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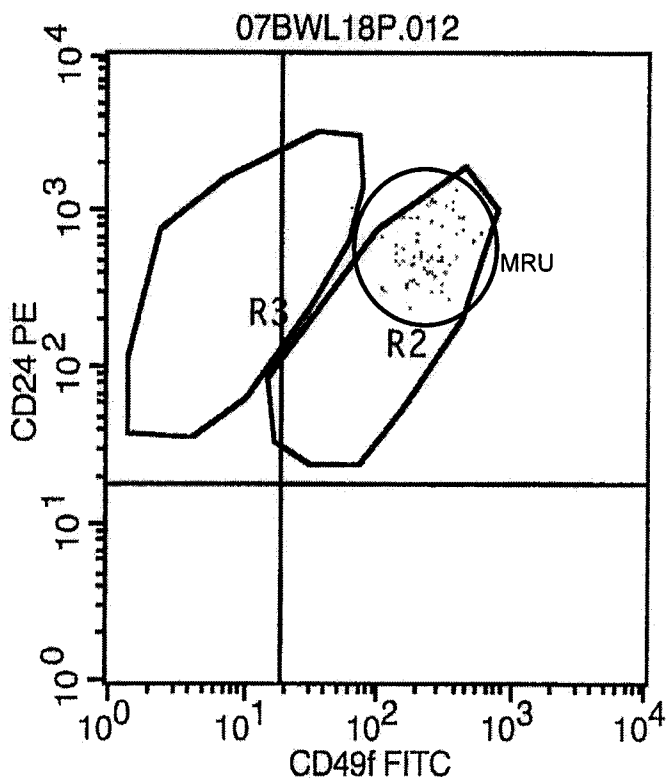
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(54) Title: LOW-DENSITY LIPOPROTEIN RECEPTOR 6 (LRP6) AS A MAMMARY STEM CELL MARKER AND RELATED METHODS



(57) Abstract: A method for enriching a population of somatic mammary stem cells or mammary tumor stem cells based on low-density lipoprotein receptor-related protein 6 (LRP6). Also included are methods for screening for LRP6 modulators, as well as methods for reducing Wnt signaling, for treating Wnt signaling-related diseases, for detecting mammary basal-like cells, for diagnosing basal-like breast cancer, and for inhibiting proliferation of a tumor expressing LRP6, and compositions thereof.

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**LOW-DENSITY LIPOPROTEIN RECEPTOR 6 (LRP6) AS A MAMMARY STEM CELL MARKER AND RELATED METHODS**CROSS-REFERENCE TO RELATED APPLICATION

[001] This application claims the benefit of US Patent Application No. 60/809,281, filed on May 30, 2006, which is herein incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

[002] The Mammary Gland and Its Development

[003] The mammary gland is a compound tubulo-alveolar gland composed of a series of branched ducts that, during lactation, drain sac-like alveoli (lobules). In humans, the mammary epithelium is embedded within a fibrous, fatty connective tissue. The mammary epithelium is composed of two lineages of epithelial cells: the luminal cells (which make milk during lactation) and basal positioned myoepithelial cells. Generation and maintenance of the mammary epithelium is via the somatic mammary stem cell. Currently, there is no single cell surface biomarker available that allows substantial enrichment of somatic mammary stem cells. All known enrichment protocols rely on combinations of cell surface markers.

[004] During embryonic development, mammatogenesis begins at E10.5 in mice [Veltmaat, J. *et al.* 2003. *Differentiation* 71:1-17]. The mammary gland is derived from both the ectoderm and the mesoderm. Mammary development specifically commences with an increase in quantity of ectodermal cells. The cells form a mammary band and then rapidly multiply and differentiate through mammary streak, line, crest, and hillock stages until they finally form the murine mammary bud at E12-13.5 [Veltmaat, J. *et al.* 2003. *Differentiation* 71:1-17]. The mammary bud is the structure from which the mammary gland develops and activation of the canonical Wnt pathway causes localization of the mammary bud and the mammary fat pad precursor [Chu, E. *et al.* 2004. *Development* 131:4819-4829].

[005] At E14 the mesenchyme, which has developed from the mesoderm, condenses and forms the fat pad precursor. At E15.5 each bud forms a sprout which invades the subcutaneous fat pad precursor. The sprouts form a lumen with an opening on the skin of the fetus and a nipple forms by epidermal invagination. Additionally, the sprouts continue their development by forming limited branches into the fat pad. At day 18.5 the sprouts have formed small mammary glands [Veltmaat, J. *et al.* 2003. *Differentiation* 71:1-17].

[006] By birth, the mammary gland is composed of a few rudimentary ducts, containing an outer layer of myoepithelial and an inner layer of luminal epithelial cells, surrounded

by the fat pad. Upon exposure to increased female sexual hormones at puberty, the ductal epithelium rapidly proliferates, elaborates its branching pattern and further invades the fat pad to create a mature mammary gland competent to respond to signals during pregnancy when the epithelium further proliferates and differentiates [Hennighausen, L. *et al.* 1998. *Genes Dev* 12:449-455]. Indeed, the sprouts of embryonic development have formed a simple mammary gland which is composed of many hollow ducts each ending in a terminal end bud (TEB). While the female is pregnant and while the female is lactating, these TEBs continue the growth of the simple mammary gland, increasing the branching of the gland, and ultimately increasing the number of alveoli in the breast tissue. When the growth of each simple mammary gland is completed, the fat pad of the breast is fully filled by the ductal trees of the simple mammary glands. The mammary gland is considered mature following this final growth during pregnancy and lactation and the complex mammary gland is composed of many simple mammary glands as a group.

[007] The lumen of the duct is lined with luminal epithelial cells near the TEB and with ductal epithelial cells in the milk ducts. At the end of each mature branch, lobular cells form secretory acinar structures which become the milk secreting alveolar cells during pregnancy [Woodward, W. *et al.* 2005. *J Cell Sci.* 118:3585-3594].

[008] The massive expansion of mammary epithelium during puberty and pregnancy, together with the remarkable regenerative capacity apparent during successive reproductive cycles, implicate the existence of a mammary stem cell. In fact, stem-like cells from mature mammary glands have been isolated and their ability to reconstitute the different epithelial lineages *in vitro* and functional ductal trees through limiting dilution transplants *in vivo* has been demonstrated [Shackleton, M., Vaillant, F., Simpson, K. J., Stingl, J., Smyth, G. K., Asselin-Labat, M. L., Wu, L., Lindeman, G. J., and Visvader, J. E. (2006), *Nature* 439, 84-88; Stingl, J., Eirew, P., Ricketson, I., Shackleton, M., Vaillant, F., Choi, D., Li, H. I., and Eaves, C. J. (2006), *Nature* 439, 993-997]. However, the signals that regulate mammary stem cells have yet not been defined.

[009] The Role of the Wnt Pathway

[0010] Wnts are cysteine-rich glycoproteins that initiates signals by binding to a protein complex containing a member of the Frizzled family of seven transmembrane receptors and a molecule with homology to the low-density lipoprotein (LDL) receptor (LRP5 or LRP6) [Logan, C.Y. and R. Nusse, *Annu Rev Cell Dev Biol*, 2004. 20:781-810]. This down-regulates glycogen synthase kinase-3 (GSK-3) activity. Normally, GSK-3 phosphorylates  $\beta$ -catenin, marking it for ubiquitin-dependent degradation. Inhibition of

GSK-3 increases  $\beta$ -catenin levels in the cytosol and nucleus, allowing physical interaction with the Tcf/Lef class of DNA-binding proteins and activation of specific target promoters [Logan, C.Y. and R. Nusse, *Annu Rev Cell Dev Biol*, 2004. 20:781-810]. Wnt proteins are a family of highly conserved secreted growth factors [Miller, J.R., 2002. *Genome Biol.* 3:3001]. Although Fzd proteins have been implicated in other pathways, recent work shows that LRP5 and LRP6 are specifically required for the canonical Wnt pathway [Liu, G., et al., 2005, *Mol Cell Biol* 25:3475-3482].

[0011] LRP5 and LRP6 are 71% identical and homologous to the low-density lipoprotein receptor (LDLR) [Brown, S.D., et al., *Biochem Biophys Res Commun*, 1998. 248(3): p. 879-88; Chen, D., W. Lathrop, and Y. Dong, *Genomics*, 1999. 55(3): 314-21; Dong, Y., et al., *Biochem Biophys Res Commun*, 1998. 251(3):784-90; Hey, P.J., et al., *Gene*, 1998. 216(1):103-11]. Several reports link *LRP5* and *LRP6* to Wnt signaling. First, *LRP6*-deficient mice display phenotypes similar to those seen in several Wnt gene knockouts [Pinson, K.I., et al., *Nature*, 2000. 407(6803):535-8]. In addition, *arrow*, the *Drosophila* homolog of *LRP5* and *LRP6*, is required for Wnt signaling in the fly [Wehrli, M., et al., *Nature*, 2000. 407(6803):527-30]. mRNA encoding *LRP6* induces a secondary axis when injected into the ventral region of the developing *Xenopus* embryo [Tamai, K., et al., *Nature*, 2000. 407(6803): p. 530-5]. *LRP5* mRNA synergizes with mRNAs from other components of the pathway to induce a secondary axis, but was unable to do so on its own. Frizzleds and LRP6 form a physical complex in a Wnt-dependent manner [Tamai, K., et al., *Nature*, 2000. 407(6803):530-5].

[0012] The Dickkopf (Dkk) family of secreted proteins is an antagonist of the canonical Wnt pathway [Bafico, A. *et al.* 2001, *Nat Cell Biol* 3:683-686.; Mao, B. *et al.* 2001, *Nature* 411:321-325]. Specifically, Dkk-1, Dkk-2, or Dkk-4 competitively inhibits Wnt signaling through the binding of LRP5 or LRP6 and Kremen cell surface receptors. Mice overexpressing Dkk1 in the skin also fail to develop mammary glands [Andl, T., et al., *Dev Cell*, 2002. 2(5):643-53]. Dkk1 inhibits the Wnt signaling pathway by binding to, and presumably inactivating, LRP5 and LRP6.

[0013] In addition, other proteins regulate the activity of the Wnt pathway at several levels. Secreted Frizzled-related proteins (SFRPs) or FRZBs as well as other secreted proteins like Norrin, connective tissue growth factor and Kremen regulate signaling at the level of the Wnt/Frizzled/LRP interaction, while other proteins, including APC, control the pathway intracellularly [Finch, P.W., et al., *Proc Natl Acad Sci U S A*, 1997. 94(13):6770-5; Wang, S., M. Krinks, and M. Moos, Jr., *Biochem Biophys Res Commun*,

1997. 236(2):502-4, Xu, Q., et al., Cell, 2004. 116(6): 883-95], Dickkopf [Semenov, M.V., et al., Curr Biol, 2001. 11(12):951-61; Mao, B., et al., Nature, 2001. 411(6835):321-5], Wise [Itasaki, N., et al., Development, 2003. 130(18):4295-305], connective tissue growth factor [Mercurio, S., et al., Development, 2004. 131(9):2137-47], and Kremen [Mao, B., et al., Nature, 2002. 417(6889):664-7; Logan, C.Y. and R. Nusse, Annu Rev Cell Dev Biol, 2004. 20:781-810].

**[0014]** Signaling by the Wnt family of secreted lipoproteins plays a central role in development and disease [Cadigan, K. M., and Nusse, R. (1997), Wnt signaling: a common theme in animal development. *Genes Dev* 11, 3286-3305; Nusse, R. (2005), *Cell Res* 15, 28-32; Polakis, P. (2000), *Genes Dev* 14, 1837-1851]. At the cellular level, Wnt proteins regulate a broad range of functions including self-renewal and differentiation of stem cells [Li, L., and Xie, T. (2005), *Annu Rev Cell Dev Biol* 21, 605-631; Reya, T., Duncan, A. W., Ailles, L., Domen, J., Scherer, D. C., Willert, K., Hintz, L., Nusse, R., and Weissman, I. L. (2003), *Nature* 423, 409-414]. Activation of the canonical Wnt cascade is initiated by binding of Wnt proteins to cell surface receptors composed of a member of the Frizzled (Fzd) protein family and one of the Low-density lipoprotein receptor-related proteins LRP5 or LRP6 [Schweizer, L., and Varmus, H. (2003), *BMC Cell Biol* 4, 4; Sharpe, C., Lawrence, N., and Martinez Arias, A. (2001), *Bioessays* 23, 311-318]. The cDNA and amino acid sequences for LRP6 for *Homo sapiens* are attached hereto as SEQ ID NOS.: 1 and 2 in the Sequence Listing. The cDNA and amino acid sequences for LRP6 for *mus musculus* are attached hereto as SEQ ID NOS.: 3 and 4 in the Sequence Listing. While Wnt-Frizzled interactions may also be involved in noncanonical Wnt signaling events, the LRP5/6 moiety appears to be specifically required for the canonical pathway [Liu, G., Bafico, A., and Aaronson, S. A. (2005). *Mol Cell Biol* 25, 3475-3482].

**[0015]** Studies in mice suggest that canonical Wnt signaling plays a significant role during normal mammary gland development which begins at approximately embryonic day 10.5 with the formation of two “mammary lines” [Andl, T., Reddy, S. T., Gaddapara, T., and Millar, S. E. (2002), *Dev Cell* 2, 643-653; Brisken, C., Heineman, A., Chavarria, T., Elenbaas, B., Tan, J., Dey, S. K., McMahon, J. A., McMahon, A. P., and Weinberg, R. A. (2000), *Genes Dev* 14, 650-654; Hsu, W., Shakya, R., and Costantini, F. (2001), *J Cell Biol* 155, 1055-1064; Tepera, S. B., McCrea, P. D., and Rosen, J. M. (2003), *J Cell Sci* 116, 1137-1149; van Genderen, C., Okamura, R. M., Farinas, I., Quo, R. G., Parslow, T. G., Bruhn, L., and Grosschedl, R. (1994), *Genes Dev* 8, 2691-2703; Veltmaat, J. M., Mailleux, A. A., Thiery, J. P., and Bellusci, S. (2003), *Differentiation* 71, 1-17]. In

response to signals from the underlying mesenchyme, the mammary lines give rise to five pairs of lens-shaped mammary placodes which subsequently transform into buds of epithelial cells and sink into the dermis. Activation of the canonical Wnt signaling pathway along the mammary lines coincides with the initiation of mammary morphogenesis, and subsequently localizes to mammary placodes and buds [Chu, E. Y., Hens, J., Andl, T., Kairo, A., Yamaguchi, T. P., Briskin, C., Glick, A., Wysolmerski, J. J., and Millar, S. E. (2004), *Development* 131, 4819-4829]. Several Wnt ligands and receptor genes, including *LRP6* (*Is this correct*), are expressed during embryonic mammary morphogenesis [Chu, E. Y., Hens, J., Andl, T., Kairo, A., Yamaguchi, T. P., Briskin, C., Glick, A., Wysolmerski, J. J., and Millar, S. E. (2004), *Development* 131, 4819-4829]. Embryos expressing the canonical Wnt inhibitor Dkk1 display a complete block in the formation of mammary placodes and mice deficient for *Lef-1* fail to maintain their mammary buds [Andl, T., Reddy, S. T., Gaddapara, T., and Millar, S. E. (2002), *Dev Cell* 2, 643-653; van Genderen, C., Okamura, R. M., Farinas, I., Quo, R. G., Parslow, T. G., Bruhn, L., and Grosschedl, R. (1994), *Genes Dev* 8, 2691-2703] suggesting that Wnt signals might regulate embryonic mammary development. Dkk1 inhibits the Wnt signaling pathway by binding to, and presumably inactivating, LRP5 and LRP6 [Bafico, A., Liu, G., Yaniv, A., Gazit, A., and Aaronson, S. A. (2001), *Nat Cell Biol* 3, 683-686].

**[0016]** In addition to playing a key role in normal embryonic development, the Wnt pathway later plays a significant role in somatic stem cell renewal and determination [Li, L., *et al.* 2005. Stem cell niche: structure and function. *Annu Rev Cell Dev Biol* 21:605-631; Reya, T. *et al.* 2003, *Nature* 423:409-414]. Based on what pathway they are active in, Wnt proteins are divided into two types: canonical and noncanonical. Wnts classified as canonical include, but are not limited to Wnt1, Wnt2, Wnt3, Wnt3a, and Wnt8 [Liu, G. *et al.* 2005, *Mol Cell Biol* 25:3475-3482].

**[0017]** Tissue specific stem cell compartments, including that of the mammary gland, are formed during embryogenesis [Li, L., and Xie, T. (2005), *Annu Rev Cell Dev Biol* 21, 605-631]. Analysis of transgenic mice carrying the TOPGAL or BAT-gal Wnt reporter gene shows that canonical Wnt signaling is specifically active during embryonic mammary development [Chu, E. Y., Hens, J., Andl, T., Kairo, A., Yamaguchi, T. P., Briskin, C., Glick, A., Wysolmerski, J. J., and Millar, S. E. (2004), *Development* 131, 4819-4829], and its requirement is acute as mammary placodes fail to develop in transgenic mice overexpressing the Wnt inhibitor Dkk1 [Andl, T., Reddy, S. T., Gaddapara, T., and Millar, S. E. (2002), *Dev Cell* 2, 643-653].

- [0018] Outgrowth of a full mammary branching tree from limiting dilutions of mammary epithelial cell transplants is considered to be an assay of clonal stem cell function [Kordon, E. C., and Smith, G. H. (1998), *Development* 125, 1921-1930]. Surgical removal of the area between the nipple and the fat pad at three weeks of age leaves a fat pad free of the endogenous mammary epithelium. Mammary cells from another syngenic animal can be implanted and will develop an epithelial tree if the transplant contains cells with stem cell activity. One benefit of this technique is that the transplanted cells are exposed to normal circulating hormone levels and wild type stroma.
- [0019] Canonical Wnt signaling has emerged as a critical regulatory pathway for stem cells. The association between ectopic activation of Wnt signaling and many different types of human cancer suggests that Wnt ligands can initiate tumor formation through altered regulation of stem cell populations.
- [0020] Tumors induced by Wnt effectors are normally composed of both epithelial and myoepithelial cells, suggesting that they are derived from the transformation of multipotential progenitor cells [Li, Y., Welm, B., Podsypanina, K., Huang, S., Chamorro, M., Zhang, X., Rowlands, T., Egeblad, M., Cowin, P., Werb, Z., *et al.* (2003), *Proc Natl Acad Sci U S A* 100, 15853-15858; Liu, B. Y., McDermott, S. P., Khwaja, S. S., and Alexander, C. M. (2004), *Proc Natl Acad Sci U S A* 101, 4158-4163; Owens, D. M., and Watt, F. M. (2003), *Nat Rev Cancer* 3, 444-451; Rosner, A., Miyoshi, K., Landesman-Bollag, E., Xu, X., Seldin, D. C., Moser, A. R., MacLeod, C. L., Shyamala, G., Gillgrass, A. E., and Cardiff, R. D. (2002), *Am J Pathol* 161, 1087-1097].
- [0021] A growing body of evidence suggests that specific subtypes of the most common human tumors including breast [Al-Hajj, M., Wicha, M. S., Benito-Hernandez, A., Morrison, S. J., and Clarke, M. F. (2003), *Proc Natl Acad Sci U S A* 100, 3983-3988], lung [Kim, C. F., Jackson, E. L., Woolfenden, A. E., Lawrence, S., Babar, I., Vogel, S., Crowley, D., Bronson, R. T., and Jacks, T. (2005), *Cell* 121, 823-835] and colon [Radtke, F., and Clevers, H. (2005), *Science* 307, 1904-1909] originate in stem cell compartments. Signaling pathways that regulate stem cell activity could therefore be effective drug targets. In fact, several studies have shown that activation of canonical Wnt signaling is common in human breast cancer [Lin, S. Y., Xia, W., Wang, J. C., Kwong, K. Y., Spohn, B., Wen, Y., Pestell, R. G., and Hung, M. C. (2000), *Proc Natl Acad Sci U S A* 97, 4262-4266; Ugolini, F., Charafe-Jauffret, E., Bardou, V. J., Geneix, J., Adelaide, J., Labat-Moleur, F., Penault-Llorca, F., Longy, M., Jacquemier, J., Birnbaum, D., and Pebusque, M. J. (2001), *Oncogene* 20, 5810-5817; Klopocki, E., Kristiansen, G., Wild, P. J., Klamann,

I., Castanos-Velez, E., Singer, G., Stohr, R., Simon, R., Sauter, G., Leibiger, H., et al. (2004), *Int J Oncol* 25, 641-649].

[0022]

A connection between mammary stem/progenitor cells and Wnt1- or  $\beta$ -catenin-induced tumorigenesis has recently been established. Transgenic expression of these genes result in widespread mammary hyperplasia and rapid tumor formation [Imbert, A., Eelkema, R., Jordan, S., Feiner, H., and Cowin, P. (2001), *J Cell Biol* 153, 555-568; Nusse, R., and Varmus, H. E. (1982), *Cell* 31, 99-109; Tsukamoto, A. S., Grosschedl, R., Guzman, R. C., Parslow, T., and Varmus, H. E. (1988), *Cell* 55, 619-625]. The hyperplastic tissue contains an increased ratio of mammary stem/progenitor cells which are thought to directly give rise to transformed cells [Li, Y., Welm, B., Podsypanina, K., Huang, S., Chamorro, M., Zhang, X., Rowlands, T., Egeblad, M., Cowin, P., Werb, Z., et al. (2003), *Proc Natl Acad Sci U S A* 100, 15853-15858; Liu, B. Y., McDermott, S. P., Khwaja, S. S., and Alexander, C. M. (2004), *Proc Natl Acad Sci U S A* 101, 4158-4163; Shackleton, M., Vaillant, F., Simpson, K. J., Stingl, J., Smyth, G. K., Asselin-Labat, M. L., Wu, L., Lindeman, G. J., and Visvader, J. E. (2006), *Nature* 439, 84-88]. Tumors arising from stem/progenitor cells often show mixed lineage differentiation [Owens, D. M., and Watt, F. M. (2003), *Nat Rev Cancer* 3, 444-451] and tumors induced by Wnt effectors indeed contain cells from both epithelial lineages [Li, Y., Welm, B., Podsypanina, K., Huang, S., Chamorro, M., Zhang, X., Rowlands, T., Egeblad, M., Cowin, P., Werb, Z., et al. (2003), *Proc Natl Acad Sci U S A* 100, 15853-15858; Liu, B. Y., McDermott, S. P., Khwaja, S. S., and Alexander, C. M. (2004), *Proc Natl Acad Sci U S A* 101, 4158-4163; Rosner, A., Miyoshi, K., Landesman-Bollag, E., Xu, X., Seldin, D. C., Moser, A. R., MacLeod, C. L., Shyamala, G., Gillgrass, A. E., and Cardiff, R. D. (2002), *Am J Pathol* 161, 1087-1097].

