain CDR2 comprising VISGDGSYTYYADSVKG (SEQ ID NO:2), and a heavy chain CDR3 comprising NFIKYVFAN (SEQ ID NO:3); and (b) a light chain CDR1 comprising SGDKLGKKYAS (SEQ ID NO:4), a light chain CDR2 comprising EKDNRPSG (SEQ ID NO:5), and a light chain CDR3 comprising SSFAGNSLE (SEQ ID NO:6). In certain embodiments, the antibody comprises (a) a heavy chain CDR1 comprising GFTFSHYTLS (SEQ ID NO:1), a heavy chain CDR2 comprising VISGDGSYTYYADSVKG (SEQ ID NO:2), and a heavy chain CDR3 comprising NFIKYVFAN (SEQ ID NO:3) and (b) a light chain CDR1 comprising SGDNIGSFYVH (SEQ ID NO:7), a light chain CDR2 comprising DKSNRPSG (SEQ ID NO:8), and a light chain CDR3 comprising QSYANTLSL (SEQ ID NO:9). In certain embodiments, the CDR(s) have been modified with 1, 2, 3, or 4 conservative amino acid substitutions. In certain embodiments, each of the CDR(s) has been modified by no more than 1-2 conservative amino acid substitutions.

[00184] The invention further provides polypeptides, including, but not limited to, antibodies that specifically bind to one or more human frizzled receptors, that comprise one, two, three, four, five and/or six of the CDRs of the anti-FZD antibody 44R24 (see Table 7 of Example 18 below) with up to four (i.e., 0, 1, 2, 3, or 4) conservative amino acid substitutions per CDR. Thus, the invention provides polypeptides, including, but not limited to, antibodies that specifically bind to one or more human frizzled receptors that comprise one, two, three, four, five and/or six of the CDRs of 44R24. In certain embodiments, the polypeptides comprise the heavy chain CDR3 of 44R24 and/or the light chain CDR3 of 44R24. In certain embodiments, the heavy chain CDR(s) are contained within a heavy chain variable region and/or the light chain CDR(s) are contained within a light chain variable region.

[00185] The invention also provides a polypeptide (e.g. an antibody) that specifically binds human FZD5 and/or FZD8, wherein the antibody comprises: (a) a heavy chain CDR1 comprising GFTFSSYYIT (SEQ ID NO:77), or a variant thereof comprising 1, 2, 3, or 4 conservative amino acid substitutions; a heavy chain CDR2 comprising TISYSSSNTYYADSVKG (SEQ ID NO:78), or a variant thereof comprising 1, 2, 3, or 4 conservative amino acid substitutions; and a heavy chain CDR3 comprising SIVFDY (SEQ ID NO:79), or a variant thereof comprising 1, 2, 3, or 4 conservative amino acid substitutions; and/or (b) a light chain CDR1 comprising SGDALGNRYVY (SEQ ID

NO:80), or a variant thereof comprising 1, 2, 3, or 4 conservative amino acid substitutions; a light chain CDR2 comprising SG (SEQ ID NO:81), or a variant thereof comprising 1, 2, 3, or 4 conservative amino acid substitutions; and a light chain CDR3 comprising GSWDTRPYPKY (SEQ ID NO:82), or a variant thereof comprising 1, 2, 3, or 4 conservative amino acid substitutions. In certain embodiments, the antibody (or other FZD-binding polypeptide) comprises: (a) a heavy chain CDR1 comprising GFTFSSYYIT (SEQ ID NO:77), a heavy chain CDR2 comprising TISYSSSNTYYADSVKG (SEQ ID NO:78), and a heavy chain CDR3 comprising SIVFDY (SEQ ID NO:79); and/or (b) a light chain CDR1 comprising SGDALGNRYVY (SEQ ID NO:80), a light chain CDR2 comprising SG (SEQ ID NO:81), and a light chain CDR3 comprising GSWDTRPYPKY (SEQ ID NO:82).

[00186] Polypeptides comprising one of the individual light chains or heavy chains described herein, as well as polypeptides (e.g., antibodies) comprising both a light chain and a heavy chain are also provided.

[00187] Also provided are polypeptides that comprise: (a) a polypeptide having at least about 80% sequence identity to SEQ ID NO:10; and/or (b) a polypeptide having at least about 80% sequence identity to SEQ ID NO:12 or SEQ ID NO:14. In certain embodiments, the polypeptide comprises a polypeptide having at least about 85%, at least about 90%, at least about 95%, at least about 97%, or at least about 99% sequence identity to SEQ ID NOs:10, 12, or 14. Thus, in certain embodiments, the polypeptide comprises (a) a polypeptide having at least about 95% sequence identity to SEQ ID NO:10, and/or (b) a polypeptide having at least about 95% sequence identity to SEQ ID NO:12 or 14. In certain embodiments, the polypeptide comprises (a) a polypeptide having the amino acid sequence of SEQ ID NO: 10; and/or (b) a polypeptide having the amino acid sequence of SEQ ID NO:12 or SEQ ID NO:14. In certain embodiments, the polypeptide comprises (a) a polypeptide having the amino acid sequence of SEQ ID NO: 11; and/or (b) a polypeptide having the amino acid sequence of SEQ ID NO:13 or SEQ ID NO:15. In certain embodiments, the polypeptide is an antibody and/or the polypeptide specifically binds one or more human frizzled receptors (e.g., FZD1, FZD2, FZD5, FZD7 and/or FZD8). For example, the invention provides an antibody that specifically binds a human frizzled receptor that comprises (a) a polypeptide having the amino acid sequence of SEQ ID NO: 10; and (b) a polypeptide having the amino acid sequence of SEQ ID NO:14. In certain embodiments the polypeptide comprising SEQ ID NO:10 is a heavy chain variable region. In certain embodiments, the polypeptide comprising SEQ ID NO:12 or 14 is a light chain variable region. In certain embodiments, the polypeptide having a certain percentage of sequence

identity to SEQ ID NO:10, 12, or 14 differs from SEQ ID NO:10, 12, or 14 by conservative amino acid substitutions only.

[00188] In certain embodiments the polypeptide or antibody comprises: (a) SEQ ID NO:10 and SEQ ID NO: 12; (b) SEQ ID NO: 10 and SEQ ID NO:14; (c) SEQ ID NO:11 and SEQ ID NO:13; or (d) SEQ ID NO:11 and SEQ ID NO: 15.

[00189] The invention further provides an antibody or other polypeptide that specifically binds to FZD5 and/or FZD8 and comprises: (a) a polypeptide having at least about 80%, at least about 85%, at least about 90%, at least about 95%, at least about 97%, or at least about 99% identity to SEQ ID NO:85; and/or (b) a polypeptide having at least about 80%, at least about 85%, at least about 90%, at least about 95%, at least about 97%, or at least about 99% identity to SEQ ID NO:86. In certain alternative embodiments, the polypeptide or antibody comprises SEQ ID NO:85 and/or SEQ ID NO:86.

[00190] In certain embodiments, the FZD-binding agent comprises, consists essentially of, or consists of an anti-FZD antibody selected from the group consisting of 18R8, 18R5, 18R4605, 18R4805, and 44R24 IgG antibodies.

[00191] In certain embodiments, the FZD-binding agent comprises the heavy chains and light chains of the 18R8 IgG2 antibody (with or without the leader sequence). In certain embodiments, the FZD-binding agent is the 18R8 IgG2 antibody. DNA encoding the heavy chains and light chains of the 18R8 IgG2 antibody was deposited with the American Type Culture Collection (ATCC), 10801 University Boulevard, Manassas, VA, USA, under the conditions of the Budapest Treaty on September 29, 2008, and assigned ATCC deposit designation number PTA-9540. In certain embodiments, the FZD-binding agent comprises the heavy chains and light chains of the 18R5 IgG2 antibody (with or without the leader sequence). In certain embodiments, the FZD-binding agent is the 18R5 IgG2 antibody. DNA encoding the heavy chains and light chains of the 18R5 IgG2 antibody was deposited with the ATCC, under the conditions of the Budapest Treaty on September 29, 2008, and assigned ATCC deposit designation number PTA-9541.

[00192] In certain embodiments, the FZD-binding agent is an IgG antibody encoded by the plasmid deposited with the ATCC on August 26, 2009, and assigned deposit designation number PTA-10307, PTA-10309, or PTA-10311.

[00193] In certain embodiments, the FZD-binding agent is an agent that competes for specific binding to FZD1, FZD2, FZD5, FZD7, and/or FZD8 with an antibody encoded by the plasmid having ATCC deposit designation number PTA-9540, PTA-9541, PTA-10307, or PTA-10309 (e.g., in a competitive binding assay). In certain alternative embodiments, the

FZD-binding agent is an agent that competes for specific binding to FZD5 and/or FZD8 with an antibody encoded by the plasmid having ATCC deposit designation number PTA-10311.

[00194] In certain embodiments, the FZD-binding agent has a circulating half-life in mice, cynomologous monkeys, or humans of at least about 10 hours, at least about 24 hours, at least about 3 days, at least about 1 week, or at least about 2 weeks. In certain embodiments, the FZD-binding agent is an IgG (e.g., IgG1 or IgG2) antibody that has a circulating half-life in mice, cynomologous monkeys, or humans of at least about 10 hours, at least about 24 hours, at least about 3 days, at least about 1 week, or at least about 2 weeks. Methods of increasing the half-life of agents such as polypeptides and antibodies are known in the art. For example, known methods of increasing the circulating half-life of IgG antibodies include the introduction of mutations in the Fc region which increase the pH-dependent binding of the antibody to the neonatal Fc receptor (FcRn) at pH 6.0 (see, e.g., U.S. Pat. Pub. Nos. 2005/0276799, 2007/0148164, and 2007/0122403). Known methods of increasing the circulating half-life of antibody fragments lacking the Fc region include such techniques as PEGylation.

[00195] Polyclonal antibodies can be prepared by any known method. Polyclonal antibodies are raised by immunizing an animal (e.g. a rabbit, rat, mouse, donkey, etc) by multiple subcutaneous or intraperitoneal injections of the relevant antigen (a purified peptide fragment, full-length recombinant protein, fusion protein, etc) optionally conjugated to keyhole limpet hemocyanin (KLH), serum albumin, etc. diluted in sterile saline and combined with an adjuvant (e.g. Complete or Incomplete Freund's Adjuvant) to form a stable emulsion. The polyclonal antibody is then recovered from blood, ascites and the like, of an animal so immunized. Collected blood is clotted, and the serum decanted, clarified by centrifugation, and assayed for antibody titer. The polyclonal antibodies can be purified from serum or ascites according to standard methods in the art including affinity chromatography, ion-exchange chromatography, gel electrophoresis, dialysis, etc.

[00196] Monoclonal antibodies can be prepared using hybridoma methods, such as those described by Kohler and Milstein (1975) Nature 256:495. Using the hybridoma method, a mouse, hamster, or other appropriate host animal, is immunized as described above to elicit the production by lymphocytes of antibodies that will specifically bind to an immunizing antigen. Lymphocytes can also be immunized in vitro. Following immunization, the lymphocytes are isolated and fused with a suitable myeloma cell line using, for example, polyethylene glycol, to form hybridoma cells that can then be selected away from unfused lymphocytes and myeloma cells. Hybridomas that produce monoclonal antibodies directed

specifically against a chosen antigen as determined by immunoprecipitation, immunoblotting, or by an in vitro binding assay (e.g. radioimmunoassay (RIA); enzyme-linked immunosorbent assay (ELISA)) can then be propagated either in vitro culture using standard methods (Goding, Monoclonal Antibodies: Principles and Practice, Academic Press, 1986) or in vivo as ascites tumors in an animal. The monoclonal antibodies can then be purified from the culture medium or ascites fluid as described for polyclonal antibodies above.

[00197] Alternatively monoclonal antibodies can also be made using recombinant DNA methods as described in U.S. Patent 4,816,567. The polynucleotides encoding a monoclonal antibody are isolated from mature B-cells or hybridoma cell, such as by RT-PCR using oligonucleotide primers that specifically amplify the genes encoding the heavy and light chains of the antibody, and their sequence is determined using conventional procedures. The isolated polynucleotides encoding the heavy and light chains are then cloned into suitable expression vectors, which when transfected into host cells such as E. coli cells, simian COS cells, Chinese hamster ovary (CHO) cells, or myeloma cells that do not otherwise produce immunoglobulin protein, monoclonal antibodies are generated by the host cells. Also, recombinant monoclonal antibodies or fragments thereof of the desired species can be isolated from phage display libraries expressing CDRs of the desired species as described (McCafferty et al., 1990, Nature, 348:552-554; Clackson et al., 1991, Nature, 352:624-628; and Marks et al., 1991, J. Mol. Biol., 222:581-597).

[00198] The polynucleotide(s) encoding a monoclonal antibody can further be modified in a number of different manners using recombinant DNA technology to generate alternative antibodies. In some embodiments, the constant domains of the light and heavy chains of, for example, a mouse monoclonal antibody can be substituted 1) for those regions of, for example, a human antibody to generate a chimeric antibody or 2) for a non-immunoglobulin polypeptide to generate a fusion antibody. In some embodiments, the constant regions are truncated or removed to generate the desired antibody fragment of a monoclonal antibody. Site-directed or high-density mutagenesis of the variable region can be used to optimize specificity, affinity, etc. of a monoclonal antibody.

[00199] In some embodiments, the monoclonal antibody against the human frizzled receptor(s) is a humanized antibody. In certain embodiments, such antibodies are used therapeutically to reduce antigenicity and HAMA (human anti-mouse antibody) responses when administered to a human subject. Humanized antibodies can be produced using various techniques known in the art. In certain alternative embodiments, the antibody to the human frizzled receptor(s) is a human antibody.

[00200] Human antibodies can be directly prepared using various techniques known in the art. Immortalized human B lymphocytes immunized in vitro or isolated from an immunized individual that produce an antibody directed against a target antigen can be generated (See, e.g., Cole et al., Monoclonal Antibodies and Cancer Therapy, Alan R. Liss, p. 77 (1985); Boemer et al., 1991, J. Immunol., 147 (1):86-95; and U.S. Patent 5,750,373). Also, the human antibody can be selected from a phage library, where that phage library expresses human antibodies, as described, for example, in Vaughan et al., 1996, Nat. Biotech., 14:309-314, Sheets et al., 1998, Proc. Nat'l. Acad. Sci., 95:6157-6162, Hoogenboom and Winter, 1991, J. Mol. Biol., 227:381, and Marks et al., 1991, J. Mol. Biol., 222:581). Techniques for the generation and use of antibody phage libraries are also described in U.S. Patent Nos. 5,969,108, 6,172,197, 5,885,793, 6,521,404; 6,544,731; 6,555,313; 6,582,915; 6,593,081; 6,300,064; 6,653,068; 6,706,484; and 7,264,963; and Rothe et al., 2007, J. Mol. Bio., doi:10.1016/j.jmb.2007.12.018 (each of which is incorporated by reference in its entirety). Affinity maturation strategies and chain shuffling strategies (Marks et al., 1992, Bio/Technology 10:779-783, incorporated by reference in its entirety) are known in the art and may be employed to generate high affinity human antibodies.

[00201] Humanized antibodies can also be made in transgenic mice containing human immunoglobulin loci that are capable upon immunization of producing the full repertoire of human antibodies in the absence of endogenous immunoglobulin production. This approach is described in U.S. Patents 5,545,807; 5,545,806; 5,569,825; 5,625,126; 5,633,425; and 5,661,016.

[00202] This invention also encompasses bispecific antibodies that specifically recognize a human frizzled receptor. Bispecific antibodies are antibodies that are capable of specifically recognizing and binding at least two different epitopes. The different epitopes can either be within the same molecule (e.g. the same human frizzled receptor) or on different molecules such that both, for example, the antibodies can specifically recognize and bind a human frizzled receptor as well as, for example, 1) an effector molecule on a leukocyte such as a T-cell receptor (e.g. CD3) or Fc receptor (e.g. CD64, CD32, or CD16) or 2) a cytotoxic agent as described in detail below. In certain embodiments, the bispecific antibody specifically binds at least one human frizzled receptor, as well as either VEGF, a Notch ligand, such as a delta-like ligand (for example, DLL4) or jagged, or at least one Notch receptor selected from the group consisting of Notch 1, Notch 2, Notch 3, and Notch 4. Bispecific antibodies can be intact antibodies or antibody fragments.

[00203] Exemplary bispecific antibodies can bind to two different epitopes, at least one of which originates in a polypeptide of the invention. Alternatively, an anti-antigenic arm of an immunoglobulin molecule can be combined with an arm which binds to a triggering molecule on a leukocyte such as a T cell receptor molecule (e.g. CD2, CD3, CD28, or B7), or Fc receptors for IgG so as to focus cellular defense mechanisms to the cell expressing the particular antigen. Bispecific antibodies can also be used to direct cytotoxic agents to cells which express a particular antigen. These antibodies possess an antigen-binding arm and an arm which binds a cytotoxic agent or a radionuclide chelator, such as EOTUBE, DPTA, DOTA, or TETA. Techniques for making bispecific antibodies are common in the art (Millstein et al., 1983, Nature 305:537-539; Brennan et al., 1985, Science 229:81; Suresh et al, 1986, Methods in Enzymol. 121:120; Traunecker et al., 1991, EMBO J. 10:3655-3659; Shalaby et al., 1992, J. Exp. Med. 175:217-225; Kostelny et al., 1992, J. Immunol. 148:1547-1553; Gruber et al., 1994, J. Immunol. 152:5368; and U.S. Patent 5,731,168). Antibodies with more than two valencies are also contemplated. For example, trispecific antibodies can be prepared (Tutt et al., J. Immunol. 147:60 (1991)). Thus, in certain embodiments the antibodies to human frizzled receptor(s) are multispecific.

[00204] Alternatively, in certain alternative embodiments, the FZD-binding agents of the invention are not bispecific antibodies.

[00205] In certain embodiments, the antibodies (or other polypeptides) described herein may be monospecific. For example, in certain embodiments, each of the one or more antigen-binding sites that an antibody contains is capable of binding (or binds) the same one or more human FZD receptors (e.g., FZD1, FZD2, FZD5, FZD7, or FZD8, or a homologous epitope on some combination of the FZDs). In certain embodiments, an antigen-binding site of a monospecific antibody described herein is capable of binding (or binds) one, two, three, four, or five (or more) human frizzled receptors.

[00206] In certain embodiments are provided an antibody fragment to, for example, increase tumor penetration. Various techniques are known for the production of antibody fragments. Traditionally, these fragments are derived via proteolytic digestion of intact antibodies (for example Morimoto et al., 1993, Journal of Biochemical and Biophysical Methods 24:107-117; Brennan et al., 1985, Science, 229:81). In certain embodiments, antibody fragments are produced recombinantly. Fab, Fv, and scFv antibody fragments can all be expressed in and secreted from E. coli or other host cells, thus allowing the production of large amounts of these fragments. Such antibody fragments can also be isolated from the antibody phage libraries discussed above. The antibody fragment can also be linear

antibodies as described in U.S. Patent 5,641,870, for example, and can be monospecific or bispecific. Other techniques for the production of antibody fragments will be apparent to the skilled practitioner.

[00207] According to the present invention, techniques can be adapted for the production of single-chain antibodies specific to one or more human frizzled receptors (see U.S. Pat. No. 4,946,778). In addition, methods can be adapted for the construction of Fab expression libraries (Huse, et al., Science 246:1275-1281 (1989)) to allow rapid and effective identification of monoclonal Fab fragments with the desired specificity for a FZD receptor, or derivatives, fragments, analogs or homologs thereof. Antibody fragments may be produced by techniques in the art including, but not limited to: (a) a F(ab')2 fragment produced by pepsin digestion of an antibody molecule; (b) a Fab fragment generated by reducing the disulfide bridges of an F(ab')2 fragment, (c) a Fab fragment generated by the treatment of the antibody molecule with papain and a reducing agent, and (d) Fv fragments.

[00208] It can further be desirable, especially in the case of antibody fragments, to modify an antibody in order to increase its serum half-life. This can be achieved, for example, by incorporation of a salvage receptor binding epitope into the antibody fragment by mutation of the appropriate region in the antibody fragment or by incorporating the epitope into a peptide tag that is then fused to the antibody fragment at either end or in the middle (e.g., by DNA or peptide synthesis).

[00209] Heteroconjugate antibodies are also within the scope of the present invention. Heteroconjugate antibodies are composed of two covalently joined antibodies. Such antibodies have, for example, been proposed to target immune cells to unwanted cells (U.S. Pat. No. 4,676,980). It is contemplated that the antibodies can be prepared in vitro using known methods in synthetic protein chemistry, including those involving crosslinking agents. For example, immunotoxins can be constructed using a disulfide exchange reaction or by forming a thioether bond. Examples of suitable reagents for this purpose include iminothiolate and methyl-4-mercaptobutyrimidate.

[00210] For the purposes of the present invention, it should be appreciated that modified antibodies can comprise any type of variable region that provides for the association of the antibody with the polypeptides of a human FZD receptor. In this regard, the variable region may comprise or be derived from any type of mammal that can be induced to mount a humoral response and generate immunoglobulins against the desired tumor associated antigen. As such, the variable region of the modified antibodies can be, for example, of human, murine, non-human primate (e.g. cynomolgus monkeys, macaques, etc.) or lupine

origin. In some embodiments both the variable and constant regions of the modified immunoglobulins are human. In other embodiments the variable regions of compatible antibodies (usually derived from a non-human source) can be engineered or specifically tailored to improve the binding properties or reduce the immunogenicity of the molecule. In this respect, variable regions useful in the present invention can be humanized or otherwise altered through the inclusion of imported amino acid sequences.

[00211] In certain embodiments, the variable domains in both the heavy and light chains are altered by at least partial replacement of one or more CDRs and, if necessary, by partial framework region replacement and sequence changing. Although the CDRs may be derived from an antibody of the same class or even subclass as the antibody from which the framework regions are derived, it is envisaged that the CDRs will be derived from an antibody of different class and preferably from an antibody from a different species. It may not be necessary to replace all of the CDRs with the complete CDRs from the donor variable region to transfer the antigen binding capacity of one variable domain to another. Rather, it may only be necessary to transfer those residues that are necessary to maintain the activity of the antigen binding site. Given the explanations set forth in U.S. Pat. Nos. 5,585,089, 5,693,761 and 5,693,762, it will be well within the competence of those skilled in the art, either by carrying out routine experimentation or by trial and error testing to obtain a functional antibody with reduced immunogenicity.

[00212] Alterations to the variable region notwithstanding, those skilled in the art will appreciate that the modified antibodies of this invention will comprise antibodies (e.g., full-length antibodies or immunoreactive fragments thereof) in which at least a fraction of one or more of the constant region domains has been deleted or otherwise altered so as to provide desired biochemical characteristics such as increased tumor localization or reduced serum half-life when compared with an antibody of approximately the same immunogenicity comprising a native or unaltered constant region. In some embodiments, the constant region of the modified antibodies will comprise a human constant region. Modifications to the constant region compatible with this invention comprise additions, deletions or substitutions of one or more amino acids in one or more domains. That is, the modified antibodies disclosed herein may comprise alterations or modifications to one or more of the three heavy chain constant domains (CH1, CH2 or CH3) and/or to the light chain constant domain (CL). In some embodiments, modified constant regions wherein one or more domains are partially or entirely deleted are contemplated. In some embodiments, the modified antibodies will comprise domain deleted constructs or variants wherein the entire CH2 domain has been

removed (ΔCH2 constructs). In some embodiments, the omitted constant region domain will be replaced by a short amino acid spacer (e.g. 10 residues) that provides some of the molecular flexibility typically imparted by the absent constant region.

[00213] Besides their configuration, it is known in the art that the constant region mediates several effector functions. For example, binding of the C1 component of complement to antibodies activates the complement system. Activation of complement is important in the opsonisation and lysis of cell pathogens. The activation of complement also stimulates the inflammatory response and can also be involved in autoimmune hypersensitivity. Further, antibodies bind to cells via the Fc region, with a Fc receptor site on the antibody Fc region binding to a Fc receptor (FcR) on a cell. There are a number of Fc receptors which are specific for different classes of antibody, including IgG (gamma receptors), IgE (eta receptors), IgA (alpha receptors) and IgM (mu receptors). Binding of antibody to Fc receptors on cell surfaces triggers a number of important and diverse biological responses including engulfment and destruction of antibody-coated particles, clearance of immune complexes, lysis of antibody-coated target cells by killer cells (called antibody-dependent cell-mediated cytotoxicity, or ADCC), release of inflammatory mediators, placental transfer and control of immunoglobulin production.

[00214] In certain embodiments, the FZD-binding antibodies provide for altered effector functions that, in turn, affect the biological profile of the administered antibody. For example, the deletion or inactivation (through point mutations or other means) of a constant region domain may reduce Fc receptor binding of the circulating modified antibody thereby increasing tumor localization. In other cases it may be that constant region modifications, consistent with this invention, moderate complement binding and thus reduce the serum half life and nonspecific association of a conjugated cytotoxin. Yet other modifications of the constant region may be used to eliminate disulfide linkages or oligosaccharide moieties that allow for enhanced localization due to increased antigen specificity or antibody flexibility. Similarly, modifications to the constant region in accordance with this invention may easily be made using well known biochemical or molecular engineering techniques well within the purview of the skilled artisan.

[00215] In certain embodiments, a FZD-binding agent that is an antibody does not have one or more effector functions. For instance, in some embodiments, the antibody has no antibody-dependent cellular cytoxicity (ADCC) activity and/or no complement-dependent cytoxicity (CDC) activity. In certain embodiments, the antibody does not bind to an Fc

receptor and/or complement factors. In certain embodiments, the antibody has no effector function.

[00216] It will be noted that in certain embodiments, the modified antibodies may be engineered to fuse the CH3 domain directly to the hinge region of the respective modified antibodies. In other constructs it may be desirable to provide a peptide spacer between the hinge region and the modified CH2 and/or CH3 domains. For example, compatible constructs could be expressed wherein the CH2 domain has been deleted and the remaining CH3 domain (modified or unmodified) is joined to the hinge region with a 5-20 amino acid spacer. Such a spacer may be added, for instance, to ensure that the regulatory elements of the constant domain remain free and accessible or that the hinge region remains flexible. However, it should be noted that amino acid spacers can, in some cases, prove to be immunogenic and elicit an unwanted immune response against the construct. Accordingly, in certain embodiments, any spacer added to the construct will be relatively non-immunogenic, or even omitted altogether, so as to maintain the desired biochemical qualities of the modified antibodies.

[00217] Besides the deletion of whole constant region domains, it will be appreciated that the antibodies of the present invention may be provided by the partial deletion or substitution of a few or even a single amino acid. For example, the mutation of a single amino acid in selected areas of the CH2 domain may be enough to substantially reduce Fc binding and thereby increase tumor localization. Similarly, it may be desirable to simply delete that part of one or more constant region domains that control the effector function (e.g. complement CLQ binding) to be modulated. Such partial deletions of the constant regions may improve selected characteristics of the antibody (serum half-life) while leaving other desirable functions associated with the subject constant region domain intact. Moreover, as alluded to above, the constant regions of the disclosed antibodies may be modified through the mutation or substitution of one or more amino acids that enhances the profile of the resulting construct. In this respect it may be possible to disrupt the activity provided by a conserved binding site (e.g. Fc binding) while substantially maintaining the configuration and immunogenic profile of the modified antibody. Certain embodiments can comprise the addition of one or more amino acids to the constant region to enhance desirable characteristics such as decreasing or increasing effector function or provide for more cytotoxin or carbohydrate attachment. In such embodiments it can be desirable to insert or replicate specific sequences derived from selected constant region domains.

