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(54) **ANTI-CANCER DRUG SCREENING METHOD USING ROR**

(57) The present invention relates to a method for screening an anticancer agent using ROR $\alpha$ , the method comprising the steps of: culturing cells; bringing a potential substance into contact with the cells; determining whether the phosphorylation level of ROR $\alpha$  in the cells

increases as compared to that in control cells (not brought into contact with the potential substance); and selecting the potential substance as an anticancer agent if the phosphorylation level of ROR $\alpha$  in the cells increases.

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**Description****Technical Field**

5 **[0001]** The Wnt genes encode a large family of cysteine-rich secreted polypeptides that mediate diverse signalling processes. Aberrant activation of Wnt signaling plays important roles as a major driving force linked to developmental defects and tumorigenesis (Klaus and Birchmeier, 2008; Korinek et al., 1997; Morin et al., 1997; Willert et al., 2003). Wnt signaling pathways have been divided into two categories; one is the canonical Wnt/ $\beta$ -catenin signaling pathway and the other is the noncanonical Wnt/ $\text{Ca}^{2+}$  signaling pathway (Kühl et al., 2000; Liang et al., 2007; Liu et al., 2005). In the absence of Wnt activation, the level of  $\beta$ -catenin in the cytoplasm remains low due to the degradation of  $\beta$ -catenin by 26S proteasome after paired phosphorylation through casein kinase I (CKI) and glycogen synthase kinase-3 $\beta$  (GSK-3 $\beta$ ) (Orford et al., 1997; Salic et al., 2000). The canonical Wnts bind to the Frizzled (Frz) family proteins and low-density lipoprotein receptor-related (LRP) 5 or 6, and this binding activates dishevelled (Dvl) and inhibits the activity of GSK-3 $\beta$ ; this inhibition results in the stabilization and subsequent translocation of  $\beta$ -catenin to the nucleus for the regulation of target gene expression with T-cell factor (TCF)/lymphoid enhancer factor (LEF) (Behrens et al., 1996; Giles et al., 2003; Molenaar et al., 1996; Moon et al., 2002).

10 **[0002]** Noncanonical Wnt signaling pathways affected by Wnt ligands such as Wnt5a have diverse and occasionally opposing roles (Slusarski et al., 1997; Torres et al., 1996). Noncanonical Wnts are both antagonistic and synergistic to canonical Wnt signalling pathways depending on their receptor context. *Wnt5a*-deficient mice show increased  $\beta$ -catenin signaling in the distal limb, indicating that Wnt5a is involved in the negative regulation of the Wnt/ $\beta$ -catenin signaling pathway (Nemeth et al., 2007). In contrast, Wnt5a has been shown to activate Wnt/ $\beta$ -catenin signaling in the presence of Frz4 and LRP5 (Mikels and Nusse, 2006). Given that the activation of the noncanonical Wnt signaling pathway results in intracellular  $\text{Ca}^{2+}$  release and activation of  $\text{Ca}^{2+}$  sensitive enzymes such as  $\text{Ca}^{2+}$ /calmodulin-dependent kinase II (CaMKII) and protein kinase C (PKC), the noncanonical Wnt pathways are apparently different from the canonical Wnt pathway.

**Background Art**

30 **[0003]** A mouse model of spontaneous intestinal tumorigenesis, designated *APC<sup>min/+</sup>* is widely used to explore Wnt/ $\beta$ -catenin signalling (Fodde et al., 1994; Shibata et al., 1997; Su et al., 1992). The genetic basis of familial associated polyposis (FAP) was mapped to the adenomatous polyposis coli (*APC*) gene, and germline and sporadic mutations in *APC* occur in most of FAP (Grodin et al., 1991; Kinzler et al., 1991). *APC<sup>min/+</sup>* mice have a mutation in the *APC* gene causing hyperactivation of Wnt/ $\beta$ -catenin signaling and die within 6 months from severe intestinal tumor development. As Wnt/ $\beta$ -catenin signaling is crucial for the maintenance of cellular homeostasis, a variety of positive and negative cellular regulators have been identified using genetic, proteomic, and RNA interference-based screening approaches.

35 Runx3 forms a ternary complex with TCF4/ $\beta$ -catenin and suppresses the DNA binding activity of TCF4/ $\beta$ -catenin (Ito et al., 2008). Wilms tumor suppressor WTX antagonizes Wnt/ $\beta$ -catenin signalling by promoting ubiquitination and degradation of  $\beta$ -catenin (Major et al., 2007). Recently, CDK8, a cyclin-dependent kinase member of the mediator complex, has been shown to be necessary for  $\beta$ -catenin-driven transcriptional activation (Firestein et al., 2008). Given that dysregulated transcriptional activity of  $\beta$ -catenin is crucial for colorectal tumorigenesis and progression, identification of genes that are responsible for genetic perturbations is important to explore complex malignant processes.

40 **[0004]** Members of the orphan nuclear receptor family play various roles in signal integration, including modulation of neurogenesis, homeostasis, and disease by regulating subsets of gene expression both positively and negatively (Blumberg and Evans, 1998; Giguère, 1999; Mangelsdorf et al., 1995). The retinoic acid-related orphan nuclear receptor (*ROR*) $\alpha$  is a member of the orphan nuclear receptor family for which no cognate ligands have been identified thus far (Giguère et al., 1994; Gold et al., 2003; Lau et al., 1994). *Staggerer* (*sg*) is a classical mutation of the *ROR* $\alpha$  gene that blocks Purkinje cell differentiation, resulting in cerebellar hypoplasia and congenital ataxia (Hamilton et al., 1996). *Sg* mice exhibit phenotypes regarding lipid metabolism, bone metabolism, hyperinflammatory responses, and mainly cerebellar development and approximately 50% of the mice die shortly after weaning, which makes studying *ROR* $\alpha$  function with *Sg* mice very difficult (Doulazmi et al., 2006).

50 **[0005]** Given that nuclear receptors function as potent regulators of normal physiology as well as pathologies such as cancer, the orphan nuclear receptors can functionally interact with potent oncogenic systems, for example, the Wnt and PKC signaling pathways (Peifer and Polakis, 2000). This interaction might elicit changes in oncogenesis and cellular adhesion (Polakis, 2000; van de Wetering et al., 2002). Compared to other classes of nuclear receptors, the function and related signaling pathways for the orphan nuclear receptor *ROR* $\alpha$  have not yet been studied extensively.

55 **[0006]** Thus, the present inventors identified a critical role of *ROR* $\alpha$  at the crossroads between - the canonical and the noncanonical Wnt signalling pathways in attenuating  $\beta$ -catenin transcriptional activity in a phosphorylation-dependent manner in colon cancer, based on cell culture, colorectal carcinoma tissues, and mouse cancer model studies. Biochem-

ical purification of ROR $\alpha$  containing complex identifies  $\beta$ -catenin as a component, providing a novel link between ROR $\alpha$  and Wnt signaling pathway. Analysis of ROR $\alpha$  interactions with  $\beta$ -catenin reveals that the ROR $\alpha$ -mediated inhibition of Wnt/ $\beta$ -catenin signalling requires Wnt5a/PKC $\alpha$  induced phosphorylation on serine residue 35 of ROR $\alpha$ , and the binding of ROR $\alpha$  to  $\beta$ -catenin is triggered and enhanced by phosphorylation of ROR $\alpha$ . Intriguingly, reduction of phosphorylation of ROR $\alpha$  concomitant with downregulation of PKC is correlated with activation of Wnt target genes and tumor progression in colorectal carcinoma tissues. The present inventors invented the present invention by revealing of role of ROR $\alpha$  in transrepression of the Wnt/ $\beta$ -catenin signalling pathway, thereby regulating cell proliferation and tumor progression in a pathophysiological model.