[0023]

Alterations in Wnt signaling occur in many human tumors [Taipale, J. and P.A. Beachy, *Nature*, 2001. 411(6835):349-54]. These changes increase the cytoplasmic level of  $\beta$ -catenin. This can occur via loss of both copies of the *adenomatous polyposis coli* (*APC*) gene. *APC* was first identified as a gene mutated in families in which individuals develop hundreds of colon polyps, some of which undergo malignant transformation [Polakis, P., *Biochim Biophys Acta*, 1997. 1332(3):F127-47]. At the cellular level, loss of *APC* function inhibits  $\beta$ -catenin degradation [Polakis, P., *Genes Dev*, 2000. 14(15):1837-51]. Thus,  $\beta$ -catenin levels increase and eventually cause excess target gene activation. Loss-of-function mutations in the *axin* or *conductin* genes are associated with hepatocellular and colorectal carcinomas [Sato, S., et al., *Nature Genetics*, 2000. 24: p.

245-250; Liu, W., et al., Nat Genet, 2000. 26(2):146-7]. Many human tumors contain alterations in  $\beta$ -catenin, typically point mutations in the GSK3 phosphorylation sites that produce a protein that cannot be degraded [Polakis, P., Current Opinion in Genetics and Development, 1999. 9:15-21]. Moreover, several human tumor types contain alterations in Wnt signaling for which the underlying mutation is undefined (for example, see [Rimm, D.L., et al., Am J Pathol, 1999. 154(2):325-9].

[0024] The association of inappropriate Wnt signaling and mammary tumorigenesis has been appreciated since the cloning of *Wnt1* as a gene whose expression was up-regulated by mouse mammary tumor virus (MMTV) integrations [Nusse, R. and H.E. Varmus, Cell, 1982. 31(1):99-109]. Alterations of several other genes in the pathway have also been associated with mammary pathology. For example, as many as 45% of breast fibromatosis cases examined in one study contained activating mutations in  *$\beta$ -catenin* [Abraham, S.C., et al., Hum Pathol, 2002. 33(1):39-46]. Fibromatosis are benign stromal lesions in the breast. A more direct link to breast carcinoma is that the large majority of human breast tumors overexpress cytoplasmic and nuclear levels of  $\beta$ -catenin, a hallmark of activation of the canonical Wnt signaling pathway [Lin, S.Y., et al., Proc Natl Acad Sci U S A, 2000. 97(8):4262-6; Ryo, A., et al., Nat Cell Biol, 2001. 3(9):793-801]. Activation of the pathway is one of the more common events associated with human breast cancer. For example, many human breast tumors up-regulate Pin1, which inhibits  $\beta$ -catenin degradation by preventing its association with APC [Ryo, A., et al., Nat Cell Biol, 2001. 3(9): p. 793-801; Wulf, G.M., et al., Embo J, 2001. 20(13):3459-72]. Another recent report links amplification and overexpression of Dishevelled1, a positively acting component of the pathway upstream of GSK3, to breast cancer [Nagahata, T., et al., Cancer Sci, 2003. 94(6):515-8]. Further reinforcing the importance of Wnt signaling in breast cancer, a recent report has linked down-regulation of the secreted Wnt inhibitors sFRP1 to breast cancer [Ugolini, F., et al., Oncogene, 2001. 20(41): p. 5810-7; Klopocki, E., et al., Int J Oncol, 2004. 25(3):641-9] and Wif1 [Wissmann, C., et al., J Pathol, 2003. 201(2):204-12].

[0025] Aberrant canonical Wnt activation in somatic stem cells has been associated with a variety of diseases in addition to breast cancer. Activating mutations have been identified in both ovarian and breast carcinomas [Bafico, A. et al. 2004. Cancer Cell 6:497-505], hepatocellular carcinoma, hepatoblastoma, gastric carcinoma, melanoma, prostate cancer, thyroid carcinoma, medulloblastoma, and Wilm's tumor [Li, Y. et al. 2005. Future Oncol 1:673-681]. Additionally, the canonical Wnt pathway has been implicated in adenomas,

pliomatricomas, and trichofolliculomas [Reya, T. *et al.* 2005. *Nature* 434:843-850]. Finally, aberrant canonical Wnt expression has been involved in neurodegeneration [Caricasole, A. *et al.* 2005. *Biosci Rep* 25:309-327], as in Alzheimer's disease and Parkinson's disease.

**[0026]** Tumors induced by Wnt effectors ultimately arise within a context of widespread mammary hyperplasia that is noticeable as early in development as embryonic day 18 [Tsukamoto, A. S., Grosschedl, R., Guzman, R. C., Parslow, T., and Varmus, H. E. (1988), *Cell* 55, 619-625]. The hyperplastic mammary tissue of Wnt1 transgenic mice contains an increased ratio of mammary progenitor cells [Li, Y., Welm, B., Podsypanina, K., Huang, S., Chamorro, M., Zhang, X., Rowlands, T., Egeblad, M., Cowin, P., Werb, Z., *et al.* (2003), *Proc Natl Acad Sci U S A* 100, 15853-15858; Liu, B. Y., McDermott, S. P., Khwaja, S. S., and Alexander, C. M. (2004), *Proc Natl Acad Sci U S A* 101, 4158-4163; Shackleton, M., Vaillant, F., Simpson, K. J., Stingl, J., Smyth, G. K., Asselin-Labat, M. L., Wu, L., Lindeman, G. J., and Visvader, J. E. (2006), *Nature* 439, 84-88]. These progenitor cells are thought to directly give rise to transformed cells.

**[0027]** Branching complexity of adult mice is a function of terminal end bud (TEB) activity during juvenile ductal extension. TEBs normally disappear when the ductal tree is fully branched and fill the fat pad.

**[0028]** Canonical Wnt signaling has been implicated in the regulation of various stem cells including hematopoietic, intestinal and epidermal stem cells [Reya, T., and Clevers, H. (2005), *Nature* 434, 843-850]. For example, soluble Wnt proteins promote growth and inhibit differentiation of hematopoietic stem cells [Reya, T., Duncan, A. W., Ailles, L., Domen, J., Scherer, D. C., Willert, K., Hintz, L., Nusse, R., and Weissman, I. L. (2003), *Nature* 423, 409-414]. Wnt signaling also inhibits differentiation of stem cells in the intestinal epithelium and in hair follicles [Huelsenken, J., Vogel, R., Erdmann, B., Cotsarelis, G., and Birchmeier, W. (2001), *Cell* 105, 533-545; Korinek, V., Barker, N., Moerer, P., van Donselaar, E., Huls, G., Peters, P. J., and Clevers, H. (1998), *Nat Genet* 19, 379-383; van de Wetering, M., Sancho, E., Verweij, C., de Lau, W., Oving, I., Hurlstone, A., van der Horn, K., Battle, E., Coudreuse, D., Haramis, A. P., *et al.* (2002), *Cell* 111, 241-250]. Importantly, in many of the same tissues where the Wnt cascade controls stem cells, deregulation of Wnt signaling leads to tumor formation. Stabilization of  $\beta$ -catenin in the intestinal epithelium or overexpression of  $\beta$ -catenin in the epidermis result in the development of intestinal adenomas and hair tumors, respectively [Dietrich, W. F., Lander, E. S., Smith, J. S., Moser, A. R., Gould, K. A., Luongo, C., Borenstein, N., and

Dove, W. (1993), *Cell* 75, 631-639; Gat, U., DasGupta, R., Degenstein, L., and Fuchs, E. (1998), *Cell* 95, 605-614]. This suggests that Wnt ligands can initiate tumor formation through altered regulation of stem cell populations. Consistently, mice that overexpress Wnt signaling effectors in the mammary epithelium develop tumors with stem/progenitor cell properties, in contrast to mice overexpressing several other oncogenes [Li, Y., Welm, B., Podsypanina, K., Huang, S., Chamorro, M., Zhang, X., Rowlands, T., Egeblad, M., Cowin, P., Werb, Z., *et al.* (2003), *Proc Natl Acad Sci U S A* 100, 15853-15858]. The pre-neoplastic hyperplasia contain an increased ratio of cells positive for various mammary progenitor cell markers and the likelihood of progression to carcinoma correlates with the overall number of progenitor cells [Li, Y., Welm, B., Podsypanina, K., Huang, S., Chamorro, M., Zhang, X., Rowlands, T., Egeblad, M., Cowin, P., Werb, Z., *et al.* (2003), *Proc Natl Acad Sci U S A* 100, 15853-15858; Liu, B. Y., McDermott, S. P., Khwaja, S. S., and Alexander, C. M. (2004), *Proc Natl Acad Sci U S A* 101, 4158-4163) (Shackleton, M., Vaillant, F., Simpson, K. J., Stingl, J., Smyth, G. K., Asselin-Labat, M. L., Wu, L., Lindeman, G. J., and Visvader, J. E. (2006), *Nature* 439, 84-88]. In addition, mammary ductal cells from pre-neoplastic Wnt1 transgenic mice exhibit an increase ability to reconstitute ductal trees in limiting dilution experiments [Liu, B. Y., McDermott, S. P., Khwaja, S. S., and Alexander, C. M. (2004), *Proc Natl Acad Sci U S A* 101, 4158-4163; Shackleton, M., Vaillant, F., Simpson, K. J., Stingl, J., Smyth, G. K., Asselin-Labat, M. L., Wu, L., Lindeman, G. J., and Visvader, J. E. (2006), *Nature* 439, 84-88], a method employed to test the frequency and division potential of ductal stem cells. This finding again demonstrates the ability of the Wnt pathway to target stem cells for transformation, possibly reflecting a role of the Wnt pathway in the self-renewal of normal breast epithelium.

[0029]            The Cancer Stem Cell Model for Carcinogenesis.

[0030]            For decades, oncologists have focused on developing therapeutic approaches that shrink tumor mass [Reya, T., et al., *Nature*, 2001. 414(6859):105-11]. Unfortunately, while many treatments could dramatically shrink tumors initially, recurrence of the initial tumor is common. Recently, a new model has been proposed that may explain these observations [Reya, T., et al., *Nature*, 2001. 414(6859):105-11]. This “cancer stem cell” model postulates that, in many cases, the cell that is transformed is a cell with pluripotent capabilities. The phenotypic manifestation seen in the tumor is mostly the result of cells that have differentiated from the transformed pluripotent cells. Treatments that shrink the majority of the tumor by attacking the differentiated cells may not affect the small

population of pluripotent cells that actually give rise to the tumor. Thus, the tumor recurs and eventually becomes resistant to any known treatment, leading to metastatic progression and, ultimately, the death of the patient. Thus, what is needed to increase success in treating cancer are therapies that target the stem cells within the tumor. Thus, various investigations have been undertaken to examine targeting stem cells as a therapy for cancer. [Yilmaz, O.H., Valdez, R., Theisen, B.K., Guo, W., Ferguson, D.O., Wu, H., Morrison, S.J., Nature, 2006; 1-8; Rossi, D.J., Weissman, I.L., Cell, April 21, 2006; 125:229-231].

**[0031]** Mammary malignancies have been shown to have a stem cell component that propagates the tumor (Al-Hajj M et al. Proc Natl Acad Sci USA 2003,100:3983-8). Thus, cell surface markers for mammary tumor stem cells are of great value in targeting the stem cell population of a mammary tumor. The strong association between Wnt signaling and stem cell regulation is of importance to targeting stem cells within tumors. Activation of the Wnt signaling pathway is associated with expansion of the hematopoietic stem cell compartment, maintenance of muscle stem cells, and regulation of stem cells in the skin [Willert, K., et al., Nature, 2003. 423(6938): p. 448-52; Reya, T., et al., Nature, 2003. 423(6938):409-14; Polesskaya, A., P. Seale, and M.A. Rudnicki, Cell, 2003. 113(7):841-52; Alonso, L. and E. Fuchs, Genes Dev, 2003. 17(10):1189-200; Merrill, B.J., et al., Genes Dev, 2001. 15(13):1688-705]. Reports link Wnt signaling to the regulation of mammary stem cells [Li, Y., et al., Proc Natl Acad Sci U S A, 2003. 100(26):15853-8; Liu, B.Y., et al., Proc Natl Acad Sci USA, 2004. 101(12):4158-63]. Overall, the present disclosure has identified Wnt signaling as a key to maintaining pluripotency, and the role of LRP6 in Wnt signaling in cancer stem cells and carcinogenesis, particularly as it relates to breast cancers involving basal-like cells.

#### SUMMARY OF THE INVENTION

**[0032]** The present invention includes a method for enriching a population of somatic mammary cells or mammary tumor cells for mammary stem cells or mammary tumor stem cells using low density lipoprotein-receptor-related protein 6 (LRP6) as a cell surface marker. This method includes obtaining said population, contacting said population with an anti-LRP6 antibody, and selecting the cells that bind the LRP6 antibody. In other embodiments, the population of mammary cells or mammary tumor cells is a population of human, mouse, or rat cells; the antibody is attached to a solid matrix; cells that bind to the antibody are selected by flow cytometry; the top 10% or higher of the highest LRP6 expressing mammary cells or mammary tumor cells of the total population is selected; or

the method is for enriching a population of mammary cells for somatic mammary stem cells. In further embodiments, the method also includes the step of contacting the population of mammary cells with an antibody against a cell surface marker for endothelial cells, hematopoietic cells, or stromal cells wherein cells that bind to the anti-LRP6 antibody but not the antibody against the cell surface marker for endothelial cells, hematopoietic cells, or stromal cells are selected; at least 1% of the selected cells are somatic mammary stem cells; or at least 5% of the selected cells are somatic mammary stem cells.

**[0033]** The present invention also includes a method of screening for agents that modulate Wnt signaling in mammary tumor stem or progenitor cells including: providing a mammary cell that has low density lipoprotein receptor-related protein 6 (LRP6) activity and attenuated low density lipoprotein receptor-related protein 5 (LRP5) activity; selecting an agent that may be an LRP6 modulator; exposing the cell to the agent; performing an assay on the cell for LRP6 activity; and concluding from the assay whether Wnt signaling is modulated in the mammary cell. In other embodiments: the cell is an LRP5 knock-out cell; the selected agent inhibits LRP6, is an RNAi for LRP6, is an antibody for LRP6, or is an antibody for LRP6 carrying a toxic moiety; or the LRP6 activity is determined by measuring the level of LRP6 mRNA or protein, by measuring the level or activity of GSK3, by measuring the level of  $\beta$ -catenin, or by measuring the activity of a Wnt pathway responsive promoter.

**[0034]** The present invention further includes a composition for reducing Wnt signaling in a cancer stem cell or progenitor cell utilizing a compound to inhibit LRP6 activity in a cancer stem cell or progenitor cell. In one embodiment of the composition, the compound inactivates LRP6 in the cancer stem cell or progenitor cell. In another embodiment the compound is an RNAi for LRP6. In a further embodiment, the mammary tumor cells or progenitor cells are basal-like cells. In further embodiments of the present invention, the compound is an antibody for LRP6, or such antibody carrying a toxic moiety.

**[0035]** The present invention further includes a method of reducing Wnt signaling in a cancer stem cell or progenitor cell in a mammal comprising administering to the mammal an effective amount of a cancer stem cell-specific or progenitor cell-specific LRP6 antagonist. In another embodiment of this method, the cancer stem cell-specific or progenitor cell-specific LRP6 antagonist inactivates LRP6 in cancer stem cells or progenitor cells in the mammal. In a further method of the present invention, the cancer stem cell-specific or progenitor cell-specific LRP6 antagonist is an RNAi for LRP6. In

another embodiment, the mammary tumor stem cell or progenitor cell is a basal-like cell. In further embodiments of the present method, the cancer stem cell-specific or progenitor cell-specific LRP6 antagonist is an antibody for LRP6, or such LRP6 antibody carries a toxic moiety.

**[0036]** The present invention also includes a method of treating a condition or disease associated with Wnt signaling comprising administering a pharmaceutical compound that inhibits LRP6 in a cancer stem cell or progenitor cell of a patient. In another embodiment, the compound is administered in an amount effective to reduce Wnt activity. In further embodiments of the present method, the pharmaceutical compound is an RNAi for LRP6, an shRNA for LRP6, an antibody specific to LRP6, or an antibody specific to LRP6 carrying a toxic moiety.

The present invention further includes a method for inhibiting the proliferation or causing the death of a mammary tumor cell that expresses LRP6 by contacting the mammary tumor cell with an agent that inhibits LRP6 activity in an amount sufficient to inhibit the proliferation or cause the death of the mammary tumor cell. In additional embodiments, the mammary tumor cell is in a mammal and the step of contacting is carried out by administering the agent to the mammal; a second tumor therapeutic agent is administered; the agent that inhibits LRP6 activity is selected from an anti-LRP6 antibody, an antisense oligonucleotide that inhibits the expression of LRP6, and an RNAi molecule that inhibits the expression of LRP6; or the anti-LRP6 antibody is linked to a cytotoxic agent. In a further embodiment, the mammary tumor cell is a basal-like cell.

**[0037]** The present invention also includes a method for detecting the presence of mammary basal-like cells in mammary tissue or a biological sample, which tissue or sample is suspected of including mammary basal-like cells, comprising the steps of: (a) contacting the tissue or sample with a diagnostically labeled LRP6 antibody; and (b) detecting the presence of the diagnostic label associated with the tissue or sample. Further embodiments of this method include contacting and detecting in vitro; contacting in vivo and detecting in vitro; and contacting and detecting in vivo. In other embodiments, the detectable label is a radionuclide, the detecting is by radioimmunosciintigraphy, or the diagnostic label is an MRI-imageable agent and the detecting is by MRI.

**[0038]** A further aspect of the present invention includes a method for diagnosing basal-like cell breast cancer comprising the steps of: (a) contacting a tissue, organ or sample of a patient with a diagnostically labeled LRP6 antibody; (b) detecting the presence of the diagnostic label associated with the tissue, organ or sample; (c) determining the level of

Lrp6 expression in the tissue, organ or sample; and (d) comparing the Lrp6 level of expression in the tissue, organ or sample to a suitable control. In an additional embodiment, the suitable control is the median or average expression level from at least 25 breast cancer patients.

**[0039]**            BRIEF DESCRIPTION OF THE DRAWINGS

**[0040]**            Figures 1A-C: LRP6 is expressed in MMTV-Wnt1 transgenic mammary glands and tumors. Shown in panels A-C are immunohistochemical staining using an LRP6 specific polyclonal antibody. LRP6 is expressed in Wnt1-induced tumors (Fig. 1A) and Wnt1-induced tumors originate from the stem cell compartment. LRP6 is also shown expressed in a fraction of mammary ductal cells from hyperplastic Wnt1 transgenic mammary gland (Fig. 1B). The arrow indicates a representative cell with positive staining. No staining was observed in *LRP6*<sup>-/-</sup> embryos, which were used as negative controls since *LRP6*<sup>-/-</sup> pups die shortly after birth (Fig. 1C).

**[0041]**            Figures 2A-D: LRP6 is expressed in the mammary. Mammary glands were isolated and stained for β-gal and β-gal is used as a marker for LRP6 expression. Fig. 2A is staining of a wild-type control mammary gland (no β-gal activity). Figs. 2B-2D are staining from *LRP6*<sup>+/-</sup> gland at various ages (β-gal expression is derived from the endogenous LRP6 locus.) Fig. 2B is an adult 11-week-old virgin female. Fig. 2C is a 5-week-old female. Fig. 2D is a female in the 12th day of pregnancy. The inset in Fig. 2C shows localization of B-gal in the myoepithelial layer (arrow) after paraffin sectioning of the whole mounts, and the stem cell population is located in the myoepithelial layer.

**[0042]**            Figure 3: *LRP6*-deficient mice have defective embryonic mammary development (whole mounts of skin pads isolated from the #4 or #9 mammary gland of E18.5 mice) and the stem cell compartment is formed during embryonic development. Note the presence of only a single mammary sprout in the *LRP6*<sup>-/-</sup> mouse relative to the *LRP6*<sup>+/+</sup> mouse (circled areas). The area of the fat pad (left panel) was abnormal in *LRP6*<sup>-/-</sup> mice (no equivalent area is present). Pictures are representative of the phenotype seen in three *LRP6*<sup>-/-</sup> embryos.

**[0043]**            Figures 4A-C: Lrp6 is expressed in the MRU fraction (stem cell fraction). Shown in Fig. 4A is a FACS sort, 10,000 events, for mammary stem cells adapted from Stingl et al, Nature. 2006 Feb 23;439(7079):993-7. The stem cells are located in the MRU fraction (right-hand-most circle). Fig. 4B is the inventors' FACS sort, 34,500 events. The luminal cells are located in the R3 fraction (left-circled portion) and the myoepithelial cells are

located in the R2 fraction (right circled-portion). LRP6 is expressed in the MRU fraction of the myoepithelial cells (Fig. 4C; R2). Only LRP6 expressing cells are shown.