[00218] The present invention further embraces variants and equivalents which are substantially homologous to the chimeric, humanized and human antibodies, or antibody fragments thereof, set forth herein. These can contain, for example, conservative substitution mutations, i.e. the substitution of one or more amino acids by similar amino acids. For example, conservative substitution refers to the substitution of an amino acid with another within the same general class such as, for example, one acidic amino acid with another acidic amino acid, one basic amino acid with another basic amino acid or one neutral amino acid by another neutral amino acid. What is intended by a conservative amino acid substitution is well known in the art.

[00219] The invention also pertains to immunoconjugates comprising an antibody conjugated to a cytotoxic agent. Cytotoxic agents include chemotherapeutic agents, growth inhibitory agents, toxins (e.g., an enzymatically active toxin of bacterial, fungal, plant, or animal origin, or fragments thereof), radioactive isotopes (i.e., a radioconjugate), etc. Chemotherapeutic agents useful in the generation of such immunoconjugates include, for example, methotrexate, adriamicin, doxorubicin, melphalan, mitomycin C, chlorambucil, daunorubicin or other intercalating agents. Enzymatically active toxins and fragments thereof that can be used include diphtheria A chain, nonbinding active fragments of diphtheria toxin, exotoxin A chain, ricin A chain, abrin A chain, modeccin A chain, alpha-sarcin, Aleurites fordii proteins, dianthin proteins, Phytolaca americana proteins (PAPI, PAPII, and PAP-S), momordica charantia inhibitor, curcin, crotin, sapaonaria officinalis inhibitor, gelonin, mitogellin, restrictocin, phenomycin, enomycin, and the tricothecenes. A variety of radionuclides are available for the production of radioconjugated antibodies including 212Bi, 131I, 131In, 90Y, and 186Re. Conjugates of the antibody and cytotoxic agent are made using a variety of bifunctional protein-coupling agents such as N-succinimidyl-3-(2-pyridyidithiol) propionate (SPDP), iminothiolane (IT), bifunctional derivatives of imidoesters (such as dimethyl adipimidate HCL), active esters (such as disuccinimidyl suberate), aldehydes (such as glutareldehyde), bis-azido compounds (such as bis(p-azidobenzoyl) hexanediamine), bis-diazonium derivatives (such as bis-(p-diazoniumbenzoyl)-ethylenediamine), diisocyanates (such as tolyene 2,6-diisocyanate), and bis-active fluorine compounds (such as 1,5-difluoro-2,4-dinitrobenzene). Conjugates of an antibody and one or more small molecule toxins, such as a calicheamicin, maytansinoids, a trichothene, and CC1065, and the derivatives of these toxins that have toxin activity, can also be used.

[00220] Conjugate antibodies are composed of two covalently joined antibodies. Such antibodies have, for example, been proposed to target immune cells to unwanted cells (U.S.

Pat. No. 4,676,980). It is contemplated that the antibodies can be prepared in vitro using known methods in synthetic protein chemistry, including those involving crosslinking agents. For example, immunotoxins can be constructed using a disulfide exchange reaction or by forming a thioether bond. Examples of suitable reagents for this purpose include iminothiolate and methyl-4-mercaptobutyrimidate.

[00221] Regardless of how useful quantities are obtained, the antibodies of the present invention can be used in any one of a number of conjugated (i.e. an immunoconjugate) or unconjugated forms. Alternatively, the antibodies of this invention can be used in a nonconjugated or "naked" form. In certain embodiments, the antibodies are used in nonconjugated form to harness the subject's natural defense mechanisms including complement-dependent cytotoxicity (CDC) and antibody dependent cellular toxicity (ADCC) to eliminate the malignant cells. In some embodiments, the antibodies can be conjugated to radioisotopes, such as ^{90}Y, ^{125}I, ^{131}I, ^{123}I, ^{111}In, ^{105}Rh, ^{153}Sm, ^{67}Cu, ^{67}Ga, ^{166}Ho, ^{177}Lu, ^{186}Re and ^{188}Re using anyone of a number of well known chelators or direct labeling. In other embodiments, the disclosed compositions can comprise antibodies coupled to drugs, prodrugs or biological response modifiers such as methotrexate, adriamycin, and lymphokines such as interferon. Still other embodiments of the present invention comprise the use of antibodies conjugated to specific biotoxins such as ricin or diptheria toxin. In yet other embodiments the modified antibodies can be complexed with other immunologically active ligands (e.g. antibodies or fragments thereof) wherein the resulting molecule binds to both the neoplastic cell and an effector cell such as a T cell. The selection of which conjugated or unconjugated modified antibody to use will depend of the type and stage of cancer, use of adjunct treatment (e.g., chemotherapy or external radiation) and patient condition. It will be appreciated that one skilled in the art could readily make such a selection in view of the teachings herein.

[00222] The polypeptides of the present invention can be recombinant polypeptides, natural polypeptides, or synthetic polypeptides comprising an antibody, or fragment thereof, against a human FZD receptor. It will be recognized in the art that some amino acid sequences of the invention can be varied without significant effect of the structure or function of the protein. Thus, the invention further includes variations of the polypeptides which show substantial activity or which include regions of an antibody, or fragment thereof, against a human FZD receptor protein. Such mutants include deletions, insertions, inversions, repeats, and type substitutions.

[00223] The polypeptides and analogs can be further modified to contain additional chemical moieties not normally part of the protein. Those derivatized moieties can improve

the solubility, the biological half life or absorption of the protein. The moieties can also reduce or eliminate any desirable side effects of the proteins and the like. An overview for those moieties can be found in REMINGTON'S PHARMACEUTICAL SCIENCES, 20th ed., Mack Publishing Co., Easton, PA (2000).

[00224] The isolated polypeptides described herein can be produced by any suitable method known in the art. Such methods range from direct protein synthetic methods to constructing a DNA sequence encoding isolated polypeptide sequences and expressing those sequences in a suitable transformed host. In some embodiments, a DNA sequence is constructed using recombinant technology by isolating or synthesizing a DNA sequence encoding a wild-type protein of interest. Optionally, the sequence can be mutagenized by site-specific mutagenesis to provide functional analogs thereof. See, e.g. Zoeller et al., Proc. Nat'l. Acad. Sci. USA 81:5662-5066 (1984) and U.S. Pat. No. 4,588,585.

[00225] In some embodiments a DNA sequence encoding a polypeptide of interest would be constructed by chemical synthesis using an oligonucleotide synthesizer. Such oligonucleotides can be designed based on the amino acid sequence of the desired polypeptide and selecting those codons that are favored in the host cell in which the recombinant polypeptide of interest will be produced. Standard methods can be applied to synthesize an isolated polynucleotide sequence encoding an isolated polypeptide of interest. For example, a complete amino acid sequence can be used to construct a back-translated gene. Further, a DNA oligomer containing a nucleotide sequence coding for the particular isolated polypeptide can be synthesized. For example, several small oligonucleotides coding for portions of the desired polypeptide can be synthesized and then ligated. The individual oligonucleotides typically contain 5' or 3' overhangs for complementary assembly.

[00226] Once assembled (by synthesis, site-directed mutagenesis or another method), the polynucleotide sequences encoding a particular isolated polypeptide of interest will be inserted into an expression vector and operatively linked to an expression control sequence appropriate for expression of the protein in a desired host. Proper assembly can be confirmed by nucleotide sequencing, restriction mapping, and expression of a biologically active polypeptide in a suitable host. As is well known in the art, in order to obtain high expression levels of a transfected gene in a host, the gene must be operatively linked to transcriptional and translational expression control sequences that are functional in the chosen expression host.

[00227] In certain embodiments, recombinant expression vectors are used to amplify and express DNA encoding antibodies, or fragments thereof, against human frizzled

receptors. Recombinant expression vectors are replicable DNA constructs which have synthetic or cDNA-derived DNA fragments encoding a polypeptide chain of an anti-FZD antibody, or fragment thereof, operatively linked to suitable transcriptional or translational regulatory elements derived from mammalian, microbial, viral or insect genes. A transcriptional unit generally comprises an assembly of (1) a genetic element or elements having a regulatory role in gene expression, for example, transcriptional promoters or enhancers, (2) a structural or coding sequence which is transcribed into mRNA and translated into protein, and (3) appropriate transcription and translation initiation and termination sequences, as described in detail below. Such regulatory elements can include an operator sequence to control transcription. The ability to replicate in a host, usually conferred by an origin of replication, and a selection gene to facilitate recognition of transformants can additionally be incorporated. DNA regions are operatively linked when they are functionally related to each other. For example, DNA for a signal peptide (secretory leader) is operatively linked to DNA for a polypeptide if it is expressed as a precursor which participates in the secretion of the polypeptide; a promoter is operatively linked to a coding sequence if it controls the transcription of the sequence; or a ribosome binding site is operatively linked to a coding sequence if it is positioned so as to permit translation. Structural elements intended for use in yeast expression systems include a leader sequence enabling extracellular secretion of translated protein by a host cell. Alternatively, where recombinant protein is expressed without a leader or transport sequence, it can include an N-terminal methionine residue. This residue can optionally be subsequently cleaved from the expressed recombinant protein to provide a final product.

[00228] The choice of expression control sequence and expression vector will depend upon the choice of host. A wide variety of expression host/vector combinations can be employed. Useful expression vectors for eukaryotic hosts, include, for example, vectors comprising expression control sequences from SV40, bovine papilloma virus, adenovims and cytomegalovirus. Useful expression vectors for bacterial hosts include known bacterial plasmids, such as plasmids from Esherichia coli, including pCR 1, pBR322, pMB9 and their derivatives, wider host range plasmids, such as M13 and filamentous single-stranded DNA phages.

[00229] Suitable host cells for expression of a FZD-binding polypeptide or antibody (or a FZD protein to use as an antigen) include prokaryotes, yeast, insect or higher eukaryotic cells under the control of appropriate promoters. Prokaryotes include gram negative or gram positive organisms, for example E. coli or bacilli. Higher eukaryotic cells include established

cell lines of mammalian origin as described below. Cell-free translation systems could also be employed. Appropriate cloning and expression vectors for use with bacterial, fungal, yeast, and mammalian cellular hosts are described by Pouwels et al. (Cloning Vectors: A Laboratory Manual, Elsevier, N.Y., 1985), the relevant disclosure of which is hereby incorporated by reference. Additional information regarding methods of protein production, including antibody production, can be found, e.g., in U.S. Patent Publication No. 2008/0187954, U.S. Patent Nos. 6,413,746 and 6,660,501, and International Patent Publication No. WO 04009823, each of which is hereby incorporated by reference herein in its entirety.

[00230] Various mammalian or insect cell culture systems are also advantageously employed to express recombinant protein. Expression of recombinant proteins in mammalian cells can be performed because such proteins are generally correctly folded, appropriately modified and completely functional. Examples of suitable mammalian host cell lines include the COS-7 lines of monkey kidney cells, described by Gluzman (Cell 23:175, 1981), and other cell lines capable of expressing an appropriate vector including, for example, L cells, C127, 3T3, Chinese hamster ovary (CHO), HeLa and BHK cell lines. Mammalian expression vectors can comprise nontranscribed elements such as an origin of replication, a suitable promoter and enhancer linked to the gene to be expressed, and other 5' or 3' flanking nontranscribed sequences, and 5' or 3' nontranslated sequences, such as necessary ribosome binding sites, a polyadenylation site, splice donor and acceptor sites, and transcriptional termination sequences. Baculovirus systems for production of heterologous proteins in insect cells are reviewed by Luckow and Summers, Bio/Technology 6:47 (1988).

[00231] The proteins produced by a transformed host can be purified according to any suitable method. Such standard methods include chromatography (e.g., ion exchange, affinity and sizing column chromatography), centrifugation, differential solubility, or by any other standard technique for protein purification. Affinity tags such as hexahistidine, maltose binding domain, influenza coat sequence and glutathione-S-transferase can be attached to the protein to allow easy purification by passage over an appropriate affinity column. Isolated proteins can also be physically characterized using such techniques as proteolysis, nuclear magnetic resonance and x-ray crystallography.

[00232] For example, supernatants from systems which secrete recombinant protein into culture media can be first concentrated using a commercially available protein concentration filter, for example, an Amicon or Millipore Pellicon ultrafiltration unit. Following the concentration step, the concentrate can be applied to a suitable purification

matrix. Alternatively, an anion exchange resin can be employed, for example, a matrix or substrate having pendant diethylaminoethyl (DEAE) groups. The matrices can be acrylamide, agarose, dextran, cellulose or other types commonly employed in protein purification. Alternatively, a cation exchange step can be employed. Suitable cation exchangers include various insoluble matrices comprising sulfopropyl or carboxymethyl groups. Finally, one or more reversed-phase high performance liquid chromatography (RP-HPLC) steps employing hydrophobic RP-HPLC media, e.g., silica gel having pendant methyl or other aliphatic groups, can be employed to further purify a FZD-binding agent. Some or all of the foregoing purification steps, in various combinations, can also be employed to provide a homogeneous recombinant protein.

[00233] Recombinant protein produced in bacterial culture can be isolated, for example, by initial extraction from cell pellets, followed by one or more concentration, salting-out, aqueous ion exchange or size exclusion chromatography steps. High performance liquid chromatography (HPLC) can be employed for final purification steps. Microbial cells employed in expression of a recombinant protein can be disrupted by any convenient method, including freeze-thaw cycling, sonication, mechanical disruption, or use of cell lysing agents.

[00234] Methods known in the art for purifying antibodies and other proteins also include, for example, those described in U.S. Patent Publication No. 2008/0312425, 2008/0177048, and 2009/0187005, each of which is hereby incorporated by reference herein in its entirety.

[00235] In certain embodiments, the FZD-binding agent is a polypeptide that is not an antibody. A variety of methods for identifying and producing non-antibody polypeptides that bind with high affinity to a protein target are known in the art. See, e.g., Skerra, Curr. Opin. Biotechnol., 18:295-304 (2007), Hosse et al., Protein Science, 15:14-27 (2006), Gill et al., Curr. Opin. Biotechnol., 17:653-658 (2006), Nygren, FEBS J., 275:2668-76 (2008), and Skerra, FEBS J., 275:2677-83 (2008), each of which is incorporated by reference herein in its entirety. In certain embodiments, phage display technology has been used to identify/produce the FZD-binding polypeptide. In certain embodiments, the polypeptide comprises a protein scaffold of a type selected from the group consisting of protein A, a lipocalin, a fibronectin domain, an ankyrin consensus repeat domain, and thioredoxin.

[00236] In some embodiments, the agent is a non-protein molecule. In certain embodiments, the agent is a small molecule. Combinatorial chemistry libraries and techniques useful in the identification of non-protein FZD-binding agents are known to those skilled in the art. See, e.g., Kennedy et al., J. Comb. Chem, 10:345-354 (2008), Dolle et al, J.

Comb. Chem., 9:855-902 (2007), and Bhattacharyya, Curr. Med. Chem., 8:1383-404 (2001), each of which is incorporated by reference herein in its entirety. In certain further embodiments, the agent is a carbohydrate, a glycosaminoglycan, a glycoprotein, or a proteoglycan.

[00237] In certain embodiments, the agent is a nucleic acid aptamer. Aptamers are polynucleotide molecules that have been selected (e.g., from random or mutagenized pools) on the basis of their ability to bind to another molecule. In some embodiments, the aptamer comprises a DNA polynucleotide. In certain alternative embodiments, the aptamer comprises an RNA polynucleotide. In certain embodiments, the aptamer comprises one or more modified nucleic acid residues. Methods of generating and screening nucleic acid aptamers for binding to proteins are well known in the art. See, e.g., U.S. Patent No. 5,270,163, U.S. Patent No. 5,683,867, U.S. Patent No. 5,763,595, U.S. Patent No. 6,344,321, U.S. Patent No. 7,368,236, U.S. Patent No. 5,582,981, U.S. Patent No. 5,756,291, U.S. Patent No. 5,840,867, U.S. Patent No. 7,312,325, U.S. Patent No. 7,329,742, International Patent Publication No. WO 02/077262, International Patent Publication No. WO 03/070984, U.S. Patent Application Publication No. 2005/0239134, U.S. Patent Application Publication No. 2005/0124565, and U.S. Patent Application Publication No. 2008/0227735, each of which is incorporated by reference herein in its entirety.

[00238] The present invention further provides methods of screening agents for efficacy in inhibiting Wnt signaling, for anti-tumor efficacy, and/or efficacy against cancer stem cells. These methods include, but are not limited to, methods comprising comparing the levels of one or more differentiation markers in a first solid tumor that has been exposed to the agent relative to the levels of the one or more differentiation markers in a second solid tumor that has not been exposed to the agent. In certain embodiments, these methods include (a) exposing a first solid tumor, but not a second solid tumor, to the agent; (b) assessing the levels of one or more differentiation markers in the first and second solid tumors; and (c) comparing the levels of the one or more differentiation markers in the first and second solid tumors. In certain embodiments, the agent is an inhibitor of the canonical Wnt signaling pathway, and/or inhibits binding of one or more human Wnt proteins to one or more human frizzled receptors. In certain embodiments, the agent is an antibody that specifically binds to one or more human frizzled receptor. In certain embodiments, increased levels of one or more differentiation markers in the first solid tumor relative to the second solid tumor indicates efficacy against solid tumor stem cells. In certain alternative embodiments, decreased levels of one or more differentiation markers (i.e., negative markers for differentiation) in the first

solid tumor relative to the second solid tumor indicates efficacy against solid tumor stem cells. In certain embodiments, the solid tumor is a pancreatic tumor. In certain embodiments, the solid tumor is a pancreatic tumor and the one or more differentiation markers may comprise one or more mucins (e.g., Muc16) and/or chromogranin A (CHGA). In certain alternative embodiments, the solid tumor is a colon tumor. In some embodiments, the solid tumor is a colon tumor and the one or more differentiation markers comprise cytokeratin 7. Other potential differentiation markers for pancreas and colon as well as other tumor types are known to those skilled in the art. The usefulness of potential differentiation markers in a screening method can be readily assessed by one skilled in the art by treating the desired tumor type with one or more of the anti-FZD antibodies disclosed herein such as 18R5 and/or 44R24 and then assessing for changes in expression of the marker by the treated tumor relative to control. Non-limiting examples of such methods, can for instance, be found in the specific Examples below.

III. Polynucleotides

[00239] In certain embodiments, the invention encompasses polynucleotides comprising polynucleotides that encode a polypeptide that specifically binds a human FZD receptor or a fragment of such a polypeptide. For example, the invention provides a polynucleotide comprising a nucleic acid sequence that encodes an antibody to a human frizzled receptor or encodes a fragment of such an antibody. The polynucleotides of the invention can be in the form of RNA or in the form of DNA. DNA includes cDNA, genomic DNA, and synthetic DNA; and can be double-stranded or single-stranded, and if single stranded can be the coding strand or non-coding (anti-sense) strand.

[00240] In certain embodiments, the polynucleotides are isolated. In certain embodiments, the polynucleotides are substantially pure.

[00241] The invention provides a polynucleotide comprising a polynucleotide encoding a polypeptide comprising a sequence selected from the group consisting of SEQ ID NOs:10, 12, 14. The invention further provides a polynucleotide comprising a polynucleotide encoding a polypeptide comprising a sequence selected from the group consisting of SEQ ID NOs: 85-86. A polynucleotide comprising polynucleotides encoding a polypeptide comprising SEQ ID NOs: 11, 13, or 15 is also provided.

[00242] The invention further provides a polynucleotide comprising a sequence selected from the group consisting of SEQ ID NOs:17, 19, and 21. Alternatively, in certain embodiments, the polynucleotide may comprise a sequence selected from the group

consisting of SEQ ID NOs: 87-90, 92, and 94-95. Polynucleotide sequences comprising SEQ ID NO: 18, 20, or 22 are also provided.

[00243] Also provided is a polynucleotide that comprises a polynucleotide that hybridizes to a polynucleotide having the sequence of SEQ ID NO: 17, 19, or 21 and/or to a polynucleotide encoding a polypeptide having the sequence of SEQ ID NO:10, 12, or 14. Also provided is a polynucleotide that comprises a polynucleotide that hybridizes to a polynucleotide having a sequence selected from the group consisting of SEQ ID NOs: 87-90, 92, and 94-95 and/or to a polynucleotide encoding a polypeptide having the sequence of SEQ ID NO: 85 or 86. In certain embodiments, the hybridization is under conditions of high stringency.

[00244] In certain embodiments the polynucleotides comprise the coding sequence for the mature polypeptide fused in the same reading frame to a polynucleotide which aids, for example, in expression and secretion of a polypeptide from a host cell (e.g. a leader sequence which functions as a secretory sequence for controlling transport of a polypeptide from the cell). The polypeptide having a leader sequence is a preprotein and can have the leader sequence cleaved by the host cell to form the mature form of the polypeptide. The polynucleotides can also encode for a proprotein which is the mature protein plus additional 5' amino acid residues. A mature protein having a prosequence is a proprotein and is an inactive form of the protein. Once the prosequence is cleaved an active mature protein remains.

[00245] In certain embodiments the polynucleotides comprise the coding sequence for the mature polypeptide fused in the same reading frame to a marker sequence that allows, for example, for purification of the encoded polypeptide. For example, the marker sequence can be a hexa-histidine tag supplied by a pQE-9 vector to provide for purification of the mature polypeptide fused to the marker in the case of a bacterial host, or the marker sequence can be a hemagglutinin (HA) tag derived from the influenza hemagglutinin protein when a mammalian host (e.g. COS-7 cells) is used.

[00246] The present invention further relates to variants of the hereinabove described polynucleotides encoding, for example, fragments, analogs, and derivatives.

[00247] In certain embodiments, the present invention provides isolated polynucleotides comprising polynucleotides having a nucleotide sequence at least 80% identical, at least 85% identical, at least 90% identical, at least 95% identical, and in some embodiments, at least 96%, 97%, 98% or 99% identical to a polynucleotide encoding a

polypeptide comprising an antibody, or fragment thereof, to a human FZD receptor described herein.

[00248] By a polynucleotide having a nucleotide sequence at least, for example, 95% "identical" to a reference nucleotide sequence is intended that the nucleotide sequence of the polynucleotide is identical to the reference sequence except that the polynucleotide sequence can include up to five point mutations per each 100 nucleotides of the reference nucleotide sequence. In other words, to obtain a polynucleotide having a nucleotide sequence at least 95% identical to a reference nucleotide sequence, up to 5% of the nucleotides in the reference sequence can be deleted or substituted with another nucleotide, or a number of nucleotides up to 5% of the total nucleotides in the reference sequence can be inserted into the reference sequence. These mutations of the reference sequence can occur at the amino- or carboxy-terminal positions of the reference nucleotide sequence or anywhere between those terminal positions, interspersed either individually among nucleotides in the reference sequence or in one or more contiguous groups within the reference sequence.

[00249] The polynucleotide variants can contain alterations in the coding regions, non-coding regions, or both. In some embodiments the polynucleotide variants contain alterations which produce silent substitutions, additions, or deletions, but do not alter the properties or activities of the encoded polypeptide. In some embodiments, nucleotide variants are produced by silent substitutions due to the degeneracy of the genetic code. Polynucleotide variants can be produced for a variety of reasons, e.g., to optimize codon expression for a particular host (change codons in the human mRNA to those preferred by a bacterial host such as E. coli).

[00250] Vectors and cells comprising the polynucleotides described herein are also provided.

IV. Methods of use and pharmaceutical compositions

[00251] The FZD-binding agents (including polypeptides and antibodies) of the invention are useful in a variety of applications including, but not limited to, therapeutic treatment methods, such as the treatment of cancer. In certain embodiments, the agents are useful for inhibiting Wnt signaling (e.g., canonical Wnt signaling), inhibiting tumor growth, inducing differentiation, reducing tumor volume, and/or reducing the tumorigenicity of a tumor. The methods of use may be *in vitro, ex vivo*, or *in vivo* methods. In certain embodiments, the FZD-binding agent or polypeptide or antibody is an antagonist of the one or more human frizzled receptors to which it binds.

[00252] In certain embodiments, the FZD-binding agents or antagonists are used in the treatment of a disease associated with Wnt signaling activation. In particular embodiments, the disease is a disease dependent upon Wnt signaling. In particular embodiments, the Wnt signaling is canonical Wnt signaling. In certain embodiments, the FZD-binding agents or antagonists are used in the treatment of disorders characterized by increased levels of stem cells and/or progenitor cells.

[00253] In certain embodiments, the disease treated with the FZD-binding agent or antagonist (e.g., an anti-FZD antibody) is a cancer. In certain embodiments, the cancer is characterized by Wnt-dependent tumors. In certain embodiments, the cancer is characterized by tumors expressing one or frizzled receptors to which the FZD-binding agent (e.g., antibody) binds. In certain embodiments, the cancer is characterized by tumors expressing one or more genes in a Wnt gene signature.

[00254] In certain embodiments, the disease treated with the FZD-binding agent or antagonist is not a cancer. For example, the disease may be a metabolic disorder such as obesity or diabetes (e.g., type II diabetes) (Jin T., Diabetologia, 2008 Oct;51(10):1771-80). Alternatively, the disease may be a bone disorder such as osteoporosis, osteoarthritis, or rheumatoid arthritis (Corr M., Nat Clin Pract Rheumatol, 2008 Oct;4(10):550-6; Day et al., Bone Joint Surg Am, 2008 Feb;90 Suppl 1:19-24). The disease may also be a kidney disorder, such as a polycystic kidney disease (Harris et al., Annu Rev Med, 2008 Oct. 23; Schmidt-Ott et al., Kidney Int, 2008 Oct;74(8):1004-8; Benzing et al., J Am Soc Nephrol, 2007 May;18(5):1389-98). Alternatively, eye disorders including, but not limited to, macular degeneration and familial exudative vitreoretinopathy may be treated (Lad et al., Stem Cells Dev, 2008 Aug. 8). Cardiovascular disorders, including myocardial infarction, atherosclerosis, and valve disorders, may also be treated (Al-Aly Z., Transl Res, 2008 May;151(5):233-9; Kobayashi et al., Nat Cell Biol, 2009 Jan;11(1):46-55; van Gijn et al., Cardiovasc Res, 2002 Jul;55(1):16-24; Christman et al., Am J Physiol Heart Circ Physiol, 2008 Jun;294(6):H2864-70). In some embodiments, the disease is a pulmonary disorder such as idiopathic pulmonary arterial hypertension or pulmonary fibrosis (Laumanns et al., Am J Respir Cell Mol Biol, 2008 Nov 21; Königshoff et al., PLoS ONE, 2008 May 14;3(5):e2142). In some embodiments, the disease treated with the FZD-binding agent is a liver disease, such as cirrhosis or liver fibrosis (Cheng et al., Am J Physiol Gastrointest Liver Physiol, 2008 Jan;294(1):G39-49).

[00255] The present invention provides for methods of treating cancer comprising administering a therapeutically effective amount of a FZD-binding agent to a subject (e.g., a

subject in need of treatment). In certain embodiments, the cancer is a cancer selected from the group consisting of colorectal cancer, pancreatic cancer, lung cancer, ovarian cancer, liver cancer, breast cancer, kidney cancer, prostate cancer, gastrointestinal cancer, melanoma, cervical cancer, bladder cancer, glioblastoma, and head and neck cancer. In certain embodiments, the cancer is pancreatic cancer. In certain embodiments, the cancer is colorectal cancer. In certain embodiments, the subject is a human.

[00256] The present invention further provides methods for inhibiting tumor growth using the antibodies or other agents described herein. In certain embodiments, the method of inhibiting the tumor growth comprises contacting the cell with a FZD-binding agent (e.g., antibody) in vitro. For example, an immortalized cell line or a cancer cell line that expresses the targeted FZD(s) is cultured in medium to which is added the antibody or other agent to inhibit tumor growth. In some embodiments, tumor cells are isolated from a patient sample such as, for example, a tissue biopsy, pleural effusion, or blood sample and cultured in medium to which is added an FZD-binding agent to inhibit tumor growth.