## SUMMARY OF THE INVENTION

**[0007]** It is an object of the present invention to provide a method for effectively screening an anticancer agent

**[0008]** Another object of the present invention is to provide a useful method for diagnosing cancer.

**[0009]** The present invention provides a method for effectively screening an anticancer agent using ROR $\alpha$ .

**[0010]** The present invention provides a useful method for diagnosing cancer using ROR $\alpha$ .

**[0011]** The inventive method for screening a substance inducing the phosphorylation of serine in the N-terminal region of ROR $\alpha$  is useful for identifying a cancer therapeutic agent. Particularly, the method of the present invention may be applied to any cancer caused by the Wnt/ $\beta$ -catenin signal, in which the cancer is preferably colorectal cancer.

**[0012]** The present invention can be advantageously used to diagnose cancer by measuring the amount of ROR $\alpha$  *in vivo*.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0013]**

Figure 1. Purification of ROR $\alpha$ -containing complex and identification of  $\beta$ -catenin as a binding partner

(A) ROR $\alpha$ -containing complex was purified from extracts obtained from HEK293 cells stably expressing Flag-tagged ROR $\alpha$ . As a negative control, a mock purification from HEK293 cells stably expressing an empty vector was performed. The bound proteins were resolved by SDS-PAGE and prepared for LC-MS/MS analysis. (B) Peptide sequences of ROR $\alpha$ -associated polypeptides obtained from LC-MS/MS analysis revealed that GRIP1 and  $\beta$ -catenin are components of the ROR $\alpha$ -containing complex. (C)  $\beta$ -catenin and GRIP1 were detected from the elutes by immunoblot analysis. (D) Coimmunoprecipitation of endogenous ROR $\alpha$  with  $\beta$ -catenin in HEK293 cells. (E) Ni<sup>2+</sup>-NTA-agarose pulldown assay was performed with plasmids expressing each GFP-tagged  $\beta$ -catenin deletion construct and HisMax-ROR $\alpha$ . (F) Illustration of the structure of various  $\beta$ -catenin deletion constructs and binding to ROR $\alpha$ .

Figure 2. Requirement of ROR $\alpha$  in mediating transcriptional repression of  $\beta$ -catenin transcriptional activity

(A) Real-time quantitative RT-PCR analysis of the *cyclin D1*, *c-myc* and *c-jun* transcripts in HCT116 cells in the presence of either shRNA against  $\beta$ -catenin or dominant negative TCF. (B) Measurement of *cyclin D1* and *c-myc* transcripts after transfection of ROR $\alpha$  in HCT116 colon cancer cells. (C and D) Overexpression of ROR $\alpha$  inhibited the TCF/ $\beta$ -catenin-mediated activation of the TOPFLASH reporter (C) and *cyclin D1* promoter reporter (D). (E) Measurement of mRNA abundance of *cyclin D1* after knockdown of ROR $\alpha$  by two independent shRNAs in HCT116 colon cancer cells. (F and G) Introduction of shRNAs against ROR $\alpha$  increased the transcriptional activation of the TOPFLASH reporter (F) or the *cyclin D1* promoter reporter (G). Data are represented as mean  $\pm$  s.d. for three independent experiments. (H) Two-step ChIP assay to determine whether ROR $\alpha$  and  $\beta$ -catenin are assembled on the same promoter. (I) HCT116 cells with or without exogenous expression of ROR $\alpha$  were coimmunoprecipitated with anti-TCF antibody and the immunoprecipitated materials were subject to immunoblotting against anti- $\beta$ -catenin antibody. Interaction between TCF and  $\beta$ -catenin was not changed with ROR $\alpha$  overexpression. (J) ChIP assay on the *cyclin D1* promoter in HCT116 cells with or without overexpression of ROR $\alpha$ . Occupancy of the *cyclin D1* promoter by ROR $\alpha$ ,  $\beta$ -catenin, TCF and RNA polymerase II is indicated. (K) The shRNA-coupled ChIP assay was performed on *cyclin D1* and *c-jun* promoters in HCT116 cells. Knockdown of  $\beta$ -catenin resulted in decreased histone acetylation as well as decreased recruitment of ROR $\alpha$  on the promoters, indicating that ROR $\alpha$  binds through  $\beta$ -catenin.

Figure 3. ROR $\alpha$  is phosphorylated by PKC $\alpha$  on serine 35

(A) Schematic representation of ROR $\alpha$  showing the location of the N-terminal domain (NTD), the DNA-binding domain (DBD), the hinge region, the ligand-binding domain (LBD), and the AF-2 domain. (B) Ni<sup>+</sup>-NTA-agarose pull-down assay revealed that ROR $\alpha$  segments that span amino acids 1-65 corresponding to NTD are sufficient to bind  $\beta$ -catenin. HEK293 cells were cotransfected with plasmids expressing each His-tagged ROR $\alpha$  deletion construct and  $\beta$ -catenin. Whole cell extracts (left panel) and Ni<sup>+</sup>-NTA-agarose pull-down materials (right panel) were analyzed by immunoblotting against anti- $\beta$ -cactin IgG or anti-Xpress IgG. (C) Illustration of the structure of deletion fragments of ROR $\alpha$ . (D) Interaction of each ROR $\alpha$  deletion construct with HisMax- $\beta$ -catenin was assessed by Ni<sup>+</sup>-NTA-agarose pull-down assay. (E) Coimmunoprecipitation of ROR $\alpha$  with various PKC isoforms. (F) Synthesized peptides of ROR $\alpha$  (NQESARKSE) were used as substrates in the kinase assay with PKC $\alpha$  enzyme. The phosphorylated peptide samples were analyzed by LC-MS analysis. (G) HCT116 cells were treated with TPA at an indicated time period, and cell lysates were immunoprecipitated with anti-ROR $\alpha$  antibody, followed by immunoblotting analysis against anti-phospho-Ser antibody indicating phosphorylated ROR $\alpha$  at endogenous level. (H) HCT116 cells were treated with TPA one day after transfection with Flag-ROR $\alpha$  WT, S35A, or S39A. Immunoprecipitation assay was conducted with anti-Flag antibody, and the phosphorylated ROR $\alpha$  was detected by immunoblot analysis with anti-phospho-Ser antibody. (I) *In vitro* kinase assays using either constitutive active form (caPKC $\alpha$ ) or kinase deficient form of PKC $\alpha$  (kdPKC $\alpha$ ) immunoprecipitated from cell lysates as the kinase and purified GST-ROR $\alpha$  N-terminal wild-type (WT) or S35A proteins as substrates were performed. The reaction samples were subjected to 12 % SDS-PAGE, and phosphorylated ROR $\alpha$  was detected by autoradiography. (J) HCT116 cells were transfected with Flag-ROR $\alpha$  WT or S35A and stained with antibodies directed against Flag epitope. The fluorescence-conjugated secondary antibody was visualized using fluorescence microscopy, and nuclear staining with DAPI was shown.