[0044] Figures 5A-C: Histological expression pattern of *Lrp6* in mammary glands from new born and adult female mice. Cells that express *Lrp6* stain blue. *Lrp6* is expressed in most ductal cells until a few days after birth. In the adult, *Lrp6* expression is restricted to a small fraction of cells located in the myoepithelial cell layer.

[0045] Figures 6A-D: Mammary BAT-gal expression in the presence or absence of *Lrp6*. X-gal stained BAT-gal embryo whole mounts (Figs. 6A and 6C) and histology sections of mammary placode (Figs. 6B and 6D) at E12.5. Cells expressing BAT-gal stain blue. At E12.5 X-gal staining reveals that the mammary placodes stain dark blue in *Lrp6*<sup>+/+</sup> embryos (Fig. 6A). In *Lrp6*<sup>-/-</sup> BAT-gal transgenic embryos the staining of the mammary placodes is significantly fainter (Fig. 6C). Arrows indicate mammary placodes number 2, 3, 4, and 5. The mammary placodes of *Lrp6*<sup>-/-</sup> embryos are significantly smaller and exhibit fewer cells with BAT-gal expression than mammary placodes from littermates carrying at least one intact copy *Lrp6* (Figs. 6B and 6D).

[0046] Figures 7A and 7B: Haploinsufficiency of *Lrp6* during normal mammary development. Fig. 7A shows representative whole mount preparations (stained with carmine to reveal the ductal tree) are shown for juvenile *Lrp6*<sup>+/+</sup> (left panel) and *Lrp6*<sup>+/-</sup> (right panel) female mice. The *arrows* indicate typical terminal end buds. *LN*, lymph node. Fig. 7B shows the result of morphometric analysis of the average number of TEBs at 5 weeks. In *Lrp6*<sup>+/-</sup> females the number of TEBs is reduced by 32% ( $p = 3.8 \times 10^{-6}$ , 2-tailed t test assuming unequal variances) compared to *Lrp6*<sup>+/+</sup> littermate controls.

[0047] Figures 8A ad 8B: Emergence of *Wnt1*-induced mammary tumors is delayed in *Lrp6*<sup>+/-</sup> mice. Nine *Lrp6*<sup>+/+</sup> and 9 *Lrp6*<sup>+/-</sup> *Wnt1* transgenic female mice were palpated weekly and dates of tumor appearance recorded. As shown in Fig. 8A, data are plotted as the proportion of mice in each of the three genotypes remaining tumor-free as a function of days of age. Fig. 8B shows standard histopathological evaluation showed that *Lrp6*<sup>+/+</sup> and *Lrp6*<sup>+/-</sup> mammary tumors are moderately differentiated alveolar adenocarcinomas with mixed lineage differentiation.

[0048] Figures 9A-9C show *LRP6* mRNA expression level is upregulated in basal-like breast cancer (BLC). The normalized mRNA expression values of *LRP6* in BLC (class 2) and non-BLC (class 1) breast tumors are shown in Fig. 9A and Fig. 9B (Richardson and Farmer studies, respectively). The line inside the boxes represents the sample with the median expression value of *LRP6*. The upper and lower bars represent samples with *LRP6*

expression values in the 75<sup>th</sup> percentile and in the 25<sup>th</sup> percentile, respectively. Asterisks indicate samples with highest or lowest *LRP6* expression values. Shown in Fig. 9C is a comparison of the normalized mRNA expression values of *LRP6* in 18 BLC and 20 non-BLC subtype tumors and seven normal breast (n) samples (expression values were downloaded from Richardson et al. Cancer Cell. 2006 Feb;9(2):121-32). The scales are in log<sub>2</sub>.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0049] The preferred embodiments of the present invention may be understood more readily by reference to the following detailed description of the specific embodiments and the Examples and Sequence Listing included hereafter.

[0050] The text file filed concurrently with this application, titled "VAN67P380.txt" contains material identified as SEQ ID NO: 1-4, which material is incorporated herein by reference. This text file was created on May 30, 2007, and is 45,056 bytes.

[0051] As used herein, "antibody" means an immunoglobulin molecule immunologically reactive with a particular antigen, and includes both polyclonal and monoclonal antibodies. The term also includes genetically engineered forms such as chimeric antibodies (e.g., humanized murine antibodies) and heteroconjugate antibodies (e.g., bispecific antibodies). A "chimeric antibody" is an antibody molecule in which (a) the constant region, or a portion thereof, is altered, replaced or exchanged so that the antigen binding site (variable region) is linked to a constant region of a different or altered class, effector function and/or species, or an entirely different molecule which confers new properties to the chimeric antibody, e.g., an enzyme, toxin, hormone, growth factor, drug, etc.; or (b) the variable region, or a portion thereof, is altered, replaced or exchanged with a variable region having a different or altered antigen specificity.

[0052] Methods for humanizing or primatizing non-human antibodies are well known in the art. Generally, a humanized antibody has one or more amino acid residues introduced into it from a source which is non-human. These non-human amino acid residues are often referred to as import residues, which are typically taken from an import variable domain. Humanization can be essentially performed following the method of Winter and co-workers (see, e.g., Jones et al., Nature 321:522-525 (1986); Riechmann et al., Nature 332:323-327 (1988); Verhoeyen et al., Science 239:1534-1536 (1988) and Presta, Curr. Op. Struct. Biol. 2:593-596 (1992)), by substituting rodent CDRs or CDR sequences for the corresponding sequences of a human antibody. Accordingly, such humanized antibodies are chimeric antibodies (U.S. Pat. No. 4,816,567), wherein substantially less

than an intact human variable domain has been substituted by the corresponding sequence from a non-human species. In practice, humanized antibodies are typically human antibodies in which some CDR residues and possibly some FR residues are substituted by residues from analogous sites in rodent antibodies.

**[0053]** The term “antibody” includes bivalent or bispecific molecules, diabodies, triabodies, and tetrabodies. Bivalent and bispecific molecules are described in, e.g., Kostelny et al. *J Immunol* 1992, 148:1547, Pack and Pluckthun *Biochemistry* 1992, 31:1579, Zhu et al. *Protein Sci* 1997, 6:781, Hu et al. *Cancer Res.* 1996, 56:3055, Adams et al. *Cancer Res.* 1993, 53:4026, and McCartney, et al. *Protein Eng.* 1995, 8:301. The term “antibody” also includes antigen binding forms of antibodies, including fragments with antigen-binding capability (e.g., Fab', F(ab')<sub>2</sub>, Fab, Fv and rIgG) and recombinant single chain Fv fragments (scFv). Antibodies exist, e.g., as intact immunoglobulins or as a number of well-characterized fragments produced by digestion with various peptidases. Thus, for example, pepsin digests an antibody below the disulfide linkages in the hinge region to produce F(ab)'.sub.2, a dimer of Fab which itself is a light chain joined to V.sub.H-C.sub.H1 by a disulfide bond. The F(ab)'.sub.2 may be reduced under mild conditions to break the disulfide linkage in the hinge region, thereby converting the F(ab)'.sub.2 dimer into an Fab' monomer. The Fab' monomer is essentially Fab with part of the hinge region (see *Fundamental Immunology* (Paul ed., 3d ed. 1993)). While various antibody fragments are defined in terms of the digestion of an intact antibody, one of skill will appreciate that such fragments may be synthesized de novo either chemically or by using recombinant DNA methodology. Thus, the term antibody, as used herein, also includes antibody fragments either produced by the modification of whole antibodies, or those synthesized de novo using recombinant DNA methodologies (e.g., single chain Fv) or those identified using phage display libraries (see, e.g., McCafferty et al., *Nature* 348:552-554 (1990)).

**[0054]** Preferably, antibodies employed to practice the present invention bind to a selected target antigen on the surface of a cell with an affinity (association constant) of greater than or equal to  $10^7 \text{ M}^{-1}$ . When an antibody is referred to as specific for a particular antigen, it means that the binding reaction is determinative of the presence of the antigen in a heterogeneous population of proteins and other biologics. Thus, under suitable conditions, the specified antibodies bind to a particular protein sequences at least two times the background and more typically more than 10 to 100 times the background.

**[0055]** As used herein, the term "an effective amount" means an amount of the compound or pharmaceutical composition that produces a statistically significant result. For example, with respect to the present invention, an effective amount of a compound or pharmaceutical composition means an amount that provides a statistically significant reduction in Wnt signaling; or the stabilization of or reversal of a disease or condition associated with Wnt signaling. An effective amount can be determined using known techniques, depending upon variables such as the particular disease or condition treated, the patient, the patient condition, the method of administration, the formulation, and other factors. An effective amount is demonstrated by a statistically significant difference in Wnt signaling between a treatment group and a control group.

**[0056]** The term "biological sample" means any fluid or other material derived from the body of a normal or diseased subject, such as blood, serum, plasma, lymph, urine, saliva, tears, cerebrospinal fluid, milk, amniotic fluid, bile, ascites fluid, pus and the like. Also included within the meaning of this term is a organ or tissue extract and a culture fluid in which any cells or tissue preparation from the subject has been incubated.

**[0057]** The term "cell" is used in its usual biological sense, and does not refer to an entire multicellular organism. The cell can, for example, be in vitro, e.g., in cell culture, or present in a multicellular organism, including, e.g., birds, plants and mammals such as humans, cows, sheep, apes, monkeys, swine, dogs, and cats. The cell can be prokaryotic (e.g., bacterial cell) or eukaryotic (e.g., mammalian or plant cell).

**[0058]** The phrase "detectable moiety" as used herein refers to a moiety that can be imaged and/or detected in vivo, ex vivo, or in vitro, by a procedure or modality described herein or known to one of skill in the art. As used herein, the detectable moiety can be directly or indirectly linked to the ligand used in the methods of the present invention.

**[0059]** The term "diagnostically labeled" means that the antibody has attached to it a diagnostically detectable label.

**[0060]** A protein that is "linked to a detectable moiety" is one that is bound, either covalently, through a linker, or through ionic, van der Waals or hydrogen bonds to a label such that the presence of the protein may be detected by detecting the presence of the label or detectable moiety bound to the protein.

**[0061]** The term "mammary tumor stem cells" means mammary tumor cells that are tumorigenic, i.e., that they can give rise to additional tumorigenic cells (self-renew) and non-tumorigenic tumor cells ("differentiation"). For example, a mammary tumor stem cell can form a new tumor when grafted to a mammary fat pad of a mouse (e.g., a nude mouse,

a NOD immuno-deficient mouse, or a NOD/SCID immuno-deficient mouse). Mammary tumor stem cells can be analyzed using dilution xenograft assay.

**[0062]** The term "somatic mammary stem cells" means cells that can generate both the ductal and lobular structures of the mammary gland, can generate all the cell lineages of the mammary epithelium (e.g., luminal cells and myoepithelial cells), and can self-renew. For example, when transplanted to a mammary fat pad in a mouse or rat *in vivo*, a somatic mammary stem cell can generate functional ductal trees. Somatic mammary stem cells can also generate mammary progenitor cells. The progenitor cells have proliferative capability and are the immediate precursors to the differentiated mammary cells such as luminal cells and myoepithelial cells. Mammary progenitor cells can be detected by their ability to generate colonies *in vitro*.

**[0063]** As used herein, the terms "treatment" or "treating" means prophylaxis and therapy. Thus, methods of treatment or treating of the present invention include treatments or treating to prevent or reduce Wnt signaling, or to stabilize or reverse conditions or diseases associated with Wnt activity.

**[0064]** The term "tumor cell" refers to a cancerous, pre-cancerous or transformed cell, either *in vivo*, *ex vivo*, and in tissue culture, that has spontaneous or induced phenotypic changes that do not necessarily involve the uptake of new genetic material. Although transformation can arise from infection with a transforming virus and incorporation of new genomic nucleic acid, or uptake of exogenous nucleic acid, it can also arise spontaneously or following exposure to a carcinogen, thereby mutating an endogenous gene. A "tumor" includes at least one tumor cell.

**[0065]** All references, patents, patent publications, articles, and databases, referred to in this application are incorporated-by-reference in their entirety, as if each were specifically and individually incorporated herein by reference.

**[0066]** It is disclosed here that Wnt signaling receptor LRP6 is highly expressed in a cell fraction that contains somatic mammary stem cell activity. The inventors established co-localization of mammary epithelial cells having high LRP6 expression with the somatic mammary stem cell-enriched fraction and determined the enhanced stem cell function of the LRP6 high fraction. *In situ* examination of LRP6 expression confirmed the heterogeneous expression of LRP6 and located the cells with high levels of LRP6 expression in the mammary ductal cell population. Similar to somatic mammary stem cells, it is expected that mammary tumor stem cells also express high levels of LRP6. Although the observations disclosed here were made with mice, it is expected that they

also apply to other mammals such as humans and rats given that the Wnt pathway and the mammary gland development are highly conserved across the mammalian species.

[0067]

In one aspect, the present invention relates to a method for enriching somatic mammary stem cells from a population of mammary cells. The method includes the steps of obtaining a population of mammary cells containing one or more somatic mammary stem cells, contacting said population of mammary cells with an anti-LRP6 antibody, and selecting cells that bind to the antibody. Preferably, at least 1%, 2%, 3%, 4%, 5%, 6%, or 7% of the selected cells are somatic mammary stem cells. As Shackleton M et al. (*Nature* 439:84-88,2006) estimated that mammary stem cells occur at a frequency of about 1 in 1,300 total mammary cells in mice, a 1% mammary stem cell concentration represents a 13-fold enrichment. While other methods of enriching for mammary stem cells that involve the use of cell surface markers are known, these methods require a combination of at least two cell surface markers (see e.g., "Stingl J et al. *Nature* 2006, 439:993-997" for the use of cell surface markers CD49f and CD24). The method provided here uses a single marker (LRP6) and can achieve a comparable enrichment level to the methods that involve the use of multiple markers.

[0068]

It is well within the capability of a skilled artisan to isolate mammary cells from a mammary gland. One example is provided in Example 1 below (see also Stingl J et al. *Nature* 2006, 439:993-997, which is herein incorporated by reference in its entirety). Other methods are known in the art. Typically, known procedures provide a population of mammary cells that is essentially free of adipocyte contamination but includes mammary epithelial cells, stromal cells (e.g., fibroblasts and other connective tissue cells), endothelial cells, and hematopoietic cells. Methods of isolating mammary epithelial cells are also well known in the art (see e.g., Gould MN et al. *Cancer Res* 1986, 46:4942-4945, which is herein incorporated by reference in its entirety). Somatic mammary stem cells can then be enriched using the LRP6 marker for positive selection from the population of mammary cells. Optionally, a somatic mammary stem cell "negative marker" (i.e., a marker not present on the cell surface of somatic mammary stem cells) is used for negative selection (i.e., for the elimination of cells that are not somatic mammary stem cells). For example, endothelial cell markers CD31 and Von Willebrand factor, hematopoietic cell markers CD45 and Ter119, and stromal cell marker CD140a can be used to eliminate certain endothelial, hematopoietic, and stromal cells to facilitate the enrichment of somatic mammary stem cells. Depending on the particular enrichment techniques, the negative markers can be used to eliminate certain non-mammary stem cells before the positive

selection with LRP6 or the positive and negative selections can be accomplished in one step. As an example for the former, antibodies to one or more of CD31, Von Willebrand factor, CD45, Ter119, and CD140a can be conjugated to a matrix such as magnetic beads to deplete the non-epithelial cells. The leftover epithelial enriched population of mammary cells is then labeled with fluorochrome-conjugated LRP6 antibodies for enriching somatic mammary stem cells by, for example, flow cytometry. As an example for the latter, antibodies to one or more of CD31, CD45, Ter119, and CD140a and antibodies to LRP6 can be conjugated to different fluorochrome so that endothelial, stromal, and/or hematopoietic cells can be gated out from LRP6 flow cytometry enrichment. Similarly, one or more mammary epithelial cell surface markers can optionally be used to enrich for mammary epithelial cells first before the LRP6 marker is used to enrich for somatic mammary stem cells.

**[0069]** Any agent that can bind to the cell surface markers can be used to practice the present invention. Antibodies specific for the markers are examples of such agents.

**[0070]** cDNA and amino acid sequences for LRP6 in various species are available and it is well within the capability of a skilled artisan to generate specific antibodies to these proteins if they are not already available. The human LRP6 cDNA and amino acid sequences are provided in the sequence listing at SEQ ID NO:1 and 2, respectively. The mouse LRP6 cDNA and amino acid sequences are provided in the sequence listing at SEQ ID NO:3 and 4, respectively.

**[0071]** In some embodiments, flow cytometry could be employed to conduct the positive selection and, if applicable, the negative selection as well. A skilled artisan is familiar with flow cytometry-related techniques such as labeling targeted cells (e.g., somatic mammary stem cells) with cell surface marker antibodies (e.g., anti-LRP6 antibodies), setting suitable parameters for sorting and collecting labeled cells, and collecting the targeted cells (see e.g., Givan A, *Flow Cytometry: First Principles*, Wiley-Liss, New York, 1992; and Owens MA & Loken MR, *Flow Cytometry: Principles for Clinical Laboratory Practice*, Wiley-Liss, New York, 1995). For the purpose of the present invention, a population of LRP6 high mammary epithelial cells is taken for the enrichment of somatic mammary stem cells. By LRP6 high mammary epithelial cells, the inventors mean the top 10% of the total mammary epithelial cell population in terms of LRP6 expression level at the cellular surface. Therefore, examples of a population of LRP6 high mammary epithelial cells that could be taken for enriching for somatic mammary stem cells include the top 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, or 1% of the total mammary epithelial

cell population in terms of LRP6 expression level at the cellular surface. Said enrichment for somatic mammary stem cells could be achieved by collecting the top 10% (in terms of LRP6 expression level at the cellular surface) or any fraction within the top 10% (e.g., top 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, or 1%) of a mammary cell population that includes the total mammary epithelial cell population (or a substantial portion thereof) and is essentially free of adipocyte contamination. In one form, the mammary cell population is depleted of certain endothelial cells, hematopoietic cells, and/or stroma cells using one or more of the following markers: CD31, Von Willebrand factor, CD45, Ter119, and CD140a. For example, the mammary cell population could be depleted of CD31+ cells. By a substantial portion of the total mammary epithelial cell population, the inventors mean at least 70%, 80%, 90%, or 95% of the total mammary epithelial cell population.

**[0072]** In some embodiments, a matrix such as magnetic beads to which an antibody (e.g., an anti-LRP6 antibody) could be conjugated directly or indirectly is employed to conduct the positive selection and, if applicable, the negative selection as well. In this regard, targeted cells could be separated from other cells by binding to the matrix through the antibody. When the matrix is used for positive selection in connection with an anti-LRP6 antibody, a skilled artisan could readily adjust and find suitable binding conditions so that LRP6 high mammary epithelial cells are bound to the matrix while other mammary epithelial cells (LRP6 negative and LRP5 low) are not.

**[0073]** In some other embodiments, flow cytometry is used to conduct the positive selection and a matrix described above is used to conduct the negative selection or vice versa.

**[0074]** Antibodies (e.g., anti-LRP6 antibodies) useful in the present invention could be labeled with a marker or they may be conjugated to a matrix. In some embodiments, the marker is used to conjugate the antibodies to the matrix. Examples of markers include biotin, which can be removed by avidin bound to a support, and fluorochromes (e.g. fluorescein), which provide for separation using fluorescence activated sorters. Examples of matrices include magnetic beads, which allow for direct magnetic separation (Kemshead JT, *J Hematother* 1992;1:35-44), panning surfaces such as plates, (Lebkowski JS et al., *J. of Cellular Biochemistry* suppl. 1994, 18b:58), dense particles for density centrifugation (Van Vlasselaer P, *Density Adjusted Cell Sorting (DACS), A Novel Method to Remove Tumor Cells From Peripheral Blood and Bone Marrow StemCell Transplants.* (1995) 3rd International Symposium on Recent Advances in Hematopoietic Stem Cell Transplantation-Clinical Progress, New Technologies and Gene Therapy, San

Diego, Calif.), dense particles alone (Zwerner et al., *Immunol. Meth.* 1996, 198:199-202), adsorption columns (Berenson et al., *Journal of Immunological Methods* 1986, 91:11-19), and adsorption membranes.

[0075] The antibodies may be directly or indirectly coupled to a matrix. For example, the antibodies may be chemically bound to the surface of magnetic particles (e.g., using cyanogen bromide). When the magnetic particles are reacted with a sample, conjugates will form between the magnetic particles with bound antibodies and the cells having the corresponding markers on their surfaces. Alternatively, the antibodies may be indirectly conjugated to a matrix. For example, the antibodies may be biotinylated and indirectly conjugated to a matrix which is labeled with avidin. Magnetic iron-dextran particles that are covalently labeled with avidin (Miltenyi S et al., *Cytometry* 1990, 11:231) can be used in this regard. Many alternative indirect ways to specifically cross-link the antibodies and matrices would also be apparent to those skilled in the art.

[0076] As another example, a matrix may be coated with a second antibody having specificity for the antibodies against the cell surface markers. By way of example, if the antibodies against the cell surface markers are mouse IgG antibodies, the second antibody may be rabbit anti-mouse IgG.

[0077] As another example, bispecific antibodies and tetrameric antibody complexes can be used. Bispecific antibodies contain a variable region of an antibody specific for a cell surface marker and a variable region specific for at least one antigen on the surface of a matrix. The bispecific antibodies may be prepared by forming hybrid hybridomas. The hybrid hybridomas may be prepared using the procedures known in the art such as those disclosed in Staerz & Bevan, (*Proc Natl Acad Sci USA* 1986, 83:1453) and Staerz & Bevan, (*Immunology Today* 1986, 7:241). Bispecific antibodies may also be constructed by chemical means using procedures such as those described by Staerz et al. (*Nature* 1985, 314:628) and Perez et al. (*Nature* 1985, 316:354), or by expression of recombinant immunoglobulin gene constructs.