[00257] In some embodiments, the method of inhibiting tumor growth comprises contacting the tumor or tumor cells with the FZD-binding agent (e.g., antibody) in vivo. In certain embodiments, contacting a tumor or tumor cell with a FZD-binding agent is undertaken in an animal model. For example, FZD-binding agents may be administered to xenografts expressing one or more FZDs that have been grown in immunocompromised mice (e.g. NOD/SCID mice) to inhibit tumor growth. In some embodiments, cancer stem cells are isolated from a patient sample such as, for example, a tissue biopsy, pleural effusion, or blood sample and injected into immunocompromised mice that are then administered a FZD-binding agent to inhibit tumor cell growth. In some embodiments, the FZD-binding agent is administered at the same time or shortly after introduction of tumorigenic cells into the animal to prevent tumor growth. In some embodiments, the FZD-binding agent is administered as a therapeutic after the tumorigenic cells have grown to a specified size.

[00258] In certain embodiments, the method of inhibiting tumor growth comprises administering to a subject a therapeutically effective amount of a FZD-binding agent. In certain embodiments, the subject is a human. In certain embodiments, the subject has a tumor or has had a tumor removed.

[00259] In certain embodiments, the tumor is a tumor in which Wnt signaling is active. In certain embodiment, the Wnt signaling that is active is canonical Wnt signaling. In certain embodiments, the tumor is a Wnt-dependent tumor. For example, in some embodiments, the tumor is sensitive to axin over-expression. In certain embodiments, the tumor does not

comprise an inactivating mutation (e.g., a truncating mutation) in the adenomatous polyposis coli (APC) tumor suppressor gene or an activating mutation in the beta-catenin gene. In certain embodiments, the tumor expresses one or more genes in a Wnt gene signature. In certain embodiments, the cancer for which a subject is being treated involves such a tumor.

[00260] In certain embodiments, the tumor expresses the one or more human frizzled receptors to which the FZD-binding agent or antibody binds. In certain embodiments, the tumor overexpresses the human frizzled receptor(s).

[00261] In certain embodiments, the tumor is a tumor selected from the group consisting of colorectal tumor, pancreatic tumor, lung tumor, ovarian tumor, liver tumor, breast tumor, kidney tumor, prostate tumor, gastrointestinal tumor, melanoma, cervical tumor, bladder tumor, glioblastoma, and head and neck tumor. In certain embodiments, the tumor is a colorectal tumor. In certain embodiments, the tumor is a pancreatic tumor.

[00262] The invention also provides a method of inhibiting Wnt signaling in a cell comprising contacting the cell with an effective amount of a FZD-binding agent. In certain embodiments, the cell is a tumor cell. In certain embodiments, the method is an in vivo method wherein the step of contacting the cell with the agent comprises administering a therapeutically effective amount of the agent to the subject. In some alternative embodiments, the method is an in vitro or ex vivo method. In certain embodiments, the Wnt signaling that is inhibited is canonical Wnt signaling. In certain embodiments, the Wnt signaling is signaling by WNT1, WNT2, WNT3, WNT3A, WNT7a, WNT7b, and/or WNT10B. In certain embodiments, the Wnt signaling is signaling by WNT1, WNT3A, WNT7b, and/or WNT10B.

[00263] In addition, the invention provides a method of reducing the tumorigenicity of a tumor in a subject, comprising administering a therapeutically effective amount of a FZD-binding agent to the subject. In certain embodiments, the tumor comprises cancer stem cells. In certain embodiments, the frequency of cancer stem cells in the tumor is reduced by administration of the agent.

[00264] Thus, the invention also provides a method of reducing the frequency of cancer stem cells in a tumor, comprising contacting the tumor with an effective amount of a FZD-binding agent (e.g., an anti-FZD antibody).

[00265] The invention further provides methods of differentiating tumorigenic cells into non-tumorigenic cells comprising contacting the tumorigenic cells with a FZD-binding agent (for example, by administering the FZD-binding agent to a subject that has a tumor comprising the tumorigenic cells or that has had such a tumor removed. In certain

embodiments, the tumorigenic cells are pancreatic tumor cells. In certain alternative embodiments, the tumorigenic cells are colon tumor cells.

[00266] The use of the FZD-binding agents, polypeptides, or antibodies described herein to induce the differentiation of cells, including, but not limited to tumor cells, is also provided. For example, methods of inducing cells to differentiate comprising contacting the cells with an effective amount of a FZD-binding agent (e.g., an anti-FZD antibody) described herein are envisioned. Methods of inducing cells in a tumor in a subject to differentiate comprising administering a therapeutically effective amount of a FZD-binding agent, polypeptide, or antibody to the subject are also provided. In certain embodiments, the tumor is a pancreatic tumor. In certain other embodiments, the tumor is a colon tumor.

[00267] Methods of treating a disease or disorder in a subject, wherein the disease or disorder is associated with Wnt signaling activation and/or is characterized by an increased level of stem cells and/or progenitor cells are further provided. In some embodiments, the treatment methods comprise administering a therapeutically effective amount of the FZD-binding agent, polypeptide, or antibody to the subject. In certain embodiments, the Wnt signaling is canonical Wnt signaling.

[00268] The present invention further provides methods of reducing myofibrolblast activation in the stroma of a solid tumor, comprising contacting the stroma with an effective amount of the FZD-binding agent, polypeptide or antibody.

[00269] The present invention further provides pharmaceutical compositions comprising one or more of the FZD-binding agents described herein. In certain embodiments, the pharmaceutical compositions further comprise a pharmaceutically acceptable vehicle. These pharmaceutical compositions find use in inhibiting tumor growth and treating cancer in human patients.

[00270] In certain embodiments, formulations are prepared for storage and use by combining a purified antibody or agent of the present invention with a pharmaceutically acceptable vehicle (e.g. carrier, excipient) (Remington, The Science and Practice of Pharmacy 20th Edition Mack Publishing, 2000). Suitable pharmaceutically acceptable vehicles include, but are not limited to, nontoxic buffers such as phosphate, citrate, and other organic acids; salts such as sodium chloride; antioxidants including ascorbic acid and methionine; preservatives (e.g. octadecyldimethylbenzyl ammonium chloride; hexamethonium chloride; benzalkonium chloride; benzethonium chloride; phenol, butyl or benzyl alcohol; alkyl parabens, such as methyl or propyl paraben; catechol; resorcinol; cyclohexanol; 3-pentanol; and m-cresol); low molecular weight polypeptides (e.g. less than

about 10 amino acid residues); proteins such as serum albumin, gelatin, or immunoglobulins; hydrophilic polymers such as polyvinylpyrrolidone; amino acids such as glycine, glutamine, asparagine, histidine, arginine, or lysine; carbohydrates such as monosacchandes, disaccharides, glucose, mannose, or dextrins; chelating agents such as EDTA; sugars such as sucrose, mannitol, trehalose or sorbitol; salt-forming counter-ions such as sodium; metal complexes (e.g. Zn-protein complexes); and non-ionic surfactants such as TWEEN or polyethylene glycol (PEG).

[00271] The pharmaceutical compositions of the present invention can be administered in any number of ways for either local or systemic treatment. Administration can be topical (such as to mucous membranes including vaginal and rectal delivery) such as transdermal patches, ointments, lotions, creams, gels, drops, suppositories, sprays, liquids and powders; pulmonary (e.g., by inhalation or insufflation of powders or aerosols, including by nebulizer; intratracheal, intranasal, epidermal and transdermal); oral; or parenteral including intravenous, intraarterial, subcutaneous, intraperitoneal or intramuscular injection or infusion; or intracranial (e.g., intrathecal or intraventricular) administration.

[00272] The therapeutic formulation can be in unit dosage form. Such formulations include tablets, pills, capsules, powders, granules, solutions or suspensions in water or non-aqueous media, or suppositories for oral, parenteral, or rectal administration or for administration by inhalation. In solid compositions such as tablets the principal active ingredient is mixed with a pharmaceutical carrier. Conventional tableting ingredients include corn starch, lactose, sucrose, sorbitol, talc, stearic acid, magnesium stearate, dicalcium phosphate or gums, and other diluents (e.g. water) to form a solid preformulation composition containing a homogeneous mixture of a compound of the present invention, or a non-toxic pharmaceutically acceptable salt thereof. The solid preformulation composition is then subdivided into unit dosage forms of the type described above. The tablets, pills, etc of the novel composition can be coated or otherwise compounded to provide a dosage form affording the advantage of prolonged action. For example, the tablet or pill can comprise an inner composition covered by an outer component. Furthermore, the two components can be separated by an enteric layer that serves to resist disintegration and permits the inner component to pass intact through the stomach or to be delayed in release. A variety of materials can be used for such enteric layers or coatings, such materials including a number of polymeric acids and mixtures of polymeric acids with such materials as shellac, cetyl alcohol and cellulose acetate.

[00273] The antibodies or agents can also be entrapped in microcapsules. Such microcapsules are prepared, for example, by coacervation techniques or by interfacial polymerization, for example, hydroxymethylcellulose or gelatin-microcapsules and poly-(methylmethacylate) microcapsules, respectively, in colloidal drug delivery systems (for example, liposomes, albumin microspheres, microemulsions, nano-particles and nanocapsules) or in macroemulsions as described in Remington, The Science and Practice of Pharmacy 20th Ed. Mack Publishing (2000).

[00274] In certain embodiments, pharmaceutical formulations include antibodies or other agents of the present invention complexed with liposomes (Epstein, et al., 1985, Proc. Natl. Acad. Sci. USA 82:3688; Hwang, et al., 1980, Proc. Natl. Acad. Sci. USA 77:4030; and U.S. Patent 4,485,045 and 4,544,545). Liposomes with enhanced circulation time are disclosed in U.S. Patent 5,013,556. Some liposomes can be generated by the reverse phase evaporation with a lipid composition comprising phosphatidylcholine, cholesterol, and PEG-derivatized phosphatidylethanolamine (PEG-PE). Liposomes are extruded through filters of defined pore size to yield liposomes with the desired diameter.

[00275] In addition sustained-release preparations can be prepared. Suitable examples of sustained-release preparations include semipermeable matrices of solid hydrophobic polymers containing the antibody, which matrices are in the form of shaped articles (e.g. films, or microcapsules). Examples of sustained-release matrices include polyesters, hydrogels such as poly(2-hydroxyethyl-methacrylate) or poly(v nylalcohol), polylactides (U.S. Patent 3,773,919), copolymers of L-glutamic acid and 7 ethyl-L-glutamate, non-degradable ethylene-vinyl acetate, degradable lactic acid-glycolic acid copolymers such as the LUPRON DEPOT TM (injectable microspheres composed of lactic acid-glycolic acid copolymer and leuprolide acetate), sucrose acetate isobutyrate, and poly-D-(-)-3-hydroxybutyric acid.

[00276] In certain embodiments, in addition to administering the FZD-binding agent, the method or treatment further comprises administering a second anti-cancer agent (prior to, concurrently with, and/or subsequently to administration of the FZD-binding agent). Pharmaceutical compositions comprising the FZD-binding agent and the second anti-cancer agent are also provided.

[00277] It will be appreciated that the combination of a FZD-binding agent and a second anti-cancer agent may be administered in any order or concurrently. In selected embodiments, the FZD-binding agents will be administered to patients that have previously undergone treatment with the second anti-cancer agent. In certain other embodiments, the

FZD-binding agent and the second anti-cancer agent will be administered substantially simultaneously or concurrently. For example, a subject may be given the FZD-binding agent while undergoing a course of treatment with the second anti-cancer agent (e.g., chemotherapy). In certain embodiments, the FZD-binding agent will be administered within 1 year of the treatment with the second anti-cancer agent. In certain alternative embodiments, the FZD-binding agent will be administered within 10, 8, 6, 4, or 2 months of any treatment with the second anti-cancer agent. In certain other embodiments, the FZD-binding agent will be administered within 4, 3, 2, or 1 week of any treatment with the second anti-cancer agent. In some embodiments, the FZD-binding agent will be administered within 5, 4, 3, 2, or 1 days of any treatment with the second anti-cancer agent. It will further be appreciated that the two agents or treatment may be administered to the subject within a matter of hours or minutes (i.e., substantially simultaneously).

[00278] Useful classes of anti-cancer agents include, for example, antitubulin agents, auristatins, DNA minor groove binders, DNA replication inhibitiors, alkylating agents (e.g., platinum complexes such as cis-platin, mono(platinum), bis(platinum) and tri-nuclear platinum complexes and carboplatin), anthracyclines, antibiotics antifolates, antimetabolites, chemotherapy sensitizers, duocarmycins, etoposides, fluorinated pyrimidines, ionophores, lexitropsins, nitrosoureas, platinols, performing compounds, purine antimetabolites, puromycins, radiation sensitizers, steroids, taxanes, topoisomerase inhibitors, vinca alkaloids, or the like. In certain embodiments, the second anti-cancer agent is an antimetabolite, an antimitotic, a topoisomerase inhibitor, or an angiogenesis inhibitor.

[00279] Anticancer agents that may be administered in combination with the FZD-binding agents include chemotherapeutic agents. Thus, in some embodiments, the method or treatment involves the combined administration of an antibody or agent of the present invention and a chemotherapeutic agent or cocktail of multiple different chemotherapeutic agents. Treatment with an antibody can occur prior to, concurrently with, or subsequent to administration of chemotherapies. Chemotherapies contemplated by the invention include chemical substances or drugs which are known in the art and are commercially available, such as Gemcitabine, Irinotecan, Doxorubicin, 5-Fluorouracil, Cytosine arabinoside ("Ara-C"), Cyclophosphamide, Thiotepa, Busulfan, Cytoxin, TAXOL, Methotrexate, Cisplatin, Melphalan, Vinblastine and Carboplatin. Combined administration can include co-administration, either in a single pharmaceutical formulation or using separate formulations, or consecutive administration in either order but generally within a time period such that all active agents can exert their biological activities simultaneously. Preparation and dosing

schedules for such chemotherapeutic agents can be used according to manufacturers' instructions or as determined empirically by the skilled practitioner. Preparation and dosing schedules for such chemotherapy are also described in Chemotherapy Service Ed., M. C. Perry, Williams & Wilkins, Baltimore, Md. (1992).

[00280] Chemotherapeutic agents useful in the instant invention also include, but are not limited to, alkylating agents such as thiotepa and cyclosphosphamide (CYTOXAN); alkyl sulfonates such as busulfan, improsulfan and piposulfan; aziridines such as benzodopa, carboquone, meturedopa, and uredopa; ethylenimines and methylamelamines including altretamine, triethylenemelamine, trietylenephosphoramide, triethylenethiophosphaoramide and trimethylolomelamime nitrogen mustards such as chlorambucil, chlornaphazine, cholophosphamide, estramustine, ifosfamide, mechlorethamine, mechlorethamine oxide hydrochloride, melphalan, novembichin, phenesterine, prednimustine, trofosfamide, uracil mustard; nitrosureas such as carmustine, chlorozotocin, fotemustine, lomustine, nimustine, ranimustine; antibiotics such as aclacinomysins, actinomycin, authramycin, azaserine, bleomycins, cactinomycin, calicheamicin, carabicin, caminomycin, carzinophilin, chromomycins, dactinomycin, daunorubicin, detorubicin, 6-diazo-5-oxo-L-norleucine, doxorubicin, epirubicin, esorubicin, idarubicin, marcellomycin, mitomycins, mycophenolic acid, nogalamycin, olivomycins, peplomycin, potfiromycin, puromycin, quelamycin, rodorubicin, streptonigrin, streptozocin, tubercidin, ubenimex, zinostatin, zorubicin; anti-metabolites such as methotrexate and 5-fluorouracil (5-FU); folic acid analogues such as denopterin, methotrexate, pteropterin, trimetrexate; purine analogs such as fludarabine, 6-mercaptopurine, thiamiprine, thioguanine; pyrimidine analogs such as ancitabine, azacitidine, 6-azauridine, carmofur, cytarabine, dideoxyuridine, doxifluridine, enocitabine, floxuridine, 5-FU; androgens such as calusterone, dromostanolone propionate, epitiostanol, mepitiostane, testolactone; anti-adrenals such as aminoglutethimide, mitotane, trilostane; folic acid replenisher such as frolinic acid; aceglatone; aldophosphamide glycoside; aminolevulinic acid; amsacrine; bestrabucil; bisantrene; edatraxate; defofamine; demecolcine; diaziquone; elformithine; elliptinium acetate; etoglucid; gallium nitrate; hydroxyurea; lentinan; lonidamine; mitoguazone; mitoxantrone; mopidamol; nitracrine; pentostatin; phenamet; pirarubicin; podophyllinic acid; 2-ethylhydrazide; procarbazine; PSK.; razoxane; sizofuran; spirogermanium; tenuazonic acid; triaziquone; 2,2',2"-trichlorotriethylamine; urethan; vindesine; dacarbazine; mannomustine; mitobronitol; mitolactol; pipobroman; gacytosine; arabinoside ("Ara-C"); cyclophosphamide; thiotepa; taxoids, e.g. paclitaxel (TAXOL, Bristol-Myers Squibb Oncology, Princeton, N.J.) and doxetaxel (TAXOTERE, Rhone-

Poulenc Rorer, Antony, France); chlorambucil; gemcitabine; 6-thioguanine; mercaptopurine; methotrexate; platinum analogs such as cisplatin and carboplatin; vinblastine; platinum; etoposide (VP-16); ifosfamide; mitomycin C; mitoxantrone; vincristine; vinorelbine; navelbine; novantrone; teniposide; daunomycin; aminopterin; xeloda; ibandronate; CPT11; topoisomerase inhibitor RFS 2000; difluoromethylornithine (DMFO); retinoic acid; esperamicins; capecitabine; and pharmaceutically acceptable salts, acids or derivatives of any of the above. Chemotherapeutic agents also include anti-hormonal agents that act to regulate or inhibit hormone action on tumors such as anti-estrogens including for example tamoxifen, raloxifene, aromatase inhibiting 4(5)-imidazoles, 4-hydroxytamoxifen, trioxifene, keoxifene, LY117018, onapristone, and toremifene (Fareston); and antiandrogens such as flutamide, nilutamide, bicalutamide, leuprolide, and goserelin; and pharmaceutically acceptable salts, acids or derivatives of any of the above.

[00281] In certain embodiments, the chemotherapeutic agent is a topoisomerase inhibitor. Topoisomerase inhibitors are chemotherapy agents that interfere with the action of a topoisomerase enzyme (e.g., topoisomerase I or II). Topoisomerase inhibitors include, but are not limited to, doxorubicin HCL, daunorubicin citrate, mitoxantrone HCL, actinomycin D, etoposide, Topotecan HCL, teniposide (VM-26), and irinotecan. In certain embodiments, the second anticancer agent is irinotecan. In certain embodiments, the tumor to be treated is a colorectal tumor and the second anticancer agent is a topoisomerase inhibitor, such as irinotecan.

[00282] In certain embodiments, the chemotherapeutic agent is an anti-metabolite. An anti-metabolite is a chemical with a structure that is similar to a metabolite required for normal biochemical reactions, yet different enough to interfere with one or more normal functions of cells, such as cell division. Anti-metabolites include, but are not limited to, gemcitabine, fluorouracil, capecitabine, methotrexate sodium, ralitrexed, Pemetrexed, tegafur, cytosine arabinoside, THIOGUANINE (GlaxoSmithKline), 5-azacytidine, 6-mercaptopurine, azathioprine, 6-thioguanine, pentostatin, fludarabine phosphate, and cladribine, as well as pharmaceutically acceptable salts, acids, or derivatives of any of these. In certain embodiments, the second anticancer agent is gemcitabine. In certain embodiments, the tumor to be treated is a pancreatic tumor and the second anticancer agent is an anti-metabolite (e.g., gemcitabine).

[00283] In certain embodiments, the chemotherapeutic agent is an antimitotic agent, including, but not limited to, agents that bind tubulin. By way of non-limiting example, the agent comprises a taxane. In certain embodiments, the agent comprises paclitaxel or

docetaxel, or a pharmaceutically acceptable salt, acid, or derivative of paclitaxel or docetaxel. In certain embodiments, the agent is paclitaxel (TAXOL), docetaxel (TAXOTERE), albumin-bound paclitaxel (e.g., ABRAXANE), DHA-paclitaxel, or PG-paclitaxel. In certain alternative embodiments, the antimitotic agent comprises a vinka alkaloid, such as vincristine, binblastine, vinorelbine, or vindesine, or pharmaceutically acceptable salts, acids, or derivatives thereof. In some embodiments, the antimitotic agent is an inhibitor of Eg5 kinesin or an inhibitor of a mitotic kinase such as Aurora A or Plk1. In certain embodiments where the chemotherapeutic agent administered in combination with the FZD-binding agent or polypeptide or antibody comprises an antimitotic agent, the cancer or tumor being treated is breast cancer or a breast tumor.

[00284] In certain embodiments, the treatment involves the combined administration of an antibody (or other agent) of the present invention and radiation therapy. Treatment with the antibody (or agent) can occur prior to, concurrently with, or subsequent to administration of radiation therapy. Any dosing schedules for such radiation therapy can be used as determined by the skilled practitioner.

[00285] In some embodiments, the second anti-cancer agent comprises an antibody. Thus, treatment can involve the combined administration of antibodies (or other agents) of the present invention with other antibodies against additional tumor-associated antigens including, but not limited to, antibodies that bind to EGFR, ErbB2, HER2, DLL4, Notch and/or VEGF. Exemplary, anti-DLL4 antibodies, are described, for example, in U.S. Patent Application Publication No. US 2008/0187532, incorporated by reference herein in its entirety. In certain embodiments, the second anti-cancer agent is an antibody that is an angiogenesis inhibitor (e.g., an anti-VEGF antibody). Additional anti-DLL4 antibodies are described in, e.g., International Patent Publication Nos. WO 2008/091222 and WO 2008/0793326, and U.S. Patent Application Publication Nos. US 2008/0014196, US 2008/0175847, US 2008/0181899, and US 2008/0107648, each of which is incorporated by reference herein in its entirety. Exemplary anti-Notch antibodies, are described, for example, in U.S. Patent Application Publication No. US 2008/0131434, incorporated by reference herein in its entirety. In certain embodiments, the second anti-cancer agent is an antibody that is an angiogenesis inhibitor (e.g., an anti-VEGF antibody). In certain embodiments, the second anti-cancer agent is an inhibitor of Notch signaling. In certain embodiments, the second anti-cancer agent is AVASTIN (Bevacizumab), Herceptin (Trastuzumab), VECTIBIX (Panitumumab), or Erbitux (Cetuximab). Combined administration can include co-administration, either in a single pharmaceutical formulation or using separate formulations,

or consecutive administration in either order but generally within a time period such that all active agents can exert their biological activities simultaneously.

[00286] Furthermore, treatment can include administration of one or more cytokines (e.g., lymphokines, interleukins, tumor necrosis factors, and/or growth factors) or can be accompanied by surgical removal of cancer cells or any other therapy deemed necessary by a treating physician.

[00287] For the treatment of the disease, the appropriate dosage of an antibody or agent of the present invention depends on the type of disease to be treated, the severity and course of the disease, the responsiveness of the disease, whether the antibody or agent is administered for therapeutic or preventative purposes, previous therapy, patient's clinical history, and so on all at the discretion of the treating physician. The antibody or agent can be administered one time or over a series of treatments lasting from several days to several months, or until a cure is effected or a diminution of the disease state is achieved (e.g. reduction in tumor size). Optimal dosing schedules can be calculated from measurements of drug accumulation in the body of the patient and will vary depending on the relative potency of an individual antibody or agent. The administering physician can easily determine optimum dosages, dosing methodologies and repetition rates. In certain embodiments, dosage is from 0.01 μg to 100 mg per kg of body weight, and can be given once or more daily, weekly, monthly or yearly. In certain embodiments, the antibody or other FZD-binding agent is given once every two weeks or once every three weeks. In certain embodiments, the dosage of the antibody or other FZD-binding agent is from about 0.1 mg to about 20 mg per kg of body weight. The treating physician can estimate repetition rates for dosing based on measured residence times and concentrations of the drug in bodily fluids or tissues.

V. Wnt gene signature and uses thereof

[00288] The present invention further provides a Wnt gene signature, a gene signature indicative of Wnt signaling activity in tumors, which may be used in the selection of tumors, patients, and/or therapy.

[00289] The Wnt gene signature comprises the differential expression of a set of genes in tumors in which Wnt signaling is activated (and/or which are dependent upon Wnt signaling), relative to tumors in which Wnt signaling is not activated. In certain embodiments, the Wnt signaling is canonical Wnt signaling. The Wnt gene signature is

useful for the identification of tumors and/or patients likely to respond to treatment with an inhibitor of Wnt signaling (e.g, a FZD-binding agent that is an antagonist of at least one human frizzled receptor and/or an inhibitor of Wnt signaling).

[00290] In certain embodiments, the Wnt gene signature comprises one or more genes (i.e., 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, or 19 genes) listed in Table 3, below. The "Probe Set ID" numbers are the probe set ID numbers for the GeneChip® Human Genome U133 Plus 2.0 Array ("HG_U133_Plus_2"; Affymetrix, Santa Clara, CA). In tumors in which Wnt signaling is active (i.e., tumors which are positive for a Wnt gene signature), the expression level(s) of the gene(s) in Table 3 that comprise the Wnt gene signature are elevated relative to tumors in which Wnt signaling is not active. In some embodiments, the Wnt gene signature comprises two or more genes listed in Table 3, below. In some embodiments, the Wnt gene signature comprises three or more, four or more, five or more, six or more, seven or more, eight or more, nine or more, ten or more, eleven or more, twelve or more, thirteen or more, fourteen or more, fifteen or more, sixteen or more, seventeen or more, eighteen or more, or nineteen of the genes listed in Table 3, below. In certain embodiments, the tumor being assessed for expression levels of the one or more genes in Table 3 is a colorectal tumor. In certain embodiments, the Wnt gene signature comprises AXIN2 and/or FOXQ1. In certain embodiments, the tumor is a colorectal tumor and the Wnt gene signature comprises AXIN2, LGR5, and/or FOXQ1.

Table 3. Exemplary Wnt gene signature genes

HG_U133_Plus_2 Probe Set ID	Gene Symbol	Description
222696_at	AXIN2	axin 2 (conductin, axil)
206286_s_at	TDGF1	teratocarcinoma-derived growth factor 1
213880_at	LGR5	leucine-rich repeat-containing G protein-coupled receptor 5
207217_s_at	NOX1	NADPH oxidase 1
209588_at	EPHB2	EPH receptor B2
212850_s_at	LRP4	low density lipoprotein receptor-related protein 4
205107_s_at	EFNA4	ephrin-A4

214058_at	MYCL1	v-myc myelocytomatosis viral oncogene homolog 1, lung carcinoma derived (avian)
209864_at	FRAT2	frequently rearranged in advanced T-cell lymphomas 2
208121_s_at	PTPRO	protein tyrosine phosphatase, receptor type, O
229376_at		unknown expressed sequence tag (EST)
202431_s_at	MYC	v-myc myelocytomatosis viral oncogene homolog (avian)
212444_at	GPCR5A	G protein-coupled receptor, family C, group 5, member A
222938_x_at	ENPP3	ectonucleotide pyrophosphatase/phosphodiesterase 3
241607_at	LOC730102	hypothetical protein LOC730102
227475_at	FOXQ1	forkhead box Q1
230398_at	TNS4	tensin 4
40284_at	FOXA2	forkhead box A2
219704_at	YBX2	Y box binding protein 2

[00291] Methods of using the Wnt gene signature to select patients (or to identify a patient) suitable for treatment with a Wnt pathway inhibitor or for assessing the efficacy of a particular therapy are also provided. In certain embodiments, the Wnt signaling inhibitor is a FZD-binding agent, such as an antagonistic FZD antibody. For example, a patient may be identified as being suitable for treatment with a FZD-binding agent (or FZD-binding agents) by determining whether a tumor in the patient or that has been removed from the patient exhibits a Wnt gene signature. In certain embodiments, detecting the Wnt gene signature comprises assessing the expression level of one or more genes in Table 3 in the tumor. If expression levels of the one or more genes in Table 3 that comprise the Wnt gene signature are elevated in the tumor (thus indicating that Wnt signaling is active in the tumor), the patient is identified as being suitable for treatment with a FZD-binding agent, such as an anti-FZD antibody that inhibits Wnt signaling. Methods of using the Wnt gene signature to select a suitable therapy for a particular patient are likewise provided.