Figure 4. PKC $\alpha$ -dependent phosphorylation of ROR $\alpha$  is crucial for downregulation of Wnt/ $\beta$ -catenin target genes

(A) The specificity of the antibody raised against phosphorylated ROR $\alpha$ S35 peptide was assessed by dot blot analysis. (B) Treatment of TPA increased phosphorylated ROR $\alpha$  on S35 site as assessed by immunoprecipitation with anti-phospho-ROR $\alpha$ S35 antibody. (C) Immunoblot against anti-phospho-ROR $\alpha$ S35 antibody indicated that caPKC $\alpha$  increased phosphorylation of ROR $\alpha$ , whereas kdPKC $\alpha$  failed to phosphorylate ROR $\alpha$ . (D) Treatment of Go6976, a PKC $\alpha$  inhibitor, abolished TPA-dependent phosphorylation of ROR $\alpha$  as assessed by immunoblotting with anti-phospho-ROR $\alpha$ S35 antibody. (E) HCT116 cells were transfected with Flag-ROR $\alpha$  WT, S35D, or S35A, and the cell extracts were immunoprecipitated with anti-Flag antibody followed by immunoblotting against anti- $\beta$ -catenin antibody. (F) Coimmunoprecipitation assay of  $\beta$ -catenin with either ROR $\alpha$ WT or S35A in HCT116 cells after treatment with TPA in the absence or presence of Go6976. (G) ChIP analysis on the *cyclin D1* promoter after transfection with Flag-ROR $\alpha$ WT, S35A, or S35D in HCT116 cells. (H) ChIP analysis on the *cyclin D7* promoter in HCT116 cells after TPA treatment for indicated time. (I) ChIP assay was performed on the *cyclin D7* promoter in the absence or presence of siRNA against PKC $\alpha$  with treatment of TPA for 90 min. (J) Real-time quantitative RT-PCR analysis of the *cyclin D7* transcript in HCT116 cells in the presence of TPA for indicated time. (K) Knockdown effect of siRNA against ROR $\alpha$  or PKC $\alpha$  was assessed in the expression of the *cyclin D1* transcript in HCT116 cells.

Figure 5. Wnt5a antagonizes the canonical Wnt signaling by transrepression function of ROR $\alpha$

(A) Treatment of Wnt5a increased phosphorylated ROR $\alpha$  and PKC $\alpha$  but decreased cyclin D1 expression as assessed by immunoblot analysis against each antibody. (B) *Cyclin D1* transcript was measured after introducing siRNAs against ROR $\alpha$  or PKC $\alpha$  in the presence of Wnt5a in HCT116 cells. (C) Real-time quantitative RTPCR analysis of the *cyclin D1* transcript in HCT116 cells after introducing ROR $\alpha$ , S35A, or S35D in the presence of Wnt5a. (D) ChIP assay on the *cyclin D1* promoter with treatment of either TPA or Wnt5a in HCT116 cells. Occupancy of the *cyclin D1* promoter by phosphorylated ROR $\alpha$ ,  $\beta$ -catenin RNA polymerase II, H3K9me2, H3K4me2, CBP, pCAF, p300, or SMRT was indicated. (E) Transwell cell migration assay for ROR $\alpha$ , ROR $\alpha$ S35A, or ROR $\alpha$ S35D-expressing HCT116 cells with treatment of Wnt5a. Values are represented as mean  $\pm$  s.d. for three independent experiments. (F) The anchorage-independent growth of HCT116 cells expressing ROR $\alpha$ , ROR $\alpha$ S35A, or ROR $\alpha$ S35D in soft agar. Values are expressed as mean  $\pm$  SEM for two experiments in 6 place wells. Colonies were counted in 10 different fields and total colony number/well was calculated. Representative image is shown for each group.

Figure 6. Reduction of ROR $\alpha$  phosphorylation in human colorectal tissues and characterization of tumors in APC<sup>min/+</sup> mice with or without ROR $\alpha$

(A) Immunoblot analysis against anti-phospho-ROR $\alpha$ S35, and anti-phospho-PKC $\alpha$  antibodies in human colorectal tumor tissue samples (T) along with matched normal tissue samples (N). (B) Effects of ROR $\alpha$  on mortality in APC<sup>min/+</sup> mice. (C) The number of visible polyps (>1.0 mm) in the small intestine was counted by stereoscopic microscopy in age (20 to 24 weeks old)-and sex-matched APC<sup>min/+</sup> mice and APC<sup>min/+</sup> ROR $\alpha$  transgenic mice. (D) Schematic model of downregulation of canonical Wnt signalling by Wnt5a/PKC $\alpha$ -dependent phosphorylation of ROR $\alpha$  in colon cancer. ROR $\alpha$  confers a transrepression function to the  $\beta$ -catenin-mediated transcriptional activation of Wnt/ $\beta$ -catenin target genes, such as *cyclin D1*, *c-myc*, and *c-jun*, by the enhanced binding to  $\beta$ -catenin via the phosphorylation on serine 35 residue of ROR $\alpha$  and possibly by competing with other coactivators for binding to  $\beta$ -catenin. This crosstalk modulates the invasive activity of tumor cells by inhibiting Wnt target genes that are involved in tumor progression, proliferation, and growth.

Figure 7 shows validation of shRNAs against ROR $\alpha$ . Knockdown of ROR $\alpha$  by two different types of shRNAs was validated by immunoblotting analysis.

Figure 8 shows mass spectrometric analysis of ROR $\alpha$ S35A peptide.

Synthesized peptides of ROR $\alpha$ S35A (NQEAARKSE) were used as substrates in the kinase assay with purified PKC $\alpha$  enzyme. The phosphorylated peptide samples were analyzed by mass spectrometric analysis.

Figure 9 shows the transcriptional activation function and DNA binding activity of ROR $\alpha$  is not required for the repressive function on Wnt target genes

(A) HCT116 cells were transfected with Flag-ROR $\alpha$  WT, DBD mutant (C90A), or  $\Delta$  AF2 mutant, and the cell extracts were immunoprecipitated with anti-Flag antibody followed by immunoblotting against anti- $\beta$ -catenin antibody. (B) Introduction of ROR $\alpha$  WT, DBD mutant (C90A), or  $\Delta$  AF2 mutant inhibited the TCF/ $\beta$ -catenin mediated activation of the *cyclin D1* promoter reporter. Data are represented as mean  $\pm$  s.d. for three independent experiments.

## DETAILED DESCRIPTION OF THE INVENTION

**[0014]** To achieve the above objects, in a first aspect, the present invention provides a method for screening an anticancer agent using ROR $\alpha$ . More specifically, the present invention provides a method for screening an anticancer agent, the method comprising the steps of: culturing cells; bringing a potential substance into contact with the cells; determining whether the phosphorylation level of ROR $\alpha$  in the cells increases as compared to that in control cells (not brought into contact with the potential substance); and selecting the potential substance as an anticancer agent if the phosphorylation level of ROR $\alpha$  increases.

**[0015]** The phosphorylation level of ROR $\alpha$  may be measured by, but not limited to, electrophoresis, fluorescence spectrometry, mass spectrometry, an immunoassay or a PCR assay. The immunoassay may be an immunoblot assay.