[0078] A tetrameric immunological complex may be prepared by mixing a first monoclonal antibody which is capable of binding to an antigen on the surface of a matrix and a second monoclonal antibody specific for a cell surface marker. The first and second monoclonal antibodies are from a first animal species. The first and second antibody are reacted with an about equimolar amount of monoclonal antibodies of a second animal species which are directed against the Fc-fragments of the antibodies of the first animal species. The first and second antibodies may also be reacted with an about equimolar

amount of the F(ab')<sub>2</sub> fragments of monoclonal antibodies of a second animal species which are directed against the Fc-fragments of the antibodies of the first animal species. (See U.S. Pat. No. 4,868,109 to Lansdorp, which is incorporated herein by reference for a description of tetrameric antibody complexes and methods for preparing same).

[0079]

In an embodiment of the invention, the cell conjugates are removed by magnetic separation using magnetic particles. Suitable magnetic particles include particles in ferrofluids and other colloidal magnetic solutions. "Ferrofluid" refers to a colloidal solution containing particles having a magnetic core, such as magnetite (Fe<sub>3</sub>O<sub>4</sub>) coated or embedded in material that prevents the crystals from interacting. Examples of such materials include proteins, such as ferritin, polysaccharides, such as dextrans, or synthetic polymers such as sulfonated polystyrene cross-linked with divinylbenzene. The core portion is generally too small to hold a permanent magnetic field. The ferrofluids become magnetized when placed in a magnetic field. Examples of ferrofluids and methods for preparing them are described by Kemshead J. T. in *J. Hematotherapy* 1992, 1:35-44, at pages 36 to 39 and Ziolo et al. *Science* 1994, 257:219 which are incorporated herein by reference. Colloidal particles of dextran-iron complex are preferably used in the process of the invention (Molday, R. S. and McKenzie, L. L. *FEBS Lett.* 1984, 170:232; Miltenyi et al. *Cytometry* 1990, 11:231; Molday, R. S. and MacKenzie, D., *J. Immunol. Methods* 1982, 52:353; Thomas et al., *J. Hematother.* 1993, 2:297; and U.S. Pat. No. 4,452,733, which are each incorporated herein by reference).

[0080]

In accordance with the magnetic separation method, a sample containing the cells to be recovered, is reacted with an antibody specific for a cellular surface marker of the cells so that the antibody binds to the cells present in the sample to form cell conjugates of the targeted cells and the antibody. The reaction conditions are selected to provide the desired level of binding of the targeted cells and the antibody. The concentration of the antibody is selected depending on the estimated concentration of the targeted cells in the sample. The magnetic particles are then added and the mixture is incubated for a suitable period of time at a suitable temperature. The sample is then ready to be separated in a magnetic device.

[0081]

In another aspect, the present invention relates to a method of enriching mammary tumor stem cells from a population of mammary tumor cells. The method includes the steps of obtaining a population of mammary tumor cells containing one or more mammary tumor stem cells, contacting said population of mammary tumor cells with an anti-LRP6 antibody, and selecting cells that bind to the antibody. Preferably, at least 1%, 2%, 3%,

4%, 5%, 6%, or 7% of the selected cells are mammary tumor stem cells. Also preferably, the mammary tumor stem cells are enriched for at least 2-fold, 3-fold, 5-fold, 7-fold, or 10-fold relative to the original tumor from which said population is derived (unfractionated tumor cells). Reagents and procedures for enriching somatic mammary stem cells can be used similarly here for enriching mammary tumor stem cells.

**[0082]** In another aspect, the present invention relates to a method for screening for an agent that may modulate (either inhibit or enhance) LRP6 activity in a cell. The method includes the steps of providing a cell that has attenuated LRP5 activity (e.g., the LRP5 activity is reduced by at least 80%, 90%, or 95%), exposing the cell to a test agent, determining the LRP6 activity in the cell, and comparing the LRP6 activity to that of a control cell (the same type of cell as the exposed cell) not exposed to the test agent wherein a higher or lower LRP6 activity in the exposed cell than that of the control cell indicates that the agent can modulate LRP6 activity. If the cell does not express any Wnt ligand or produces an insufficient amount of Wnt for the purpose of conducting the screening assay, a Wnt ligand such as Wnt1 or Wnt3a may be added exogenously to stimulate Wnt signaling through LRP6. Alternatively, a DNA construct for expressing a Wnt ligand (e.g., a Wnt expression vector) can be introduced into the cell to express a Wnt protein.

**[0083]** A cell with attenuated LRP5 activity can be provided by using a LRP5-specific antibody to block its activity or by using antisense oligonucleotides, siRNA, or shRNA to block LRP5 gene expression so that the level of LRP5 protein in the cell is reduced by at least 80%, 90%, or 95% (see e.g., Young JJ et al. PLoS Pathog 2007, 3:e27). Agents that can inhibit LRP6 activity specifically are useful for treating mammary tumor or breast cancer.

**[0084]** Optionally, a cell that has wild-type LRP5 activity can also be employed in the screening assay as a control to select for agents that specifically modulate LRP6-mediated signaling. Those agents that can modulate Wnt signaling in LRP5 attenuated cells but not wild-type LRP5 control cells are identified as specific modulators of LRP6-mediated signaling.

**[0085]** In a preferred embodiment, a LRP5 null (knockout) cell is used in the screening. By a LRP5 null cell, the inventors mean that no detectable level of functional LRP5 is produced. Such a cell can be provided by, for example, introducing one or more mutations into the LRP5 nucleic acid gene sequence (including complete deletion of the gene sequence). In one form, the LRP5 gene is disrupted so that the cell does not express

any part of the LRP5 coding sequence at the mRNA level. Preferably, both chromosomal copies of the LRP5 nucleic acid sequence are disrupted in the cell.

[0086] A LRP5 null animal such as a LRP5 null mouse or rat can be a source of LRP5 null cells. Null or knockout animals such as knockout mice and rats are routinely generated in the art. A LRP5 knockout rat can be generated by a variety method such as that described in published U.S. patent application 20030150001, which is herein incorporated by reference in its entirety. The term null or knockout animals are used broadly to encompass a knockout fetus and as well as a knockout neonate and adult animal.

[0087] The LRP5 gene may be disrupted using a variety of technologies familiar to those skilled in the art. For example, a stop codon may be introduced into the gene by homologous recombination. Alternatively, a deletion may be introduced into the gene by homologous recombination. In some embodiments, stop codons may be introduced into all reading frames in the sequence downstream of the deletion to eliminate artifactual translation products. In further embodiments, the gene may be disrupted by inserting a gene encoding a marker protein, for example, via homologous recombination.

[0088] Examples of suitable cells that can be used in the screening method include mouse or rat embryonic fibroblasts (MEFs), primary keratinocyte cultures (e.g., mouse or rat primary keratinocyte cultures), and mouse or rat embryonic stem cells. A skilled artisan could readily isolate from *Lrp5*<sup>-/-</sup> murine animals murine embryonic fibroblasts from mid-gestational embryos, primary keratinocyte cultures from later stage embryos, or murine embryonic stem cells. For example, to establish murine embryonic fibroblast lines, one could isolate *Lrp5*<sup>-/-</sup> embryos (or control littermate embryos) at embryonic day 12 or 13, remove the head and internal organs, and then disassociate the remaining tissue with a razor blade in the presence of trypsin. These cells will be useful for up to 6-7 passages.

[0089] LRP6 activity can be measured by any part of the Wnt pathway at or downstream of LRP6. For example, the level of LRP6 at the mRNA or protein level can be measured. Phosphorylation of the C-terminus of LRP6 can also be measured. Alternatively, the activity of glycogen synthase kinase-3 (GSK3) activity can be measured. An increase in GSK3 activity indicates an inhibition of LRP6 activity and a decrease in GSK3 activity indicates an increase in LRP6 activity.  $\beta$ -catenin level such as that in the cytosol and/or nucleus can also be measured as a reflection of LRP6 activity. An increase in  $\beta$ -catenin level indicates an increase in LRP6 activity and vice versa. In one embodiment, the  $\beta$ -catenin level in the nucleus is measured wherein an increase in level indicates more LRP6

activity and vice versa. Alternatively, a Wnt reporter construct containing a reporter operably linked to a suitable promoter responsive to Wnt pathway activity can be provided in a cell for measuring LRP6 activity. Examples of suitable promoters include promoters for Wnt/ $\beta$ -catenin-responsive genes such as Axin2, CyclinD1, PPAR-delta, TCF, and LEF1 (see e.g., Yan D et al. Proc Natl Acad Sci USA 2001, 98:14973-8; Lustig B et al. Mol Cell Biol 2002, 22:1184-93; Jho EH et al. Mol Cell Biol 2002, 2:1172-83; Tetsu O et al. Nature 1999, 398:422-6; Shtutman M et al. Proc Natl Acad Sci USA 1999, 96:5522-7; He TC et al. Cell 1999, 99:335-45; Roose J et al. Science 1999, 285:1923-6; Hovanes K et al. Nat Genet 2001, 28:53-7; and Filali M et al. J Biol Chem 2002, 277:33398-410). A skilled artisan is familiar with these promoters. For example, a TCF-luciferase reporter gene assay (TOPFLASH) is commercially available (Mao et al. Nature 2001, 411:321-325).

**[0090]** Additional examples of Wnt/ $\beta$ -catenin-responsive genes include c-myc, c-jun, fra-1, uPAR, matrix metalloproteinase MMP-7, Nr-CAM, ITF-2, Gastrin, CD44, EphB/ephrin-B, BMP4, claudin-1, Survivin, VEGF, FGF18, Hath1, Met, endothelin-1, c-myc binding protein, L1 neural adhesion, Id2, Tiam1, Nitric Oxide, Synthase 2, Dickkopf, FGF9, FGF20, Sox9, Runx2, SALL4, RANK ligand, CCN1/Cyr61, Sox2, Pituitary tumor transforming gene (PTTG), Delta-like 1, FoxN1, matrix metalloproteinase-26, nanog, Frizzled 7, Follistatin, Siamois, fibronectin, myogenic bHLH, engrailed-2, Xnr3, connexin43, twin, connexin 30, retinoic acid receptor gamma, dharma/bozozok, MITF/nacre, Wrch-1, TNF family 41BB ligand, ephrinB1, Stra6, autotoxin, ISLR, Twist, Stromelysin, WISP, Brachyury, Proglucagon, Osteocalcin, cyclooxygenase-2, Irx3, Six3, neurogenin 1, WISP-1, WISP-2, IGF-II, Proliferin-2, Proliferin-3, Emp, IGF-I, VEGF-C, MDR1, IL-6, periostin, Cdx1, Cdx4, betaTrCP, sFRP-2, Pitx2, EGF receptor, Eda (TNF-related), E-cadherin, Keratin, movo1, Jagged1, mBTEB2, FGF4, Interleukin8, ret, connexin43, versican, Ubx, wingless, Dpp, Engrailed, Dfrizzled2, shavenbaby, stripe, and Nemo.

**[0091]** A reporter gene is defined broadly here to refer to a DNA sequence whose expression in a cell can be measured. Preferably, the reporter gene produces a polypeptide product whose function can be measured. Examples of such reporter genes include but are not limited to a  $\beta$ -galactosidase gene, a luciferase gene, and a green fluorescent protein (GFP) gene. An increase in the expression (at the mRNA or protein level) or activity of the reporter gene indicates an increase in LRP6 activity and vice versa. As another example, the reporter gene can be an inhibitor of the expression of a killer gene (the

product of which lead to the death of the host cell) from another expression construct introduced into the cell. This is especially useful for screening for agents that can inhibit the activity of LRP6. For example, when an agent sufficiently inhibits the activity of LRP6, the expression of reporter gene will be sufficiently inhibited resulting in the expression of the killer gene and in turn the death of the cell. In this regard, cell death is the end point of the screening.

**[0092]** In another aspect, the present invention relates to a method for inhibiting the proliferation or causing the death of a mammary tumor cell that expresses LRP6. The method includes the step of contacting the mammary tumor cell with an agent that inhibits LRP6 activity in an amount sufficient to inhibit the proliferation or causing the death of the mammary tumor cell. Preferably, the mammary tumor cell expresses a high level of LRP6. For example, the mammary tumor cell can be a mammary tumor stem cell. Since mammary tumor stem cells are expected to co-localize with the fraction of high level LRP6 mammary tumor cells, mammary tumor stem cells can be treated by contacting a population of mammary tumor cells that express a high level of LRP6.

**[0093]** In one embodiment, the above method is used to treat a mammary tumor in a mammal (e.g., a human, mouse, or rat) *in vivo* by administering an agent that inhibits LRP6 activity into the mammal in an amount sufficient to inhibit the proliferation or causing the death of mammary tumor cells such as mammary tumor stem cells. As mammary tumor stem cells express a high level of LRP6, the method is especially useful to inhibit the growth or causing the death of mammary tumor stem cells. Optionally, another mammary tumor/breast cancer therapeutic agent such as a chemotherapeutic agent or radiation is administered in connection with the agent that inhibits LRP6 activity. This other mammary tumor/breast cancer therapeutic agent in some cases may eradicate the non-stem cell population in the mammary tumor.

**[0094]** One example of agents that inhibit LRP6 activity is an anti-LRP6 antibody (e.g., specific for LRP6). As LRP6 is a cellular surface receptor with an extracellular domain, an anti-LRP6 antibody directed to an epitope in the extracellular domain can readily inhibit the activity of LRP6.

**[0095]** In some instances, the antibody belongs to a sub-type that activates serum complement when complexed with the transmembrane protein thereby mediating cytotoxicity or antigen-dependent cytotoxicity (ADCC).

**[0096]** The LRP6 antibody can also be conjugated to a mammary tumor/breast cancer therapeutic agent (e.g., a chemotherapeutic agent) to deliver the therapeutic agent to the

targeted tumor cells. In this case, the LRP6 antibody serves as a delivering vehicle. The therapeutic agent can be conjugated to the antibody either covalently, through a linker or a chemical bond, or noncovalently, through ionic, van der Waals, electrostatic, or hydrogen bonds. The therapeutic agent is typically a cytotoxic agent that can cause the death of the target cell.

**[0097]** Another example of the agents that inhibit LRP6 activity is a nucleic acid molecule that inhibits LRP6 gene expression. Examples of such nucleic acid molecules include antisense oligonucleotides, RNA interference (RNAi) molecules such as siRNA (small interfering RNA) molecules, and shRNA (short hairpin RNA) molecules. Given the cDNA sequences of LRP6 for various species are known in the art, it is well within the capability of a skilled artisan to develop such nucleic acid molecules. Both non-viral and viral vector delivery systems can be used to deliver the nucleic acid molecules. For a review of gene therapy procedures, see Anderson, *Science* 1992, 256:808-813; Nabel & Felgner, *TIBTECH* 1993, 11:211-217; Mitani & Caskey, *TIBTECH* 1993, 11:162-166; Dillon, *TIBTECH* 1993, 11:167-175; Miller, *Nature* 1992, 357:455-460; Van Brunt, *Biotechnology* 1988, 6:1149-1154; Vigne, *Restorative Neurology and Neuroscience* 1995, 8:35-36; Kremer & Perricaudet, *British Medical Bulletin* 1995, 51:31-44; Haddada et al., in *Current Topics in Microbiology and Immunology* Doerfler and Bohm (eds) (1995); and Yu et al., *Gene Therapy* 1994, 1:13-26.

**[0098]** In some embodiments, small interfering RNAs are administered. In mammalian cells, introduction of long dsRNA (>30 nt) often initiates a potent antiviral response, exemplified by nonspecific inhibition of protein synthesis and RNA degradation. The phenomenon of RNA interference is described and discussed, e.g., in Bass, *Nature* 2001, 411:428-29; Elbahir et al., *Nature* 2001, 411:494-98; and Fire et al., *Nature* 1998, 391:806-11, where methods of making interfering RNA also are discussed. The siRNA inhibitors are less than 100 base pairs, typically 30 bps or shorter, and are made by approaches known in the art. Exemplary siRNAs according to the invention can have up to 29 bps, 25 bps, 22 bps, 21 bps, 20 bps, 15 bps, 10 bps, 5 bps or any integer thereabout or therebetween.

**[0099]** Methods of non-viral delivery of nucleic acid molecules include lipofection, microinjection, biolistics, virosomes, liposomes, immunoliposomes, polycation or lipid: nucleic acid conjugates, naked DNA, artificial virions, and agent-enhanced uptake of DNA. Lipofection is described in e.g., U.S. Pat. No. 5,049,386, U.S. Pat. No. 4,946,787; and U.S. Pat. No. 4,897,355 and lipofection reagents are sold commercially (e.g.,

Transfectam™ and Lipofectin™). Cationic and neutral lipids that are suitable for efficient receptor-recognition lipofection of polynucleotides include those of Felgner, WO 91/17424 and WO 91/16024. Delivery can be to cells (*ex vivo* administration) or target tissues (*in vivo* administration). The preparation of lipid: nucleic acid complexes, including targeted liposomes such as immunolipid complexes, is well known to one of ordinary skill in the art (see e.g., Crystal, Science 1995, 270:404-410; Blaese et al., Cancer Gene Ther. 1995, 2:291-297; Behr et al., Bioconjugate Chem. 1994, 5:382-389; Remy et al., Bioconjugate Chem. 1994, 5:647-654; Gao et al., Gene Therapy 1995, 2:710-722; Ahmad et al., Cancer Res. 1992, 52:4817-4820; and U.S. Pat. Nos. 4,186,183, 4,217,344, 4,235,871, 4,261,975, 4,485,054, 4,501,728, 4,774,085, 4,837,028, and 4,946,787).

**[00100]** The use of RNA or DNA viral based systems for the delivery of the nucleic acid molecules are known in the art. Conventional viral based systems for the delivery of such nucleic acid molecules include retroviral, lentivirus, adenoviral, adeno-associated and herpes simplex virus vectors for gene transfer.

**[00101]** It may be desirable that the gene therapy vector be delivered with a high degree of specificity to a particular tissue type such as mammary tumor. A viral vector is typically modified to have specificity for a given cell type by expressing a ligand as a fusion protein with a viral coat protein on the viruses outer surface. The ligand is chosen to have affinity for a receptor known to be present on the cell type of interest. For example, Han et al., Proc Natl Acad Sci USA 1995, 92:9747-9751, reported that Moloney murine leukemia virus can be modified to express human heregulin fused to gp70, and the recombinant virus infects certain human breast cancer cells expressing human epidermal growth factor receptor. This principle can be extended to other pairs of virus expressing a ligand fusion protein and target cell expressing a receptor. For example, filamentous phage can be engineered to display antibody fragments (e.g., FAB or Fv) having specific binding affinity for virtually any chosen cellular receptor. Although the above description applies primarily to viral vectors, the same principles can be applied to nonviral vectors. Such vectors can be engineered to contain specific uptake sequences thought to favor uptake by specific target cells.

**[00102]** Gene therapy vectors can be delivered *in vivo* by administration to an individual patient (include humans and other mammals such as mice and rats), typically by systemic administration (e.g., intravenous, intraperitoneal, intramuscular, subdermal, or intracranial infusion) or topical application, as described below.

**[00103]** Vectors (e.g., retroviruses, adenoviruses, liposomes, etc.) containing therapeutic nucleic acids can also be administered directly to the patient for transduction of cells *in vivo*. Alternatively, naked DNA can be administered. Administration is by any of the routes normally used for introducing a molecule into ultimate contact with blood or tissue cells. Suitable methods of administering such nucleic acids are available and well known to those of skill in the art, and, although more than one route can be used to administer a particular composition, a particular route can often provide a more immediate and more effective reaction than another route.

**[00104]** Pharmaceutically acceptable carriers are determined in part by the particular composition being administered, as well as by the particular method used to administer the composition. Accordingly, there is a wide variety of suitable formulations of pharmaceutical compositions of the present invention, as described below (see, e.g., Remington's Pharmaceutical Sciences, 17th ed., 1989).

**[00105]** The agents that inhibit LRP6 activity can be administered by a variety of methods including, but not limited to parenteral (e.g., intravenous, intramuscular, intradermal, intraperitoneal, and subcutaneous routes), topical, oral, local, or transdermal administration. These methods can be used for prophylactic and/or therapeutic treatment.

**[00106]** The compositions for administration will commonly comprise an agent that inhibits LRP6 activity dissolved in a pharmaceutically acceptable carrier, preferably an aqueous carrier. A variety of aqueous carriers can be used, e.g., buffered saline and the like. These solutions are preferably sterile and generally free of undesirable matter. These compositions may be sterilized by conventional, well known sterilization techniques. The compositions may contain pharmaceutically acceptable auxiliary substances as required to approximate physiological conditions such as pH adjusting and buffering agents, toxicity adjusting agents and the like, for example, sodium acetate, sodium chloride, potassium chloride, calcium chloride, sodium lactate and the like. The concentration of active agent in these formulations can vary widely, and will be selected primarily based on fluid volumes, viscosities, body weight and the like in accordance with the particular mode of administration selected and the patient's needs.

**[00107]** The pharmaceutical compositions can be administered in a variety of unit dosage forms depending upon the method of administration. For example, unit dosage forms suitable for oral administration include, but are not limited to, powder, tablets, pills, capsules and lozenges. It is recognized that antibodies when administered orally, should be protected from digestion. This is typically accomplished either by complexing the

molecules with a composition to render them resistant to acidic and enzymatic hydrolysis, or by packaging the molecules in an appropriately resistant carrier, such as a liposome or a protection barrier. Means of protecting agents from digestion are well known in the art.