[00292] The invention provides a method of treating cancer in a patient having a tumor or from whom a tumor has been removed, comprising (a) providing the expression level of one or more genes in Table 3 in the tumor (b) selecting the patient for beginning or continuing treatment with a FZD-binding agent based on the expression level of the one or more genes, and (c) administering the FZD-binding agent to the patient. In certain embodiments, the method comprises measuring the expression level of the one or more genes in the tumor. In certain embodiments, the expression level of the one or more genes is compared to a control or reference level.

[00293] Methods of identifying tumor which may be responsive to treatment with an inhibitor of Wnt signaling are also provided. In certain embodiments, the inhibitor of Wnt signaling is a FZD-binding agent. In certain embodiments, the methods comprise testing the tumor for a Wnt gene signature. In certain embodiments, the methods comprise assessing the expression level of one or more genes in Table 3 in the tumor.

[00294] Methods of screening drug candidates against tumors identified as exhibiting the Wnt gene signature are also provided. In certain embodiments, the drug candidates are Wnt signaling inhibitors. Such drug candidates are preferably tested for efficacy on those tumors in which Wnt signaling is active and/or which are dependent upon Wnt signaling. The present invention also provides a method of screening a drug candidate comprising assessing the expression level of one or more genes in Table 3 in a tumor (b) selecting the tumor for testing with the drug candidate based (at least in part) on the expression level of the one or more genes, and (c) testing the effect of the drug candidate on the tumor.

[00295] In addition, in certain embodiments, the effect of a drug on the Wnt gene signature may be determined and used to assess the efficacy of a treatment of a tumor in which Wnt signaling is active. In certain embodiments, this provides a method of monitoring treatment of a patient. In some alternative embodiments, this provides a method of assessing the efficacy of a drug candidate. In certain embodiments, a decrease in the expression levels of one or more genes in Table 3 (i.e., a reduction in or elimination of the Wnt gene signature) indicates efficacy of the treatment.

[00296] In certain embodiments, assessing the level of one or more genes in a Wnt gene signature comprises determining the expression levels of polynucleotides of the one or more genes. In certain embodiments, detecting a Wnt gene signature comprises detecting mRNA expression of polynucleotides of the one or more genes that comprise the signature. In some embodiments, the detection of mRNA expression is via Northern blot. In some embodiments, the detection of mRNA expression is via RT-PCR, real-time PCR or

quantitative PCR using primer sets that specifically amplify the polynucleotides comprising the cancer stem cell signature. In certain embodiments, the detection of mRNA comprises exposing a sample to nucleic acid probes complementary to polynucleotides comprising a cancer stem cell gene signature. In some embodiments, the mRNA of the sample is converted to cDNA prior to detection. In some embodiments, the detection of mRNA is via microarrays that comprise polynucleotides that hybridize to one or more genes in the Wnt gene signature.

[00297] In certain embodiments, assessing the level of one or more genes in a Wnt gene signature comprises detecting polypeptides encoded by the one or more genes. In some embodiments, the assessment of levels of the polypeptide expression products of the one or more genes comprises exposing a sample to antibodies specific to the polypeptides and detecting the binding of the antibodies to the polypeptides by, for example, quantitative immunofluorescence, or ELISA. Other detection means are known to one of ordinary skill in the art see e.g., U.S. Patent No. 6,057,105.

[00298] An array comprising polynucleotides that hybridize under stringent conditions to one or more genes in Table 3 are also provided. A kit comprising the array is also provided.

[00299] Kits comprising antibodies that bind the expression product of one or more genes in Table 3 are also provided.

VI. Kits comprising Fzd-binding agents

[00300] The present invention provides kits that comprise the antibodies or other agents described herein and that can be used to perform the methods described herein. In certain embodiments, a kit comprises at least one purified antibody against one or more human frizzled receptors in one or more containers. In some embodiments, the kits contain all of the components necessary and/or sufficient to perform a detection assay, including all controls, directions for performing assays, and any necessary software for analysis and presentation of results. One skilled in the art will readily recognize that the disclosed antibodies or agents of the present invention can be readily incorporated into one of the established kit formats which are well known in the art.

[00301] Further provided are kits comprising a FZD-binding agent (e.g., a FZD-binding antibody), as well as a second anti-cancer agent. In certain embodiments, the second anti-cancer agent is a chemotherapeutic agent (e.g., gemcitabine or irinotecan). In certain

embodiments, the second anti-cancer agent is an angiogenesis inhibitor. In certain embodiments, the second anti-cancer agent is an inhibitor of Notch signaling (e.g., an anti-DLL4 or anti-Notch antibody).

[00302] Also provided are kits comprising a FZD-binding agent and a reagent or reagents for assessing the expression of one or more gene in Table 3, above ("Exemplary Wnt gene signature genes").

[00303] Embodiments of the present disclosure can be further defined by reference to the following non-limiting examples, which describe in detail preparation of certain antibodies of the present disclosure and methods for using antibodies of the present disclosure. It will be apparent to those skilled in the art that many modifications, both to materials and methods, may be practiced without departing from the scope of the present disclosure.

EXAMPLES

[00304] It is understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art and are to be included within the spirit and purview of this application.

Example 1

Identification/generation of anti-FZD antibodies

[00305] Human antibodies that specifically recognize one or more human Frizzled receptors can be isolated using phage display. For example, a synthetic antibody library containing human antibody variable domains may be panned for specific and high affinity recognition of the extracellular domain of the human FZD7 receptor. Once a specific Fab with the desired characteristics has been identified, the human variable regions of the Fab are then cloned into an Ig expression vector containing human IgG2 heavy-chain and light-chain (kappa or lambda) for expression of human antibodies in CHO cells.

[00306] Phage display was used to identify a specific Fab, 18R8, that binds to the extracellular domain of FZD7. $2x10^{13}$ Fab displaying phage particles from a human Fab phage library were incubated with passively immobilized recombinant FZD7 ECD Fc protein. The non-specific phage were washed off, and then specific phage were eluted with DTT. The eluted output was used to infect TG1 F+ bacteria, rescued with helper phage. Fab display was then induced with IPTG (0.25 mM). The output of this rescued round one served

as the starting point for further selection rounds. The selections were continued to round 3, and then the output was screened in ELISA for specific Fabs to recombinant FZD7 ECD Fc protein. A Fab that specifically bound to human FZD7 was identified.

[00307] The sequences of the variable regions of the identified Fab were obtained. An N-linked glycosylation site was removed from the parent sequence through site-directed mutagenesis. The N-linked glycosylation site, Asn, in the heavy chain CDR1 was changed to His. This mutation was made to prevent glycosylation during expression in mammalian systems. The resulting Fab was designated 18R8. The heavy chain and light chain CDR sequences of 18R8 are shown below in Table 4, below. The VH and VL sequences of 18R8 are provided in SEQ ID NO: 10 and SEQ ID NO: 12, respectively.

Table 4. CDRs of 18R8 and 18R5 human antibodies

Lead	Heavy Chain			Light Chain		
	CDR1	CDR2	CDR3	CDR1	CDR2	CDR3
18R8	GFTFS**H**YTLS (SEQ ID NO:1)	VISGDGSYTYYADSVKG (SEQ ID NO:2)	NFIKYVFAN (SEQ ID NO:3)	SGDKLGKKYAS (SEQ ID NO:4)	EKDNRPSG (SEQ ID NO:5)	SSFAGNSLE (SEQ ID NO:6)
18R5	GFTFS**H**YTLS (SEQ ID NO:1)	VISGDGSYTYYADSVKG (SEQ ID NO:2)	NFIKYVFAN (SEQ ID NO:3)	SGDNIGSFYVH (SEQ ID NO:7)	DKSNRPSG (SEQ ID NO:8)	QSYANTLSL (SEQ ID NO:9)

* Site directed change to remove N-linked glycosylation site is underlined.

[00308] Anti-FZD Fab 18R5 was generated by associating the VH-CH1 chains of 18R8 Fab with a variety of VL-CL chains from the original Fab phage library from which 18R8 was identified. 18R5 was isolated from the library after three rounds of panning with immobilized recombinant FZD7 ECD Fc protein. The sequences of the CDRs of 18R5 are shown in Table 4, above. The VL of the 18R5 antibody has the sequence shown in SEQ ID NO:14. The heavy chain CDRs and the VH of the 18R5 antibody are identical to that of the 18R8 antibody.

[00309] The human variable regions of the 18R8 and 18R5 Fabs were cloned into Ig expression vector containing human IgG2 heavy-chain and light-chain (lambda) for expression in CHO cells. The amino acid sequence of the heavy chain and light chain of the 18R8 IgG antibody (including signal sequences) are provided in SEQ ID NO:11 and SEQ ID NO:13, respectively. The signal sequence at the N-terminus of the amino acid sequence of each of the chains is cleaved upon secretion. The nucleic acid sequences encoding the heavy and light chains of the 18R8 IgG antibody are provided in SEQ ID NO:18 and SEQ ID NO:20, respectively. The amino acid sequence of the heavy chain and light chain of the

18R5 IgG antibody are provided in SEQ ID NO:11 and SEQ ID NO:15, respectively. (Again, the signal sequence at the N-terminus of the amino acid sequence of each of the chains is cleaved upon secretion.) The nucleic acid sequences encoding the heavy and light chains of the 18R5 IgG antibody are provided in SEQ ID NO:18 and SEQ ID NO:22, respectively. Protein A purification was used to purify the antibodies.

[00310] The K_Ds of 18R8 and 18R5 antibodies were determined using the Biacore 2000 system from Biacore Lifescience (GE Healthcare). Specifically, purified anti-Fzd7 antibodies were serially diluted in 2-fold increments from 100 to 0.78 nM in HBS-P (0.01 M HEPES pH 7.4, 0.15 M NaCl, 0.005% v/v Surfactant P20). Each dilution was tested against recombinant Fzd Fc proteins immobilized onto a CM5 Biacore chip. The association and dissociation rates were measured and K_D values determined using the Biaevaluation software program (Table 5, below).

Table 5. Affinity of 18R8 and 18R5 IgG antibodies

	18R8	18R5
FZD	K_D (nM)	K_D (nM)
1	15.6	4.6
2	6.2	3.3
5	4.2	1.9
7	5.2	1.8
8	29.3	5.8

Example 2

FACS analysis of anti-FZD antibodies demonstrates binding to multiple cell-surface human FZDs

[00311] Flow cytometry analysis was utilized to determine the ability of antibodies to bind to cell surface expressed FZD proteins.

[00312] To enable robust cell surface expression of selected FZD proteins, mammalian expression plasmids comprising a CMV promoter upstream of polynucleotides that encode FZD were generated using standard recombinant DNA technology (such constructs were termed "FL no FLAG"). Similar expression plasmids were generated for each of the ten human frizzled proteins. Alternative versions of the FZD expression vectors were also prepared in which polynucleotides encoding an N-terminal signal sequence-FLAG epitope tag fused to the N-terminus of the mature FZD protein were also generated by standard recombinant technology (such constructs were termed "FL flag"). Additionally, expression plasmids were designed which encoded chimeric proteins comprised of either the CRD

domain (also referred to as the "fri" domain) of the FZD or the entire N-terminal extracellular domain of the FZD protein fused to an N-terminal signal sequence-FLAG epitope (termed "fri flag" and "ECD flag" respectively), as well as a C-terminal section encoding the transmembrane and cytoplasmic domain of human CD4 protein.

[00313] To measure antibody binding to FZD by flow cytometry HEK293 cells were co-transfected with FZD expression vectors and the transfection marker GFP. Twenty-four to forty-eight hours post-transfection, cells were collected in suspension and incubated on ice with anti-FZD antibodies (10 μg/ml unless otherwise indicated) or control IgG to detect background antibody binding. The cells were washed and primary antibodies detected with Fc domain-specific secondary antibodies conjugated to a fluorescent chromophore (e.g. phycoerythrin conjugated anti-human IgG). Labeled cells were then analyzed by flow cytometry to identify anti-FZD antibodies that specifically recognize cell surface expression of FZD protein. Monoclonal antibodies 18R5 and 18R8 recognized FZD on transfected cells. As shown in Figure 1 and Figure 2, both 18R8 and 18R5 bind to multiple FZD including FZD1, FZD2, FZD5, FZD7, and FZD8. To examine the relative ability of 18R8 and 18R5 to bind to each FZD protein, titration analysis was conducted wherein the amount of antibody in the binding reaction was varied (Figure 2). This analysis demonstrated that 18R5 displayed greater binding potency to each of the FZD receptors (FZD1, FZD2, FZD5, FZD7, and FZD8) than 18R8.

Example 3

Inhibition of Wnt signaling by 18R8 and 18R5

[00314] The ability of the anti-FZD IgG antibodies 18R8 and 18R5 to block activation of the Wnt signaling pathway was determined *in vitro* using luciferase reporter assays.

[00315] STF293 cells were cultured in DMEM supplemented with antibiotics and 10% FCS. The STF293 cells are 293 cells in which the following have been stably integrated: (1) an 8xTCF Luc reporter vector containing seven copies of the TCF binding site linked to a promoter upstream of a firefly luciferase reporter gene to measure canonical Wnt signaling levels (Gazit et al., 1999, *Oncogene* 18:5959-66) and (2) a Renilla luciferase reporter (Promega; Madison, WI) as an internal control for transfection efficiency. The cells were added to cultures plates. The FZD antibodies to be tested (or no antibodies) were added. The cells were then incubated in the presence or absence of Wnt3A-conditioned medium that had been prepared from L cells that stably express Wnt3a (ATCC CRL-2647) or control

conditioned media from L cells not overexpressing Wnt3A (ATCC cell line CRL-2648). After overnight incubation, luciferase levels were measured using a dual luciferase assay kit (Promega; Madison, WI) with firefly luciferase activity normalized to Renilla luciferase activity.

[00316] The ability of the 18R8 and 18R5 antibodies to inhibit Wnt-induced pathway activation was thus determined. STF293 cells were treated with different concentrations of 18R8 or 18R5 IgG antibodies and Wnt3A-conditioned medium was added. The cells were assayed 18 hours later using the dual luciferase assay kit. The results are shown in Figure 3. Greater inhibition of the TCF signaling of the Wnt3a pathway was observed with the anti-FZD antibody 18R5.

[00317] In further experiments, the ability of the 18R8 antibody to antagonize signaling by different Wnt ligands was determined. HEK 293 cells were transfected with Wnt1, Wnt2, Wnt2b2, Wnt3, Wnt3a, Wnt7a, Wnt7b, Wnt8a, Wnt9b, and Wnt10b for forty eight hours by Fugene 6 (Roche). Wnt3A conditioned medium ("WNT3ACM") was used as a positive control of activation. STF293 cells, were cultured in DMEM supplemented with antibiotics and 10% FCS and treated with 20 μg/ml 18R8 antibody or no antibody. The Wnt-overexpressing HEK293 cells were then added. Eighteen hours following treatment, luciferase levels were measured using a dual luciferase assay kit. The results are shown in Figure 4. The anti-FZD antibody 18R8 was shown to inhibit signaling of a variety of Wnts, including inhibiting Wnt1, Wnt2, Wnt3, Wnt7A, Wnt7B, and Wnt10B, in addition to Wnt3A.

Example 4

18R8 blocks binding of FZD to Wnt

[00318] To assess the ability of 18R8 to block the binding of FZD to Wnt, 2 μl of 1.32 μg/μl soluble FZD8-Fc containing the Fri domain (amino acids 1-157 of FZD8 linked in-frame to human IgG1 Fc) was added to culture medium to bind Wnt3A (added as 20μl of Wnt3A conditioned medium) either alone or in the presence of the 18R8 IgG antibody (added as 4 μl of 3.71 μg/μl). The mixtures were incubated either alone or in the presence of Protein A sepharose beads (GE Healthcare products; 20μl of 50% solution in PBS) for two hrs at 4°C. After the incubation, the protein A beads (and any proteins complexed to the protein A beads) in each sample were removed by spinning and the supernatant was assayed for ability to induce 8xTCF luciferase activity. The supernatant was added to STF293 cells, which stably express 8xTCF (eight copies of the TCF-binding domain upstream of a firefly

luciferase reporter gene) to measure canonical Wnt signaling levels and which were cultured in DMEM supplemented with antibiotics and 10% FCS. Eighteen hours following treatment of the STF293 cells, luciferase levels were measured using a dual luciferase assay kit (Promega; Madison, WI).

[00319] As seen in Figure 5, Wnt 3A plus Protein A induces a strong activation of the reporter gene as measured by luciferase units (RLU) (Figure 5, column 1). Addition of Fzd8-fc induces a complex between Wnt 3A-Fzd8 and the Fc fusion protein with the Protein A sepharose beads, and once the Protein A-Wnt3A-Fzd8 complex is removed by centrifugation, the resulting supernatant is no longer capable of activating the reporter gene (Figure 5, column 2). Upon addition of 18R8, this complex is presumably disrupted by the blockade of the antibody upon the Wnt3A interacting domain of Fzd8, because although the Protein A-Fzd8-fc complex is removed along with 18R8 which can readily interact with Protein A through its own Fc portion, reporter activity can be readily observed, suggesting sufficient levels of uncomplexed Wnt 3A (Figure 5, column 3). 18R8 also functions on the endogenous Fzd's present on the STF293 cells, because failure to remove 18R8 by Protein A does not show the return of Wnt 3A activation (Figure 5, column 6).

[00320] The data in Figure 5 show that the presence of the 18R8 IgG antibody in the incubation reaction resulted in retention of Wnt3A activity within the supernatant relative to the activity observed with FZD8-Fc alone. These results indicate that 18R8 blocked the ability of FZD8 to bind to Wnt3A and indicate that antibody binding to the epitope recognized by 18R8 is able to block Wnt-FZD interactions.

Example 5

Epitope mapping of 18R8 and 18R5

[00321] To identify the FZD epitope recognized by the 18R8 IgG antibody, epitope mapping was performed. Flow cytometry analysis of cell surface expressed FZD was utilized to measure antibody binding. Mammalian expression plasmid vectors comprising a CMV promoter upstream of polynucleotides that encode an N-terminal signal sequence FLAG epitope tag fused to the N-terminus of the Fri domain of FZD8 in turn fused to the transmembrane domain and intracellular domain of CD4 protein were generated by standard recombinant technology. This expression construct allows expression of the FZD8 Fri domain on the cell surface, as well as expression of a FLAG epitope tag to monitor expression. Site-direct mutagenesis was then used to modify selected amino acids within the

extracellular domain of FZD. HEK293 cells were co-transfected with expression vectors encoding the FZD and the transfection marker GFP. Forty-eight hours post-transfection, cells were collected in suspension and incubated on ice with anti-FZD antibody or control IgG to detect background antibody binding. The cells were washed and primary antibodies detected with anti-antibody secondary antibodies conjugated to a fluorescent chromophore. Labeled cells were then analyzed by flow cytometry to measure the binding of anti-FZD antibody to cell surface FZD.

[00322] In this manner, specific amino acids within the FZD extracellular domain that were important for the binding of anti-FZD antibodies were identified. When amino acid residues 82-83 of FZD8 were mutated from PD to SQ, binding of the FZD8 by 18R8 was largely unaffected (Figure 6). Similarly, when amino acid 109S was changed to 109Q, no appreciable effect on binding was observed. On the other hand, when residues 70- 71 of FZD8 were changed from HQ to AE, binding of the FZD8 on cells by 18R8 was clearly diminished (Figure 6 and Figure 7). When amino acids 66-67 were mutated from GL to AA, or when amino acids 68-69 were mutated from EV to QL, or when amino acids 126-127 were mutated from FG to NV, binding of the 18R8 antibody to FZD8 on the cells was similarly lost. The loss of binding to FZD when certain amino acids had been substituted the extracellular domain of FZD revealed specific recognition sites of the antibody. Thus, the antibody 18R8 was determined to bind to an epitope comprising amino acids 66-71 GLEVHQ (SEQ ID NO:25) of FZD8 and amino acids 124-128 GF of human FZD8. This epitope region is well conserved across the human frizzled receptors to which FZD8 binds (i.e., FZD1, FZD2, FZD5, FZD7, and FZD8), and not highly conserved in those human frizzled receptors to which FZD8 does not bind (i.e., FZD3, FZD4, FZD6, FZD9, or FZD10).

[00323] FACS experiments comparing the binding of 18R5 IgG and 18R8 IgG to the wild-type and mutant FZD8 on cells were also performed. These experiments demonstrated that the 18R8 antibody and the 18R5 antibody bind to a similar epitope on FZD8 (Figure 7).

Example 6

Identification of the Biological Binding Site (BBS of the FZD receptors)

[00324] The discovery of antibodies that inhibit Wnt signaling and the discovery of the epitope within the FZD protein bound by these antibodies has now enabled the analysis of which regions of the FZD protein structure are important for Wnt signaling. To examine this, the crystal structure of the Fri domain of mouse Fzd 8 was examined. We identified the

binding epitope of 18R8 and 18R5 as lying within a region of the FZD structure for which a specific functional role had not previously been appreciated. Moreover the epitope contained two separate surface elements of the Fzd (which we termed "top edge" and "bottom edge") separated by a cleft. It was also discovered upon comparison of the ten human frizzled receptors that there was striking conservation of the identity of amino acids that lined the bottom of this cleft. The region comprising this cleft, as well as the "top edge" and "bottom edge" to which 18R8 and 18R5 bind has been designated the Biological Binding Site (BBS) of FZD. Shown in Figure 9 are images of the structure of a Fzd Fri domain based on analysis of the previously reported crystal structure of mouse FZD8 (Dann CE et al., *Nature* 412 (6842) 86-90, 2001) and analysis done using the software program Pymol. Shown in the upper left image is a surface view of the FZD Fri domain with the region of the Fzd protein comprising the biological binding site (BBS) indicated by a white circle. The regions designated as the "top edge", "bottom edge" and the "cleft" of the BBS are each highlighted in darker surface coloration in separate images at the bottom of the panel. The upper right image of Figure 9 highlights in a darker surface the residues that are conserved in 9 or 10 of ten human Fzd family members.

Example 7

Inhibition of tumor growth *in vivo* by 18R5

Prevention of Wnt-dependent Tumor Growth by 18R5

[00325] Female NOD/SCID mice were injected at age 5-7 weeks with 50,000 mouse mammary tumor virus (MMTV)-WNT1 tumor derived cells in the upper right mammary fat pad. Transgenic (MMTV)-Wnt-1 mice exhibit discrete steps of mammary tumorigenesis, including hyperplasia, invasive ductal carcinoma, and distant metastasis, and thus this mouse model of breast cancer provides a useful tool for analyzing the role of Wnts in tumor formation and growth (Nusse and Varmus (1982) *Cell* 31:99-109). Tumors from these mice were dissociated and these dissociated tumor cells used for tumor propagation purposes. Mice with tumor cells implanted in the mammary fat pad were monitored twice a week. Once tumors were palpable, tumors were measured twice weekly and tumor volume was determined using the formula ½(a x b^2); where a = length, and b = breadth. Data are expressed as mean and mean ±S.E.M. Group means were compared using Student's two-tailed, unpaired t test. Probability (p) values of <0.05 were interpreted as significantly different. On day 19, mice with average tumor volume of 44 mm^3 were randomized into 2

groups of 10 animals each. Animals were injected with either control antibody, or 18R5 IgG antibody (10mg/kg). Administration of the antibodies was performed via injection into the intra-peritoneal cavity, twice weekly. Treatment with the antibody 18R5 completely abolished tumor growth as compared to tumors treated with control antibody (Figure 10; p = 0.002).

Reduction of OMP-C28 xenograft tumor growth by combination treatment of 18R5 and irinotecan

[00326] In another embodiment anti-FZD antibodies were analyzed for their ability to reduce the growth of OMP-C28 colon tumor xenografts. Dissociated human OMP-C28 cells (10,000 per animal) were injected subcutaneously into 6-8 week old male NOD/SCID mice. Tumor growth was monitored weekly and tumor measurements were initiated once tumors were palpable. On day 24 mice with average tumor volume of 129 mm^3 were randomized into 4 groups of 10 animals each. Animals were injected with either control antibody, or 18R5 IgG antibody (10 mg/kg), or irinotecan (7.5 mg/kg) or combination of both 18R5 and irinotecan. Administration of the antibodies and irinotecan was performed via injection into the intra-peritoneal cavity, twice weekly. Tumors were measured twice a week and tumor volume was determined using the formula $\frac{1}{2}(a \times b^2)$; where a = length, and b = breadth. Data are expressed as mean and mean ±S.E.M. Group means were compared using Student's two-tailed, unpaired t test. Probability (p) values of <0.05 were interpreted as significantly different. Treatment with 18R5 resulted in a 40% reduction in tumor growth, as shown in Figure 11 (p = 0.02). Furthermore, treatment with 18R5 and irinotecan resulted in a 53% reduction of tumor growth relative to treatment with irinotecan alone (p = 0.0002 vs. irinotecan alone) (Figure 11). Thus, 18R5 demonstrated anti-tumor growth activity in OMP-C28 colon tumor model as a single agent as well as in combination with irinotecan.

Reduction of OMP-Pn4 xenograft tumor growth by combination treatment of 18R5 and gemcitabine

[00327] In another embodiment, anti-FZD antibodies were analyzed for their ability to reduce the growth of OMP-Pn4 pancreatic tumor xenografts. NOD/SCID mice were purchased from Harlan (Indianapolis, Indiana) and allowed to acclimate for several days prior to the studies. The establishment and characterization of *in vivo* cancer stem cell-driven pancreas xenograft models were described previously (Li et al., *Cancer Res.*, 67:1030-7, 2007). For efficacy studies, OMP-Pn4 human pancreatic tumor cells were dissociated into single cell suspensions, resuspended in 1:1 (v/v) mixture of FACS buffer (Hank's balanced salt solution [HBSS] supplemented with 2% heat-inactivated fetal bovine serum and 20 mM

Hepes) and Matrigel (BD Bioscience, San Jose, CA) and implanted subcutaneously into the right flank region of 6-7 weeks old male NOD/SCID mice with a 25-gauge needle containing 50,000 cells/ 100μL. Tumor growth was monitored weekly and tumor measurements were initiated once tumors were palpable. At day 36, the mean tumor volumes reached about 120 mm^3 and the tumor-bearing animals were randomized (4 groups of 9 per group). Treatment was initiated two days later. Animals were injected with control antibody, with 18R5 IgG antibody (10 mg/kg), with gemcitabine (40 mg/kg), or with a combination of both 18R5 IgG antibody and gemcitabine. Administration of the antibodies and/or gemcitabine was performed via injection into the intra-peritoneal cavity, once weekly. Tumor growth was measured by with an electronic caliper (Coast Tools Company, San Leandro, CA). Tumors were measured once a week and tumor volume was determined using the formula $½(a \times b^2)$; where a = length (longest axis of the tumor), and b = breadth (shortest axis of the tumor). Animals were weighed every day if they showed more than 15% body weight loss and euthanized if they showed 20% body weight. Data are expressed as mean ±S.E.M. Differences in mean values between groups were analyzed by non-parimetric t test. Multiple comparisons used one-way ANOVA test with posthoc t test comparison. Differences of $p<0.05$ are considered significantly different. Software for statistical analysis was by GraphPad Prism4 (GraphPad Software Inc., San Diego, CA). At the end of the study, the mice were euthanized using a CO_2 chamber followed by cervical dislocation. Tumors were collected for RNA and histologic analysis. The remaining tumors were transferred into cold medium 199 for processing into single cell suspensions for analysis of cancer stem cell frequency.