**[0016]** The phosphorylation level of ROR $\alpha$  may be measured by analyzing the expression level of a Wnt target gene. The Wnt target gene may be any one selected from the group consisting of cyclin D1, c-myc, and c-jun. The expression level of the Wnt target gene may be analyzed by any of electrophoresis, fluorescence spectrometry, mass spectrometry, an immunoassay and a PCR assay. Preferably, the expression level of the Wnt target gene may be analyzed by an RT-PCR assay. The method for screening the anticancer agent may be applied to any cancer.

**[0017]** The cancer cells that are used to screen the anticancer agent are preferably cells of the same origin, but are not limited thereto. For example, cells that are used to screen an agent for treating colorectal cancer are preferably colorectal cells.

**[0018]** In a second aspect, the present invention provides a method of diagnosing cancer by measuring the amount of ROR $\alpha$  *in vivo*. More preferably, the present invention provides a method for diagnosing cancer, the method comprising the steps of: collecting cells from a subject; measuring the phosphorylation level of ROR $\alpha$  in the cells collected from the subject; and determining that cancer is highly likely to develop if the phosphorylation level of ROR $\alpha$  in the cells is lower than in that in cells of a normal person.

**[0019]** The phosphorylation level of ROR $\alpha$  may be measured by, but not limited to, electrophoresis, fluorescence spectrometry, mass spectrometry, an immunoassay or a PCR assay. The immunoassay may be an immunoblot assay.

**[0020]** In a third aspect, the present invention provides a ROR $\alpha$ -overexpressed APC<sup>min/+</sup> ROR $\alpha$  mouse. The mouse is useful for studies on anticancer agents.

**[0021]** Hereinafter, the present invention will now be described in detail with reference to examples. However, these examples are not intended to limit the scope of the present invention as defined in the appended claims.

### Example 1: Materials and Reagents

**[0022]** The following antibodies were purchased from Santa Cruz Biotechnology: anti- $\beta$ -catenin, cyclin D1, phospho-

PKC $\alpha$ , and ROR $\alpha$ . The following commercially available antibodies were used: anti-acetyl-histone H3, acetyl-histone H4, dimethyl-H3K9, and dimethyl-H3K4 antibodies (Upstate Biotechnology), anti-FLAG (Sigma), anti-RNA polymerase II (Berkeley Antibody Company), anti-Xpress (Invitrogen), and anti-phospho-Ser antibodies (Alexis). Anti-phospho-ROR $\alpha$ S35 antibody was generated by Abmat PKC $\alpha$  enzyme was purchased from Cell Signaling.

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Example 2: Mouse strains and generation of ROR $\alpha$  transgenic mice

**[0023]** A pair of APC<sup>min/+</sup> mice were purchased from the Jackson Laboratory and housed in the animal facility of the Seoul National University according to standards of the Association for Assessment and Accreditation of Laboratory Animal Care. To construct ROR $\alpha$  transgenic mice, full-length human ROR $\alpha$  cDNA fused in frame with Myc tag was subcloned into the pCAGGS expression vector under the control of human CMV immediate early enhancer linked to the chicken  $\beta$ -actin promoter. To derive ROR $\alpha$  transgenic mice, the pCAGGS-ROR $\alpha$  Sall/HindIII fragment was microinjected into fertilized eggs derived from C57BL/6J mice. Integration of the transgene into the offspring genome was assessed by PCR analysis. The experiments were carried out with approval of the Institutional Animal Care and Ethics Committee.

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Example 3: Human colon cancer tissue specimens

**[0024]** For the analysis of phosphorylated ROR $\alpha$  and PKC $\alpha$  expression in human tissue samples, 30 paired fresh frozen colon cancer tissues and matched normal mucosa tissues were selected. The frozen fresh human tissue specimens were supplied from the Liver Cancer Specimen Bank supported by National Research Resource Bank Program of the Korea Science and Engineering Foundation in the Ministry of Science and Technology. The consents to use the tissue specimens for research purposes were obtained from patients, and the utilization of the specimens for this research was authorized by the Institutional Review Board of College of Medicine, Yonsei University.

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Example 4: Purification of ROR $\alpha$ -containing complex

**[0025]** ROR $\alpha$ -containing complex was purified from extracts obtained from HEK293 cells stably expressing Flag-tagged ROR $\alpha$ . As a negative control, a mock purification from HEK293 cells stably expressing an empty vector was performed. The ROR $\alpha$ -containing complex was immunoprecipitated using anti-Flag antibody-conjugated agarose beads from extracts that were washed to remove non-specific contaminants, and the bound materials were eluted by competition with the Flag peptide (0.1 mg/ml). The bound proteins were resolved by sodium dodecyl sulphate-polyacrylamide gel electrophoresis (SDS-PAGE) and prepared for LCMS/MS analysis.

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Example 5: *In vitro* kinase assay

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**[0026]** *In vitro* kinase assays using PKC $\alpha$  immunoprecipitated from HEK293 cell lysates or purified PKC $\alpha$  enzyme as the kinase and purified GST-ROR $\alpha$  proteins as substrates were performed at 30°C for 30 min in kinase assay buffer containing 40 mM Tris-HCl (pH 7.5), 10 mM MgCl<sub>2</sub>, 1 mM dithiothreitol (DTT), and 10  $\mu$ Ci of [ $\gamma$ -<sup>32</sup>P]ATP. The reactions were terminated by adding 5X Laemmli sample buffer and by boiling for 10 min. Samples were subjected to 12% SDS-PAGE, and phosphorylated ROR $\alpha$  was detected by autoradiography.

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Example 6: Liquid Chromatography-Mass Spectrometry

**[0027]** Small quantities (100 $\mu$ M) of synthetic peptides (ROR $\alpha$  or ROR $\alpha$ S35A) were used as substrates in the kinase assay with PKC $\alpha$  enzyme; the reaction was stopped by 10% TCA precipitation for 10 min at 4°C. After removing the precipitates by centrifugation, the supernatants were retrieved and phosphorylated peptides in the supernatants were analyzed by LC-MS at the Korea Basic Science Institutes

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Example 7: Reporter assays

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**[0028]** Using a luciferase system (Promega), the luciferase activity was measured using a luminometer 48 hr after transfection and normalized by  $\beta$ -galactosidase expression. Values are expressed as means  $\pm$  standard deviations for at least three independent experiments.

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Example 8: CHIP, two-step CHIP, and shRNA-coupled CHIP assays.

**[0029]** The CHIP, two-step CHIP, and shRNA-coupled CHIP assays were conducted as previously described (Baek et al., 2002; Kim et al., 2005).

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### Example 9: Construction of plasmids and shRNAs

**[0030]** ROR $\alpha$  DBD mutant (C90A) was generated by site-directed mutagenesis, and the cysteine at Cys90 was replaced by alanine. ROR $\alpha\Delta$  AF2 was generated as follows: *EcoRI* at the 5' ends and *BamHI* site at the 3' ends of ROR $\alpha$  (amino acids 1 to 505) was amplified by PCR and the fragment was subcloned into the *EcoRI/BamHI* sites of 3X Flag tagged-CMV 10 vector. The constructs were verified by DNA sequencing. The target sequences of shRNA against ROR $\alpha$ ,  $\beta$ -catenin, and non-specific (NS) shRNAs are as follows: shROR $\alpha$ -1, 5'-CGGUGCGCAGACAGAGCUAUU-3' (Sequence number 1); shROR $\alpha$ -2, 5'-GAGGUAUCUCAGUAACGAAGA-3' (Sequence number 2); sh $\beta$ -catenin, 5'-GUC-CUGUAUGAGUGGGAAC-3' (Sequence number 3) (Kim et al., 2005), and shNS, 5'-CUGGACUUCAGAAACAUC-3' (Sequence number 4). Oligonucleotide of siPKC $\alpha$  duplex sequence is follows: 5'-GAUCCGCGUCCUGUUGUAU-GAAUUUCAAGAGAA-3' (Sequence number 5) (Hsieh et al., 2007).