**[00108]** The compositions containing agents that inhibit LRP6 activity (e.g., antibodies) can be administered for therapeutic or prophylactic treatments. In therapeutic applications, compositions are administered to a patient suffering from breast cancer/mammary tumor in an amount sufficient to cure or at least partially arrest the disease and its complications. An amount adequate to accomplish this is defined as a "therapeutically effective dose." Amounts effective for this use will depend upon the severity of the disease and the general state of the patient's health. Single or multiple administrations of the compositions may be administered depending on the dosage and frequency as required and tolerated by the patient. In any event, the composition should provide a sufficient quantity of the agents to effectively treat the patient. An amount of an agent that is capable of preventing or slowing the development of breast cancer in a patient is referred to as a "prophylactically effective dose." The particular dose required for a prophylactic treatment will depend upon the medical condition and history of the patient as well as other factors such as age, weight, gender, administration route, efficiency, etc. Such prophylactic treatments may be used, e.g., in a patient who has previously had breast cancer/mammary tumor to prevent a recurrence of the cancer/tumor, or in a patient who is suspected of having a significant likelihood of developing breast cancer/mammary tumor.

**[00109]** In another aspect, the present invention relates to a method for detecting or imaging mammary or mammary tumor cells that express a high level of LRP6 such as somatic mammary stem cells and mammary tumor stem cells. The method includes the steps of administering an LRP6 antibody based contrast agent and obtaining an image of the labeled mammary or mammary tumor cells. This method is useful for monitoring the effectiveness of breast cancer treatment by determining whether the mammary tumor stem cells have been inhibited or eradicated. Any suitable medical imaging techniques can be used in this regard. Examples of such techniques include ultrasound, computerized tomography (CT), magnetic resonance imaging (MRI), and nuclear medicine techniques such as gamma ray detection by a gamma ray detector (e.g., a gamma scintillation camera or a 3-dimensional imaging camera), positron emission tomography (PET) and single photon emission computed tomography (SPECT). A skilled artisan can readily make the suitable contrast agents using the LRP6 antibody, for example, by attaching a detectable label for a particular imaging technique to a LRP6 antibody (e.g., covalently through a

linker or a chemical bond). For example, for MRI detection, a superparamagnetic iron oxide nanoparticle (SPION) can be conjugated to an LRP6 antibody for administering and MRI detection. For nuclear medicine detection, radionuclide-labeled LRP6 antibody can be administered and radiation emission from the nucleotide can be measured and an image thereof can be obtained.

**[00110]** In another aspect, the present invention relates to the detection of mammary basal-like cells. In this method an agent is used to detect Lrp6 expression in a tissue or biological sample suspected of including mammary basal-like cells. Any agent that can bind to LRP6 can be used to practice the invention. Antibodies specific to LRP6 are examples of such agents. The antibody is detected in the tissue or sample by linking a detectable moiety to the antibody, contacting the antibody with the tissue or sample, and detecting the presence of the detectable moiety in the tissue or sample.

**[00111]** For preparation of antibodies, e.g., recombinant, monoclonal, or polyclonal antibodies, many techniques known in the art can be used (see, e.g., Kohler & Milstein, *Nature* 256:495-497 (1975); Kozbor et al., *Immunology Today* 4: 72 (1983); Cole et al., pp. 77-96 in *Monoclonal Antibodies and Cancer Therapy*, Alan R. Liss,-Inc. (1985); Coligan, *Current Protocols in Immunology* (1991); Harlow & Lane, *Antibodies, A Laboratory Manual* (1988); and Goding, *Monoclonal Antibodies: Principles and Practice* (2d ed. 1986)). The genes encoding the heavy and light chains of an antibody of interest can be cloned from a cell, e.g., the genes encoding a monoclonal antibody can be cloned from a hybridoma and used to produce a recombinant monoclonal antibody. Gene libraries encoding heavy and light chains of monoclonal antibodies can also be made from hybridoma or plasma cells. Random combinations of the heavy and light chain gene products generate a large pool of antibodies with different antigenic specificity (see, e.g., Kuby, *Immunology* (3.sup.rd ed. 1997)). Techniques for the production of single chain antibodies or recombinant antibodies (U.S. Pat. No. 4,946,778, U.S. Pat. No. 4,816,567) can be adapted to produce antibodies to polypeptides of this invention. Also, transgenic mice, or other organisms such as other mammals, may be used to express humanized or human antibodies (see, e.g., U.S. Pat. Nos. 5,545,807; 5,545,806; 5,569,825; 5,625,126; 5,633,425; 5,661,016, Marks et al., *Bio/Technology* 10:779-783 (1992); Lonberg et al., *Nature* 368:856-859 (1994); Morrison, *Nature* 368:812-13 (1994); Fishwild et al., *Nature Biotechnology* 14:845-51 (1996); Neuberger, *Nature Biotechnology* 14:826 (1996); and Lonberg & Huszar, *Intern. Rev. Immunol.* 13:65-93 (1995)). Alternatively, phage display technology can be used to identify antibodies and heteromeric Fab fragments that

specifically bind to selected antigens (see, e.g., McCafferty et al., *Nature* 348:552-554 (1990); Marks et al., *Biotechnology* 10:779-783 (1992)). Antibodies can also be made bispecific, i.e., able to recognize two different antigens (see, e.g., WO 93/08829, Traunecker et al., *EMBO J.* 10:3655-3659 (1991); and Suresh et al., *Methods in Enzymology* 121:210 (1986)). Antibodies can also be heteroconjugates, e.g., two covalently joined antibodies, or immunotoxins (see, e.g., U.S. Pat. No. 4,676,980, WO 91/00360; WO 92/200373; and EP 03089).

**[00112]** Antibodies can be detectably labeled and used, for example, to detect LRP6 on the surface or in the interior of a mammary basal-like cell. The fate of the antibody during and after binding can be followed in vitro or in vivo by using the appropriate method to detect the label. The labeled antibody may be utilized in vivo for diagnosis.

**[00113]** There are many different labels and methods of labeling known to those of ordinary skill in the art. Examples of the types of labels which can be used in the present invention include radioactive isotopes, paramagnetic isotopes, and compounds which can be imaged by positron emission tomography (PET). Those of ordinary skill in the art will know of other suitable labels for binding to the antibodies used in the invention, or will be able to ascertain such, by routine experimentation. Diagnostically-labeled (e.g., radiolabeled) antibodies are effective.

**[00114]** Suitable detectable labels for diagnosis and imaging include radioactive, fluorescent, fluorogenic, chromogenic, or other chemical labels. Useful radiolabels, which are detected simply by gamma counter, scintillation counter, PET scanning or autoradiography include <sup>3</sup>H, <sup>124</sup>I, <sup>125</sup>I, <sup>131</sup>I, <sup>35</sup>S and <sup>14</sup>C. In addition, <sup>131</sup>I is a useful therapeutic isotope (see below).

**[00115]** Common fluorescent labels include fluorescein, rhodamine, dansyl, phycoerythrin, phycocyanin, allophycocyanin, o-phthaldehyde and fluorescamine. The fluorophore, such as the dansyl group, must be excited by light of a particular wavelength to fluoresce. See, for example, Haugland, *Handbook of Fluorescent Probes and Research Chemicals*, Sixth Ed., Molecular Probes, Eugene, Oreg., 1996). Fluorescein, fluorescein derivatives and fluorescein-like molecules such as Oregon Green.TM. and its derivatives, Rhodamine Green.TM. and Rhodol Green.TM., are coupled to amine groups using the isothiocyanate, succinimidyl ester or dichlorotriazinyl-reactive groups. Similarly, fluorophores may also be coupled to thiols using maleimide, iodoacetamide, and aziridine-reactive groups. The long wavelength rhodamines, which are basically Rhodamine Green.TM. derivatives with substituents on the nitrogens, are among the most photostable fluorescent labeling reagents

known. Their spectra are not affected by changes in pH between 4 and 10, an important advantage over the fluoresceins for many biological applications. This group includes the tetramethylrhodamines, X-rhodamines and Texas Red.TM. derivatives. Other preferred fluorophores for derivatizing the peptide according to this invention are those which are excited by ultraviolet light. Examples include cascade blue, coumarin derivatives, naphthalenes (of which dansyl chloride is a member), pyrenes and pyridyloxazole derivatives. Also included as labels are two related inorganic materials that have recently been described: semiconductor nanocrystals, comprising, for example, cadmium sulfate (Bruchez, M. et al., Science 281:2013-2016 (1998)), and quantum dots, e.g., zinc-sulfide-capped cadmium selenide (Chan, W. C. W. et al., Science 281:2016-2018 (1998)).

[00116] In yet another approach, the amino groups of a anti-LRP6 antibody are allowed to react with a reagent that yields a fluorescent product, for example, fluorescamine, dialdehydes such as o-phthaldialdehyde, naphthalene-2,3-dicarboxylate and anthracene-2,3-dicarboxylate. 7-nitrobenz-2-oxa-1,3-diazole (NBD) derivatives, both chloride and fluoride, are useful to modify amines to yield fluorescent products.

[00117] The antibodies can also be labeled for detection using fluorescence-emitting metals such as  $^{152}\text{Eu}^+$ , or others of the lanthanide series. These metals can be attached to the peptide using such metal chelating groups as diethylenetriaminepentaacetic acid (DTPA) or ethylenediamine-tetraacetic acid (EDTA). DTPA in anhydride form can readily modify the NH<sub>2</sub>-containing antibodies.

[00118] For in vivo diagnosis, radionuclides may be bound to the antibody either directly or indirectly using a chelating agent such as DTPA and EDTA. Examples of such radionuclides are  $^{99}\text{Tc}$ ,  $^{123}\text{I}$ ,  $^{125}\text{I}$ ,  $^{131}\text{I}$ ,  $^{111}\text{In}$ ,  $^{97}\text{Ru}$ ,  $^{67}\text{Cu}$ ,  $^{67}\text{Ga}$ ,  $^{68}\text{Ga}$ ,  $^{72}\text{As}$ ,  $^{89}\text{Zr}$ ,  $^{90}\text{Y}$  and  $^{201}\text{Tl}$ . Generally, the amount of labeled antibody needed for detectability in diagnostic use will vary depending on considerations such as age, condition, sex, and extent of disease in the patient, contraindications, if any, and other variables, and is to be adjusted by the individual physician or diagnostician. Dosage can vary from 0.01 mg/kg to 100 mg/kg.

[00119] The antibodies can also be made detectable by coupling them to a phosphorescent or a chemiluminescent compound. The presence of the chemiluminescent-tagged peptide is then determined by detecting the presence of luminescence that arises during the course of a chemical reaction. Examples of particularly useful chemiluminescers are luminol, isoluminol, therromatic acridinium ester, imidazole, acridinium salt and oxalate ester. Likewise, a bioluminescent compound may be used to label the peptides. Bioluminescence

is a type of chemiluminescence found in biological systems in which a catalytic protein increases the efficiency of the chemiluminescent reaction. The presence of a bioluminescent protein is determined by detecting the presence of luminescence. Important bioluminescent compounds for purposes of labeling are luciferin, luciferase and aequorin.

**[00120]** In yet another embodiment, colorimetric detection is used, based on chromogenic compounds which have, or result in, chromophores with high extinction coefficients.

**[00121]** In situ detection of the labeled antibody may be accomplished by removing a histological specimen from a subject and examining it by microscopy under appropriate conditions to detect the label. Those of ordinary skill will readily perceive that any of a wide variety of histological methods (such as staining procedures) can be modified in order to achieve such in situ detection.

**[00122]** For diagnostic in vivo radioimaging, the type of detection instrument available is a major factor in selecting a radionuclide. The radionuclide chosen must have a type of decay, which is detectable by a particular instrument. In general, any conventional method for visualizing diagnostic imaging can be utilized in accordance with this invention. Another factor in selecting a radionuclide for in vivo diagnosis is that its half-life be long enough so that the label is still detectable at the time of maximum uptake by the target tissue, but short enough so that deleterious irradiation of the host is minimized. In one preferred embodiment, a radionuclide used for in vivo imaging does not emit particles, but produces a large number of photons in a 140-200 keV range, which may be readily detected by conventional gamma cameras.

**[00123]** A preferred diagnostic method is radioimmunoscintigraphic analysis, which is preferably performed in a manner that results in serial total body gamma camera images and allows determination of regional activity by quantitative "region-of-interest" (ROI) analysis.

**[00124]** The diagnostically labeled antibodies may be incorporated into convenient dosage forms. Preferably, for diagnosis, the labeled antibodies are administered systemically, e.g., by injection or infusion. When used, injection or infusion may be by any known route, preferably intravenous injection or infusion, subcutaneous injection, intramuscular, intracranial or intrathecal injection or infusion, or intraperitoneal administration. Injectables can be prepared in conventional forms, either as solutions or suspensions, solid forms.

- [00125] A preferred way to label the antibody or fragment is by linking it to an enzyme and using it in an enzyme immunoassay (EIA), or enzyme-linked immunosorbent assay (ELISA). Such assays are described in greater detail in: Butler, J. E., The Behavior of Antigens and Antibodies Immobilized on a Solid Phase (Chapter 11) In: STRUCTURE OF ANTIGENS, Vol. 1 (Van Regenmortel, M., CRC Press, Boca Raton 1992, pp. 209-259; Butler, J. E., ELISA (Chapter 29), In: van Oss, C. J. et al., (eds), IMMUNOCHEMISTRY, Marcel Dekker, Inc., New York, 1994, pp. 759-803 Butler, J. E. (ed.), IMMUNOCHEMISTRY OF SOLID-PHASE IMMUNOASSAY, CRC Press, Boca Raton, 1991; Voller, A. et al., Bull. WHO 53:55-65 (1976); Voller, A. et al., J. Clin. Pathol. 31:507-520 (1978); Butler, J. E., Meth. Enzymol. 73:482-523 (1981); Maggio, E. (ed.), Enzyme Immunoassay, CRC Press, Boca Raton, 1980 Ishikawa, E. et al. (eds.) Enzyme Immunoassay, Kagaku Shoin, Tokyo, 1981.
- [00126] This enzyme, in turn, when later exposed to its substrate, will react with the substrate in such a manner as to produce a chemical moiety which can be detected, for example, by spectrophotometric, fluorometric or by visual means. Enzymes which are commonly used for this purpose include horseradish peroxidase, alkaline phosphatase, glucose-6-phosphate dehydrogenase, malate dehydrogenase, staphylococcal nuclease, .DELTA.-V-steroid isomerase, yeast alcohol dehydrogenase, .alpha.-glycerophosphate dehydrogenase, triose phosphate isomerase, asparaginase, glucose oxidase, .beta.-galactosidase, ribonuclease, urease, catalase, glucoamylase and acetylcholinesterase.
- [00127] Radioimmunoscintigraphy is an important and attractive modality for experimental and clinical molecular imaging of cancer. One can raise, characterize, and propagate antibodies reactive against virtually any given protein antigen, even those present as minor components of complex protein mixtures or as minor surface components of whole cells. Established methods for radiolabeling antibodies in suitable quantity and of appropriate quantity for scintigraphy are available, feasible, relatively inexpensive, and adaptable to virtually any antibody regardless of its epitopic specificity. New radiolabeling methods are continually emerging, and many laboratories are evaluating a wide range of antibody derivatives--from full-length chimeric and humanized molecules, to monomeric and multimeric antibody fragments, to immunoconjugates--as potentially superior imaging and therapeutic agents, with improved targeting selectivity and more favorable biological turnover kinetics (Program and Abstracts, Ninth Conference on Cancer Therapy with Antibodies and Immunoconjugates. 2002. Cancer Biotherapy & Radiopharmaceuticals 17:465-494).

**[00128]** Moreover, the reagents, supplies, and equipment required to perform radioimmunoscintigraphy in experimental animals and in humans are commonplace. For decades decommissioned or refurbished clinical gamma cameras have proven satisfactory for animal imaging applications, and they continue to do so. Modified or custom-built gamma cameras adapted for small animal imaging are becoming more widely available.

**[00129]** The major advantage of scintigraphy as a molecular imaging modality (not limited to imaging with antibodies) is that the acquired images are inherently quantitative. The physics of gamma radiation and the mathematical analysis of nuclear images, including corrections for photon attenuation and other artifacts, are well understood. In animal models as well as in human studies one can noninvasively and accurately measure net accumulation and some kinetic parameters of radiopharmaceutical interactions with target lesions, and the concurrent collection of even a small set of biological samples (e.g., blood and excreta) for direct counting combined with quantitative analysis of diagnostic images enables useful dosimetry estimates for therapeutic purposes.

**[00130]** Many different radiopharmaceuticals are available for imaging neoplasms. They range from classical agents such as sodium iodide ( $^{131}\text{I}$ ), thallium chloride ( $^{201}\text{TlCl}$ ), and gallium citrate ( $^{67}\text{Ga}$ -citrate) to highly selective positron-emitting reporter gene detection systems (Vallabhajosula S (2001), In: Nuclear Oncology. I Khalkhali et al., eds. Lippincott Williams & Wilkins, Philadelphia, Pa. pp. 31-62; Iyer M et al. (2001) J Nucl Med 42, 96-105). Radiolabeled molecules that bind to specific cell surface components provide one successful approach to tumor imaging and therapy. Examples are OctreoScan.RTM. for imaging and potentially treating neuroendocrine neoplasms, CEAScan.RTM. and OncoScint.RTM. for imaging colorectal and ovarian cancers, and Bexxar.RTM. and Zevalin.RTM. for detecting and treating certain lymphomas.

**[00131]** In another aspect, the present invention relates to a method of diagnosing basal-like breast cancer. The method utilizes an agent to detect Lrp6 expression in a tissue, organ, or biological sample of a patient suspected of having basal-like cell breast cancer, and that agent is linked to a detectable moiety. The presence of the detectable moiety is detected and the Lrp6 expression level in the tissue, organ, or sample is determined and compared to a suitable control.

**[00132]** Although Example 1 below showed that Lrp6 is useful as a basal-like cell breast cancer diagnostic marker at the mRNA level, it is expected that LRP6 protein level can be used the same way. Therefore, Lrp6 expression level can be measured either at the mRNA

level or at the protein level to practice the method of the present invention. Based on the data presented in Example 1 below, a skilled artisan can readily set up suitable controls as reference points of comparison for the expression of Lrp6. One suitable control is the median or average expression level of many breast cancer patients that do not have basal-like cell breast cancer. Another suitable control is the median or average expression level of many patients without breast cancer. In one particular embodiment, both of the above controls are used. The larger the number of patients used to establish a median or average level of Lrp6 expression as a control, the more accurate the diagnostic determination. Preferably, at least 25, 50, or 100 patients are used to establish the control level of expression.

**[00133]** An example of a pharmaceutical composition or compound of the present invention is an RNAi for LRP6. Preferably, the RNAi would include an internal promoter driving the expression of the RNAi only in cancer stem cells or progenitor cells. More preferably, a short hairpin-based (shRNA) approach to RNAi could be used to antagonize, or inactivate the transcript for LRP6. siRNA has been directed against LRP6 in an effort to confirm the existence of an autocrine Wnt signaling loop [Bafico, A., Liu, G., Goldin, L., Harris, V., Aaronson, S. A., *Cancer Cell*. Nov. 2004; 6:497-506].

**[00134]** Another example of a pharmaceutical composition or a compound of the present invention is an antibody specific to LRP6. In this composition, an antibody specific to LRP6 is an antagonist that competitively inhibits binding of the Wnt ligand to the LRP6 and thereby inhibits activation of the Wnt signaling pathway. Known examples of antagonistic antibodies against other receptors include Erbitux and Herceptin. Applications of antibodies as a composition or a therapeutic are generally known, see for example U.S. Patent Publication Nos. 2006/0093607 and 2005/0003465. Moreover, a therapeutic agent (drug, chemotoxin, radiotherapeutic, small molecule) can be conjugated to such an antibody, ensuring delivery of the therapeutic agent to a specific target. (U.S. Patent No. 6,989,144.) Moreover, internalizing antibodies can be conjugated to such a therapeutic agent, ensuring delivery of the therapeutic agent into the cytoplasm of a target cell. Antibodies conjugated to a therapeutic toxin for delivery to a target receptor site can be selected from monoclonal antibodies (humanized, fully human, or other), Fabs, or scFvs. Antibodies conjugated to a therapeutic agent which is internalized into a cell may also be monoclonal antibodies, but are more generally Fabs or scFvs. Further, such an antibody can be conjugated to a detectable reporting agent to indicate delivery of the antibody to a target site for imaging studies.

[00135] Methods for administering a pharmaceutical composition or compound to the patient are known in the art. For example, shRNA can be delivered to a mammalian cell by a vector, such as an adenovirus or retrovirus, in a target-specific manner. [Mize-Omata, S., Yuichi, O., Shigeru, I., Mize, N., Doi, T.S., Biochem Biophys Res Commun. 2005 Mar 25; 328(4):1034-42; see also Edwin, F., Singh, R., Endersby, R., Baker, S., Patel, T., J. Biol. Chem., Vol. 281, Issue 8, 4816-4822, February 24, 2006; Lee, S., Choi, E., Jin, C., Kim, D., Gynecol Oncol. 2005 Apr; 97(1):26-34; Zhang, C., Comai, L., Johnson, D., Molecular and Cellular Biology, Sug. 2005, 6899-6911]. According to the present invention, the target for the shRNA is the transcript for LRP6.

[00136] Retroviral vectors used to express shRNA could be put under the control of an RNA polymerase III (pol III) promoter, such as U6 or H1 for the purpose of inhibiting gene expression in a sequence specific manner. Several replication-competent retroviral vectors have been developed for this general purpose [Bromberg-White, J.L., Webb, C.P., Patacsil, V.S., Miranti, C.K., Williams, B.O., and Holman, S.L., 2004 Journal of Virology, May:4914-4916].