[00328] The results of the OMP-Pn4 xenograft study are shown in Figure 12. Treatment with the 18R5 antibody as monotherapy did not result in a significant reduction in tumor growth in this experiment. However, treatment with 18R5 and gemcitabine resulted in a reduction of tumor growth by 42% over treatment with gemcitabine (Figure 12; $p = < 0.001$ vs gemcitabine alone). Thus, 18R5 demonstrated synergistic anti-tumor growth activity in OMP-Pn4 pancreatic tumor model in combination with gemcitabine, an approved standard-of-care chemotherapy agent.

Reduction of PE-13 breast tumor growth by combination treatment of 18R5 and paclitaxel

[00329] 10,000 PE-13 human breast tumor cells (HER2-negative) were implanted in NOD-SCID mice and allowed to grow for 22 days until they reached an average volume of approximately 120 mm^3. The animals were then randomized into 4 groups of 10 animals each and dosed with either a control antibody, anti-FZD 18R5, paclitaxel (TAXOL®), or 18R5

plus paclitaxel. Figure 37 shows the average tumor volumes of the mice dosed with control antibody, anti-FZD 18R5, paclitaxel, or 18R5 plus paclitaxel. Antibodies were dosed at 10 mg/kg, IP, twice per week. Paclitaxel was dosed at 10 mg/kg, IP, once per week. Tumors were measured on the days indicated in Figure 37. Figure 38 shows the tumor growth of the individual animals in the 18R5 plus paclitaxel group. 18R5 plus paclitaxel treatment was shown to result in anti-tumor activity and regression of established breast tumors.

Example 8

Assays to determine effect on cancer stem cell frequency

[00330] Limiting dilution assays (LDAs) can be used to assess the effect of a FZD-binding agent or antibody on solid tumor cancer stem cells and on the tumorigenicity of a tumor comprising the cancer stem cells. The assays can be used to determine the frequency of cancer stem cells in tumors from animals treated with the FZD-binding antibody or other agent and to compare that frequency to the frequency of cancer stem cells in tumors from control animals.

Effect of combination treatment of 18R5 and irinotecan on cancer stem cells in OMP-C28 tumors

[00331] Control and treated tumors from the OMP-C28 xenograft study described above (Example 7) were harvested at the end of the study (day 48). The tumors were processed and dissociated into single cells. Tumor cells were then incubated with biotinylated mouse antibodies (α-mouse CD45-biotin 1:200 dilution and rat α-mouse H2Kd-biotin 1:100 dilution, BioLegend, San Diego, CA) on ice for 30 min followed by addition of streptavidin-labeled magnetic beads (Invitrogen, Carlsbad, CA) to remove mouse cells with the aid of a magnet.

[00332] For the LDA, the human cells in the suspension were harvested, counted, and appropriate cell doses (5, 25, and 125 cells) in FACS buffer were mixed in a 1:1 mixture with Matrigel and injected subcutaneously in NOD/SCID mice (10 mice per cell dose per treatment group). Tumors are allowed to grow for up to 4 months. At the desired time point, the percentage of mice with detectable tumors is determined in all groups injected with anti-FZD antibody treated tumor cells and compared to the percentage of mice with detectable tumors in the controls. For example, the number of mice injected with 125 control-treated tumor cells that have detectable tumors is determined and compared to the number of mice injected with 125 FZD-antibody treated tumor cells that have detectable tumors. The cancer

stem cell frequency is then calculated using L-CalcTM software (StemCell Technologies Inc.). Briefly, based on Poisson statistics, exactly one cancer stem cell exists among the known number of injected cells if 37% of the animals fail to develop tumors.

[00333] For analysis of cell surface markers, the single tumor cell suspension was stained with anti-ESA (Biomeda) and anti-CD44 (BD Biosciences) antibodies which were directly conjugated to fluorochromes. Dead cells were excluded by using the viability dye DAPI. Flow cytometry was performed using a FACS Aria (Becton Dickinson). Side scatter and forward scatter profiles were used to eliminate cell clumps. Analysis of the tumors treated with control antibody revealed that 64% of the bulk tumor population expressed both ESA and CD44 at high levels (Figure 39). The double positive population was not significantly affected by treatment with irinotecan alone (55%), as shown in Figure 39, but treatment with either 18R5 or the combination of 18R5 with irinotecan reduced the double positive population (40% and 32% respectively).

Effect of combination treatment of 18R5 and gemcitabine on cancer stem cells in OMP-Pn4 tumors

[00334] Control and treated tumors from the OMP-Pn4 xenograft study described above (Example 7) were harvested at the end of 41 days treatment. The tumors were processed and dissociated into single cells. Tumor cells were then incubated with biotinylated mouse antibodies (α-mouse CD45-biotin 1:200 dilution and rat α-mouse H2Kd-biotin 1:100 dilution, BioLegend, San Diego, CA) on ice for 30 min followed by addition of streptavidin-labeled magnetic beads (Invitrogen, Carlsbad, CA) to remove mouse cells. The remaining human cells in the suspension were collected, counted and diluted to appropriate cell doses (30, 90, 270 and 810 cells), mixed in the mixture of 1:1 (v/v) FACS buffer and Matrigel and injected subcutaneously in NOD/SCID mice (10 mice per cell dose per treatment group). Tumors were allowed to grow for 75 days as shown in Figure 40. Each dot in Figure 40 represents the tumor volume of an individual mouse. The percentage of mice with detectable tumors was determined in all groups injected with anti-FZD antibody treated tumor cells and compared to the percentage of mice with detectable tumors in the controls. For example, the number of mice injected with 810 control-treated tumor cells that have detectable tumors was determined and compared to the number of mice injected with 810 FZD-antibody treated tumor cells that have detectable tumors. The tumor growth frequency was used to calculate the cancer stem cell frequency using L-CalcTM software. The calculated cancer stem cell frequencies for each of the treatment groups are shown in Figure 41. Treatment with 18R5

alone and treatment with 18R5 in combination with gemcitabine reduced cancer stem cell frequency, while treatment with gemcitabine alone had no effect.

Example 9

Production of FZD antibodies

Antigen Production

[00335] Recombinant polypeptide fragments of the extracellular domain (ECD) or Fri domain (Fri) of human FZD receptors (FZDs) are generated as antigens for antibody production. Standard recombinant DNA technology is used to isolate polynucleotides encoding the amino acids of these domains of the desired human frizzled receptor or receptors. These polynucleotides are ligated in-frame N-terminal to either a human Fc-tag or histidine-tag and cloned into a transfer plasmid vector for baculovirus mediated expression in insect cells. Standard transfection, infection, and cell culture protocols are used to produce recombinant insect cells expressing the corresponding FZD polypeptides (O'Reilley et al., Baculovirus expression vectors: A Laboratory Manual, Oxford: Oxford University Press (1994)).

[00336] Antigen protein is purified from insect cell conditioned medium using Protein A and Ni++-chelate affinity chromatography. Purified antigen protein is dialyzed against PBS (pH=7), concentrated to approximately 1 mg/ml, and sterile filtered in preparation for immunization.

Immunization

[00337] Mice are immunized with purified FZD antigen protein using standard techniques. Blood from individual mice are screened approximately 70 days after initial immunization for antigen recognition using ELISA and FACS analysis (described in detail below). The two animals with the highest antibody titers are selected for final antigen boost after which spleen cells are isolated for hybridoma production. Hybridoma cells are plated at 1 cell per well in 96 well plates, and the supernatant from each well are screened by ELISA and FACS analysis against antigen protein. Several hybridomas with high antibody titer are selected and scaled up in static flask culture. Antibodies are purified from the hybridoma supernatant using protein A or protein G agarose chromatography. Purified monoclonal antibodies are again tested by FACS and are isotyped to select for IgG and IgM antibodies.

Epitope Mapping

[00338] To identify antibodies that recognize specific regions of the FZD extracellular domain including the cysteine-rich domain, epitope mapping is performed. Mammalian expression plasmid vectors comprising a CMV promoter upstream of polynucleotides that encode fragments of the extracellular FZD domain are generated using standard recombinant DNA technology. Recombinant proteins are then expressed in cultured mammalian cells by transient transfection. Twenty-four to 48 hours following transfection, cells are harvested and cell lysate protein separated on SDS-PAGE acrylamide gels for Western blotting using antibodies from mice immunized with FZD antigen. Antibodies that recognize the ligand binding domain of FZD can be further analyzed for competitive binding with Wnt proteins by ELISA.

[00339] To identify specific epitopes within the extracellular domains recognized by an antibody against FZD the SPOTs system is used (Sigma Genosys, The Woodlands, TX). A series of 10-residue linear peptides overlapping by one amino acid and covering the entire FZD extracellular domain are synthesized and covalently bound to a cellulose membrane by the SPOT synthesis technique. The membrane is preincubated for 8 hours at room temperature with blocking buffer and hybridized with antibody overnight at 4°C. The membrane is then washed, incubated with a secondary antibody conjugated to horseradish peroxidase (HRP) (Amersham Bioscience, Piscataway, NJ), re-washed, and visualized with signal development solution containing 3-amino-9-ethylcarbazole. Specific epitopes recognized by an antibody are thus determined.

FACS Analysis

[00340] To select monoclonal antibodies produced by hybridomas clones that recognize native cell-surface FZD protein, FACs analysis is used. HEK293 cells are transfected with an expression vector encoding a full-length cDNA clone of the corresponding FZD either alone or co-transfected with a vector expressing GFP. A Flag epitope tag may be introduced at the amino-terminus, which allows verification of expression of the tagged FZD receptors on the cell surface. Twenty-four to 48-hours post-transfection, cells are collected in suspension and incubated on ice with anti-FZD antibodies, FLAG antibodies, immune serum (for FZD5 expressing cells), or control IgG to detect background antibody binding. The cells are washed and primary antibodies detected with anti-mouse secondary antibodies conjugated to a fluorescent chromophore. Labeled cells are then sorted by FACS to identify anti-FZD antibodies that specifically recognize cell surface expression

of the corresponding FZD receptor. Antibodies that recognize the desired human frizzled receptor(s) are identified.

Chimeric Antibodies

[00341] After monoclonal antibodies that specifically recognize a FZD receptor are identified, these antibodies are modified to overcome the human anti-mouse antibody (HAMA) immune response when rodent antibodies are used as therapeutics agents. The variable regions of the heavy-chain and light-chain of the selected monoclonal antibody are isolated by RT-PCR from hybridoma cells and ligated in-frame to human IgG1 heavy-chain and kappa light chain constant regions, respectively, in mammalian expression vectors. Alternatively a human Ig expression vector such as TCAE 5.3 is used that contains the human IgG1 heavy-chain and kappa light-chain constant region genes on the same plasmid (Preston et al., 1998, Infection & Immunity 66:4137-42). Expression vectors encoding chimeric heavy- and light-chains are then co-transfected into Chinese hamster ovary (CHO) cells for chimeric antibody production. Immunoreactivity and affinity of chimeric antibodies are compared to parental murine antibodies by ELISA and FACS.

Humanized Antibodies

[00342] As chimeric antibody therapeutics are still frequently antigenic, producing a human anti-chimeric antibody (HACA) immune response, chimeric antibodies against a FZD receptor can undergo further humanization. To generate humanized antibodies, key aspects of the specificity determining motifs of the antibody, potentially including elements from both the three short hypervariable sequences, or complementary determining regions (CDRs), and/or the framework regions required to correctly position the CDR regions of the antibody heavy- and light-chain variable domains described above are engineered using recombinant DNA technology into the germline DNA sequences of human heavy- and light-chain antibody genes, respectively, and then cloned into a mammalian expression vector for expression in CHO cells. The immunoreactivity and affinity of the humanized antibodies are compared to parental chimeric antibodies by ELISA and FACS. Additionally, site-directed or high-density mutagenesis of the variable region can be used to optimize specificity, affinity, etc. of the humanized antibody.

Human Antibodies

[00343] In some embodiments, human antibodies that specifically recognize the extracellular domain of a FZD receptor are isolated using phage display technology. A phage display antibody library containing human antibody variable domains displayed as single

chain Fv or as fab domains is screened for specific and high affinity recognition of a FZD receptor antigen described above. The identified variable domain antibody sequences are then reformatted into an Ig expression vector containing human IgG1 heavy-chain and kappa light-chain for expression of human antibodies in CHO cells.

Example 10

Production of antibodies that recognize specific epitopes

Monoclonal antibodies from hybridomas

[00344] In certain embodiments, antibodies recognizing functional epitopes of FZD receptors are generated by immunizing mice with one or more of the FZD receptor antigens. Mice are immunized with the purified FZD antigen protein using standard techniques. In certain embodiments mice are immunized sequentially with distinct FZD receptor antigens. Blood from individual mice are screened approximately 70 days after initial immunization. Animals with the high antibody titer for the FZD antigen are selected for final antigen boost after which spleen cells are isolated for hybridoma production. Hybridoma cells are plated at 1 cell per well in 96 well plates, and the supernatants from each well are screened by ELISA and flow cytometry analysis. To identify monoclonal antibodies that recognize specific epitopes, including epitopes within or overlapping with the Biological Binding Site (BBS), the hybridoma supernatant is screened both for antibody binding to the desired FZD(s) and for failure to bind to FZD that have specific amino acid substitutions within the desired specific epitope (e.g. the BBS).

Human antibodies

[00345] A phage display library may be used to identify antibodies that recognize the desired epitopes of the FZD receptors (e.g., epitopes common to multiple FZD and/or epitopes within or overlapping with the BBS or a portion thereof). For example, the Fri domain of a selected FZD is expressed as recombinant protein and coated on an appropriate surface at 10 μg/mL. A human phage library is then panned through two or more rounds of enrichment (See e.g., Griffiths et al., *EMBO J.* 12:715-34). Optionally, the subsequent rounds of panning may be performed using distinct FZD proteins. Optionally, each round of the panning may be performed in the presence of decoy soluble FZD protein containing specific amino acid substitutions within the desired target epitope region (e.g. including the epitopes within the Biological Binding Site (BBS)). Individual clones of the output from the panning selections are then screened for the ability to bind to desired FZD protein(s) by

ELISA or flow cytometry analysis and binding to a desired epitope is assessed by lack of binding to FZD protein containing specific amino acid substitutions within the desired target epitope. Genes encoding the antigen binding domain are then recovered from the phage and used to construct a complete human antibody molecule by joining the antigen binding domain with constant regions for expression in a suitable host cell line. Antibodies are identified and tested for the ability to prevent tumor cell growth as described elsewhere herein.

Example 11

Additional *in vitro* assays to evaluate antibodies against a FZD Receptor

[00346] This example describes representative *in vitro* assays to test the activity of antibodies generated against a FZD receptor on cell proliferation, pathway activation, and cytotoxicity.

Proliferation Assay

[00347] The expression of a FZD receptor by different cancer cell lines is quantified using Taqman analysis. Cell lines identified as expressing a FZD receptor are plated at a density of 104 cell per well in 96-well tissue culture microplates and allowed to spread for 24 hours. Subsequently cells are cultured for an additional 12 hours in fresh DMEM with 2% FCS at which point anti-FZD antibodies versus control antibodies are added to the culture medium in the presence of 10 μmol/L BrdU. Following BrdU labeling, the culture media is removed, and the cells fixed at room temperature for 30 minutes in ethanol and reacted for 90 minutes with peroxidase-conjugated monoclonal anti-BrdU antibody (clone BMG 6H8, Fab fragments). The substrate is developed in a solution containing tetramethylbenzidine and stopped after 15 minutes with 25 μl of 1 mol/L H_2SO_4. The color reaction is measured with an automatic ELISA plate reader using a 450 nm filter (UV Microplate Reader; Bio-Rad Laboratories, Richmond, CA). All experiments are performed in triplicate. The ability of anti-FZD antibodies to inhibit cell proliferation compared to control antibodies is determined.

Pathway Activation Assay

[00348] In certain embodiments, the ability of antibodies against a FZD receptor to block activation of the Wnt signaling pathway is determined *in vitro*. For example, HEK 293 cells cultured in DMEM supplemented with antibiotics and 10% FCS are co-transfected with 1) Wnt7B and FZD10 expression vectors to activate the Wnt signaling pathway; 2) a TCF/Luc wild-type or mutant reporter vector containing three or eight copies of the TCF-binding domain upstream of a firefly luciferase reporter gene to measure canonical Wnt

signaling levels (Gazit et al., 1999, *Oncogene* 18:5959-66); and 3) a Renilla luciferase reporter (Promega; Madison, WI) as an internal control for transfection efficiency. Anti-FZD10 and control antibodies are then added to the cell culture medium. Forty-eight hours following transfection, luciferase levels are measured using a dual luciferase assay kit (Promega; Madison, WI) with firefly luciferase activity normalized to Renilla luciferase activity. Three independent experiments are preformed in triplicate. The ability of the FZD antibodies to inhibit Wnt pathway activation is thus determined.

Complement-Dependent Cytotoxicity Assay

[00349] In certain embodiments, cancer cell lines expressing a FZD receptor or cancer stem cells isolated from a patient sample passaged as a xenograft in immunocompromised mice are used to measure complement dependent cytotoxicity (CDC) mediated by an antibody against a FZD receptor. Cells are suspended in 200 µl RPMI 1640 culture medium supplemented with antibiotics and 5% FBS at 106 cells/ml. Suspended cells are then mixed with 200 µl serum or heat-inactivated serum with antibodies against a FZD receptor or control antibodies in triplicate. Cell mixtures are incubated for 1 to 4 hours at 37°C in 5% CO_2. Treated cells are then collected, resuspended in 100 µl FITC-labeled annexin V diluted in culture medium and incubated at room temperature for 10 minutes. One hundred microliters of a propidium iodide solution (25 µg/ml) diluted in HBSS is added and incubated for 5 minutes at room temperature. Cells are collected, resuspended in culture medium and analyzed by flow cytometry. Flow cytometry of FITC stained cells provides total cell counts, and propidium iodide uptake by dead cells as a percentage of total cell numbers is used to measure cell death in the presence of serum and antibodies against a FZD compared to heat-inactivated serum and control antibodies. The ability of anti-FZD antibodies to mediate complement-dependent cytotoxicity is thus determined.

Antibody-Dependent Cellular Cytotoxicity Assay

[00350] Cancer cell lines expressing a FZD receptor or cancer stem cells isolated from a patient's sample passaged as a xenograft in immunocompromised mice may be used to measure antibody dependent cellular cytotoxicity (ADCC) mediated by an antibody against a FZD receptor. Cells are suspended in 200 µl phenol red-free RPMI 1640 culture medium supplemented with antibiotics and 5% FBS at 106 cells/ml. Peripheral blood mononuclear cells (PBMCs) are isolated from heparinized peripheral blood by Ficoll-Paque density gradient centrifugation for use as effector cells. Target cells (T) are then mixed with PBMC effector cells (E) at E/T ratios of 25:1, 10:1, and 5:1 in 96-well plates in the presence of at

least one FZD receptor antibody or a control antibody. Controls include incubation of target cells alone and effector cells alone in the presence of antibody. Cell mixtures are incubated for 1 to 6 hours at 37°C in 5% CO2. Released lactate dehydrogenase (LDH), a stable cytosolic enzyme released upon cell lysis, is then measured by a colorimetric assay (CytoTox96 Non-radioactive Cytotoxicity Assay; Promega; Madison, WI). Absorbance data at 490 nm are collected with a standard 96-well plate reader and background corrected. The percentage of specific cytotoxicity is calculated according to the formula: % cytotoxicity = 100 x (experimental LDH release – effector spontaneous LDH release – target spontaneous LDH release) / (target maximal LDH release – target spontaneous LDH release). The ability of antibodies against a FZD receptor to mediate antibody dependent cellular cytotoxicity is thus determined.

Example 12

In vivo prevention of tumor growth using anti-FZD receptor antibodies

[00351] This example describes a use of anti-FZD receptor antibodies to prevent tumor growth in a xenograft model. In certain embodiments, tumor cells from a patient sample (solid tumor biopsy or pleural effusion) that have been passaged as a xenograft in mice are prepared for repassaging into experimental animals. Tumor tissue is removed under sterile conditions, cut up into small pieces, minced completely using sterile blades, and single cell suspensions obtained by enzymatic digestion and mechanical disruption. Specifically, pleural effusion cells or the resulting tumor pieces are mixed with ultra-pure collagenase III in culture medium (200-250 units of collagenase per mL) and incubated at 37°C for 3-4 hours with pipetting up and down through a 10-mL pipette every 15-20 minutes. Digested cells are filtered through a 45 μM nylon mesh, washed with RPMI/20% FBS, and washed twice with HBSS. Dissociated tumor cells are then injected subcutaneously into the mammary fat pads of NOD/SCID mice to elicit tumor growth.

[00352] In certain embodiments, dissociated tumor cells are first sorted into tumorigenic and non-tumorigenic cells based on cell surface markers before injection into experimental animals. Specifically, tumor cells dissociated as described above are washed twice with Hepes buffered saline solution (HBSS) containing 2% heat-inactivated calf serum (HICS) and resuspended at 106 cells per 100 μl. Antibodies are added and the cells incubated for 20 minutes on ice followed by two washes with HBSS/2% HICS. Antibodies include anti-ESA (Biomeda, Foster City, CA), anti-CD44, anti-CD24, and Lineage markers anti-CD2, -CD3, -CD10, -CD16, -CD18, -CD31, -CD64, and -CD140b (collectively referred

to as Lin; PharMingen, San Jose, CA). Antibodies are directly conjugated to fluorochromes to positively or negatively select cells expressing these markers. Mouse cells are eliminated by selecting against H2Kd+ cells, and dead cells are eliminated by using the viability dye 7AAD. Flow cytometry is performed on a FACSVantage (Becton Dickinson, Franklin Lakes, NJ). Side scatter and forward scatter profiles are used to eliminate cell clumps. Isolated ESA+, CD44+, CD24-/low, Lin- tumorigenic cells are then injected subcutaneously into NOD/SCID mice to elicit tumor growth.

[00353] By way of example, anti-FZD antibodies are analyzed for their ability to reduce the growth of tumor cells. Dissociated tumor cells (10,000 per animal) are injected subcutaneously into the flank region of 6-8 week old NOD/SCID mice. Two days after tumor cell injection, animals are injected intraperitoneal (i.p.) with 10 mg/kg either anti-FZD antibodies two times per week. Tumor growth is monitored weekly until growth is detected, after which point tumor growth is measured twice weekly for a total of 8 weeks. FZD-binding antibodies which significantly reduce tumor growth as compared to PBS injected controls are thus identified.

Example 13

In vivo treatment of tumors using Anti-FZD receptor antibodies

[00354] This example describes a use of anti-FZD receptor antibodies to treat cancer in a xenograft model. In certain embodiments, tumor cells from a patient sample (solid tumor biopsy or pleural effusion) that have been passaged as a xenograft in mice are prepared for repassaging into experimental animals. Tumor tissue is removed, cut up into small pieces, minced completely using sterile blades, and single cell suspensions obtained by enzymatic digestion and mechanical disruption. Dissociated tumor cells are then injected subcutaneously either into the mammary fat pads, for breast tumors, or into the flank, for non-breast tumors, of NOD/SCID mice to elicit tumor growth. Alternatively, ESA+, CD44+, CD24-/low, Lin- tumorigenic tumor cells are isolated as described above and injected.

[00355] Following tumor cell injection, animals are monitored for tumor growth. Once tumors reach an average size of approximately 150 to 200 mm, antibody treatment begins. Each animal receives 100 μg FZD receptor antibodies or control antibodies i.p. two to five times per week for a total of 6 weeks. Tumor size is assessed twice a week during these 6 weeks. The ability of FZD receptor antibodies to prevent further tumor growth or to reduce tumor size compared to control antibodies is thus determined.

[00356] At the end point of antibody treatment, tumors are harvested for further analysis. In some embodiments a portion of the tumor is analyzed by immunofluorescence to assess antibody penetration into the tumor and tumor response. A portion of each harvested tumor from anti-FZD receptor treated and control antibody treated mice is fresh-frozen in liquid nitrogen, embedded in O.C.T., and cut on a cryostat as 10 μm sections onto glass slides. In some embodiments, a portion of each tumor is formalin-fixed, paraffin-embedded, and cut on a microtome as 10 μm section onto glass slides. Sections are post-fixed and incubated with chromophore labeled antibodies that specifically recognize injected antibodies to detect anti-FZD receptor or control antibodies present in the tumor biopsy. Furthermore antibodies that detect different tumor and tumor-recruited cell types such as, for example, anti-VE cadherin (CD144) or anti-PECAM-1 (CD31) antibodies to detect vascular endothelial cells, anti-smooth muscle alpha-actin antibodies to detect vascular smooth muscle cells, anti-Ki67 antibodies to detect proliferating cells, TUNEL assays to detect dying cells, anti-β-catenin antibodies to detect Wnt signaling, and anti-intracellular domain (ICD) Notch fragment antibodies to detect Notch signaling can be used to assess the effects of antibody treatment on, for example, angiogenesis, tumor growth and tumor morphology.

[00357] In certain embodiments, the effect of anti-FZD receptor antibody treatment on tumor cell gene expression is also assessed. Total RNA is extracted from a portion of each harvested tumor from FZD antibody treated and control antibody treated mice and used for quantitative RT-PCR. Expression levels of FZD receptors, components of Wnt signaling pathway including, for example, Wnt1 and β-catenin, as well as addition cancer stem cell markers previously identified (e.g. CD44) are analyzed relative to the house-keeping gene GAPDH as an internal control. Changes in tumor cell gene expression upon FZD receptor antibody treatment are thus determined.

[00358] In addition, the effect of anti-FZD receptor antibody treatment on the frequency of cancer stem cells in a tumor is assessed. Tumor samples from FZD versus control antibody treated mice are cut up into small pieces, minced completely using sterile blades, and single cell suspensions obtained by enzymatic digestion and mechanical disruption. Dissociated tumor cells are then analyzed by FACS analysis for the presence of tumorigenic cancer stem cells based on ESA+, CD44+, CD24-/low, Lin- surface cell marker expression as described in detail above.

[00359] The tumorigenicity of cells isolated based on ESA+, CD44+, CD24-/low, Lin- expression following anti-FZD antibody treatment can then assessed. ESA+, CD44+, CD24-/low, Lin- cancer stem cells isolated from FZD antibody treated versus control antibody

treated mice are re-injected subcutaneously into the mammary fat pads of NOD/SCID mice. The tumorigenicity of cancer stem cells based on the number of injected cells required for consistent tumor formation is then determined.

Example 14

Identification of a Wnt gene signature

[00360] Experiments were conducted to identify a group of genes whose expression is specific for Wnt signaling pathway activation in human colon tumors.

Abrogation of tumor growth by axin overexpression

[00361] Axin is an important regulator of the canonical Wnt pathway. It is part of the multiprotein complex that triggers β-catenin degradation, thus keeping the pathway silent in the absence of Wnt. This effect is reversed by Wnt, which removes axin from the destruction complex, allowing for β-catenin translocation and TCF-mediated activation of specific target genes. Both exogenous axin over-expression and expression of a dominant negative truncated form of TCF (DNTCF4) represent well-characterized means to block the Wnt signaling pathway.