### Example 10: Real-Time quantitative RT-PCR

**[0031]** The abundance of mRNA was detected by an ABI prism 7300 system with SYBR Green (molecular probes). Primer pairs were designed to amplify 90-150 bp mRNA specific fragments, and confirmed to be unique products by melting curve analysis. The PCR conditions were 95°C (5 min) and 40 cycles of 95°C (30 s), 57°C (30 s), and 72°C (30 s). **[0032]** The quantity of mRNA was calculated using the  $\Delta\Delta Ct$  method and normalized by using primers to detect  $\beta$ -actin or HPRT. All reactions were performed in triplicates.

### Example 11: Indirect immunofluorescence analysis

**[0033]** HCT116 cells were grown on coverslips, and were washed three times with phosphate-buffered saline (PBS) 12 hrs after transfection. The cells were then fixed with 2% paraformaldehyde in PBS for 30 min at room temperature, washed in PBS, and permeabilized with 0.5% Triton X-100 in PBS (PBS-T) for 30 min at room temperature. Blocking was performed with 3% horse serum and 10% gelatin in PBS-T for 30 min. For staining, cells were incubated with affinity-purified anti-Flag IgG for 1 hr, followed by three washes in PBS-T. The stained cells were incubated for 1 hr with fluorescein isothiocyanate-conjugated secondary antibodies (Jackson Immuno Research Lab.), followed by three washes in PBS-T.

### Example 12: Transwell cell migration assay

**[0034]** HCT116 cells stably expressing ROR $\alpha$ , ROR $\alpha$ S35A, or ROR $\alpha$ S35D were used in Transwell cell migration assays along with control cells. Transwell cell migration assay was conducted as previously described (Kim et al., 2006). Cultured cells were pretreated with Wnt5a (100ng/ml) for 2 hr, and  $2.5 \times 10^4$  HCT116 cells were loaded onto the top of a 24-well Transwell chamber assay plate (BD Biosciences). Conditioned McCoy's 5A medium containing 15% fetal bovine serum was added to the bottom chamber as a chemoattractant. After 22 hr incubation, the cells that had migrated to the lower chamber of the filter were fixed with 100% methanol, stained with DAPI, and quantified by counting the total number of cells in four different fields. All experimental studies were performed according to the manufacturer's protocols. Values are expressed as means  $\pm$  standard deviations for at least three independent experiments.

### Example 13: Anchorage-independent growth assay

**[0035]** Anchorage-independent growth of HCT116 cells containing ROR $\alpha$ , ROR $\alpha$ S35A, or ROR $\alpha$ S35D was determined by analyzing cellular growth in semisolid medium.  $10^5$  cells were placed in McCoy's 5A media containing 0.4% noble agar containing 10% FCS. Cells were allowed to grow for 3 weeks in 5% CO $_2$ , and the formation of colonies containing >50 cells was analysed.

### Example 14: Statistical analysis

**[0036]** Statistical differences in test and control samples were determined by student's t-test using the Statview package (Abacus Concepts, Inc., Berkeley, CA).

### Example 15: Purification of ROR $\alpha$ -containing complex and identification of $\beta$ -catenin as a binding partner

**[0037]** To investigate the as-yet-unidentified functional modules of ROR $\alpha$ , we used a Flag epitope-tag strategy to purify ROR $\alpha$ -containing complexes. We generated cell lines that stably express Flag-tagged ROR $\alpha$ , and incubated the extracts in anti-Flag M2 affinity gel. After washing with buffer containing increasing salt concentrations of up to 500 mM, the proteins retained on the affinity chromatography column were eluted with buffer containing Flag peptide. We employed

liquid chromatography mass spectrometry/mass spectrometry (LC-MS/MS) to identify proteins in the ROR $\alpha$ -containing complex purified from the Flag M2 affinity column. Transcriptional coactivators such as glucocorticoid receptor-interacting protein 1 (GRIP1) and  $\beta$ -catenin were copurified with Flag-ROR $\alpha$  (Figures 1A and 1B). The presence of GRIP1 coactivator, a well-known binding partner for ROR $\alpha$  (Atkins et al., 1999), confirms and delineates the functional link between these molecules. The binding of  $\beta$ -catenin to ROR $\alpha$  was confirmed by both immunoblotting analysis of elutes and an endogenous coimmunoprecipitation assay (Figures 1C and 1D). The binding site mapping for ROR $\alpha$  on  $\beta$ -catenin indicated that ROR $\alpha$  interacted with the armadillo repeat domains of  $\beta$ -catenin, and not with the N- and C-terminal domains, which overlap with the binding sites for a subset of coactivators (Figures 1E and 1F). These data suggest the possibility that ROR $\alpha$  might function as a coregulator for Wnt/ $\beta$ -catenin signaling. Taken together, the identification of  $\beta$ -catenin from ROR $\alpha$ -containing complex suggested the probable functional link between the ROR $\alpha$  and the Wnt/ $\beta$ -catenin signaling pathways.

#### Example 16: Attenuation of $\beta$ -catenin transcriptional activity by ROR $\alpha$

**[0038]** We used the HCT116 colorectal cancer cell line in which Wnt/ $\beta$ -catenin signaling pathway is constitutively active to examine whether ROR $\alpha$  is directly involved in the modulation of Wnt target genes in well-established Wnt signaling-dependent colon cancer cells. In addition to TOPFLASH reporter that has TCF/LEF binding site, *cyclin D1* or *c-myc* gene transcripts are used as readout for Wnt signaling activation. Knockdown of  $\beta$ -catenin with shRNA or introduction of dominant negative form of TCF attenuated induction of *cyclin D1* or *c-myc* gene transcripts (Figure 2A), suggesting that increased *cyclin D1* or *c-myc* transcript is related to Wnt signaling activation in HCT116 colon cancer cells. Introduction of ROR $\alpha$  suppressed the induction of *cyclin D1* and *c-myc* transcripts (Figure 2B). The overexpression of ROR $\alpha$  almost entirely repressed the TCF/ $\beta$ -catenin-mediated activation of TOPFLASH and the *cyclin D1* promoter-luciferase reporters (Figures 2C and 2D). We silenced the expression of endogenous ROR $\alpha$  by using shRNAs and validated the functional knockdown effects of two independent shRNAs on Wnt target genes by immunoblotting analysis (Figure 7). In contrast to ROR $\alpha$  overexpression, silencing of endogenous ROR $\alpha$  by specific shRNAs caused further activation of Wnt target gene (Figure 2E) as well as the TOPFLASH and the *cyclin D1* promoter-luciferase reporters (Figures 2F and 2G). These data suggest that ROR $\alpha$  is involved in the attenuation of  $\beta$ -catenin-mediated transcriptional activation and the overexpression of ROR $\alpha$  has an opposing effect on the expression of Wnt target genes.