[00137] Having now generally described the invention, the same will be more readily understood through reference to the following examples, which are provided by way of illustration, and are not intended to be limiting of the present invention, unless specified.

#### EXAMPLES

[00138] *Example 1: The Wnt Signaling Receptor LRP6 is Required for Mammary Stem Cell Activity and Wnt1-Induced Tumorigenesis.*

[00139] Signaling by the Wnt family of secreted lipoproteins plays a central role in development and disease (1). At the cellular level, Wnt proteins regulate a broad range of functions including the self-renewal and differentiation of stem cells (2). Activation of the canonical Wnt cascade is initiated by the binding of Wnt proteins to cell surface receptors composed of a member of the Frizzled (Fzd) protein family and one of the low-density lipoprotein receptor-related proteins LRP5 or LRP6 (3, 4). Signaling from Wnt receptors increases cytoplasmic levels of  $\beta$ -catenin, which binds to transcription factors such as those of the LEF-1/TCF family and modulates the transcription of specific target genes. While Wnt-Frizzled interactions may also be involved in non-canonical Wnt signaling events, the LRP5/6 moiety appears to be specifically required for the canonical pathway (5).

[00140] Studies in mice suggest that canonical Wnt signaling plays a significant role during normal mammary gland development (6-11), which begins at about embryonic day 10.5

with the formation of two “mammary lines” (12). In response to signals from the underlying mesenchyme, the mammary lines give rise to five pairs of lens-shaped mammary placodes that grow and invaginate downwards into dermis to colonize the rudimentary fat pad. Activation of the canonical Wnt signaling pathway along the mammary lines coincides with the initiation of mammary morphogenesis and subsequently localizes to mammary placodes and buds (13, 14). Several Wnt ligands and receptor genes, including Lrp6, are expressed during embryonic mammary morphogenesis (13). Embryos expressing the canonical Wnt inhibitor Dkk1 display a complete block in the formation of mammary placodes and mice deficient for Lef-1 fail to maintain their mammary buds (6, 7), showing that Wnt signals are necessary for embryonic mammary development.

**[00141]** By birth, the mammary gland is composed of a few rudimentary ducts—containing an outer layer of myoepithelial and an inner layer of luminal epithelial cells—surrounded by the fat pad. During pre-pubertal and pubertal development, the ductal epithelium proliferates, until the fat pad is fully colonized with a sparse ductal tree. Lobuloalveolar precursor cells respond to endocrine signals during pregnancy, to colonize all the inter-ductal spaces, increasing cell number at least 10-fold (15). The expansion of mammary epithelium during juvenile growth, estrous and pregnancy, together with the remarkable regenerative capacity apparent during successive reproductive cycles, imply the existence of a mammary stem cell. In fact a subset of mammary cells that are enriched for stem cells have recently been isolated by fluorescence-activated cell sorting (FACS) of freshly isolated mammary cells. These cells express CD24 and CD49f but not CD31 (endothelial cell marker) and not CD45/TER119 (hematopoietic cell markers) (Stingl et al, Nature. 2006 Feb 23;439(7079):993-7). They are defined as CD31<sup>-</sup>CD45<sup>-</sup>CD119<sup>-</sup>/CD24<sup>+</sup>/CD49f<sup>high</sup>, and are comprised of approximately 8% of all CD31<sup>-</sup>CD45<sup>-</sup>CD119<sup>-</sup> mammary cells. While not every cell in this subset of cells is a true stem cell, transplantation experiments have established a single cell in this population can sometimes regenerate a whole ductal tree.

**[00142]** A connection between mammary stem/progenitor cells and Wnt1- or  $\beta$ -catenin-induced tumorigenesis has recently been established. Transgenic expression of these genes results in widespread mammary hyperplasia and rapid tumor formation (11, 18). The hyperplastic tissue contains an increased fraction of mammary stem/progenitor cells which are thought to directly give rise to transformed cells (17, 19, 20). Tumors arising from stem/progenitor cells often show mixed lineage differentiation (21) and tumors induced by

Wnt effectors indeed contain cells from both epithelial lineages (19, 20). Shown here is that the LRP6 receptor is expressed in the mammary stem cell fraction by FACS. Furthermore, LRP6 is required both during normal development and for Wnt1-induced tumorigenesis. In MMTV-Wnt1 transgenic mice loss of one copy of *Lrp6* markedly reduces both the early proliferation of the progenitor cell population and the subsequent formation of mammary tumors. Furthermore, mammary placode and ductal tree development is inhibited in *Lrp6*<sup>-/-</sup> embryos. Taken together, these results suggest that canonical signaling through the LRP6 receptor is critical for mammary stem cell activity.

**[00143] Material and Methods.**

**[00144] Mice.**

**[00145]** *Lrp6*<sup>+/-</sup> mice were obtained from Dr. Skarnes. These mice had been back-crossed to C57Bl/6J (B6) mice for six generations to create congenic *Lrp6* mouse on a B6 background (to minimize genetic variation). *MMTV-Wnt1* transgenic mice (maintained on a FVB/N background) and *BAT-gal* transgenic mice (maintained on a B6D2F1 background) were crossed with *Lrp6*<sup>+/-</sup> mice. PCR-based strategies were then used to genotype these mice (details available upon request). All experiments performed were in compliance with the guiding principles of the "Care and Use of Animals" available at [www.nap.edu/books/0309053773/html](http://www.nap.edu/books/0309053773/html) and were approved in advance by the Van Andel Research Institute Institutional Animal Care and Use Committee. To assay the appearance of mammary tumors, the mice were inspected weekly and were euthanized when tumors appeared.

**[00146] Immunohistochemistry for LRP6.**

**[00147]** Mammary tissues were fixed for 2 hours in 4% paraformaldehyde at 4°C and then embedded in paraffin and sectioned (5 µm). Immunohistochemistry was performed by using Vector ABC and DAB kits according to the manufacturer's recommendations (Vector Laboratories). Rabbit polyclonal antibody against *Lrp6* was used at a 1:250 dilution. The antibody was purchased from Zymed Laboratories, CA.

**[00148] Mammary Whole Mounts.**

**[00149]** Inguinal mammary glands were dissected, fixed overnight in Carnoy formula (6:3:1 ratio of ethanol:chloroform:glacial acetic acid), rehydrated and stained overnight in Carmine alum stain. The stained glands were dehydrated, cleared in Xylene and stored in Methyl Green. After whole mount pictures had been taken, the tissues were embedded in paraffin for sectioning. Sections (5 µm) were rehydrated and counterstained with H&E.

**[00150] Analysis of BAT-gal Expression**

**[00151]** For the analysis of BAT-gal expression whole mount embryos were fixed (0.2% glutaraldehyde, 1.5% formaldehyde, 5 mM EGTA, 2 mM MgCl<sub>2</sub> in PBS), washed (2 mM MgCl<sub>2</sub>, 0.01% sodium deoxycholate, 0.02% NP-40 in PBS) and stained with X-Gal (1 mg/ml X-gal, 2 mM MgCl<sub>2</sub>, 0.01% sodium deoxycholate, 0.02% NP-40, 5 mM Fe<sub>3</sub>(CN)<sub>6</sub>, 5 mM Fe<sub>4</sub>(CN)<sub>6</sub> in PBS) at 30 °C for 30 minutes, dehydrated and cleared in Xylene. After whole mount pictures had been taken, the embryos were embedded in paraffin for sectioning. Sections (5 µm) were rehydrated and counterstained with eosin. Embryonic stage was confirmed by analysis of limb morphology.

**[00152] Analysis of β-galactosidase Expression.**

**[00153]** *Lrp6*<sup>+/-</sup> and *Lrp6*<sup>+/+</sup> (negative control) mammary glands were isolated and fixed in 2% paraformaldehyde plus 0.25% glutaraldehyde in PBS at 4 °C for 2 h. Glands were rinsed in 2 mM MgCl<sub>2</sub>, 0.1% sodium deoxycholate, and 0.2% NP40 in PBS at room temperature for 2x 1 h and stained overnight at 30 °C in X-gal buffer (1 mg/ml X-gal, 5 mM K-ferricyanide, 5 mM K-ferro in rinse buffer). Glands were rinsed in PBS, dehydrated and cleared in BABB (2:1 ratio of benzyl alcohol:bezyl benzoate), and briefly stored in Xylene. After whole mount pictures had been taken, the tissues were embedded in paraffin for sectioning. Sections (5 µm) were counterstained with 0.1% Nuclear Fast Red.

**[00154] Isolation of Mammary Ductal Cells.**

**[00155]** Mammary glands were obtained from *Lrp6*<sup>+/-</sup> and *Lrp6*<sup>+/+</sup> 12 week old, virgin Balb/c mice. The glands were harvested and minced with fine scissors on ice. Mammary organoids were dissociated by enzymatic digestion with hyaluronidase and collagenase for seven hours at 37°C (reagents and protocol from Stem Cell Technologies, Vancouver, Canada). The mammary organoids were then further dissociated into single cells by brief trypsin and dispase exposures (reagents and protocol from Stem Cell Technologies). Single mammary epithelial cell preparations were then stained with CD45, Ter119, or CD31 antibodies. Single cells that did not express these markers were then stained with CD24 and CD49f and exposed to 10µm 9H-(1,3-dichloro-9,9-dimethylacridin-2-one-7-yl) β-D-galactopyranoside (DDAOG) in Hanks buffer for 30 minute. All reagents and protocols for this experiment except DDAOG were from Stem Cell Technologies. DDAOG was purchased from Invitrogen.

**[00156] Results****[00157] LRP6 is expressed in the mammary gland.**

**[00158]** *LRP6*-deficient mice were exploited to assess LRP6 expression. These mice were originally created in a large-scale mutagenesis screen designed to inactivate proteins containing signal peptides [Soriano, P., Nat Genet, 1999. 21(1): 70-1]. As part of this work, a targeting vector was used allowing for expression of the  $\beta$ -galactosidase ( $\beta$ -gal) gene from the promoter of the gene that was disrupted. Thus, the inventors used  $\beta$ -gal activity as a surrogate marker for LRP6 expression and found that LRP6 is expressed in the normal adult virgin mammary and during pregnancy (Fig. 2).  $\beta$ -gal reactive cells were present in the myoepithelial cell layer.

**[00159] *Lrp6* is Specifically Expressed in the Mammary Stem Cell Population.**

**[00160]** A cell population enriched for mammary stem cells can be identified by FACS. These cells often referred to as MRUs (mammary repopulating units) express medium levels of CD24 and high levels of CD49f but do not express CD45, Ter119, or CD31. The method for isolating MRUs was first described by Stingl et al. (Nature. 2006 Feb 23;439(7079):993-7). By performing single cell transplantations they found that the MRU cell population has a mammary stem cell frequency of 1/90 cells, compared to 1/1400 in unsorted mammary cells. Fig. 4A show a CD24, CD49f FACS sort of CD45<sup>-</sup>Ter119<sup>-</sup>CD31<sup>-</sup> mammary cells (adapted from Stingl et al, Nature. 2006 Feb 23;439(7079):993-7).

**[00161]** To determine which cell population in the mammary expressed LRP6, FACS was performed as described by Stingl.  $\beta$ -galactosidase was used as a surrogate marker for LRP6 expression. The targeting vector used to create the *Lrp6*<sup>-/-</sup> mouse strain contained the  *$\beta$ -galactosidase* gene and as a result  $\beta$ -galactosidase expression was directed from the *Lrp6* promoter in *Lrp6*<sup>+/-</sup> and *Lrp6*<sup>-/-</sup> mice. Mammary ductal cells were isolated from adult virgin *Lrp6*<sup>+/-</sup> and *Lrp6*<sup>+/+</sup> control females and an antibody mixture was used to selected cells that were CD45<sup>-</sup>Ter119<sup>-</sup>CD31<sup>-</sup>. Labelled *Lrp6*<sup>+/-</sup> and *Lrp6*<sup>+/+</sup> cells were used with CD24 and CD49 antibodies, and DDAOG. DDAOG (9H-(1,3-dichloro-9,9-dimethylacridin-2-one-7-yl)  $\beta$ -D-galactopyranoside) binds  $\beta$ -galactosidase and has far red fluorescent properties that can be detected by FACS (Wehrman et al, Nat Genet. 2004 Feb;36(2):183-9.). Shown in Fig. 4B is the FACS sort for CD24 and CD49. The cell population labelled R3 contain the luminal epithelial cells, while R2 contain myoepithelial cells. The MRU cell population is indicated by the right-hand-most circle. Fig. 4C shows

the cells that are positive for DDAOG, therefore expressing LRP6. DDAOG positive cells were exclusively found in the MRU cell population among the myoepithelial cells. 0.17% or 1/565 mammary cells were found to express *Lrp6*. Background DDAOG positive cells were not seen in the *Lrp6*<sup>+/+</sup> control mammary cells (data not shown).

[00162]           **Histological Expression Pattern of *Lrp6*.**

[00163]           The FACS results suggested that in adult females LRP6 is expressed in a small fraction (the stem cell fraction) of the myoepithelial cell lineage. In order to confirm this on the histological level, the inventors determined the expression pattern of LRP6 in mammary whole mount sections from different developmental time points. Again,  $\beta$ -galactosidase expression was used as a surrogate marker for *Lrp6* expression. The targeting vector used to create the *Lrp6*<sup>-/-</sup> mouse strain contained the  $\beta$ -galactosidase gene. As a result  $\beta$ -galactosidase expression is directed from the *Lrp6* promoter in *Lrp6*<sup>+/+</sup> and *Lrp6*<sup>-/-</sup> mice and can be used.

[00164]           *Lrp6* was expressed throughout embryonic and post-natal mammary development. During embryonic ductal development and until a few days after birth *Lrp6* was expressed in both the basal myoepithelial and luminal epithelial cell layer (Fig. 5A). In juvenile and adult females *Lrp6* expression was restricted to a small fraction of cells in the myoepithelial cell layer of the mammary ducts (Fig. 5B). No staining was seen in the negative control (Fig. 5C). These findings are consistent with the inventors' FACS results and LRP6 being a marker for stem cells in the adult mammary gland.

[00165]           **Impaired Mammary Development in *Lrp6*<sup>-/-</sup> Embryos.**

[00166]           *Lrp6*<sup>-/-</sup> mice die around birth [Pinson, K.I., et al., Nature, 2000. 407(6803): p. 535-8], precluding examination of the effects on *LRP6* deficiency on the adult mammary. To determine whether the LRP6 receptor is required for embryonic mammary development, embryos were analyzed at embryonic day (E) 12.5 and E18.5. Mammary development begins at about E10.5 with the formation of two "mammary lines". By E12.5 the mammary lines have evolved into five pairs of lens-shaped mammary placodes presumed to contain the stem cells necessary for the outgrowth of the ductal tree. Normally at E18.5, the mammary epithelium has just started to grow into the presumptive mammary fat pad and started the branching process (Fig. 3). However, the *LRP6*-deficient mice reproducibly showed a lack of mammary epithelial branching, typically displaying only a single epithelial sprout (Fig. 3). Furthermore, the presumptive mammary fat pad appeared to be absent (Fig. 3).

[00167] To determine whether LRP6-mediated Wnt signaling is required for the development of mammary placodes, *Lrp6*<sup>-/-</sup> and *Lrp6*<sup>+/+</sup> littermate whole embryos were analyzed at E12.5 (Figs. 6A-6D). These embryos also contained a BAT-gal  $\beta$ -galactosidase reporter gene that is expressed at sites of canonical pathway activity.  $\beta$ -galactosidase expression induced by BAT-gal reporter gene activity can be discriminated from  $\beta$ -galactosidase expression induced by *Lrp6* promoter activity due to a large difference in the time it takes to detect the  $\beta$ -galactosidase by X-gal staining. While BAT-gal associated  $\beta$ -galactosidase expression is detected within 20 minutes of X-gal staining, *Lrp6* associated  $\beta$ -galactosidase expression is not detected until after 12 hours of X-gal staining. The results show that loss of *Lrp6* compromises canonical signaling in the developing mammary placodes and interferes with their formation (Figs. 6A-6D). BAT-gal reporter gene activity was significantly reduced in *Lrp6*<sup>-/-</sup> embryos (Fig. 6C) relative to littermate controls (Fig. 6A). On the histological level the mammary placodes of *Lrp6*<sup>-/-</sup> embryos (Fig. 6D) were significantly smaller and contained fewer cells with reporter gene activity (Fig. 6B). This suggests that *Lrp6*-mediated Wnt signaling is essential for the development of the primitive mammary stem cell compartment during embryogenesis.

[00168] **Reduced Number of Terminal End Buds in Juvenile *Lrp6*<sup>+/-</sup> Mammary Glands.**

[00169] *Lrp6*<sup>+/-</sup> mice live and are fertile. To test whether *Lrp6* is required for post-natal mammary development, ductal branching and extension were examined in virgin *Lrp6*<sup>+/-</sup> females. Whole-mount preparations of inguinal mammary glands are shown in (Fig. 7A). The number of terminal end buds (TEBs) was reduced by 32% in juvenile *Lrp6*<sup>+/-</sup> mice compared with littermate wild-type mice ( $p = 3.8 \times 10^{-6}$ ) (Figs. 7A and 7B). TEBs are club-shaped epithelial thickenings at the distal ends of growing ducts presumed to be rich in mammary stem cells (Kenny - J Biomed Biotechnol. 2001;1(3):133-143.), and are the sites of most rapid cell proliferation. The branching complexity in adult mice is a function of terminal end bud activity during juvenile ductal extension. Morphometric analysis showed that the branching complexity of adult *Lrp6*<sup>+/-</sup> glands was decreased by 15% compared with littermate wild-type mice (data not shown).

[00170] ***Lrp6*<sup>+/-</sup> Mice Are Resistant to MMTV-Wnt1-Induced Tumorigenesis.**

[00171] Female mice expressing the *Wnt1* gene under the control of the MMTV promoter reproducibly develop mammary adenocarcinomas within one year (Tsukamoto AS -Cell. 1988 Nov 18;55(4):619-25.). The tumors develop in a context of widespread hyperplasia. The hyperplastic mammary tissue has been shown to contain an increased fraction of

mammary stem/progenitor cells that are thought to directly give rise to transformed cells (Alexander - Proc Natl Acad Sci U S A. 2004 Mar 23;101(12):4158-63., Li - Proc Natl Acad Sci U S A. 2003 Dec 23;100(26):15853-8.). Tumors arising from stem/progenitor cells often show mixed lineage differentiation and mammary tumors induced by Wnt1 indeed contain cells from both epithelial lineages (Owens DM, Watt FM. - Nat Rev Cancer. 2003 Jun;3(6):444-51,

[00172] Wnt1 transgenic mammary tissue and tumors normally express LRP6 (Figs. 1A-1C). To test whether LRP6-mediated Wnt signaling is required for Wnt1-induced tumorigenesis, the development of mammary tumors in *Wnt1;Lrp6<sup>+/-</sup>* and *Wnt1;Lrp6<sup>+/+</sup>* female mice was monitored. The gene dose of *Lrp6* had a dramatic effect on Wnt1-induced tumorigenesis. Tumor appearance was significantly delayed in *Wnt1;Lrp6<sup>+/-</sup>* mice ( $p = 0.001$ ). Within 10 months, 100% of *Wnt1;Lrp6<sup>+/+</sup>* females developed tumors with a median time of onset of 25 weeks, and 50% of *Wnt1;Lrp6<sup>+/-</sup>* females formed tumors with a median time of onset of 43 weeks (Fig. 8A). Histopathological examination of the tumors in this study revealed that all *Lrp6<sup>+/+</sup>* and *Lrp6<sup>+/-</sup>* tumors were moderately differentiated alveolar mammary adenocarcinomas and exhibited show mixed lineage differentiation (Fig. 8B). Taken together, these data suggest that *Lrp6<sup>+/-</sup>* tumors also originate from the mammary progenitor cell population. The delay in tumorigenesis could thus be explained by a reduction in the number of transformable progenitor cells.

[00173] **LRP6 is Expressed in Human Basal Like Breast Cancer.**

[00174] There are several molecular subgroups of human breast cancer. Basal-like breast cancer (BLC) is a newly recognized subtype, which express genes that are characteristic of basal epithelial cells, and are associated with poor relapse-free and overall survival (Finnegan, T.G., Carey, L.A., Gene-expression analysis and the basal-like breast cancer subtype.

Future Oncol. 2007 Feb;3(1):55-63. Review).

[00175] The tumors are estrogen receptor-negative and HER2/ErbB2-negative and are often referred to as triple negative (since they also lack expression of the progesterone receptor). A number of studies have suggested that the tumor precursor of BLC is a mammary stem cell. Yehiely F et al. Trends Mol Med. 2006 Nov;12(11):537-44; Birnbaum D et al. Int J Oncol. 2004 Aug;25(2):249-58. However, the genetic alterations that are responsible for these tumors are not well understood, thereby hindering efforts to develop targeted therapies.

[00176] In order to investigate whether *LRP6* is expressed in BLC the inventors analyzed the data sets of two published gene expression studies (Richardson et al. Cancer Cell. 2006 Feb;9(2):121-32 and Farmer et al. Oncogene. 2005 Jul 7;24(29):4660-71) using the software Oncomine. The inventors found that the population of breast cancer patients with tumors of the BLC subtype express a higher level of LRP6 in the tumor cells at the mRNA level than the population of breast cancer patients with tumors that fall into the other subtypes ( $p = 3.5 \times 10^{-5}$ ; Richardson et al. data analyzed) and ( $p = 0.009$ ; Farmer, et al. data analyzed) (Figs. 9A and 9B). Therefore LRP6 could be used as a marker to diagnose BLC and as a drug target for breast cancer therapies.