[00362] We showed that lentivirus-mediated axin overexpression completely abrogated the growth of UM-PE13 and UM-T3 breast tumors as well as the growth of OMP-C11 and OMP-C17 colon tumors in NOD/SCID mice. Stable expression of DNTCF4 in UM-T3 tumor cells had the same effect. Taken together, these data demonstrate that intracellular Wnt blockade can negatively affect the development of different tumor types, supporting the Wnt pathway as a relevant target for the treatment of breast and colon cancers.

[00363] The Wnt signaling pathway is constitutively activated in many tumor types. In most colon tumors this activation is due to truncating mutation of APC or activating mutations of β-catenin. Such mutations have not been reported for other tissues, in which the Wnt signaling pathway could be activated through another set of mutations or an autocrine mechanism. In those tumors where the Wnt signaling pathway remains responsive to autocrine stimuli, blocking the pathway using extracellular means such as antibodies or other soluble protein inhibitors should be feasible and impact tumor development. Identifying such Wnt-dependent tumors would be helpful in developing anti-Wnt agents and defining tumor types to target in the clinic.

[00364] Immunohistochemical data showed that most OMP-C11 tumor cells express high levels of cytoplasmic/nuclear β-catenin, suggesting that the Wnt signaling pathway is

constitutively activated in this tumor type. This was confirmed by the detection of high levels of β-catenin in OMP-C11 by Western blot. The combination of Wnt pathway activation and sensitivity to axin overexpression makes OMP-C11 a good tumor in which to study the regulation of gene expression in response to Wnt and Wnt blockade and from which to derive a Wnt gene signature.

Microarray analysis of differential gene expression in response to axin overexpression

[00365] The differential gene expression upon treatment of OMP-C11 colon tumor cells with axin was determined by microarray analysis.

[00366] Human colon OMP-C11 tumors freshly removed from NOD/SCID mice (xenograft tumor model) were used as a source for the colon tumor cells. Two lentiviral vectors were generated for the delivery of a constitutive axin-IRES-GFP expression cassette and a control IRES-GFP expression cassette that were termed LOM91 and LOM92, respectively.

[00367] OMP-C11 tumors were processed to a single cell suspension and depleted from the mouse lineage cells. The lin-depleted cells were infected with LOM91 (axin) or 92 (control) lentiviral vectors using a multiplicity of infection of 2.5, maintained in culture for 3-4 days and sorted for GFP expression. Total RNA was extracted from each sample of sorted cells. The RNAs were analyzed on the GeneChip® Human Genome U133 Plus 2.0 microarray (Affymetrix, Santa Clara, California). The experiment was repeated twice.

[00368] A gene signature containing a core set of genes regulated by the Wnt pathway was generated by analysis of the genes that are differentially expressed following axin treatment and that also exhibit correlation with the expression of axin2 across a panel of normal and malignant colon tumor samples. Genes were identified from the axin microarray experiment (above) that showed down regulation in response to axis overexpression. The cutoff for this selection was down-regulation by 50% or more in Axin1 over-expressing samples comparing to control samples (log2ratio of Axin1 over-expressing samples over control samples has to be -1 or smaller), with T test p value smaller than 0.1. As Axin1 is a known Wnt pathway inhibitor, genes down-regulated by Axin1 over expression will be direct or indirect Wnt pathway targets. This selection was then further refined by identification of those genes which showed high correlation (correlation value > 0.3) with axin2 among a set of colon/intestine/other digestive tissue malignant tumor samples (232 samples). Since Axin2 is a known Wnt target, genes showing similar expression pattern as Axin2 will likely be Wnt target as well. This analysis produced a gene signature for Wnt pathway activity

(Table 6). The expression levels of the genes in this signature can be used to assess whether individual tumor samples or different types of tumors show evidence of altered Wnt pathway signaling.

Table 6. Wnt gene signature list derived from colon tumors

HG_U133_Plus_2 Probe Set ID	Correlation	log2ratio	Gene Symbol	Description
222696_at	1	-1.52705	AXIN2	axin 2 (conductin, axil)
206286_s_at	0.81941	-1.15086	TDGF1	teratocarcinoma-derived growth factor 1
213880_at	0.787599	-3.32482	LGR5	leucine-rich repeat-containing G protein-coupled receptor 5
207217_s_at	0.781543	-1.15534	NOX1	NADPH oxidase 1
209588_at	0.762464	-1.09556	EPHB2	EPH receptor B2
212850_s_at	0.75362	-2.00386	LRP4	low density lipoprotein receptor-related protein 4
205107_s_at	0.744062	-1.01296	EFNA4	ephrin-A4
214058_at	0.718735	-1.74381	MYCL1	v-myc myelocytomatosis viral oncogene homolog 1, lung carcinoma derived (avian)
209864_at	0.714811	-1.25716	FRAT2	frequently rearranged in advanced T-cell lymphomas 2
208121_s_at	0.711694	-1.87702	PTPRO	protein tyrosine phosphatase, receptor type, O
229376_at	0.711672	-1.73296		Unknown expressed sequence tag (EST)
202431_s_at	0.659255	-1.49975	MYC	v-myc myelocytomatosis viral oncogene homolog (avian)
212444_at	0.656023	-2.15908	GPCR5A	G protein-coupled receptor, family C, group 5, member A
222938_x_at	0.654955	-2.43139	ENPP3	ectonucleotide pyrophosphatase/phosphodiesterase 3
241607_at	0.640554	-1.00413	LOC730102	hypothetical protein LOC730102
227475_at	0.637963	-3.60987	FOXQ1	forkhead box Q1

230398_at	0.628654	-1.65124	TNS4	tensin 4
40284_at	0.601382	-1.21862	FOXA2	forkhead box A2
219704_at	0.557276	-1.33216	YBX2	Y box binding protein 2

Example 15

Treatment of human cancer using anti-FZD receptor antibodies

[00369] This example describes methods for treating cancer using antibodies against a FZD receptor to target tumors comprising cancer stem cells and/or tumor cells in which FZD receptor expression has been detected and/or tumor cells having a Wnt gene signature indicating that they are responsive to inhibition of Wnt signaling (e.g., the Wnt gene signature of Example 14).

[00370] The presence of cancer stem cell marker or FZD receptor or the expression of one or more genes in a Wnt gene signature can first be determined from a tumor biopsy. Tumor cells from a biopsy from a patient diagnosed with cancer are removed under sterile conditions. In some embodiments the tissue biopsy is fresh-frozen in liquid nitrogen, embedded in O.C.T., and cut on a cryostat as 10 μm sections onto glass slides. In some embodiments, the tissue biopsy is formalin-fixed, paraffin-embedded, and cut on a microtome as 10 μm section onto glass slides.

[00371] Sections are incubated with antibodies against a FZD receptor to detect FZD protein expression. Alternatively, sections can be analyzed for the presence of one or more genes in the Wnt gene signature as described in Example 14.

[00372] The presence of cancer stem cells also may be determined. Tissue biopsy samples are cut up into small pieces, minced completely using sterile blades, and cells subject to enzymatic digestion and mechanical disruption to obtain a single cell suspension. Dissociated tumor cells are then incubated with anti-ESA, -CD44, -CD24, –Lin, and –FZD antibodies to detect cancer stem cells, and the presence of ESA+, CD44+, CD24-/low, Lin-, FZD+ tumor stem cells is determined by flow cytometry as described in detail above.

[00373] Cancer patients whose tumors are diagnosed as expressing a FZD receptor and/or one or more genes in the Wnt gene signature are treated with anti-FZD receptor antibodies. In certain embodiments, humanized or human monoclonal anti-FZD receptor antibodies generated as described above are purified and formulated with a suitable pharmaceutical vehicle for injection. In some embodiments, patients are treated with the FZD antibodies at least once a month for at least 10 weeks. In some embodiments, patients

are treated with the FZD antibodies at least once a week for at least about 14 weeks. Each administration of the antibody should be a pharmaceutically effective dose. In some embodiments, between about 2 to about 100 mg/ml of an anti-FZD antibody is administered. In some embodiments, between about 5 to about 40 mg/ml of an anti-FZD antibody is administered. The antibody can be administered prior to, concurrently with, or after standard radiotherapy regimens or chemotherapy regimens using one or more chemotherapeutic agent, such as oxaliplatin, fluorouracil, leucovorin, or streptozocin. Patients are monitored to determine whether such treatment has resulted in an anti-tumor response, for example, based on tumor regression, reduction in the incidences of new tumors, lower tumor antigen expression, decreased numbers of cancer stem cells, or other means of evaluating disease prognosis.

Example 16

Differentiation of pancreatic tumor cells following treatment with 18R5 and gemcitabine

Gene expression analysis of treated pancreatic tumor cells by quantitative PCR (Q-PCR)

[00374] PN4 xenograft tumors treated with either control Ab, 18R5 IgG antibody, gemcitabine, or the combination of gemcitabine and 18R5 IgG antibody as described above (Example 7) were analyzed for expression of chromogranin A (CHGA) by quantitative PCR analysis. CHGA is well known to be a marker for neuroendocrine differentiation of various tumors including breast, colon, lung and pancreatic tumors and elevated expression of CHGA in pancreatic tumors has been found to be associated with improved survival (Tezel et al. 2000. Cancer 89, 2230-6).

[00375] Total RNA was prepared from 5-tumors of each group in the PN4 xenograft study and was evaluated by one-step reverse transcription (RT)-PCR using Applied Biosystems Taqman® inventoried probes according to standard protocols. The probe-primer set (Hs00154441_m1) used for analysis of CHGA included a FAM-dye labeled probe and the following primer: 5'-CGCTCTCCAAGGCGCCAAGGAGAGG-3' (SEQ ID NO:75). Gus B was used as internal control. Briefly, RT was done at 48°C for 30 min, initial denaturation at 95°C for 10 min, followed by 40 cycles of denaturation at 95°C for 15 seconds, and extension at 60°C for 1 min and the amplification/ incorporation of fluorescent probes was observed real-time.

[00376] The islet beta cell marker CHGA was elevated significantly only in samples from mice treated with both gemcitabine and 18R5. Tumors from the control Ab, 18R5, and gemcitibine alone groups expressed similar levels of CHGA RNA while tumors from the combination group showed a clear increase in CHGA expression. CHGA levels were elevated 10-fold and 7-fold in two experiments in tumors treated with both 18R5 and gemcitabine. The results of a representative experiment are shown in Figure 42.

Gene expression analysis of treated pancreatic tumor cells by immunohistochemistry

[00377] The increased expression of CHGA was also observed at the protein level by immunohistochemistry on tissue sections prepared from treated tumors (data not shown). Control Ab treated tumors showed intense staining of a small subset of cells scattered throughout tumors. Tumors treated with 18R5 alone or gemcitabine alone expressed CHGA at similar levels as the controls. In contrast, tumors treated with the combination of 18R5 and gemcitabine showed an increase in the number of CHGA-positive cells, consistent with the increased RNA expression detected by Q-PCR.

Staining with alcian blue and antibody to ki67

[00378] Another characteristic of endocrine, secretory or ductal cells is the production of mucin and these cells can be detected by alcian blue staining (van Es et al. 2005. Nature 435 959-63). It was observed during harvesting and processing of tumors that the 18R5 treated tumors were much more mucinous than control treated tumors. Therefore, PN4 tumors sections from mice treated with control antibody, gemcitabine alone, 18R5 alone, or 18R5 plus gemcitabine were stained with alcian blue. The 18R5 treated tumors showed a clear increase in alcian blue staining in both the 18R5 alone and the 18R5 plus gemcitabine groups relative to controls and the gemcitabine alone group (data not shown).

[00379] Increased mucinous cells were also noted in a second pancreatic tumor line, PN13, following treatment with 18R5 or control antibody (Figure 43). In this experiment mice bearing PN13 tumors were treated as described above (Example 7). Tumors sections were stained with alcian blue to reveal mucinous cells and also stained by immunohistochemistry with an antibody to ki67 to reveal cells undergoing proliferation. The results show that 18R5 treatment resulted in greatly increased numbers of alcian blue positive mucinous cells. Additionally, the frequency of ki67 positive cells was reduced by 18R5 treatment. Interestingly there was not an overlap between the mucinious cells and cells that were ki67 positive, suggesting that the mucinous cells are not proliferative. This provides

evidence that 18R5 treatment is promoting the differentiation of tumor cells into non-proliferative progeny.

[00380] In summary, the increased expression of CHGA, the increased production of mucins as evidenced by alcian blue staining, and the production of non-proliferative progeny as evidenced by staining with antibody to ki67 are consistent with a model that inhibiting Wnt-FZD signaling with 18R5 treatment promotes the differentiation of pancreatic tumor cells towards multiple distinct cell types with features characteristic of non-proliferative differentiated cells.

Example 17

Additional *in vivo* efficacy studies with 18R5 alone and/or in combination with other anti-cancer agents

Effect on OMP-LU24 xenograft tumor growth

[00381] The efficacy of anti-FZD antibody 18R5, both alone and in combination with Taxol® (paclitaxel), in inhibiting the growth of OMP-LU24 human lung tumors *in vivo* was assessed.

[00382] 50,000 OMP-LU24 human lung tumor cells were injected subcutaneously in NOD-SCID mice. Tumors were allowed to grow for 27 days until they reached an average volume of 143 mm^3. The animals were randomized into 4 groups (n=9 per group) and treated with either control antibody ("Control Ab"), anti-FZD 18R5 ("18R5"), Taxol® ("Taxol") or the combination of 18R5 plus Taxol® ("18R5+Taxol"). Tumor measurements were made on the days indicated in Figure 44. Antibodies were dosed at 10 mg/kg intraperitoneal (IP), once per week and Taxol® was dosed at 15 mg/kg, IP, once per week.

[00383] The results are shown in Figure 44. Anti-FZD treatment was seen to reduce tumor growth, and the combination treatment showed enhanced anti-tumor activity relative to Taxol® alone.

Effect on OMP-LU33 xenograft tumor growth

[00384] The efficacy of anti-FZD antibody 18R5, both alone and in combination with Avastin® (bevacizumab), in inhibiting the growth of OMP-LU33 human lung tumors *in vivo* was also tested.

[00385] 10,000 OMP-LU33 human lung tumor cells were injected subcutaneously in NOD-SCID mice. Tumors were allowed to grow for 30 days until they reached an average volume of 124 mm^3. The animals were randomized into 4 groups (n=10 per group) and

treated with either control antibody (squares), Avastin® (triangles pointing down), anti-FZD 18R5 (triangles pointing up), or the combination of 18R5 plus Avastin® (circles). Tumor measurements were made on the days indicated in Figure 45. Antibodies were dosed at 10 mg/kg IP, twice per week.

[00386] The results are shown in Figure 45. Anti-FZD treatment was seen to reduce tumor growth, and the combination treatment showed enhanced anti-tumor activity relative to Avastin® alone.

Effect on T3 xenograft tumor growth

[00387] The efficacy of anti-FZD antibody 18R5, both alone and in combination with Herceptin® (trastuzumab), in inhibiting the growth of T3 human HER2-positive breast tumors *in vivo* was also assessed.

[00388] 50,000 T3 human breast tumor cells were injected subcutaneously in NOD-SCID mice. Tumors were allowed to grow for 32 days until they reached an average volume of 125 mm^3. The animals were randomized into 4 groups (n=10 per group) and treated with either control antibody (squares), anti-FZD 18R5 (triangles), Herceptin® (small filled circles), or the combination of 185 plus Herceptin® (open circles). Tumor measurements were made on the days indicated in Figure 46. Antibodies were dosed at 10 mg/kg IP, twice per week.

[00389] The results are shown in Figure 46. The combination treatment with 18R5 and Herceptin® showed enhanced anti-tumor activity relative to Herceptin® alone.

EXAMPLE 18

Anti-FZD antibody sequences

[00390] Heavy chain and light chain CDRs of anti-FZD antibodies are provided in Tables 7 and 8, below, respectively. The heavy chain variable regions (VH) and light chain variable regions (VL) of the anti-FZD antibodies and their coding sequences are identified in Table 9, below. The amino acid and polynucleotide sequences of the VH and VL listed in Table 9 are provided in Figures 13-15 or Tables 10 and 11, below. Sequences encoding the heavy chain or light chains of the anti-FZD antibodies are provided in Figures 14-15 or Table 12, below.

Table 7. Heavy chain CDRs of anti-FZD human antibodies

Ab(s)	Heavy Chain

	CDR1	CDR2	CDR3
18R8	GFTFSHYTLS (SEQ ID NO:1)	VISGDGSYTYYADSVKG (SEQ ID NO:2)	NFIKYVFAN (SEQ ID NO:3)
18R5 18R4605 18R4805	GFTFSHYTLS (SEQ ID NO:1)	VISGDGSYTYYADSVKG (SEQ ID NO:2)	NFIKYVFAN (SEQ ID NO:3)
44R24	GFTFSSYYIT (SEQ ID NO:77)	TISYSSSNTYYADSVKG (SEQ ID NO:78)	SIVFDY (SEQ ID NO:79)

Table 8. Light chain CDRs of anti-FZD human antibodies

Ab(s)	Light Chain		
	CDR1	CDR2	CDR3
18R8	SGDKLGKKYAS (SEQ ID NO:4)	EKDNRPSG (SEQ ID NO:5)	SSFAGNSLE (SEQ ID NO:6)
18R5 18R4605 18R4805	SGDNIGSFYVH (SEQ ID NO:7)	DKSNRPSG (SEQ ID NO:8)	QSYANTLSL (SEQ ID NO:9)
44R24	SGDALGNRYVY (SEQ ID NO:80)	SG (SEQ ID NO:81)	GSWDTRPYPKY (SEQ ID NO:82)

Table 9. VH and VL of ant-FZD human antibodies

Ab(s)	Heavy Chain Variable Region (VH) amino acid sequence	Light Chain Variable Region (VL) amino acid sequence	Heavy Chain Variable Region (VH) Coding Sequence	Light Chain Variable Region (VL) Coding Sequence
18R8	SEQ ID NO:10	SEQ ID NO:12	SEQ ID NO:17	SEQ ID NO:19
18R8 (codon optimized)	SEQ ID NO:10	SEQ ID NO:12	SEQ ID NO:87	SEQ ID NO:88
18R5	SEQ ID NO:10	SEQ ID NO:14	SEQ ID NO:17	SEQ ID NO:21
18R5 (codon optimized)	SEQ ID NO:10	SEQ ID NO:14	SEQ ID NO:87	SEQ ID NO:89
18R4605	SEQ ID NO:10	SEQ ID NO:14	SEQ ID NO:87	SEQ ID NO:90

18R4805	SEQ ID NO:10	SEQ ID NO:14	SEQ ID NO:87	SEQ ID NO:92
44R24	SEQ ID NO:85	SEQ ID NO:86	SEQ ID NO:94	SEQ ID NO:95

Table 10. Additional anti-FZD VH and VL amino acid sequences

SEQUENCE (SEQ ID NO:)
44R24 VH (SEQ ID NO:85): EVQLVESGGGLVQPGGSLRLSCAASGFTFSSYYITWVRQAPGKGLEWVSTISYSSSNTYY ADSVKGRFTISRDNSKNTLYLQMNSLRAEDTAVYYCARSIVFDYWGQGTLVTVSS
44R24 VL (SEQ ID NO:86): DIELTQPPSVSVAPGQTARISCSGDALGNRYVYWYQQKPGQAPVLVIPSGIPERFSGSNS GNTATLTISGTQAEDEADYYCGSWDTRPYPKYVFGGGTKLTVLG

Table 11. Additional nucleotide sequences encoding VH and VL of anti-FZD antibodies

SEQUENCE (SEQ ID NO:)
18R5/18R8 VH coding sequence (codon-optimized) (SEQ ID NO:87): GAGGTGCAGCTGGTCGAGTCTGGCGGCGGACTGGTGCAGCCTGGCGGCTCCCTGAGACTG TCCTGCGCCGCCTCCGGCTTCACCTTCTCCCACTACACCCTGTCCTGGGTGCGCCAGGCA CCAGGGAAGGGACTGGAGTGGGTCTCCGTGATCTCCGGCGACGGCTCCTACACCTACTAC GCCGACTCCGTGAAGGGCCGGTTCACCATCTCCTCCGACAACTCCAAGAACACCCTGTAC CTGCAGATGAACTCTCTGAGAGCCGAGGACACCGCCGTGTACTACTGCGCCCGGAACTTC ATCAAGTACGTGTTCGCCAACTGGGGCCAGGGCACCCTGGTGACCGTGTCCTCC
18R8 VL coding sequence (codon-optimized) (SEQ ID NO:88): GACATCGAGCTGACCCAGCCTCCCTCCGTGTCTGTGGCTCCTGGCCAGACCGCCCGGATC TCCTGCTCCGGCGACAAGCTGGGCAAGAAGTACGCCTCCTGGTATCAGCAGAAGCCTGGA CAGGCCCCTGTGCTGGTCATCTACGAGAAGGACAACCGGCCTAGCGGCATCCCTGAGCGG TTCTCCGGCTCCAACTCCGGCAACACCGCCACCCTGACCATCTCCGGCACCCAGGCCGAG GACGAGGCCGACTACTACTGCTCCTCCTTCGCCGGCAACTCCCTGGAAGTGTTCGGCGGA GGCACCAAGCTGACCGTGCTGGGC
18R5 VL coding sequence (codon-optimized) (SEQ ID NO:89): GACATCGAGCTGACCCAGCCTCCCTCCGTGTCCGTGGCCCCTGGCCAGACCGCCCGGATC TCCTGCTCCGGCGACAACATCGGCAGCTTCTACGTGCACTGGTATCAGCAGAAACCTGGA CAGGCCCCTGTGCTGGTGATCTACGACAAGTCCAACCGGCCTTCCGGCATCCCTGAGCGG TTCTCCGGCTCCAACTCCGGCAACACCGCCACCCTGACCATCTCCGGCACCCAGGCCGAG GACGAGGCCGACTACTACTGCCAGTCCTACGCCAACACCCTGTCCCTGGTGTTTGGCGGC GGAACAAAGCTGACCGTGCTGGGC
18R4605 VL coding sequence (SEQ ID NO:90): GACATAGAACTAACTCAGCCACCCTCTGTTAGCGTTGCACCGGGACAGACGGCACGTATA TCGTGCTCGGGAGACAATATAGGAAGTTTCTATGTACATTGGTATCAACAGAAACCTGGT CAAGCACCTGTATTAGTAATCTATGACAAAAGTAACCGACCTTCCGGAATACCTGAGCGT TTCAGTGGTTCGAACTCCGGCAACACTGCAACTTTAACTATATCTGGAACTCAGGCGGAG GATGAGGCTGACTACTACTGCCAGAGTTACGCAAACACTCTGTCCCTGGTGTTTGGCGGC GGAACAAAGTTAACCGTGCTGGGC
18R4805 VL coding sequence (SEQ ID NO:92): GACATAGAACTAACTCAGCCGCCGTCTGTTAGCGTTGCACCGGGACAGACGGCACGTATA TCGTGCTCGGGAGACAATATTGGTTCTTTCTATGTACATTGGTATCAACAGAAACCTGGT CAAGCACCTGTATTAGTAATATATGACAAAAGTAACCGTCCTTCGGGAATACCTGAGCGT

TTCAGTGGTTCGAACTCGGGCAACACTGCAACTTTAACTATATCTGGAACGCAGGCGGAG GATGAGGCGGACTACTATTGCCAAAGTTACGCAAACACTCTATCCTTAGTGTTTGGTGGA GGAACAAAGTTAACCGTGCTAGGC
44R24 VH coding sequence (SEQ ID NO:94): GAGGTGCAGCTGGTGGAGTCTGGCGGAGGACTGGTGCAGCCTGGCGGCTCCCTGAGACTG TCTTGCGCCGCCTCCGGCTTCACCTTCTCCTCTTACTACATCACCTGGGTGCGCCAGGCT CCTGGCAAGGGACTGGAATGGGTGTCCACCATCTCCTACTCCTCCAGCAACACCTACTAC GCCGACTCCGTGAAGGGCCGGTTCACCATCTCCCGGGACAACTCCAAGAACACCCTGTAC CTGCAGATGAACTCCCTGAGGGCCGAGGACACCGCCGTGTACTACTGCGCCCGGTCCATC GTGTTCGACTACTGGGGCCAGGGCACCCTGGTGACCGTGTCCTCT
44R24 VL coding sequence (SEQ ID NO:95): GACATCGAGCTGACCCAGCCTCCCTCTGTGTCTGTGGCCCCTGGCCAGACCGCCAGGATC TCTTGCTCTGGCGACGCCCTGGGCAACAGATACGTGTACTGGTATCAGCAGAAGCCAGGC CAGGCCCCTGTGCTGGTGATCCCTTCCGGCATCCCTGAGCGGTTCTCCGGCTCCAACTCC GGCAACACCGCCACCCTGACCATCTCTGGCACCCAGGCCGAGGACGAGGCCGACTACTAC TGCGGCTCCTGGGACACCCGGCCTTACCCTAAGTACGTGTTCGGCGGAGGCACCAAGCTG ACCGTGCTGGGC

Table 12. Additional nucleotide sequences encoding heavy chains (HC) or light chains (LC) of anti-FZD IgG antibodies (including signal sequences)

SEQUENCE (SEQ ID NO:)
18R5/18R8/18R4605/18R4805 IgG2 HC coding sequence (codon-optimized) (SEQ ID NO:96): ATGAAGCACCTGTGGTTCTTTCTGCTGCTGGTCGCCGCTCCTAGATGGGTGCTGTCCGAG GTGCAGCTGGTCGAGTCTGGCGGCGGACTGGTGCAGCCTGGCGGCTCCCTGAGACTGTCC TGCGCCGCCTCCGGCTTCACCTTCTCCCACTACACCCTGTCCTGGGTGCGCCAGGCACCA GGGAAGGGACTGGAGTGGGTCTCCGTGATCTCCGGCGACGGCTCCTACACCTACTACGCC GACTCCGTGAAGGGCCGGTTCACCATCTCCTCCGACAACTCCAAGAACACCCTGTACCTG CAGATGAACTCTCTGAGAGCCGAGGACACCGCCGTGTACTACTGCGCCCGGAACTTCATC AAGTACGTGTTCGCCAACTGGGGCCAGGGCACCCTGGTGACCGTGTCCTCCGCCTCCACC AAGGGCCCTTCCGTGTTCCCTCTGGCCCCTTGCTCCCGGTCCACCTCCGAGTCCACCGCC GCTCTGGGCTGCCTGGTGAAGGACTACTTCCCTGAGCCTGTGACAGTGTCCTGGAACTCT GGCGCCCTGACCTCCGGCGTGCACACCTTCCCTGCCGTGCTGCAGTCCTCCGGCCTGTAC TCCCTGTCCTCCGTGGTGACAGTGCCTTCCTCCAACTTCGGCACCCAGACCTACACCTGC AACGTGGACCACAAGCCTTCCAACACCAAGGTGGACAAGACCGTGGAGCGGAAGTGCTGC GTGGAGTGCCCTCCTTGCCCTGCCCCTCCTGTGGCTGGTCCTAGCGTGTTCCTGTTCCCT CCTAAGCCTAAGGACACCCTGATGATCTCCCGGACCCCTGAGGTGACCTGCGTGGTGGTG GACGTGTCCCACGAGGATCCTGAAGTCCAGTTCAATTGGTACGTGGACGGCGTGGAGGTG CACAACGCCAAGACCAAGCCTCGGGAGGAGCAGTTCAACTCCACCTTCCGGGTGGTGTCC GTGCTGACCGTGGTGCACCAGGACTGGCTGAACGGCAAAGAATACAAGTGCAAAGTCTCC AACAAGGGCCTGCCTGCCCCTATCGAAAAGACCATCAGCAAGACCAAGGGCCAGCCTCGC GAGCCTCAGGTGTACACCCTGCCTCCCTCTCGCGAAGAGATGACCAAGAACCAGGTGTCC CTGACCTGTCTGGTGAAGGGCTTCTACCCTTCCGATATCGCCGTGGAGTGGGAGTCCAAC GGCCAGCCTGAGAACAACTACAAGACCACCCCTCCTATGCTGGACTCCGACGGCTCTTTC TTCCTGTACTCCAAGCTGACAGTGGACAAGTCCCGGTGGCAGCAGGGCAACGTGTTCTCC TGCTCCGTGATGCACGAGGCCCTGCACAATCACTACACCCAGAAGTCCCTGTCCCTGTCT CCTGGCAAG
18R8 lambda LC coding sequence (codon-optimized) (SEQ ID NO:97): ATGGCCTGGGCCCTGCTGCTGCTGACCCTGCTGACACAGGGCACCGGCTCTTGGGCCGAC ATCGAGCTGACCCAGCCTCCCTCCGTGTCTGTGGCTCCTGGCCAGACCGCCCGGATCTCC TGCTCCGGCGACAAGCTGGGCAAGAAGTACGCCTCCTGGTATCAGCAGAAGCCTGGACAG GCCCCTGTGCTGGTCATCTACGAGAAGGACAACCGGCCTAGCGGCATCCCTGAGCGGTTC