**[0039]** These unexpected findings led us to explore the molecular mechanism of the ROR $\alpha$  mediated transcriptional repression of Wnt target genes in detail. The repression of  $\beta$ -catenin-mediated transcriptional activation by ROR $\alpha$  can be postulated by two mechanisms. First, ROR $\alpha$  directly interacts with  $\beta$ -catenin and sequesters it away from its transcription factor, TCF in a DNA binding-independent manner. Second, ROR $\alpha$  transrepresses  $\beta$ -catenin-mediated transcription by directly binding to  $\beta$ -catenin and possibly inhibiting the recruitment of other coactivators to the Wnt target promoters for transcriptional repression. In order to examine whether a sequestering or a transrepression process is involved in the repression of  $\beta$ -catenin-mediated transcriptional activation by ROR $\alpha$ , we performed a two-step chromatin immunoprecipitation (ChIP) assay on the *cyclin D1* promoter (Figure 2H). Soluble chromatin was divided into two aliquots. One of these aliquots was immunoprecipitated with anti-ROR $\alpha$  antibodies followed by release of the immune complexes and reimmunoprecipitated with anti- $\beta$ -catenin antibodies. The other aliquot was first immunoprecipitated with anti- $\beta$ -catenin antibodies followed by reimmunoprecipitation with anti-ROR $\alpha$  antibodies. The two-step ChIP assay revealed that both ROR $\alpha$  and  $\beta$ -catenin were simultaneously detected on the promoter (Figure 2H). This supports a model in which ROR $\alpha$  transrepresses  $\beta$ -catenin-mediated transcriptional activation by directly binding to  $\beta$ -catenin on the same promoter. To exclude the possibility that ROR $\alpha$  completely displaces TCF from  $\beta$ -catenin, which may lead to the inhibition of TOPFLASH reporter, coimmunoprecipitation assay was performed to examine whether the direct simultaneous interaction of  $\beta$ -catenin with ROR $\alpha$  and TCF occurs. Increased expression of ROR $\alpha$  failed to affect the interaction of  $\beta$ -catenin with TCF, supporting our model of simultaneous binding of  $\beta$ -catenin to ROR $\alpha$  and TCF (Figure 2I).

**[0040]** Additional ChIP assays on *cyclin D1* promoter revealed that the overexpression of ROR $\alpha$  significantly repressed the  $\beta$ -catenin-mediated transcriptional activation with a concomitant increase in ROR $\alpha$  binding and decrease in the recruitment of RNA polymerase II (Figure 2J). Recruitment of  $\beta$ -catenin and TCF was not affected by ROR $\alpha$  overexpression. In parallel, we performed shRNA-coupled ChIP assay on *cyclin D1* and *c-jun* promoters by employing shRNA against ROR $\alpha$  or  $\beta$ -catenin (Figure 2K). Knockdown of  $\beta$ -catenin resulted in the failure of histone acetylation and exhibited diminished ROR $\alpha$  recruitment, suggesting that the recruitment of ROR $\alpha$  to the promoter is through  $\beta$ -catenin. Consistent with these data, the knockdown of ROR $\alpha$  did not change the recruitment of  $\beta$ -catenin; however, it induced a significant increase in the histone acetylation levels (Figure 2K). These data suggest that the binding of ROR $\alpha$  on the *cyclin D1* and *c-jun* promoters is mediated through  $\beta$ -catenin and the binding of ROR $\alpha$  to  $\beta$ -catenin confers a repressive effect on Wnt target genes.

Example 17: ROR $\alpha$  is phosphorylated by protein kinase C $\alpha$  on serine 35

**[0041]** To investigate the domains of ROR $\alpha$  that are capable of direct physical interactions with  $\beta$ -catenin, we prepared various ROR $\alpha$  deletion mutants (Figure 3A). Ni<sup>2+</sup>-NTA-agarose pulldown assay indicated that the N-terminal domain of ROR $\alpha$  is responsible for  $\beta$ -catenin binding (Figure 3B). We further prepared serial deletion mutants of the N-terminal domain of ROR $\alpha$  and wished to search for molecular determinants of  $\beta$ -catenin binding (Figure 3C). Fine deletion mapping revealed that N-terminal fragment of ROR $\alpha$  spanning amino acids 32 to 41 is indispensable for  $\beta$ -catenin binding (Figure 3D). Since phosphorylation is a dynamic process and the removal and addition of phosphate can change the protein binding affinity, we searched for putative phosphorylation sites. Identification of a PKC consensus site (S/TX<sub>0-2</sub>R/K<sub>1-3</sub>) in the region of ROR $\alpha$  spanning amino acids 32 to 41 permitted us to perform a coimmunoprecipitation assay with various PKCs to investigate whether ROR $\alpha$  binds to specific PKC isoforms. *In vivo* coimmunoprecipitation assays indicated that ROR $\alpha$  specifically bound to PKC $\alpha$ , whereas other isoforms of PKCs, including PKC $\beta$ 2, PKC $\chi$ , PKC $\delta$ , PKC $\epsilon$ , PKC $\eta$ , PKC $\theta$ , PKC $\iota$ , PKC $\kappa$ , PKC $\lambda$ , PKC $\mu$ , PKC $\nu$ , PKC $\xi$ , PKC $\zeta$  failed to bind ROR $\alpha$  (Figure 3E).

**[0042]** The selective binding of PKC $\alpha$  to ROR $\alpha$  led us to investigate whether PKC $\alpha$  is directly responsible for ROR $\alpha$  phosphorylation. Mass spectrometric analysis of ROR $\alpha$  peptide after the PKC $\alpha$  kinase assay revealed that ROR $\alpha$  is phosphorylated by PKC $\alpha$  (Figure 3F). The calculated molecular mass of the ROR $\alpha$  peptide is 1620.8 Da, and addition of a phosphate group increases the mass by 113 Da. The phosphorylated ROR $\alpha$  peptide had its main peak at 1734.1 Da. Treatment with a PKC activator, 12-O-tetradecanoylphorbol-13-acetate (TPA) increased phosphorylation of endogenous ROR $\alpha$  (Figure 3G). ROR $\alpha$ S35A mutant, in which serine residue is mutated to alanine, was not phosphorylated in the presence of TPA, whereas either wild-type (WT) or S39A mutant exhibited TPA-induced phosphorylation (Figure 3H). Mass spectrometric analysis confirmed that no peaks corresponding to phosphorylated forms of the ROR $\alpha$ S35A peptide after PKC $\alpha$  kinase assay were detected (Figure 8). These data demonstrate the site-specific phosphorylation on the S35 site of ROR $\alpha$  by PKC $\alpha$ .

**[0043]** To further examine whether PKC $\alpha$  directly phosphorylates ROR $\alpha$  on S35, we performed an *in vitro* kinase assay using the constitutive active form of PKC $\alpha$  (caPKC $\alpha$ ) or kinase deficient mutant form of PKC $\alpha$  (kdPKC $\alpha$ ) immunoprecipitated from cell lysates with anti-Flag antibodies. The immunoprecipitated materials from either caPKC $\alpha$  or kdPKC $\alpha$  were incubated with bacterially expressed and purified glutathione-S-transferase (GST)ROR $\alpha$ WT or S35A proteins. Indeed, caPKC $\alpha$  phosphorylated purified ROR $\alpha$  proteins, whereas kdPKC $\alpha$  failed to phosphorylate ROR $\alpha$  proteins (Figure 3I). As expected, the ROR $\alpha$ S35A proteins failed to be phosphorylated by caPKC $\alpha$ , thus confirming the S35 site-specific phosphorylation of ROR $\alpha$  by PKC $\alpha$ . Immunohistochemical studies revealed that both ROR $\alpha$  and ROR $\alpha$ S35A exhibited an almost exclusive nuclear staining pattern in HCT116 cells, indicating that phosphorylation of ROR $\alpha$  did not alter the nuclear localization (Figure 3J).