[00177] In summary, disclosed herein is a requirement for the Wnt co-receptor *Lrp6* in normal mammary morphogenesis and tumor formation mediated by putative ductal stem cells. Importantly, *Lrp6*<sup>+/-</sup> mice are resistant to Wnt1-induced tumors, which have been shown to be derived from the mammary stem/progenitor cell population (Fig. 8). These mice exhibit a delay in tumorigenesis that is associated with reduced Wnt1-induced hyperplasia. In addition to the tumor-resistance phenotype, loss of *Lrp6* impairs various stem cell activities required for normal mammary development (Fig. 6 and 7). *Lrp6*<sup>-/-</sup> embryos also exhibit substantially impaired canonical Wnt signaling in the primitive stem cell compartment of the mammary placode (Figs. 6C and 6D). Most importantly, the inventors also show that *Lrp6* is specifically expressed in the mammary stem cell fraction by FACS (Fig. 4C).

[00178] Canonical Wnt signaling has been implicated in the regulation of various stem cells including hematopoietic, intestinal, and epidermal stem cells (30). For example, soluble Wnt proteins promote growth and inhibit differentiation in hematopoietic stem cells (2). Wnt signaling also inhibits the differentiation of stem cells in the intestinal epithelium and in hair follicles (31, 32). Importantly, in many of the same tissues where the Wnt pathway controls stem cells, deregulation of Wnt signaling leads to tumor formation. Stabilization of  $\beta$ -catenin in the intestinal epithelium or overexpression of  $\beta$ -catenin in the epidermis results in the development of intestinal adenomas or hair tumors, respectively (33, 34). This suggests that Wnt ligands can initiate tumor formation through altered regulation of stem cell populations. Consistently, mice that overexpress Wnt signaling effectors in the mammary epithelium develop tumors with stem/progenitor cell properties, in contrast to mice overexpressing several other oncogenes (19).

[00179] The pre-neoplastic hyperplasia contains an increased fraction of cells positive for molecular markers that have been associated with mammary progenitor cells, and the

likelihood of progression to carcinoma correlates with the overall number of progenitor cells (17, 19, 20). In addition, mammary ductal cells from pre-neoplastic Wnt1 transgenic mice show an increased frequency of cells with stem cell activity, measured by transferring limiting dilutions of cells to fat pads in vivo (17, 20). This finding again demonstrates the ability of the Wnt pathway to target stem/progenitor cells for transformation, possibly reflecting a role of the Wnt pathway in the self-renewal of normal breast epithelium.

[00180]

Herein disclosed is the loss of Lrp6-mediated canonical Wnt signaling impairs the mammary stem cell compartment. Furthermore, LRP6 is specifically expressed by CD24<sup>medium</sup>CD49f<sup>high</sup> mammary stem cells. During normal development, the ductal tree fills the mammary fat pad by the end of puberty and TEBs disappear. In *Lrp6*<sup>+/-</sup> females, juvenile ductal branching and extension is supported by fewer TEBs and is significantly delayed (Figs. 7A and 7B). The ductal branching of adult *Lrp6*<sup>+/-</sup> mammary glands is reduced by 15%. There are various ways to explain why *Lrp6*<sup>+/-</sup> mammary glands are relatively normal but contain a reduced number of stem cells: 1) fewer primitive mammary stem cells develop (leading to very low stem cell fractions in the adult mammary gland, 2) the proportion of stem cells dividing by self-renewal (and symmetric division) is decreased, leading to progenitor-based organogenesis (either because the stem cell niche is ineffective, or the cells differentiate precociously), 3) canonical Wnt signaling is required for stem/progenitor survival (35). The inventors have no data to support or refute the second and third proposals, but in support of the first proposal, our analysis of Wnt reporter mice shows that *Lrp6*<sup>-/-</sup> embryos develop abnormally small mammary placodes with significantly reduced canonical signaling relative to littermate controls. Previous literature on Wnt reporter mice have shown that canonical Wnt signaling is specifically active during embryonic mammary development (13, 14). Furthermore, Wnt signaling is absolutely required, because mammary placodes fail to develop in transgenic mice overexpressing the Wnt inhibitor Dkk1 (6). Dkk1 inhibits the Wnt signaling pathway by binding to, and presumably inactivating, LRP5 and LRP6.

[00181]

Finally, a growing body of evidence suggests that specific subtypes of the most common human tumors—including breast (36), lung (37), and colon (38)—originate in stem cell compartments. Signaling pathways that regulate stem cell activity could therefore be effective drug targets. In fact, several studies have shown that activation of canonical Wnt signaling is common in human breast cancer (39-41). The inventors show that in *Lrp6*<sup>+/-</sup> mice, the response to ectopically expressed Wnt1 is inhibited as

demonstrated by an increased latency in tumor development (Fig. 8). The mammary tumors that arise in *Lrp6*<sup>+/-</sup> mice exhibit histology and differentiation similar to those of *Lrp6*-expressing tumors (Fig. 8), suggesting that *Lrp6*<sup>+/-</sup> tumors also originate from the mammary progenitor cell population. The delay in tumorigenesis could thus be explained by a reduction in the number of transformable progenitor cells. In concordance with this, the inventors found that LRP6 is upregulated in a subtype of human breast cancer presumed to originate from the mammary stem cell compartment (Fig. 9). Taken together, these findings suggest that the *Lrp6* receptor may be a highly effective target for inhibiting oncogenic canonical Wnt signaling in human malignancies.

[00182] *Example 2: Method of Screening for LRP6-Specific Inhibitors.*

[00183] First, establish mouse embryonic fibroblasts (MEFs) from control mouse embryos (CONTROL) or from *Lrp5*-deficient (*Lrp5*<sup>-/-</sup>) embryos. These MEFs would also contain a reporter gene (Bat-Gal) that directs the expression of  $\beta$ -galactosidase under the control of a  $\beta$ -catenin-responsive promoter. Thus,  $\beta$ -catenin signaling activity could be measured by analyzing the level of  $\beta$ -galactosidase activity in lysates prepared from these cells. Next, expose CONTROL and *Lrp5*<sup>-/-</sup> MEFs to exogenously added Wnt ligands which are commercially available. After 4-12 hours, measure the amount of  $\beta$ -galactosidase activity in the lysates. Any activity noted in the *Lrp5*<sup>-/-</sup> lysates would be due to Wnt signaling through the LRP6 molecule. Then, screen for compounds that inhibit the ability of Wnt ligands to increase  $\beta$ -galactosidase activity in *Lrp5*<sup>-/-</sup> MEFs. Compounds identified in this screen would subsequently be used to test their ability to inhibit signaling in CONTROL MEFs. Those that inhibit signaling in *Lrp5*<sup>-/-</sup> but not CONTROL, MEFs would be strong candidates to be specific inhibitors of LRP6-mediated signaling.

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What is claimed is:

1. A method of screening for agents that modulate Wnt signaling in mammary tumor stem or progenitor cells comprising: (1) providing a mammary cell that has low density lipoprotein receptor-related protein 6 (LRP6) activity and attenuated low density lipoprotein receptor-related protein 5 (LRP5) activity; (2) selecting an agent that may be an LRP6 modulator; (3) exposing the cell to the agent; (4) performing an assay on the cell for LRP6 activity; and (5) concluding from the assay whether Wnt signaling is modulated in the mammary cell.
2. The method of Claim 1 wherein the cell is an LRP5 knockout cell.
3. The method of Claim 1 wherein the selected agent inhibits LRP6.
4. The method of Claim 1 wherein the selected agent is an RNAi for LRP6.
5. The method of Claim 1 wherein the LRP6 activity is determined by measuring the level of LRP6 mRNA or protein, by measuring the level or activity of GSK3, by measuring the level of  $\beta$ -catenin, or by measuring the activity of a Wnt pathway responsive promoter.
6. The method of Claim 1 wherein the selected agent is an antibody for LRP6.
7. The method of Claim 6 wherein the antibody for LRP6 is carrying a toxic moiety.
8. A composition for inhibiting Wnt signaling in a mammary tumor stem or progenitor cell, wherein the compound inhibits the activity of LRP6 in the mammary stem cells or progenitor cell.
9. The compound of Claim 8 wherein the compound inactivates LRP6 in mammary tumor stem cells or progenitor cells.
10. The compound of Claim 8 wherein the compound is an RNAi for LRP6.
11. The compound of Claim 10 wherein the RNAi is an shRNA.

12. The compound of Claim 8 wherein the compound is an antibody for LRP6.
13. The compound of Claim 12 wherein the antibody is carrying a toxic moiety.
14. A method of reducing Wnt signaling in a mammary tumor stem cell or progenitor cell in a mammal comprising administering to the mammal an effective amount of a mammary tumor stem cell-specific LRP6 antagonist or a cancer progenitor cell-specific LRP6 antagonist.
15. The method of Claim 14 wherein the LRP6 antagonist reduces LRP6 activity in mammary tumor stem cells or progenitor cells in the mammal.
16. The method of Claim of 14 wherein the LRP6 antagonist is an RNAi for LRP6.
17. The method of Claim 16 wherein the mammary tumor stem cell or progenitor cell is a basal-like cell.
18. The method of Claim 14 wherein the LRP6 antagonist is an antibody for LRP6.
19. The method of Claim 18 wherein the LRP6 antibody carries a toxic moiety.
20. A method of treating a condition associated with Wnt signaling comprising administering a compound that reduces the Wnt signaling activity of LRP6 in mammary tumor stem cells or progenitor cells.
21. The method of Claim 20 wherein the compound is administered in an amount effective to inhibit Wnt activity.
22. The method of Claim 20 wherein the compound is an RNAi for LRP6.
23. The method of Claim 22 wherein the mammary tumor cells or progenitor cells are basal-like cells.
24. The method of Claim 20 wherein the compound is an antibody specific to LRP6.

25. The method of Claim 24 wherein the antibody specific to LRP6 is carrying a toxic moiety.
26. The method of Claims 1, 8, 14, 20 wherein the agent, compound, or antagonist is a fusion protein.
27. The method of Claim 26 wherein the fusion protein is composed of two parts: the binding domains of both LRP6 and Frizzled fused to a toxic moiety.
28. A method for enriching a population of mammary cells or mammary tumor cells for somatic mammary stem cells or mammary tumor stem cells, the method comprising the steps of:
- obtaining a population of mammary cells or mammary tumor cells containing one or more somatic mammary stem cells or mammary tumor stem cells;
  - contacting said population of mammary cells or mammary tumor cells with an LRP6 antibody; and
  - selecting cells that bind to the antibody.
29. The method of Claim 28, wherein the population of mammary cells or mammary tumor cells is a population of human, mouse, or rat cells.
30. The method of Claim 28, wherein the antibody is attached to a solid matrix.
31. The method of Claim 28, wherein cells that bind to the antibody are selected by flow cytometry.
32. The method of Claim 31 wherein the top 10% or higher of the highest LRP6 expressing mammary cells or mammary tumor cells of the total population is selected.
33. The method of Claim 28, wherein the method is for enriching a population of mammary cells for somatic mammary stem cells.
34. The method of Claim 33 further comprising the step of contacting said population of mammary cells with an antibody against a cell surface marker for endothelial cells,

hematopoietic cells, or stromal cells wherein cells that bind to the anti-LRP6 antibody but not the antibody against the cell surface marker for endothelial cells, hematopoietic cells, or stromal cells are selected.

35. The method of Claim 33, wherein at least 1% of the selected cells are somatic mammary stem cells.

36. The method of Claim 33, wherein at least 5% of the selected cells are somatic mammary stem cells.

37. A method for inhibiting the proliferation or causing the death of a mammary tumor cell that expresses LRP6, the method comprising the step of:

contacting the mammary tumor cell with an agent that inhibits LRP6 activity in an amount sufficient to inhibit the proliferation or cause the death of the mammary tumor cell.

38. The method of Claim 37, wherein the mammary tumor cell is in a mammal and the step of contacting is carried out by administering the agent to the mammal.

39. The method of Claim 38, further comprising the step of administering a second tumor therapeutic agent.

40. The method of Claim 37, wherein the agent that inhibits LRP6 activity is selected from an anti-LRP6 antibody, an antisense oligonucleotide that inhibits the expression of LRP6, and an RNAi molecule that inhibits the expression of LRP6.

41. The method of Claim 40, wherein the anti-LRP6 antibody is linked to a cytotoxic agent.

42. The method of Claim 37 wherein the mammary tumor cell is a basal-like cell.

43. A method for detecting the presence of mammary basal-like cells in mammary tissue or a biological sample, which tissue or sample is suspected of including mammary basal-like cells, comprising the steps of: (a) contacting the tissue or sample with a

diagnostically labeled LRP6 antibody; and (b) detecting the presence of the diagnostic label associated with the tissue or sample.

44. The method of Claim 43, wherein the contacting and the detecting are in vitro.

45. The method of Claim 43, wherein the contacting is in vivo and the detecting is in vitro.

46. The method of Claim 43, wherein the contacting and the detecting are in vivo.

47. The method of Claim 43, wherein the detectable label is a radionuclide.

48. The method of Claim 43, wherein the detecting is by radioimmunosciintigraphy.

49. The method of Claim 43, wherein the diagnostic label is an MRI-imageable agent and the detecting is by MRI.

50. A method for diagnosing basal-like cell breast cancer comprising the steps of:

(a) contacting a tissue, organ or sample of a patient with a diagnostically labeled LRP6 antibody;

(b) detecting the presence of the diagnostic label associated with the tissue, organ or sample;

(c) determining the level of Lrp6 expression in the tissue, organ or sample; and

(d) comparing the Lrp6 level of expression in the tissue, organ or sample to a suitable control.

51. The method of Claim 50, wherein the suitable control is the median or average expression level from at least 25 breast cancer patients.