TCCGGCTCCAACTCCGGCAACACCGCCACCCTGACCATCTCCGGCACCCAGGCCGAGGAC
GAGGCCGACTACTACTGCTCCTCCTTCGCCGGCAACTCCCTGGAAGTGTTCGGCGGAGGC
ACCAAGCTGACCGTGCTGGGCCAGCCTAAGGCCGCTCCTTCCGTGACCCTGTTCCCTCCT
TCCTCCGAGGAACTGCAGGCCAACAAGGCCACCCTGGTCTGCCTGATCTCCGACTTCTAC
CCTGGCGCCGTGACCGTGGCCTGGAAGGCCGACTCCTCCCCTGTGAAGGCCGGCGTGGAG
ACAACCACCCCTTCCAAGCAGTCCAACAACAAGTACGCCGCCTCCTCCTACCTGTCCCTG
ACCCCTGAGCAGTGGAAGTCCCACCGGTCCTACTCTTGCCAGGTCACCCACGAGGGCTCC
ACCGTGGAAAAGACAGTGGCCCCCACCGAGTGCTCC

18R5 LC coding sequence (codon-optimized) (SEQ ID NO:76):
ATGGCCTGGGCCCTGCTGCTGCTGACCCTGCTGACACAGGGCACCGGCTCTTGGGCCGAC
ATCGAGCTGACCCAGCCTCCCTCCGTGTCCGTGGCCCCTGGCCAGACCGCCCGGATCTCC
TGCTCCGGCGACAACATCGGCAGCTTCTACGTGCACTGGTATCAGCAGAAACCTGGACAG
GCCCCTGTGCTGGTGATCTACGACAAGTCCAACCGGCCTTCCGGCATCCCTGAGCGGTTC
TCCGGCTCCAACTCCGGCAACACCGCCACCCTGACCATCTCCGGCACCCAGGCCGAGGAC
GAGGCCGACTACTACTGCCAGTCCTACGCCAACACCCTGTCCCTGGTGTTTGGCGGCGGA
ACAAAGCTGACCGTGCTGGGCCAGCCTAAGGCCGCTCCTTCCGTGACCCTGTTCCCTCCT
TCCTCCGAGGAGCTGCAGGCCAACAAGGCCACCCTGGTGTGCCTGATCTCCGACTTCTAC
CCTGGCGCTGTGACTGTGGCTTGGAAGGCCGACTCCTCCCCTGTGAAGGCCGGCGTGGAG
ACAACCACCCCTTCCAAGCAGTCCAACAACAAGTACGCCGCCTCCTCCTACCTGTCCCTG
ACCCCTGAGCAGTGGAAGTCCCACCGGTCCTACTCTTGCCAGGTGACCCACGAGGGCTCC
ACCGTGGAAAAGACAGTGGCACCCACCGAGTGCTCC

18R4605 LC coding sequence (SEQ ID NO:83):
ATGGCATGGGCATTATTGCTACTTACTCTATTGACGCAAGGAACGGGTTCATGGGCAGAC
ATAGAACTAACTCAGCCACCCTCTGTTAGCGTTGCACCGGGACAGACGGCACGTATATCG
TGCTCGGGAGACAATATAGGAAGTTTCTATGTACATTGGTATCAACAGAAACCTGGTCAA
GCACCTGTATTAGTAATCTATGACAAAAGTAACCGACCTTCCGGAATACCTGAGCGTTTC
AGTGGTTCGAACTCCGGCAACACTGCAACTTTAACTATATCTGGAACTCAGGCGGAGGAT
GAGGCTGACTACTACTGCCAGAGTTACGCAAACACTCTGTCCCTGGTGTTTGGCGGCGGA
ACAAAGTTAACCGTGCTGGGCCAGCCTAAGGCCGCACCTTCGGTGACCCTATTCCCTCCT
TCATCCGAGGAGCTACAGGCCAACAAGGCCACCTTAGTGTGCCTAATCTCCGACTTCTAT
CCTGGTGCTGTAACGGTAGCGTGGAAGGCCGACTCATCGCCGGTGAAGGCCGGTGTGGAG
ACAACGACTCCTTCCAAGCAGTCCAACAACAAATACGCCGCGTCCTCCTACCTGTCCCTA
ACCCCTGAGCAGTGGAAGTCCCACCGTTCATACTCGTGCCAGGTGACGCACGAGGGTTCA
ACGGTCGAAAAGACAGTAGCACCTACTGAATGCTCA

18R4805 LC coding sequence (SEQ ID NO:84):
ATGGCATGGGCATTATTACTACTTACTCTACTTACGCAAGGAACGGGTTCATGGGCAGAC
ATAGAACTAACTCAGCCGCCGTCTGTTAGCGTTGCACCGGGACAGACGGCACGTATATCG
TGCTCGGGAGACAATATTGGTTCTTTCTATGTACATTGGTATCAACAGAAACCTGGTCAA
GCACCTGTATTAGTAATATATGACAAAAGTAACCGTCCTTCGGGAATACCTGAGCGTTTC
AGTGGTTCGAACTCGGGCAACACTGCAACTTTAACTATATCTGGAACGCAGGCGGAGGAT
GAGGCGGACTACTATTGCCAAAGTTACGCAAACACTCTATCCTTAGTGTTTGGTGGAGGA
ACAAAGTTAACCGTGCTAGGCCAGCCTAAGGCCGCACCTTCGGTGACCCTATTCCCTCCT
TCATCCGAGGAGCTACAGGCGAACAAAGCCACCTTAGTGTGCCTAATCTCAGACTTTTAT
CCTGGTGCTGTAACGGTAGCGTGGAAGGCGGACTCATCGCCGGTGAAGGCCGGTGTGGAG
ACAACGACTCCTTCCAAGCAGTCCAACAACAAATACGCAGCGAGTAGTTACCTGTCCCTA
ACCCCTGAGCAGTGGAAGTCGCACCGTTCATACTCGTGCCAGGTTACGCACGAGGGTTCA
ACGGTCGAAAAGACAGTAGCACCTACGGAATGCTCA

44R24 HC coding sequence (SEQ ID NO:91):
ATGAAGCACCTGTGGTTCTTTCTGCTGCTGGTGGCCGCTCCTAGATGGGTGCTGTCC
GAGGTGCAGCTGGTGGAGTCTGGCGGAGGACTGGTGCAGCCTGGCGGCTCCCTGAGACTG
TCTTGCGCCGCCTCCGGCTTCACCTTCTCCTCTTACTACATCACCTGGGTGCGCCAGGCT
CCTGGCAAGGGACTGGAATGGGTGTCCACCATCTCCTACTCCTCCAGCAACACCTACTAC
GCCGACTCCGTGAAGGGCCGGTTCACCATCTCCCGGGACAACTCCAAGAACACCCTGTAC
CTGCAGATGAACTCCCTGAGGGCCGAGGACACCGCCGTGTACTACTGCGCCCGGTCCATC

GTGTTCGACTACTGGGGCCAGGGCACCCTGGTGACCGTGTCCTCTTCCGTGTTCCCTCTG
GCCCCTTGCTCCCGGTCCACCTCTGAGTCTACCGCCGCTCTGGGCTGCCTGGTGAAGGAC
TACTTCCCTGAGCCTGTGACCGTGTCCTGGAACTCTGGCGCCCTGACCTCTGGCGTGCAC
ACCTTCCCTGCCGTGCTGCAGTCCTCCGGCCTGTACTCCCTGTCCTCCGTGGTGACCGTG
CCTTCCTCCAACTTCGGCACCCAGACCTACACCTGCAACGTGGACCACAAGCCTTCCAAC
ACCAAGGTGGACAAGACCGTGGAGCGGAAGTGCTGCGTGGAGTGCCCTCCTTGTCCTGCT
CCTCCTGTGGCTGGCCCTTCTGTGTTCCTGTTCCCTCCTAAGCCTAAGGACACCCTGATG
ATCTCCCGGACCCCTGAAGTGACCTGCGTGGTGGTGGACGTGTCCCACGAGGACCCTGAG
GTGCAGTTCAATTGGTACGTGGACGGCGTGGAGGTGCACAACGCCAAGACCAAGCCTCGG
GAGGAACAGTTCAACTCCACCTTCCGGGTGGTGTCTGTGCTGACCGTGGTGCACCAGGAC
TGGCTGAACGGCAAAGAATACAAGTGCAAGGTGTCCAACAAGGGCCTGCCTGCCCCTATC
GAAAAGACCATCTCTAAGACCAAGGGCCAGCCTCGCGAGCCTCAGGTCTACACCCTGCCT
CCTAGCCGGGAGGAAATGACCAAGAACCAGGTGTCCCTGACCTGTCTGGTGAAGGGCTTC
TACCCTTCCGATATCGCCGTGGAGTGGGAGTCTAACGGCCAGCCTGAGAACAACTACAAG
ACCACCCCTCCTATGCTGGACTCCGACGGCTCCTTCTTCCTGTACTCCAAGCTGACAGTG
GACAAGTCCCGGTGGCAGCAGGGCAACGTGTTCTCCTGCTCCGTGATGCACGAGGCCCTG
CACAACCACTACACCCAGAAGTCCCTGTCCCTGTCTCCTGGCAAGTGA

<u>44R24 LC coding sequence (SEQ ID NO:93):</u>

ATGGCTTGGGCTCTGCTGCTGCTGACCCTGCTGACACAGGGCACCGGCTCTTGGGCC
GACATCGAGCTGACCCAGCCTCCCTCTGTGTCTGTGGCCCCTGGCCAGACCGCCAGGATC
TCTTGCTCTGGCGACGCCCTGGGCAACAGATACGTGTACTGGTATCAGCAGAAGCCAGGC
CAGGCCCCTGTGCTGGTGATCCCTTCCGGCATCCCTGAGCGGTTCTCCGGCTCCAACTCC
GGCAACACCGCCACCCTGACCATCTCTGGCACCCAGGCCGAGGACGAGGCCGACTACTAC
TGCGGCTCCTGGGACACCCGGCCTTACCCTAAGTACGTGTTCGGCGGAGGCACCAAGCTG
ACCGTGCTGGGCCCTTCCGTGACCCTGTTCCCTCCATCCTCCGAGGAACTGCAGGCCAAC
AAGGCCACCCTGGTGTGCCTGATCTCCGACTTCTACCCTGGCGCCGTGACCGTGGCTTGG
AAGGCCGACTCTAGCCCTGTGAAGGCCGGCGTGGAGACAACCACCCCTTCCAAGCAGTCC
AACAACAAGTACGCCGCCTCCTCCTACCTGTCCCTGACCCCTGAGCAGTGGAAGTCCCAC
CGGTCCTACTCTTGCCAGGTGACCCACGAGGGCTCCACCGTGGAAAAGACCGTGGCCCCT
ACCGAGTGCTCCTAG

[00391] Plasmids isolated from *E. coli* encoding the anti-FZD IgG antibodies 18R4605 (ATCC deposit no. PTA-10307), 18R4805 (ATCC deposit no. PTA-10309), and 44R24 (ATCC deposit no. PTA-10311) were deposited with the American Type Culture Collection (ATCC), 10801 University Boulevard, Manassas, VA, USA, under the conditions of the Budapest Treaty on August 26, 2009.

EXAMPLE 19

Binding profiles of anti-FZD antibodies

[00392] FACS analysis was used to characterize the FZD1, 2, 5, 7 and 8 binding profiles of anti-FZD monoclonal antibodies (mAbs).

[00393] HEK293 cells were co-transfected with a plasmid DNA expressing full-length FZD1, 2, 5, 7 or 8 along with another plasmid expressing the reporter gene GFP used as a

transfection marker. Fugene 6 (Roche) was used as transfection reagent according to the manufacturer directions. Transfected cells were incubated twenty-four to forty-eight hours at 37°C and 5% CO_2. The anti-FZD mAbs were then diluted in a final volume of 50µl starting with a concentration of 20 µg/ml and serially diluted 4-fold for a total of 8 dilutions. Each FZD/GFP 293 transiently tranfectant pool was collected in suspension and 100,000 transfected cells were incubated on ice 30-60 minutes with the diluted anti-FZD mAb to be tested. The cells were washed and bound anti-Fzd antibodies were detected with a secondary anti-human antibody conjugated to a fluorescent chromophore. Labeled cells were then detected and counted by FACS. The FACS data generated were expressed in Mean Fluorescence Intensity (MFI) units. GraphPad Prism software was used to graph and analyze the data. MFIs were plotted as a function of Ab concentration to establish dose-response curves. A non-linear regression was applied to the numbers to fit the curve and calculate EC50s.

[00394] The binding profiles for the mAbs 18R5 and 44R24 were determined and compared. The dose-reponse curve representing the binding of each of 18R5 and 44R24 to Fzd1, 2, 5, 7 and 8 is shown in Figure 47. The EC50s (nM) calculated for the two mAbs is shown in Table 13. 44R24 bound Fzd5 and Fzd8 with good affinity. A sigmoidal dose-response curve could not be established for the other 3 Fzd receptors, suggesting that 44R24 does not bind Fzd1, 2 and 7. High affinity binding of Fzd1, 2, 5 and 7 was confirmed for 18R5.

Table 13. EC50s (nM) for the mAbs 18R5 and 44R24

EC50 (nM)	Fzd1	Fzd2	Fzd5	Fzd7	Fzd8
18R5	0.41	0.62	1.10	0.58	12.00
44R24	117.95	no binding	1.89	92.31	1.09

EXAMPLE 20

Evaluation of anti-Wnt activity of anti-FZD mAbs in cell-based assays

[00395] The ability of 18R5 and 44R24 to inhibit Wnt signaling in STF-293 cells was determined and compared. STF cells are Human Embryonic Kidney (HEK)-293 cells stably transfected with the Super Top Flash (STF) reporter cassette in which the expression of the Luciferase (Luc) reporter gene is regulated by multiple copies of the TCF binding site upstream of a minimal promoter. A low basal Luc expression can be induced 30-60 fold in response to Wnt3a, providing a large window to assess the inhibitory activity of the anti-Fzd Abs.

[00396] To assess the mAbs, STF-293 cells were grown in DMEM-10% FBS. On day 1, 10,000 cells were plated per well in 96-well Optical Bottom White plates (Nunc #165306). The cells were incubated O.N. at 37°C and 5% CO_2. On day 2, the Abs to be tested were diluted to a final concentration of 40 μg/μl using culture medium. Seven 5-fold serial dilutions were performed. The STF-293 cells culture medium was replaced with a mixture containing 50 μl Ab dilution, 25 μl Wnt3a-conditioned medium from Wnt3a stable L-cells and 25 μl DMEM-10% FBS. For each Ab, the final concentrations tested were 20, 4, 0.8, 0.16, 0.03, 0.006, 0.0013, 0.0003 μg/ml. Each Ab concentration was tested in triplicate. A human anti-hapten Ab, LZ1, was used as negative control Ab. A non-Wnt3a-conditioned medium from parental L-cells was used as negative control inducer. The plates were returned to the incubator. Luciferase activity was measured on day 3, using Promega Steady Glo kit (VWR # PAE2550-A) according to the manufacturer specifications. The results were expressed in photons per sec. GraphPad Prism software was used to graph and analyze the data. Luciferase activities were plotted as a function of Ab concentration to establish dose-response curves. A non-linear regression was applied to the numbers to fit the curve and calculate IC50s.

[00397] The ability of 44R24 and 18R5 to inhibit Wnt signaling in STF cells was likewise determined and compared as described above. The results are shown in Figure 48 and Table 14. 44R24 activity was only detected at higher Ab concentrations, reflecting the antibody's low activity in the assay. 44R24's IC50 was calculated to be 13 fold lower than 18R5's.

Table 14. IC50s for inhibition of Wnt signaling in ST-293 cells by 18R5 and 44R24

	18R5	44R24
IC50 (nM)	2.73	34.43

[00398] The ability of 18R5 and 44R24 to inhibit Wnt signaling in A549 cells was also determined. A549 cells are human lung carcinoma cells in which the Axin2 gene is highly expressed, translating endogenous activity of Wnt signaling. Axin2 is a well know Wnt target gene that responds to activation of the pathway by up-regulating its transcription and eventually down-regulating Wnt signaling through a feed-back loop mechanism. This system was used to test the impact of the anti-Fzd Abs on Axin2 mRNA levels by qPCR.

[00399] 12-well plates were seeded with 30,000 A549 cells per well and grown for 3 days in DMEM+10% FBS. Antibodies were added at varying concentrations (5, 1, 0.2, 0.04, 0.008 μg/ml) for 24 hours and total RNA was extracted from the cells. LZ1, a nonbinding antibody, was used as negative control at only the highest concentration.

[00400] 30,000 A549 cells were seeded into 12-well plates and grown for 3 days in DMEM+10% FBS. Anti-FZD antibody 18R5 or 44R24 were added at varying concentrations (5, 1, 0.2, 0.04, 0.008 ug/ml), and LZ1, a nonbinding antibody, was used as a negative control at only the highest concentration. RNA was made 24 hours post treatment and then treated with Dnase.

[00401] Axin2 is known to be a robust target gene in Wnt signaling and its expression level was examined by doing a Taqman relative expression (ΔΔCT) assay using an Applied Biosystems 7900 HT machine. 50 ng of RNA was used per point in triplicate and a GUSB probe was used for endogenous control. All results were normalized to Axin2 levels in the LZ1 control sample.

[00402] The dose response curve showing the inhibition of basal level of axin2 gene expression by 18R5 and 44R24 and the calculated EC50 values for these antibodies are shown in Figure 49. 18R5 and 44R24 inhibit Axin2 basal levels relative to LZ1 control with comparable efficiencies.

EXAMPLE 21

Evaluation of anti-tumor activity of anti-FZD mAbs in pancreatic xenograft models

OMP-PN13 pancreatic tumors:

[00403] Frozen OMP-PN13 tumor cells that have been passaged twice in mice were obtained from Oncomed's tumor bank. They were thawed and injected subcutaneously into the left flank of NOD/SCID mice immediately following thawing. ~25,000 viable cells were injected per animal. The mice were monitored weekly for tumor growth. After their

onset, the size of the tumors was measured once weekly by caliper. 200-300 mm^3 tumor-bearing mice were dispatched in treatment groups that each contained 5 animals. The average tumor size was comparable in each group. Ab treatment was initiated the day after randomization. LZ1 was used as the negative control Ab. 3 doses of 10 mg/kg of Ab were administered via intra-peritoneal injection over a 12-day period. Mice were euthanized 24 hours after the last injection. Tumor, duodenum and liver were harvested.

[00404] Tumor tissues were fixed in formalin for paraffin embedding and sectioning. Muc16 detection was performed by immunohistochemical (IHC) to monitor the appearance of Mucin-producing cells. Mucins are specific for a subtype of differentiated cells in the pancreas, and as such are used as differentiation markers in the tumor model.

[00405] Formalin-fixed, paraffin-embedded (FFPE) sections were de-parrafinized. The slides were first de-parrafinized by sequential treatment with xylene twice for 5 minutes each. The tissue was then rehydrated by immersion in an ethanol series of 100% twice for 3 minutes each, 90% once for 1 minute, 80% once for 1 minute, and 70% once 1 minute in water. The tissue was washed with flowing distilled water for 1 minute.

[00406] Mucin 16 antibody (clone X325 from AbCAM, catalog ab10033) was used for IHC detection of mucin 16 expressing cells in FFPE tissue sections. Heat-induced antigen retrieval was carried out with 10mM citrate buffer pH 6.0 in an autoclave. The slides were then kept at room temperature and the proteins allowed to recover antigenicity slowly (approximately 2 hours).

[00407] Tissue sections were blocked with 3% hydrogen peroxide solution in water, washed , and then blocked again using Normal Horse serum Blocking solution (for 50 mL; PBS (38.5 mL),10% NHS (5 mL),1% BSA (5 mL), 0.1% gelatin (500 µL), 0.1% Tx-100 (500 µL), 0.05% NaN3 (500 µL)) for 1 hour at room temperature. Sections were then stained with 1:200 dilution of Muc16 primary antibody in Da Vinci Green Diluent pH 7.3 (PD 900, Biocare Medical) for 1 hour at room temperature followed by three washes using phosphate buffered saline containing 0.1% triton X-100. Sections were then stained with 3 drops of ImmPress anti-mouse IgG HRP-conjugate (Catalog 101098-260, VWR) for 30 minutes at room temperature followed by three washes using phosphate buffered saline containing 0.1% triton X-100. Slides were placed in petridishes and developed using Vector NovaRed kit (SK4800, Vector labs) for 1-2 minutes. Reaction was stopped by adding distilled water. Slides were rinsed thoroughly under flowing distilled water. Tissue sections were then counterstained using Hematoxylin (Catalog H3401, Vector Labs Gill's formula) for 1 minute,

washed, and then neutralized using blueing solution for 30 seconds. Slides were left to dry overnight and mounted using VectaMount (Vector Labs).

[00408] Representative fields of tumors treated with control Ab (LZ1), 18R5, or 44R24 are shown in Figure 50. While LZ1 was associated with low intensity staining, higher levels of staining with Muc16 antibody were detected in the tumors treated with 18R5. This suggests that tumor cells were induced to differentiate towards the mucin-producing cell lineage by 18R5. Levels of Muc16 staining in the 44R24-treated tumors were more moderate than in the 18R5 treated tumors but still appeared to be slightly higher than in the LZ1-treated tumors in this experiment.

[00409] Total RNAs were also extracted from tumor, duodenum and liver for Wnt target gene expression analyses using qPCR.

[00410] Tissues were immediately transferred into RNAlater (QIAGEN) at the time of harvest. RNA was extracted using the QIAGEN RNeasy for Fibrous Tissue mini kit according to the manufacturer instructions. 50 ng total RNA were submitted to gene expression analyses using ABI one-step RT-PCR protocol and reagents. GusB gene expression was used as endogenous control. Triplicates were setup for each sample. All 5 tumors of each treatment group were analyzed. ABI 7900 TaqMan machine was used to run the experiments. ABI SDS 2.2.1 software was used to analyze the data and calculate DeltaCt values that were converted into relative quantities. The triplicate values of all 5 tumors were averaged for each treatment group. Fold inhibition factors were then calculated relative to control antibody (LZ1).

[00411] The results are shown in Table 15. Wnt target genes were variably affected by the anti-FZD Abs. 18R5 induced 2.3x and 8x inhibition in tumor and liver, while remaining unaffected in the duodenum. The changes induced by 44R24 were more moderate.

Table 15. qPCR gene expression analysis of Wnt target genes in 18R5- and 44R24-treated tissues.

	tumor	Liver					duodenum	
	Axin2	Axin2	Rhbg	Glul	Lect2	Lgr5	Axin2	Lgr5
18R5	-2.3x *-2.5x*	-8x *-13x*	-6.5x *-5x*	-19x	-8x	-26x	NS	-2.6x

44R24	*-1.8x*	*-2.4x*	*-1.9x*	ND	ND	ND	ND	ND

ND: not done
Separate experiments are shown in italics

OMP-PN4 pancreatic tumors:

[00412] The impact of 18R5 on tumor stroma in the OMP-PN4 pancreatic tumor xenograft model was also investigated. Several genes were identified by microarray whose expression levels were altered by the treatment. Amongst them, ACTA2, which encodes for the smooth muscle actin (SMA) protein, is of particular interest. SMA has been shown to be associated with activated tumor stroma. Its down-regulation can therefore be viewed as a sign of decreased tumorgenic phenotype.

[00413] As described in Example 7 above, OMP-PN4 tumor-bearing NOD/SCID mice were treated with control Ab (LZ-1), 18R5, gemcitabine, or the combination of 18R5 and gemcitabine once a week for 6 weeks. The antibodies were administered at a concentration of 10 mg/kg. After they were harvested, the tumors from that experiment were analyzed for the expression of Wnt target genes at both the RNA and protein levels, using microarray and IHC, respectively.

[00414] Total RNA was extracted from the tumors, amplified, and subjected to microarray analysis. Total RNAs were amplified using the Ovation RNA Amplification System V2 (NuGEN, San Carlos, CA). Resulting amplified, antisense ss-cDNA was fragmented and biotinylated using the FL-Ovation cDNA Biotin Module V2 (NuGEN) for use on Affymetrix chips. Affymetrix HG-U133 plus 2 or MG 430 2.0 oligonucleotide microarrays were used in these experiments (performed at Almac Diagnostics, Durham, NC). After hybridization, Gene Chips were washed, stained, and scanned according to the manufacturer's instructions (Affymetrix, Santa Clara, CA). The quality of the cDNA and the fragmented cDNA were assessed by spectrophotometer and the Bioanalyzer before the array hybridization. The scanned raw chip data were quantified and scaled using the GCOS software package (Affymetrix) and subjected to a comprehensive assessment of Gene Chip Quality Control recommended by Affymetrix to detect any chips defects and outliers, which were excluded from the subsequent data analysis.

[00415] Array background adjustment and signal intensity normalization were performed with GCRMA algorithm in the open-source Bioconductor software (www.bioconductor.org). Genes differentially expressed between two groups or time points

were identified with Bayesian t-test (Cyber-T), which combines student's t-test with a Bayesian estimate of the intra-group variance obtained from the observed variance of probe sets at a similar expression levels (Baldi P, Long AD. A Bayesian framework for the analysis of microarray expression data: regularized t -test and statistical inferences of gene changes. Bioinformatics. 2001;17(6):509–19).

[00416] For the human tumor gene chip analysis, samples were assayed on both human and mouse chips to assess treatment effects on bulk human tumor and on mouse stroma independently. Those Affymetrix probe sets that were not species-specific were omitted from the analysis.

[00417] In preparation for Smooth Muscle Actin alpha (SMAa) immunofluorescence, tumor tissue was frozen using OCT. 4 micron sections were obtained and stored frozen at -80°C. For SMAa staining, tissue was fixed using chilled acetone at -20°C for 15 minutes and then allowed to dry and come to room temperature and then marked using a hydrophobic PAP pen. Slides were then washed using phosphate buffered saline (PBS). Tissue was blocked using normal horse serum R.T.U. (Vector Labs) for 2 hours at room temperature. Primary antibody staining was performed with 1:10,000 dilution of FITC-conjugated Smooth muscle actin alpha antibody (cline 1A4, #F3777, SIGMA) for 1 hour. Sections were washed 3 times using PBS containing 0.1% triton X-100. Slides were then air-dried and then mounted using Hard set mounting medium containing DAPI (vectashied H-500).