Example 18: Phosphorylation of ROR $\alpha$  by PKC $\alpha$  is crucial for downregulation of Wnt/ $\beta$ -catenin target genes

**[0044]** The antibody raised against phosphorylated ROR $\alpha$ S35 peptide specifically recognized the phosphorylated peptide as assessed by dot blot analysis (Figure 4A). Immunoprecipitation analysis by specific, purified anti-phospho-ROR $\alpha$ S35 IgG revealed that the wild-type, but not S35A of ROR $\alpha$  was subject to phosphorylation by TPA treatment (Figure 4B). Consistent with these data, introduction of caPKC $\alpha$ , not kdPKC $\alpha$ , increased phosphorylation of ROR $\alpha$ , whereas treatment of Go6976, a specific PKC $\alpha$  inhibitor, abolished the TPA-induced phosphorylation of ROR $\alpha$ , as assessed by immunoblotting against anti-phospho-ROR $\alpha$ S35 IgG (Figures 4C and 4D). These data demonstrate that TPA-dependent activation of PKC $\alpha$  is responsible for the phosphorylation of ROR $\alpha$  on the S35 site.

**[0045]** Since protein phosphorylation alters the binding affinity of proteins, we examined whether the phosphorylation of ROR $\alpha$  affected its binding affinity toward  $\beta$ -catenin. ROR $\alpha$ S35D, which mimics constitutive phosphorylation of ROR $\alpha$ , exhibited strong binding to  $\beta$ -catenin, whereas ROR $\alpha$ S35A exhibited little or no binding to  $\beta$ -catenin (Figure 4E). Consistent with these data, the binding of ROR $\alpha$  to  $\beta$ -catenin was significantly increased by TPA treatment and TPA-induced increased binding was almost completely abolished by treatment with Go6976 (Figure 4F). Failure of TPA-induced phosphorylation of ROR $\alpha$ S35A abrogated the binding of ROR $\alpha$  to  $\beta$ -catenin, confirming that phosphorylation of the S35 site of ROR $\alpha$  is crucial for the binding to  $\beta$ -catenin. These data clearly indicate that TPA/PKC $\alpha$  dependent phosphorylation of ROR $\alpha$  modulates binding affinity of ROR $\alpha$  toward  $\beta$ -catenin.

**[0046]** To further examine whether the ROR $\alpha$ -mediated downregulation of Wnt target genes is affected by ROR $\alpha$  phosphorylation that leads to increased binding to  $\beta$ -catenin, we performed a ChIP assay on *cyclin D1* promoter with the introduction of either ROR $\alpha$ S35A or ROR $\alpha$ S35D. As expected, ROR $\alpha$ S35A exhibited diminished recruitment to the promoter, whereas ROR $\alpha$ S35D resulted in increased recruitment to the promoter (Figure 4G). Both ROR $\alpha$ DAF2 mutant that has impaired transcriptional activation function and ROR $\alpha$ C90A mutant that has impaired DNA binding activity exhibited similar binding affinity to  $\beta$ -catenin (Figure 9A) and repressive functions on TCF/ $\beta$ -catenin-mediated activation (Figure 9B), indicating that neither the transcriptional activity nor DNA binding activity of ROR $\alpha$  is required for the

repressive function on Wnt target genes. TPA treatment increased the recruitment of phosphorylated ROR $\alpha$  as assessed by anti-phospho-ROR $\alpha$ S35 IgG on the *cyclin D1* promoter along with concomitant decrease in RNA polymerase II recruitment, whereas the recruitment of  $\beta$ -catenin on the promoter was not altered by TPA treatment (Figure 4H).

**[0047]** Further, knockdown of PKC $\alpha$  diminished the recruitment of ROR $\alpha$  on the *cyclin D1* promoter, confirming that increased binding of ROR $\alpha$  on the promoter is due to the PKC-dependent phosphorylation of ROR $\alpha$  (Figure 4I). Reverse transcriptase-polymerase chain reaction (RT-PCR) analysis indicated that TPA treatment resulted in the downregulation of the *cyclin D1* transcript in HCT116 cells (Figure 4J). In support of the phosphorylation-triggered transrepression mechanism of ROR $\alpha$  on Wnt target genes, the knockdown of either PKC $\alpha$  or ROR $\alpha$  abolished TPA-mediated downregulation of Wnt target gene expression (Figure 4K). Taken together, these data strongly demonstrate that PKC $\alpha$ -dependent phosphorylation of ROR $\alpha$  triggers increased binding of ROR $\alpha$  to the target promoters through  $\beta$ -catenin and this increased binding is directly responsible for the downregulation of Wnt target genes.

**[0048]** Example 19: Wnt5a antagonizes the canonical Wnt signalling by transrepression function of ROR $\alpha$ .

**[0049]** Since the noncanonical Wnt signalling pathway triggered by the Wnt5a, a noncanonical Wnt ligand, activates downstream PKCs and CaMKII (Jonsson et al., 1998; Weeraratna et al., 2002), we examined whether Wnt5a induces PKC $\alpha$  activation leading to the following ROR $\alpha$  phosphorylation and downregulation of Wnt target genes in colon cancer cells. Wnt5a treatment increased phosphorylation of PKC $\alpha$  as assessed by immunoblotting against anti-phospho-PKC $\alpha$  antibody that recognizes active form of PKC $\alpha$  (Figure 5A). Further immunoblotting analysis against anti-phospho-ROR $\alpha$ S35 IgG revealed that treatment of Wnt5a increased phosphorylation of ROR $\alpha$  concomitant with downregulation of cyclin D1 expression in colon cancer cells (Figure 5A). Consistent with these data, Wnt5a treatment reduced the expression of *cyclin D1* transcript, and the knockdown of PKC $\alpha$  or ROR $\alpha$  by each shRNA abolished Wnt5a-dependent downregulation of *cyclin D1* transcript (Figure 5B). These data confirm that the downregulation of Wnt target genes by Wnt5a is indeed mediated by PKC $\alpha$  activation. Thereafter, we examined whether Wnt5a/PKC $\alpha$ -dependent ROR $\alpha$  phosphorylation is capable of suppressing  $\beta$ -catenin-mediated activation of Wnt target genes. Quantitative RT-PCR analysis revealed that ROR $\alpha$ S35D, not ROR $\alpha$ S35A, induced the downregulation of the *cyclin D1* transcript (Figure 5C). These data suggest that ROR $\alpha$  mediates Wnt5a-dependent suppressive effects on the canonical Wnt signaling pathway in a phosphorylation-dependent manner in colon cancer cells.