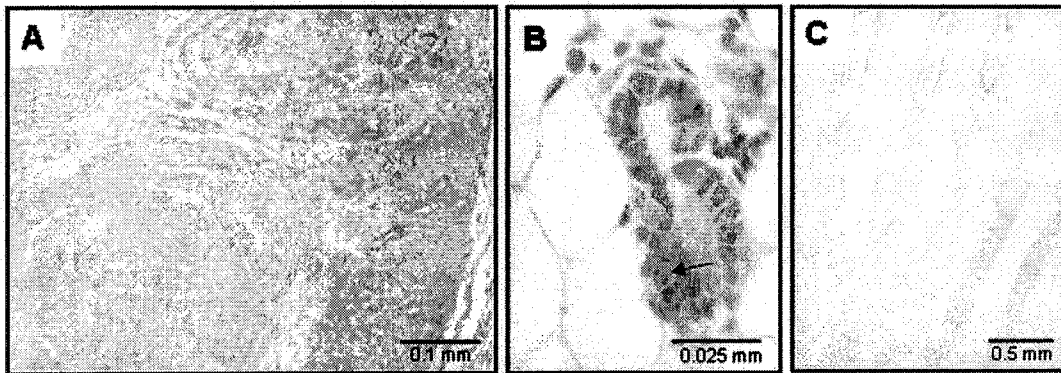


FIGURE 1

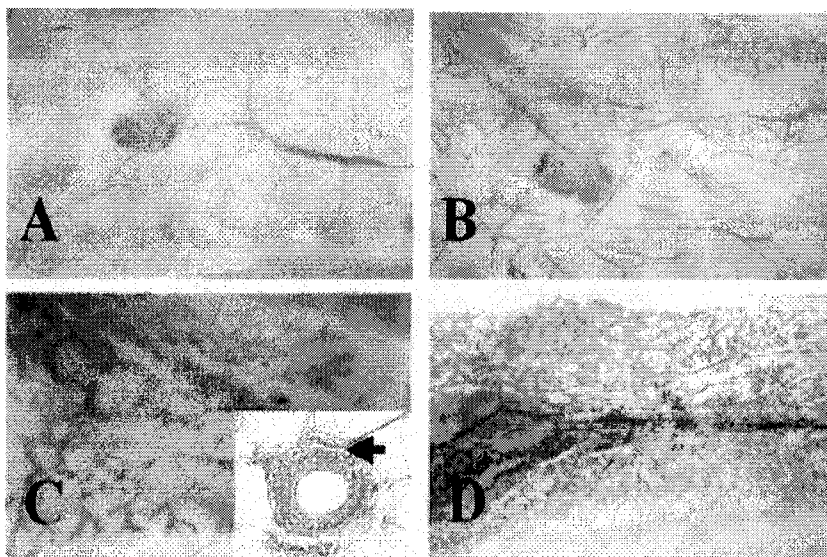


FIGURE 2

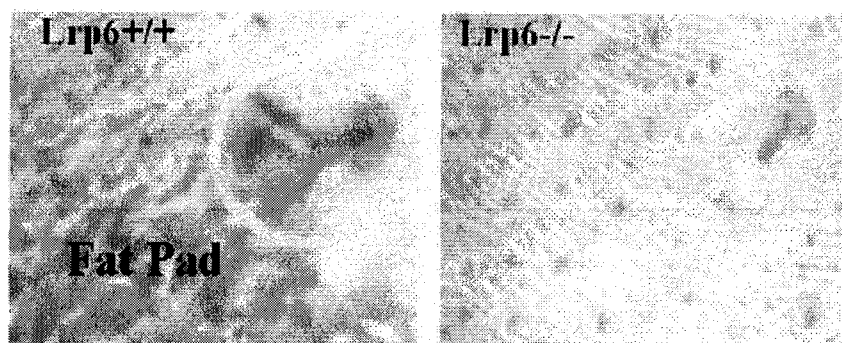


FIGURE 3

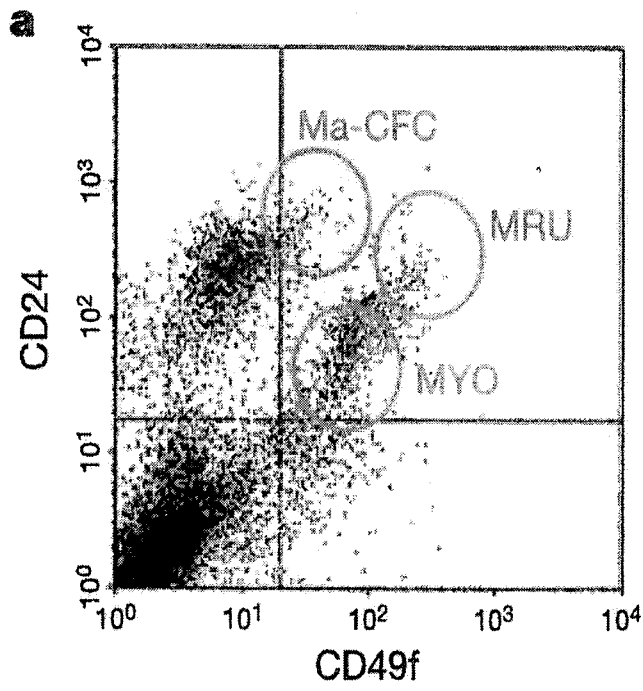


FIGURE 4A

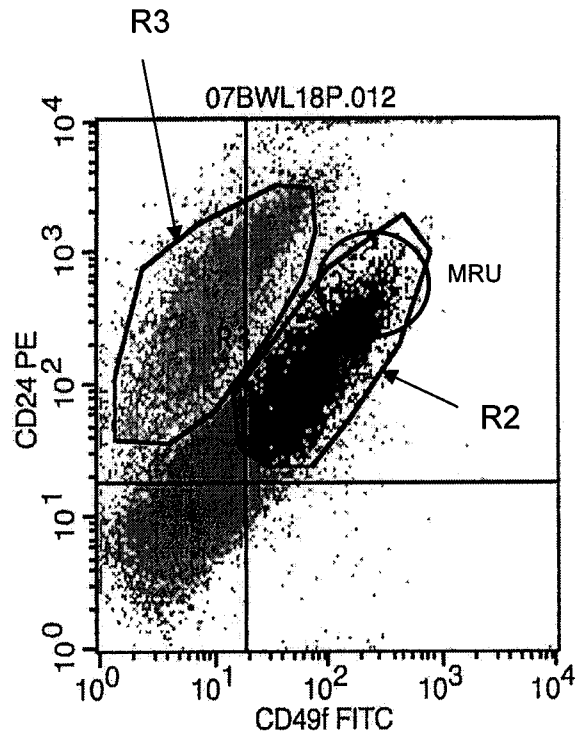


FIGURE 4B

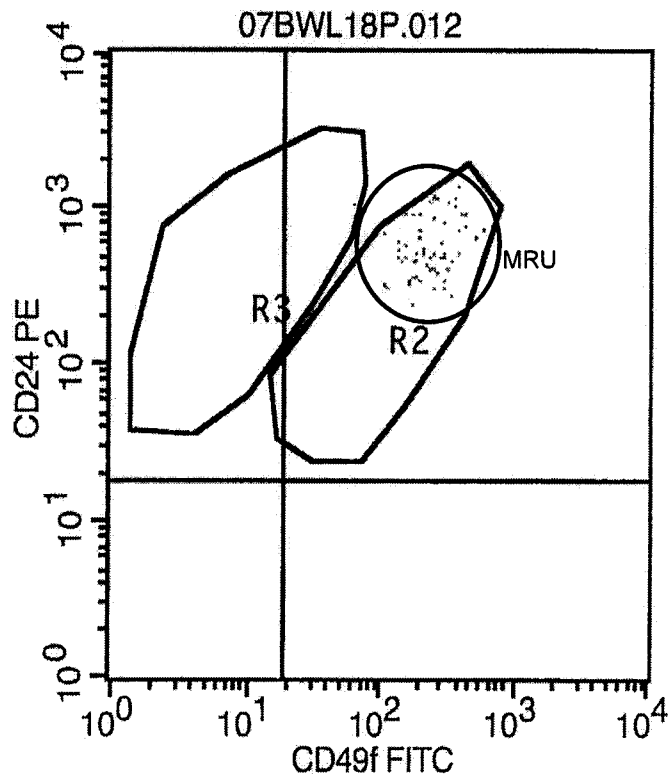


FIGURE 4C

FIGURE 5A

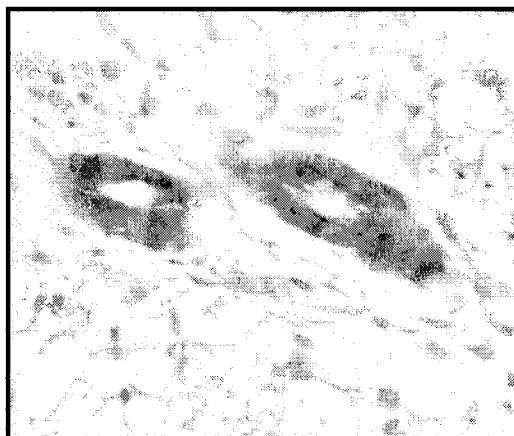


FIGURE 5B

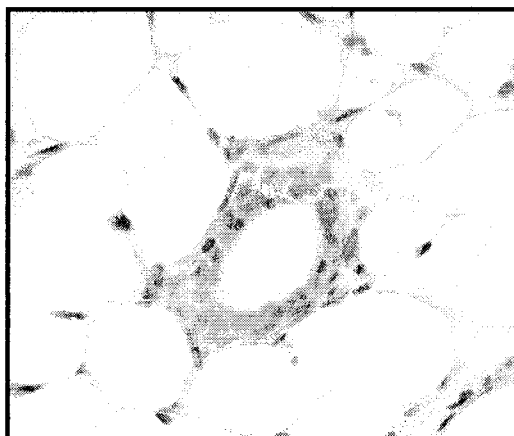


FIGURE 5C

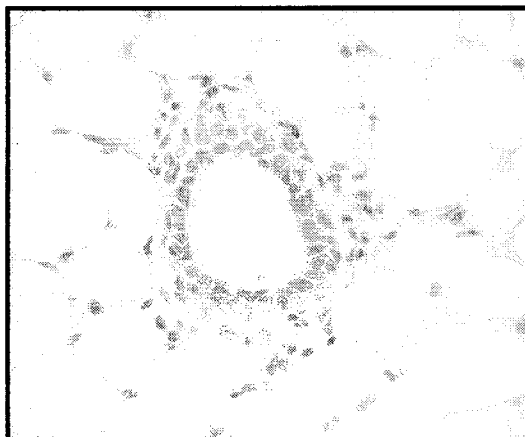


FIGURE 6A



FIGURE 6B

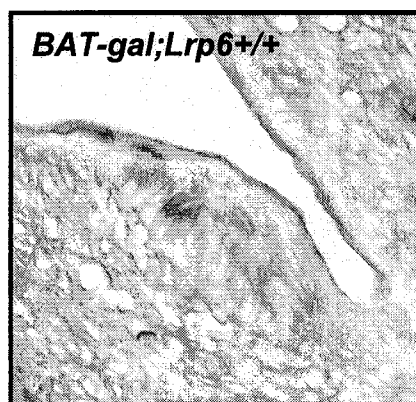
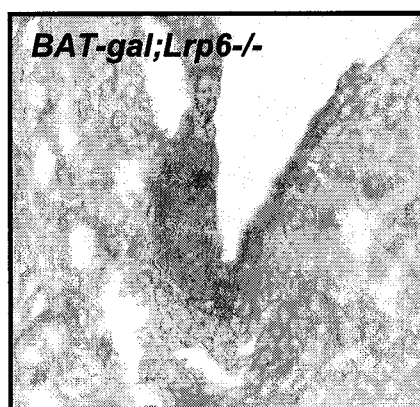


FIGURE 6C



FIGURE 6D



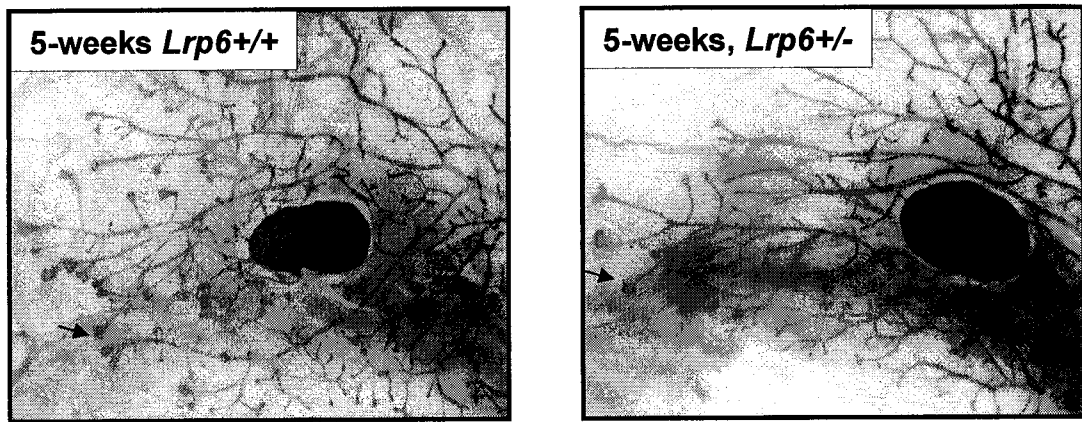


FIGURE 7A

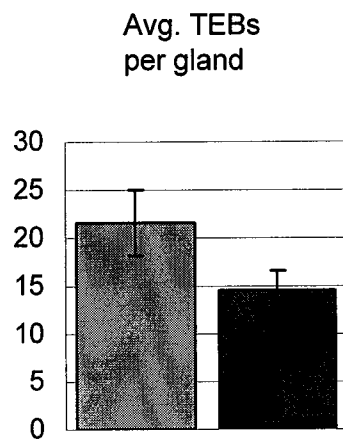


FIGURE 7B

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Kaplan Meier Plots

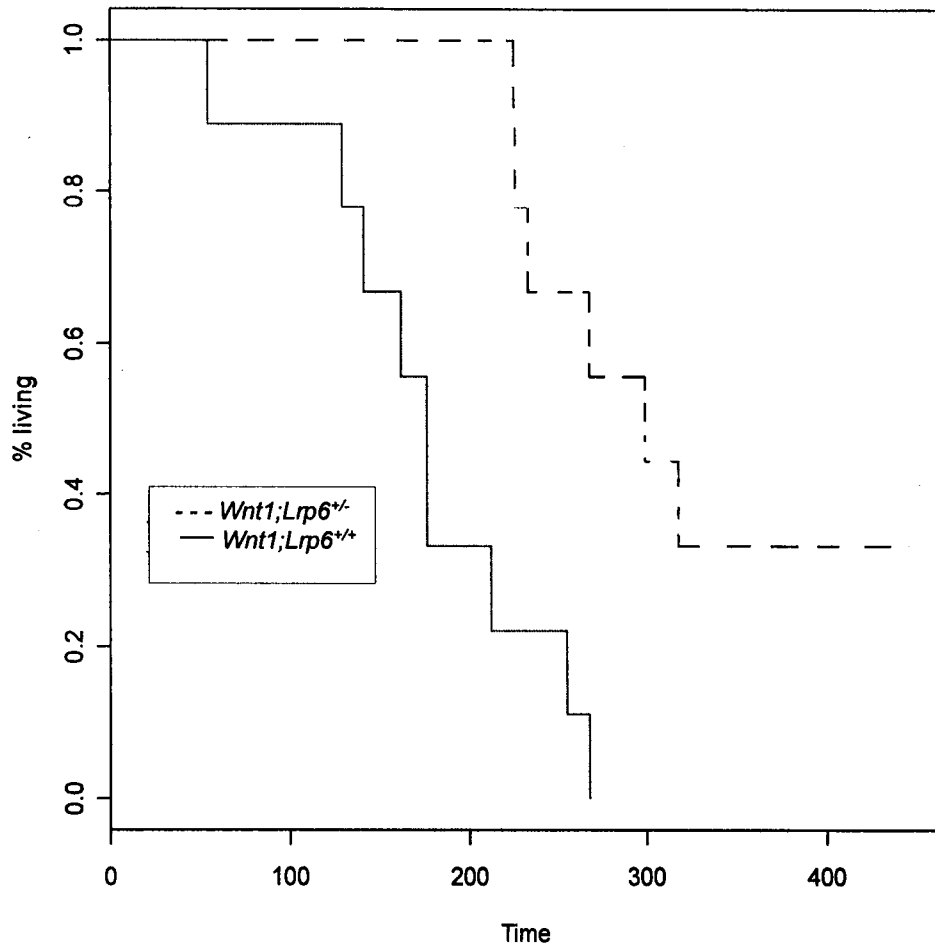


FIGURE 8A

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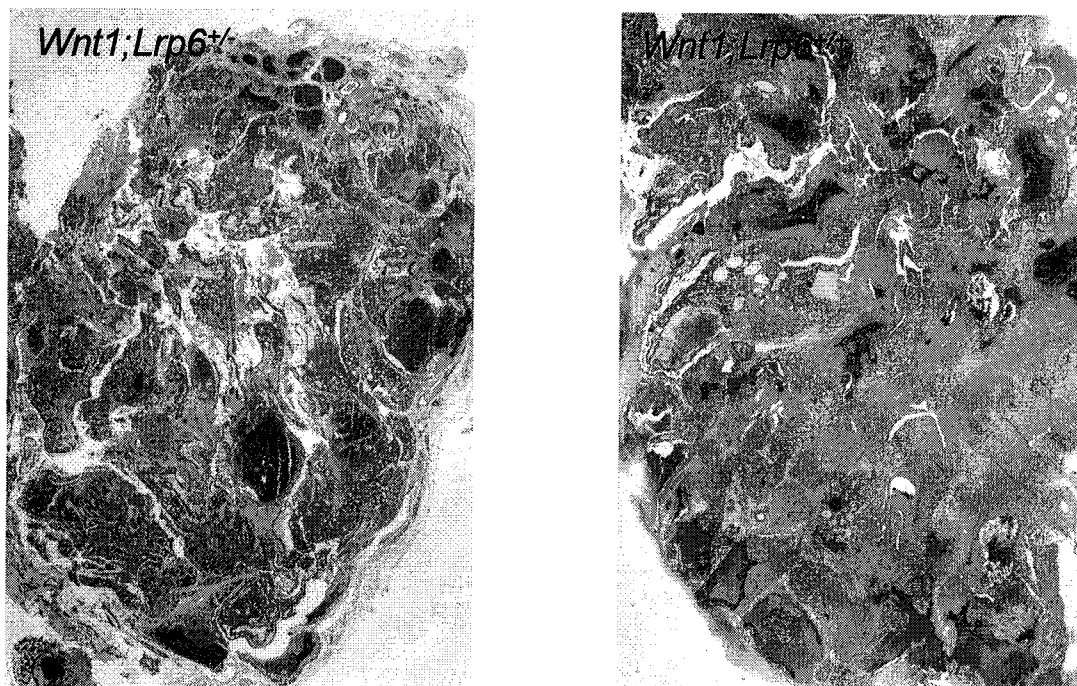
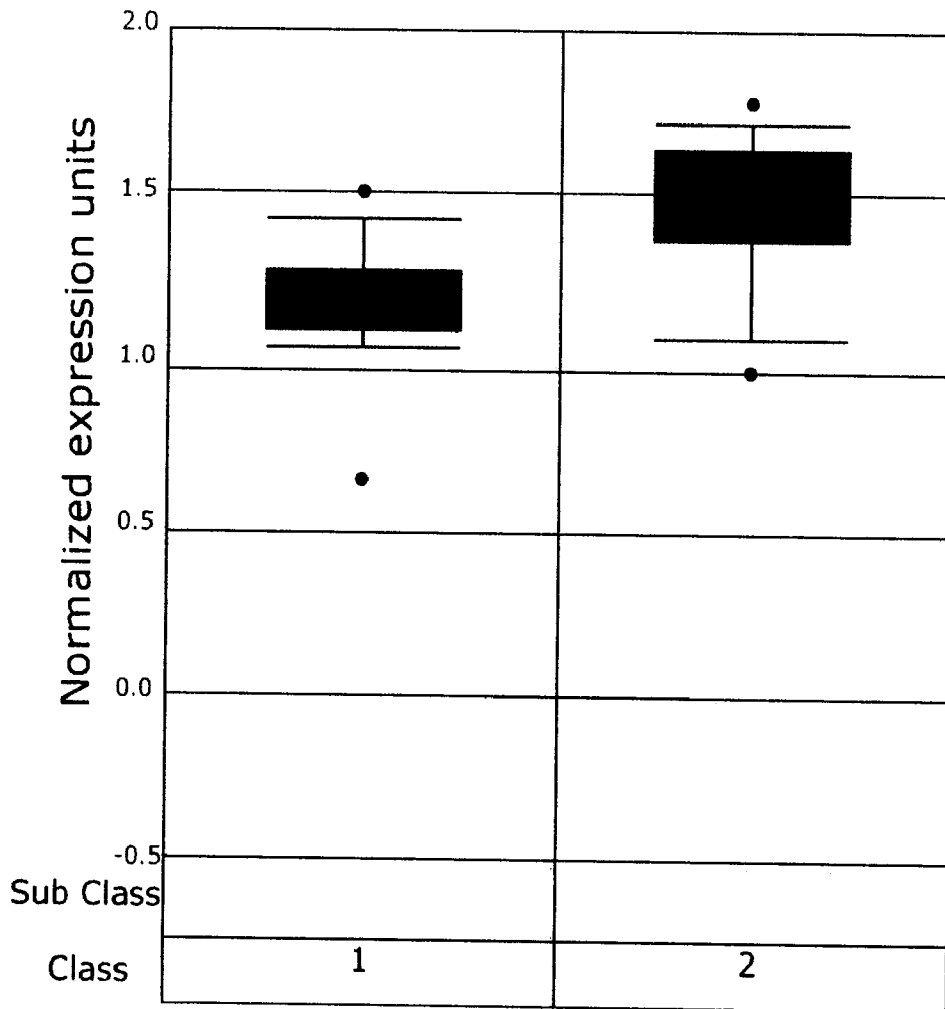


FIGURE 8B

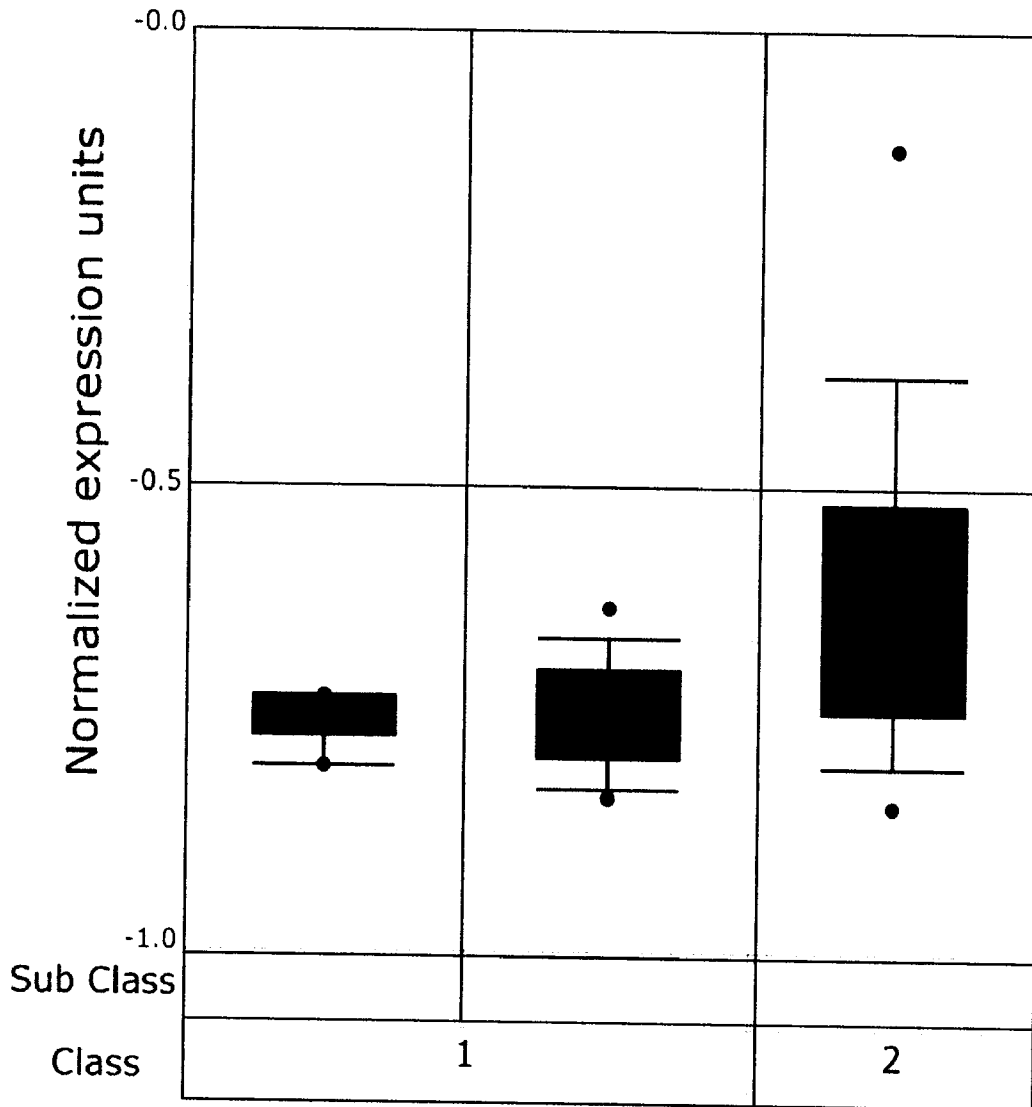
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Box Plot - Description

FIGURE 9A

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Box Plot - Description

FIGURE 9B

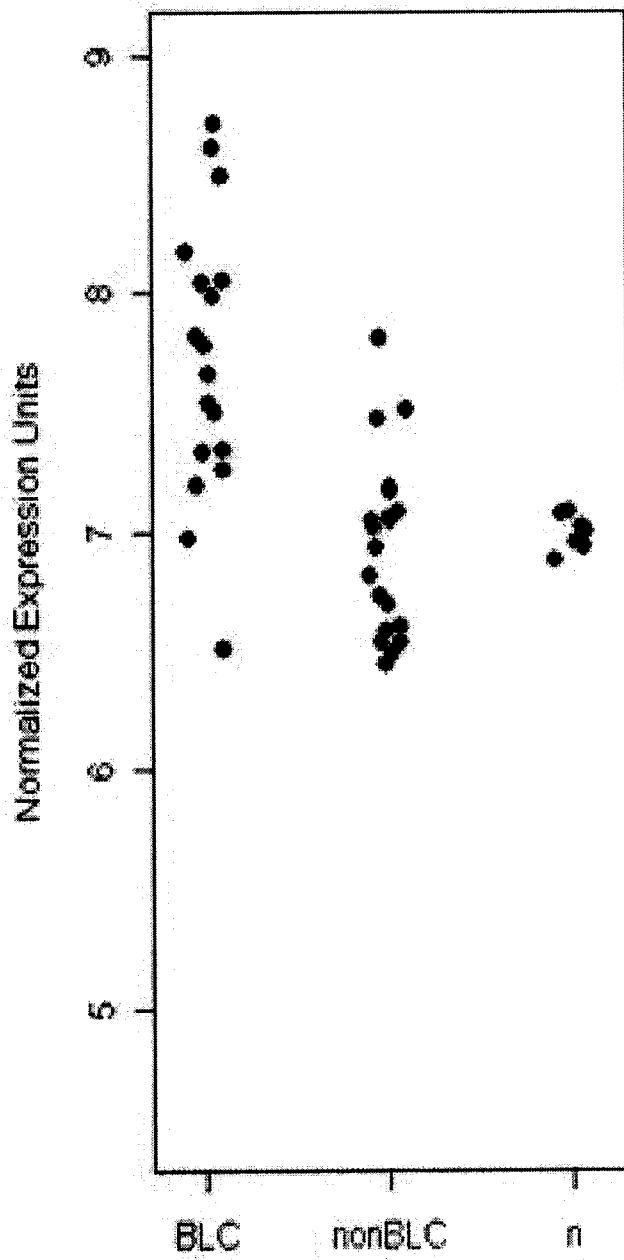


FIGURE 9C

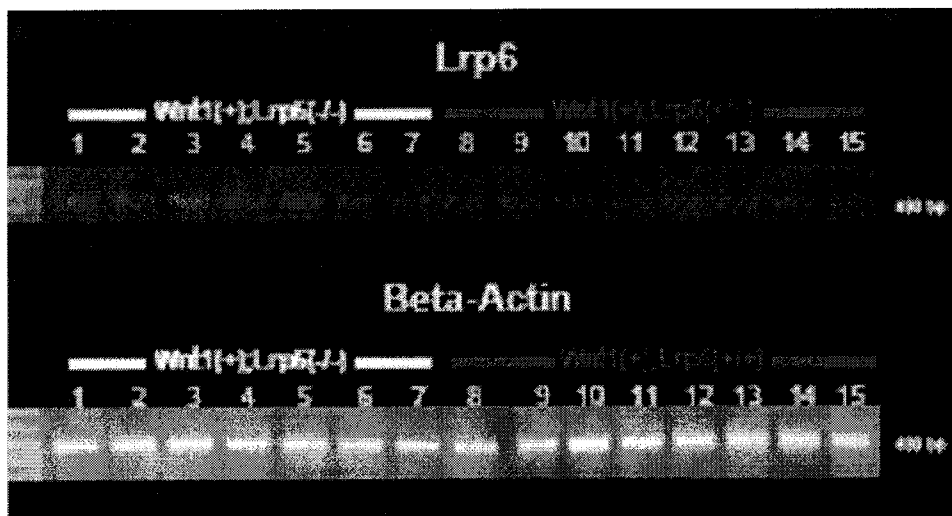


FIGURE 10