[00418] Figure 51A shows the ACTA2 gene expression levels as detected by microarray. Tumors treated with the anti-FZD antibody 18R5 showed decreased levels of ACTA2 expression. Figure 51B shows the results of the Smooth Muscle Actin alpha (SMAa) immunofluorescence on control mAb (upper panel) and 18R5 (lower panel) –treated OMP-PN4 tumors. Reduced amounts of SMAa was detected on the 18R5-treated tumors. The expression of ACTA2 and the amount of SMA were dramatically reduced in the tumor stroma in response to 18R5, suggesting that Wnt blockade (i) impacts this tumor compartment and (ii) does so by reducing a well established tumorgenicity marker. These results suggest that reduction of myofibroblast activation may be one of 18R5's anti-tumor mechanisms of action.

EXAMPLE 22

Evaluation of the tumorgenic potential of Muc16-positve OMP-PN13 cells

[00419] As described above, 18R5 treatment induced gene expression and cell phenotype changes in pancreatic tumors, including increased mucin expression. In particular, IHC performed on treated PN-13 tumors revealed an increased number of Muc16-positive cells. Muc16 gene expression levels were also higher in treated tumors than in control tumors. The tumorigenicity of the 18R5-induced Muc16-positive cells was assessed to test the hypothesis that the 18R5-induced Muc16-positive cells are representative of a differentiated tumor cell sub-population.

[00420] OMP-PN13-bearing mice were treated with 18R5 according to the protocol described in Example 21. Mice were euthanized 12 days after initiation of the Ab treatment. Tumors were harvested and processed to obtain a single cell suspension using collagenase III to digest the tissues. Mouse stromal cells were stained with a biotinylated anti-H-2Kd antibody and a biotinylated anti-CD45 antibody. They were then incubated with magnetic beads conjugated to streptavidin (Thermo MagnaBind) and depleted using a Dynal magnet. The resulting lin-depleted tumor cells were stained with an anti-Muc16 mAb detected with a PE-conjugated secondary Ab. Muc16-positive and Muc16-negative cells were sorted using an ARIA FACS machine ran by the DIVA software. See Figure 52A. Cells were re-injected subcutaneously in the left flank of NOD/SCID mice for comparison of their tumorgenic potentials. Each cell type was injected into 10 mice. Each mouse received 75 cells. Representative pictures of tumors resulting from the injection of Muc16- (upper panel) and Muc16+ (lower panel) cells are shown in Figure 52B. The growth curves for the Muc16- and Muc16+ tumors following injection into the mice are shown in Figure 52C. No tumor grew after injection of the Muc16+ cells, while 7 of the 10 mice injected with the Muc16- cells developed tumors. The data suggest that 18R5-induced Muc16+ cells are non-tumorgenic, supporting induction of differentiation as an underlying mechanism of 18R5 anti-tumor activity.

EXAMPLE 23

Additional in vivo studies with anti-FZD antibodies

[00421] PE13 breast tumor recurrence study with 18R5 mAb: PE13 breast tumor cells were injected into Nod-Scid mice and allowed to grow until the tumors had reached approximately 100 mm^3. The animals were randomized into two groups (n=10) and given taxol (15 mg/kg, twice per week) + Control antibody (black squares) or the same dose of

taxol + Anti-FZD 18R5 (gray open circles). Antibodies were dosed at 20 mg/kg once per week. Taxol treatments were stopped at day 70 and the antibody treatments continued. The results are shown in Figure 53. 18R5 was observed to enhance the rate of tumor regression and to delay tumor recurrence after stopping taxol treatment.

[00422] PE13 breast tumor limiting dilution assay (LDA) study with 18R5 mAb: Animals bearing PE13 breast tumors were treated with either control antibody (gray circles), 18R5 (open triangles), taxol (black circles), or the combination of taxol and 18R5 (open squares). Taxol was dosed at 15 mg/kg twice per week and the antibodies were dosed 20 mg/kg once per week. Tumors were harvested and the human tumor cells were purified by lin depletion. 50, 150, or 500 tumor cells were injected into a new cohort of mice (n=10 per cell dose). The results are shown in Figure 54. Tumor growth frequency was monitored after 59 days and used to calculate the CSC frequency (L-calc).

[00423] PN4 pancreatic tumor recurrence study with 18R5 mAb: PN4 pancreatic tumor cells were injected into Nod-Scid mice and allowed to grow until the tumors had reached approximately 250 mm^3. The animals were given gemcitabine (75 mg/kg, once per week) for 5 weeks until tumors had regressed. The animals were randomized into two groups and given control antibody (black squares) or anti-FZD 18R5 (gray open circles). Antibodies were dosed at 10 mg/kg once per week. The results are shown in Figure 55. 18R5 was observed to delay tumor recurrence after gemcitabine treatment.

[00424] PN4 pancreatic tumor growth study with 44R24 mAb: PN4 pancreatic tumors were injected into Nod-Scid mice. Tumors were allowed to grow until they had reached a volume of approximately 150 mm^3. Animals were randomized into 4 groups (n=10 per group) and given control antibody (black squares), anti-FZD5/8 44R24 (gray open triangles), gemcitabine (filled triangles), or combination of 44R24 plus gemcitabine (gray open circles). Gemcitabine was dosed at 15 mg/kg once per week and the antibodies were dosed at 20 mg/kg twice week. The results are shown in Figure 56. 44R24 was observed to reduce tumor growth in combination with gemcitabine relative to gemcitabine alone.

EXAMPLE 24

Epitope mapping of anti-FZD antibody 44R24

[00425] Epitope mapping for the anti-FZD antibody 44R24 was performed in a manner similar to that described above in Example 5 for the antibodies 18R8 and 18R5. The ability of 44R24 to bind to a similar epitope as 18R8 was assessed by flow cytometry using a

series of amino acid variants of FZD8 previously shown to disrupt binding of 18R8 (see Example 5 and Figures 6 and 7). Amino acids 126-127 of FZD8 were found to be required for binding 44R24 as indicated by reduced staining within the co-transfected (GFP positive) cell population. The results of the FACS experiments are shown in Figure 57. These results show that 44R24 binds to an epitope that overlaps with the epitope of 18R8 and comprises shared amino acids 126-127.

EXAMPLE 25

C28 colon tumor growth study with anti-FZD antibodies 18R5, 18R8 and 44R24.

[00426] C28 tumor cells were injected sub-cutaneously in Nod-Scid mice. Tumors were allowed to grow until they had reached an average volume of 126 mm^3. Tumor bearing animals were groups were randomized into four groups (n =10 mice per group) and treated with either Control Ab (black squares), 18R8 (gray triangles), 44R24 (black open circles), or 18R5 (gray circles) (Figure 58). Antibodies were dosed intraperitoneally at 15 mg/kg, twice per week. Tumor volumes are indicated. Treatment with antibodies 44R24 and 18R5 reduced growth relative to the control group, while 18R8 had no effect (Figure 58).

[00427] Following treatment of the animals in the experiment shown in Figure 58, tumors were harvested, fixed in formalin, embedded in paraffin, and cut in 5 micron sections. Tumor sections were analyzed for Cytokeratin 7 expression, a marker of colon cell differentiation, by immunohistochemistry (Vectastain kit, Vector Labs). Cytokeratin 7 expression was seen to be elevated after treatment with 44R24 or 18R5 (Figure 59).

[00428] All publications, patents, patent applications, internet sites, and accession numbers/database sequences (including both polynucleotide and polypeptide sequences) cited herein are hereby incorporated by reference in their entirety for all purposes to the same extent as if each individual publication, patent, patent application, internet site, or accession number/database sequence were specifically and individually indicated to be so incorporated by reference.

What we claim is:

1. An agent that specifically binds to a human frizzled receptor selected from the group consisting of FZD1, FZD2, FZD5, FZD7, and FZD8, wherein the agent:

(a) binds to at least part of a sequence Q(DE/ED)AGLEVHQF(Y/W)PL (SEQ ID NO:24) within the human frizzled receptor; and/or

(b) binds to at least part of a sequence (K/Q)(F/Y)GF(Q/A) (SEQ ID NO:69) within the human frizzled receptors.

2. The agent of claim 1, which specifically binds to more than one human frizzled receptor selected from the group consisting of FZD1, FZD2, FZD5, FZD7, and FZD8.

3. The agent of claim 1 or 2, which binds to at least part of a sequence GLEVHQ (SEQ ID NO:25) within the human frizzled receptor(s).

4. The agent of claim 2 or 3, wherein the human frizzled receptors to which the agent binds comprise FZD5 and FZD8.

5. An agent that competes for specific binding to human FZD1, FZD2, FZD5, FZD7, and/or FZD8 with an antibody in a competitive binding assay, wherein the antibody comprises a heavy chain variable region comprising SEQ ID NO:10 and a light chain variable region comprising SEQ ID NO:12 or SEQ ID NO:14.

6. An agent that competes for specific binding to human FZD5 and/or FZD8 with an antibody in a competitive binding assay, wherein the antibody comprises a heavy chain variable region comprising SEQ ID NO:85 and a light chain variable region comprising SEQ ID NO: 86.

7. An agent that specifically binds to human FZD8, wherein the agent:

(a) binds to at least part of a sequence GLEVHQ (SEQ ID NO: 25) within FZD8; and/or

(b) binds to at least part of a sequence QYGFA (SEQ ID NO:66) within FZD8.

8. The agent of claim 7, which further specifically binds human FZD1, FZD2, FZD5, and/or FZD7.

9. An agent that specifically binds to three or more human frizzled receptors, wherein the three or more human frizzled receptors comprise FZD1, FZD2, FZD5, FZD7, and/or FZD8.

10. The agent of claim 9, wherein the three or more human frizzled receptors further comprise FZD3, FZD4, FZD6, FZD9, and/or FZD10.

11. The agent of claim 9 or 10, wherein the three or more human receptors comprise FZD5 and FZD8.

12. The agent of claim 11, wherein the three or more human frizzled receptors comprise FZD1, FZD2, FZD5, FZD7, and FZD8.

13. An agent that specifically binds a human frizzled receptor, wherein the agent binds to at least part of the Biological Binding Site (BBS) within the human frizzled receptor.

14. The agent of claim 13, wherein the human frizzled receptor is FZD8 and the agent binds to at least part of:

(a) a conformational epitope formed by amino acids 72(F), 74-75(PL), 78(I), 92(Y), 121-122(LM), and 129-132(WPDR);

(b) a region consisting of the sequence QDEAGLEVHQFWPL (SEQ ID NO:67); and/or

(c) a region consisting of the sequence QYGFA (SEQ ID NO:66).

15. An agent that specifically binds a human frizzled receptor, wherein:

(a) if the human frizzled receptor is FZD8, the agent binds to at least part of a region of FZD8 consisting of the sequence QDEAGLEVHQFWPL (SEQ ID NO:67); and

(b) if the human frizzled receptor is FZD1, FZD2, FZD3, FZD4, FZD5, FZD6, FZD7, FZD9, or FZD10, the agent binds to at least part of a region of the human frizzled receptor corresponding to the region of FZD8 consisting of the sequence QDEAGLEVHQFWPL (SEQ ID NO:67).

16. The agent of claim 15, wherein

(a) if the human frizzled receptor is FZD8, the agent further binds to at least part of a region of FZD8 consisting of the sequence QYGFA (SEQ ID NO:66); and

(b) if the human frizzled receptor is FZD1, FZD2, FZD3, FZD4, FZD5, FZD6, FZD7, FZD9, or FZD10, the agent further binds to at least part of a region of the human frizzled receptor corresponding to the region of FZD8 consisting of the sequence QYGFA (SEQ ID NO:66).

17. An agent that specifically binds a human frizzled receptor, wherein:

(a) if the human frizzled receptor is FZD8, the agent binds to at least part of a region of FZD8 consisting of the sequence QYGFA (SEQ ID NO:66); and

(b) if the human frizzled receptor is FZD1, FZD2, FZD3, FZD4, FZD5, FZD6, FZD7, FZD9, or FZD10, the agent binds to at least part of a region of the human frizzled receptor corresponding to said region of FZD8.

18. The agent of any one of claims 13 or 15-17, wherein the human frizzled receptor is selected from the group consisting of FZD1, FZD2, FZD5, FZD7, and FZD8, and combinations thereof.

19. The agent of any one of claims 13-18, which specifically binds at least two human frizzled receptors.

20. The agent of claim 19, wherein each of the at least two human frizzled receptors is selected from the group consisting of FZD1, FZD2, FZD5, FZD7, and FZD8.

21. The agent of claim 20, wherein the at least two human frizzled receptors comprise FZD5 and FZD8.

22. The agent of claim 19 or 21, which specifically binds at least three human frizzled receptors.

23. The agent of claim 22, wherein each of the at least three human frizzled receptors is selected from the group consisting of FZD1, FZD2, FZD5, FZD7, and FZD8.

24. The agent of any one of claims 1-23, which is not an antibody.

25. The agent of any one of claims 1-23, which is an antibody.

26. The agent of claim 25, which comprises an antigen-binding site that specifically binds the human frizzled receptor(s).

27. An antibody that specifically binds a human frizzled receptor selected from the group consisting of FZD1, FZD2, FZD5, FZD7, and FZD8, wherein the antibody comprises a heavy chain variable region comprising:

(a) a heavy chain CDR1 comprising GFTFSHYTLS (SEQ ID NO:1), or a variant thereof comprising 1, 2, 3, or 4 amino acid substitutions; a heavy chain CDR2 comprising VISGDGSYTYYADSVKG (SEQ ID NO:2), or a variant thereof comprising 1, 2, 3, or 4 amino acid substitutions; and a heavy chain CDR3 comprising NFIKYVFAN (SEQ ID NO:3), or a variant thereof comprising 1, 2, 3, or 4 amino acid substitutions; and/or

(b) a light chain CDR1 comprising SGDKLGKKYAS (SEQ ID NO:4), SGDNIGSFYVH (SEQ ID NO:7), or a variant of either SEQ ID NO:4 or SEQ ID NO:7 comprising 1, 2, 3, or 4 conservative amino acid substitutions; a light chain CDR2 comprising EKDNRPSG (SEQ ID NO:5), DKSNRPSG (SEQ ID NO:8), or a variant of either SEQ ID NO:5 or SEQ ID NO:8 comprising 1, 2, 3, or 4 conservative amino acid substitutions; and a light chain CDR3 comprising SSFAGNSLE (SEQ ID NO:6), QSYANTLSL (SEQ ID NO:9), or a variant of either SEQ ID NO:6 or SEQ ID NO:9 comprising 1, 2, 3, or 4 conservative amino acid substitutions.

28. An antibody that specifically binds a human frizzled receptor selected from the group consisting of FZD1, FZD2, FZD5, FZD7, and FZD8, wherein the antibody comprises:

(a) a heavy chain CDR1 comprising GFTFSHYTLS (SEQ ID NO:1), a heavy chain CDR2 comprising VISGDGSYTYYADSVKG (SEQ ID NO:2), and a heavy chain CDR3 comprising NFIKYVFAN (SEQ ID NO:3); and/or

(b) a light chain CDR1 comprising SGDNIGSFYVH (SEQ ID NO:7), a light chain CDR2 comprising DKSNRPSG (SEQ ID NO:8), and a light chain CDR3 comprising QSYANTLSL (SEQ ID NO:9).

29. An antibody that specifically binds a human frizzled receptor selected from the group consisting of FZD1, FZD2, FZD5, FZD7, and FZD8, wherein the antibody comprises:

(a) a heavy chain CDR1 comprising GFTFSHYTLS (SEQ ID NO:1), a heavy chain CDR2 comprising VISGDGSYTYYADSVKG (SEQ ID NO:2), and a heavy chain CDR3 comprising NFIKYVFAN (SEQ ID NO:3); and/or

(b) a light chain CDR1 comprising SGDKLGKKYAS (SEQ ID NO:4), a light chain CDR2 comprising EKDNRPSG (SEQ ID NO:5), and a light chain CDR3 comprising SSFAGNSLE (SEQ ID NO:6).

30. A polypeptide that specifically binds a human frizzled receptor selected from the group consisting of FZD1, FZD2, FZD5, FZD7, and FZD8, wherein said polypeptide comprises:

(a) a polypeptide having at least about 80% sequence identity to SEQ ID NO:10; and/or

(b) a polypeptide having at least about 80% sequence identity to SEQ ID NO:12 or SEQ ID NO:14.

31. A polypeptide that specifically binds a human frizzled receptor selected from the group consisting of FZD1, FZD2, FZD5, FZD7, and FZD8, wherein said polypeptide comprises:

(a) a polypeptide having the amino acid sequence of SEQ ID NO: 10; and/or

(b) a polypeptide having the amino acid sequence of SEQ ID NO:12 or SEQ ID NO:14.

32. The polypeptide of claim 30 or 31, which is an antibody.

33. The antibody or polypeptide of any one of claims 27-32 which specifically binds both FZD5 and FZD8.

34. The antibody or polypeptide of claim 33, which specifically binds human FZD1, FZD2, FZD5, FZD7, and FZD8.

35. An antibody that specifically binds human FZD5 and/or FZD8, wherein the antibody comprises:

(a) a heavy chain CDR1 comprising GFTFSSYYIT (SEQ ID NO:77), or a variant thereof comprising 1, 2, 3, or 4 conservative amino acid substitutions; a heavy chain CDR2 comprising TISYSSSNTYYADSVKG (SEQ ID NO:78), or a variant thereof comprising 1, 2, 3, or 4 conservative amino acid substitutions; and a heavy chain CDR3 comprising SIVFDY (SEQ ID NO:79), or a variant thereof comprising 1, 2, 3, or 4 conservative amino acid substitutions; and/or

(b) a light chain CDR1 comprising SGDALGNRYVY (SEQ ID NO:80), or a variant thereof comprising 1, 2, 3, or 4 conservative amino acid substitutions; a light chain CDR2 comprising SG (SEQ ID NO:81), or a variant thereof comprising 1, 2, 3, or 4

conservative amino acid substitutions; and a light chain CDR3 comprising GSWDTRPYPKY (SEQ ID NO:82), or a variant thereof comprising 1, 2, 3, or 4 conservative amino acid substitutions.

36. An antibody that specifically binds human FZD5 and/or FZD8, wherein the antibody comprises:

(a) a heavy chain CDR1 comprising GFTFSSYYIT (SEQ ID NO:77), a heavy chain CDR2 comprising TISYSSSNTYYADSVKG (SEQ ID NO:78), and a heavy chain CDR3 comprising SIVFDY (SEQ ID NO:79); and/or

(b) a light chain CDR1 comprising SGDALGNRYVY (SEQ ID NO:80), a light chain CDR2 comprising SG (SEQ ID NO:81), and a light chain CDR3 comprising GSWDTRPYPKY (SEQ ID NO:82).

37. A polypeptide that specifically binds FZD5 and/or FZD8, wherein said polypeptide comprises:

(a) a polypeptide having at least about 80% identity to SEQ ID NO:85; and/or

(b) a polypeptide having at least about 80% identity to SEQ ID NO: 86.

38. A polypeptide that specifically binds FZD5 and/or FZD8, wherein said polypeptide comprises:

(a) a polypeptide having the amino acid sequence of SEQ ID NO:85; and/or

(b) a polypeptide having the amino acid sequence of SEQ ID NO: 86.

39. The polypeptide of claim 37 or 38, which is an antibody.

40. An antibody that competes for specific binding to human FZD1, FZD2, FZD5, FZD7, and/or FZD8 with 18R8, 18R5, 18R4605, or 18R4805.

41. An antibody that competes for specific binding to human FZD5 and/or FZD8 with 44R24.

42. The agent, antibody, or polypeptide of any one of claims 1-41 which is an antagonist of the human frizzled receptor(s).

43. The agent, antibody, or polypeptide of any one of claims 1-42 which is an IgG1 or IgG2 antibody.

44. The agent, antibody, or polypeptide of any one of claims 1-42 which is an antibody fragment.

45. The agent, antibody, or polypeptide of any one of claims 1-43 which is a monoclonal antibody.

46. The agent, antibody, or polypeptide of any one of claims 1-43 which is a human antibody.

47. The agent, antibody, or polypeptide of any one of claims 1-43 which is a humanized antibody.

48. The agent, polypeptide, or antibody of any one of claims 1-47, which inhibits binding of a Wnt to the human frizzled receptor.

49. The agent, polypeptide, or antibody of any one of claims 1-48, which inhibits canonical Wnt signaling.

50. The agent, polypeptide, or antibody of any one of claims 1-49, which inhibits tumor growth.

51. The agent, polypeptide, or antibody of any one of claims 1-50 which binds to an extracellular domain of the human frizzled receptor(s).

52. The agent, polypeptide, or antibody of claim 51, which binds to the Fri domain of the human frizzled receptor(s).

53. The agent, polypeptide, or antibody of any one of claims 1-52, which binds to the human frizzled receptor(s) with a K_D of about 100 nM or less.

54. An antibody encoded by the sequence of a plasmid deposited with the ATCC as accession number PTA-9540 or PTA-9541.

55. The agent, polypeptide, or antibody of any one of claims 1-54, which is isolated.

56. The agent, polypeptide, or antibody of claim 55, which is substantially pure.

57. An isolated cell producing the agent, polypeptide, or antibody of any one of claims 1-54.

58. A pharmaceutical composition comprising the agent, polypeptide, or antibody of any one of claims 1-54 and a pharmaceutically acceptable vehicle.

59. A pharmaceutical composition comprising the agent, polypeptide, or antibody of any one of claims 1-54 and a second anti-cancer agent.

60. A kit comprising the agent, polypeptide, or antibody of any one of claims 1-54 and a second anti-cancer agent.

61. A method of inhibiting canonical Wnt signaling in a cell, comprising contacting the cell with the agent, polypeptide, or antibody of any one of claims 1-54.

62. The method of claim 61, wherein the cell is a tumor cell.

63. A method of inhibiting tumor growth in a subject, comprising administering a therapeutically effective amount of the agent, polypeptide, or antibody of any one of claims 1-54 to the subject.

64. A method of reducing the tumorigenicity of a tumor that comprises cancer stem cells in a subject, said method comprising administering a therapeutically effective amount of the agent, polypeptide, or antibody of any one of claims 1-54 to the subject, wherein the frequency of cancer stem cells in the tumor is reduced by administration of the agent, polypeptide, or antibody.

65. A method of inducing cells in a tumor in a subject to differentiate, said method comprising administering a therapeutically effective amount of the agent, polypeptide, or antibody of any one of claims 1-54 to the subject.

66. The method of claim 65, wherein the tumor is a pancreatic tumor or a colon tumor.

67. The method of any one of claims 62-65, wherein the tumor is a tumor selected from the group consisting of colorectal tumor, pancreatic tumor, lung tumor, ovarian tumor, liver tumor, breast tumor, kidney tumor, prostate tumor, gastrointestinal tumor, melanoma, cervical tumor, bladder tumor, glioblastoma, and head and neck tumor.

68. The method of claim 67, wherein the tumor is a colorectal tumor, a breast tumor, or a pancreatic tumor.

69. A method of treating cancer in a subject, comprising administering a therapeutically effective amount of the agent, polypeptide, or antibody of any one of claims 1-54 to the subject.

70. The method of claim 69, wherein the cancer is a cancer selected from the group consisting of colorectal cancer, pancreatic cancer, lung cancer, ovarian cancer, liver cancer, breast cancer, kidney cancer, prostate cancer, gastrointestinal cancer, melanoma, cervical cancer, bladder cancer, glioblastoma, and head and neck cancer.

71. The method of claim 70, wherein the cancer is colorectal cancer, breast cancer, or pancreatic cancer.

72. The method of any one of claims 63-71, which further comprises administering a second anti-cancer agent to the subject.

73. The method of claim 72, wherein the second anti-cancer agent is a chemotherapeutic agent.

74. The method of claim 73, wherein the chemotherapeutic agent is an anti-metabolite.

75. The method of claim 74, wherein the chemotherapeutic agent is gemcitabine.

76. The method of claim 72, wherein the chemotherapeutic agent is a topoisomerase inhibitor.

77. The method of claim 76, wherein the chemotherapeutic agent is irinotecan.

78. The method of claim 72, wherein the chemotherapeutic agent is an antimitotic agent.

79. The method of claim 78, wherein the agent comprises a taxane.

80. The method of claim 79, wherein the taxane is paclitaxel.

81. The method of claim 72, wherein the second anti-cancer agent is an angiogenesis inhibitor.

82. The method of claim 81, wherein the angiogenesis inhibitor is an anti-VEGF antibody.

83. The method of claim 72, wherein the second anti-cancer agent is an inhibitor of Notch signaling.

84. The method of claim 83, wherein the inhibitor of Notch signaling is an anti-Notch antibody or an anti-DLL4 antibody.

85. A method of treating a disease in a subject wherein the disease is associated with Wnt signaling activation, comprising administering a therapeutically effective amount of the agent, polypeptide, or antibody of any one of claims 1-54 to the subject.

86. The method of claim 85, wherein the Wnt signaling is canonical Wnt signaling.

87. A method of treating a disorder in a subject, wherein the disorder is characterized by an increased level of stem cells and/or progenitor cells, comprising administering a therapeutically effective amount of the agent, polypeptide, or antibody of any one of claims 1-54 to the subject.

88. The method of any one of claims 63-87, wherein the subject is human.

89. An isolated polypeptide comprising a sequence selected from the group consisting of SEQ ID NOs: 10-15 and SEQ ID NOs: 85-86.

90. An isolated polynucleotide comprising a polynucleotide encoding the polypeptide of claim 89.

91. An isolated polynucleotide comprising a sequence selected from the group consisting of SEQ ID NOs: 17-22, 87-90, 92, and 94-95.

92. An isolated polynucleotide that comprises a polynucleotide that hybridizes under conditions of high stringency to:

(a) a polynucleotide selected from the group consisting of SEQ ID NOs: 17, 19, 21, 87-90, 92, and 94-95; or

(b) a polynucleotide encoding a polypeptide selected from the group consisting of a sequence SEQ ID NOs:10, 12, 14, and 85-86.

93. A vector comprising the polynucleotide of any one of claims 90-92.

94. An isolated cell comprising the polynucleotide of any one of claims 90-92.

95. A method of screening an agent for activity against cancer stem cells, comprising:

comparing the levels of one or more differentiation markers in a first solid tumor that has been exposed to the agent to the levels of the one or more differentiation markers in a second solid tumor that has not been exposed to the agent.

96. A method of screening an agent for activity against cancer stem cells, comprising:

(a) exposing a first solid tumor, but not a second solid tumor, to the agent;

(b) assessing the levels of one or more differentiation markers in the first and second solid tumors; and

(c) comparing the levels of the one or more differentiation markers in the first and second solid tumors.

97. The method of claim 95 or 96, wherein the agent specifically binds to one or more human frizzled receptors.

98. The method of claim 95 or 96, wherein increased levels of the one or more differentiation markers in the first solid tumor relative to the second solid tumor indicates efficacy against solid tumor stem cells.

99. The method of claim 95 or 96, wherein the solid tumor is a pancreatic tumor.

100. The method of claim 99, wherein the one or more differentiation markers comprise (a) one or more mucins or (b) chromogranin A (CHGA).

101. The method of claim 100, wherein the one or more differentiation markers comprise Mucin 16 (Muc16).

102. The method of claim 95 or 96, wherein the solid tumor is a colon tumor.

103. The method of claim 102, wherein the one or more differentiation markers comprise cytokeratin 7.

104. The method of claim 95 or 96, wherein the agent is an antibody that specifically binds to one or more human frizzled receptor.

105. A method of reducing myofibroblast activation in the stroma of a solid tumor, comprising contacting the stroma with an effective amount of the agent, polypeptide, or antibody of any one of claims 1-54.

106. A method of inducing cells in a tumor to differentiate, said method comprising contacting the tumor with an effective amount of an antibody that specifically binds to and is an antagonist of a human frizzled receptor.

107. A method of reducing myofibroblast activation in the stroma of a solid tumor, comprising contacting the stroma with an effective amount of an antibody that specifically binds to and is an antagonist of a human frizzled receptor.