**[0050]** Given that ROR $\alpha$  exerts its repressive effect by directly binding to  $\beta$ -catenin on the promoter and the binding site for ROR $\alpha$  on  $\beta$ -catenin resides in the armadillo repeat domains of  $\beta$ -catenin that demonstrate overlap with the binding sites of a subset of coactivators (Figure 1E), the transrepression mechanism of ROR $\alpha$  on  $\beta$ -catenin might be achieved by competition for  $\beta$ -catenin binding with a subset of coactivators. ChIP assay on the *cyclin D1* promoter revealed that treatment with Wnt5a or TPA increased the recruitment of phosphorylated ROR $\alpha$  to the promoter, whereas the recruitment of CBP, p300, and pCAF coactivators to the promoter was significantly decreased (Figure 5D). Indeed, the TPA or Wnt5a-dependent phosphorylation of ROR $\alpha$  attenuated the  $\beta$ -catenin-dependent transcriptional activation, leading to the increased methylation of histone H3K9 and decreased RNA polymerase II recruitment (Figure 5D). These results indicate that the downregulation of Wnt target genes is a direct consequence of ROR $\alpha$  binding triggered by phosphorylation, and the transrepression mechanism of ROR $\alpha$  on  $\beta$ -catenin is achieved, at least in part, by competition with a subset of coactivators for  $\beta$ -catenin binding and possibly recruitment of histone lysine methyltransferases for transcriptional repression.

**[0051]** As upregulation of cyclin D1, c-myc, or c-jun is correlated with cell proliferation and migration, we next examined whether phosphorylation of ROR $\alpha$  could inhibit cellular migration. Transwell cell migration assay that measured the increase in cell number for ROR $\alpha$ , ROR $\alpha$ S35A, or ROR $\alpha$ S35D-expressing HCT116 colon cancer cells revealed that Wnt5a treatment attenuated migration of HCT116 colon cancer cells compared to non-treated cells and ROR $\alpha$ S35D-expressing cells exhibited a significant decrease of cell migration in the presence of Wnt5a (Figure 5E and data not shown). These results suggest that a mechanism underlying ROR $\alpha$ -mediated inhibition of cell migration is, at least in part, through the inhibition of Wnt target genes in a phosphorylation-dependent manner.

**[0052]** We then considered other properties known to be important for cell and tumor growth. As anchorage-independent growth is an important property of tumor cell growth, we asked whether ROR $\alpha$ S35D, but not ROR $\alpha$ S35A could suppress the colony-forming ability of HCT116 cells in soft agar. Consistent with the anti-proliferative properties of ROR $\alpha$ S35D, HCT116 cells expressing ROR $\alpha$ S35D grew significantly slower than control cells (Figure 5F and data not shown). Furthermore, the size of the colonies formed by ROR $\alpha$ S35D-expressing cells was much smaller than those formed by the control cells. These data suggest that ROR $\alpha$  has a significant role in regulating cellular growth in phosphorylation-dependent manner.

Example 20: Reduction of ROR $\alpha$  phosphorylation is frequent in human colorectal cancers

**[0053]** To find the clinical relevance of our findings, we examined the expression of phosphorylated ROR $\alpha$  and PKC $\alpha$  in the 30 colorectal cancer tissues and matched normal mucosa specimens. Immunoblot analysis against anti-phospho-ROR $\alpha$ S35 IgG revealed the reduction of ROR $\alpha$  phosphorylation in 22 out of 30 (>73%) cases, and of these 22 cases,

14 cases of them (>46%) exhibited the reduction of phosphorylation of PKC $\alpha$  (Table 1 and Figure 6A). We further investigated the expression of Wnt target genes in these normal and tumor samples by quantitative RT-PCR. All of the cases in which reduction of ROR $\alpha$  phosphorylation and PKC $\alpha$  inactivation exhibited the increased expression of Wnt target genes (Table 1). Wnt5a expression has been reported to be down-regulated in multiple tumors including colon, breast, and prostate, whereas it is upregulated in brain, stomach, kidney, and skin tumors (Blanc et al., 2005; Iozzo et al., 1995; Kremenevskaja et al., 2005). Further quantitative RT-PCR analysis supported the idea that downregulation of Wnt5a in colon tumor correlates with inactivation of PKC $\alpha$  and reduction of ROR $\alpha$  phosphorylation (Table 1). These data suggest that reduction of ROR $\alpha$  phosphorylation along with inactivation of PKC $\alpha$  and downregulation of Wnt5a is frequent event in colorectal cancer.

Table 1  
Fold (Tumor/Normal tissues)

No.	phospho-ROR $\alpha$	phospho-PKC $\alpha$	Wnt targets			
			<i>Wnt5a</i>	<i>CyclinD1</i>	<i>c-Myc</i>	<i>c-Jun</i>
1	$\Delta$	$\Delta$	+42 $\Delta$	-1.4 $\nabla$	+56 $\Delta$	+18 $\Delta$
2	NC	$\Delta$	+56 $\Delta$	+42 $\Delta$	+12 $\Delta$	+56 $\Delta$
3	NC	$\Delta$	+160 $\Delta$	+6.0 $\Delta$	+49 $\Delta$	+58 $\Delta$
4	$\nabla$	$\Delta$	+16 $\Delta$	-69 $\nabla$	+11 $\Delta$	+2.3 $\Delta$
5	$\nabla$	$\nabla$	-42 $\nabla$	+120 $\Delta$	+25 $\Delta$	NC
6	$\nabla$	$\nabla$	-66 $\nabla$	+13 $\Delta$	+16 $\Delta$	+4.4 $\Delta$
7	$\nabla$	$\nabla$	-6.3 $\nabla$	+8.4 $\Delta$	+132 $\Delta$	+20 $\Delta$
8	NC	$\Delta$	+32 $\Delta$	+45 $\Delta$	+50 $\Delta$	NC
9	$\nabla$	$\nabla$	-18 $\nabla$	+9.1 $\Delta$	+430 $\Delta$	NC
10	$\nabla$	$\nabla$	-20 $\nabla$	+1.4 $\Delta$	+1.8 $\Delta$	+20 $\Delta$
11	$\nabla$	$\nabla$	-24 $\nabla$	+6.7 $\Delta$	+1.3 $\Delta$	+4.9 $\Delta$
12	NC	NC	+13 $\Delta$	-2.5 $\nabla$	-1.8 $\nabla$	-1.7 $\nabla$
13	$\nabla$	$\nabla$	-11 $\nabla$	+1.3 $\Delta$	+8.4 $\Delta$	+5.1 $\Delta$
14	$\nabla$	$\nabla$	-13 $\nabla$	NC	+7.4 $\Delta$	+3.3 $\Delta$
15	NC	$\Delta$	+16 $\Delta$	+4.5 $\Delta$	+6.1 $\Delta$	+11 $\Delta$
16	$\nabla$	NC	+190 $\Delta$	-1.8 $\nabla$	+9.4 $\Delta$	+10 $\Delta$
17	$\nabla$	NC	+49 $\Delta$	+3.2 $\Delta$	+14 $\Delta$	NC
18	$\nabla$	$\nabla$	NC	+3.5 $\Delta$	+5.4 $\Delta$	+1.7 $\Delta$
19	$\nabla$	$\nabla$	-23 $\nabla$	+3.0 $\Delta$	+9.4 $\Delta$	+1.8 $\Delta$
20	NC	$\nabla$	+47 $\Delta$	NC	NC	NC
21	$\Delta$	$\nabla$	+38 $\Delta$	+3.4 $\Delta$	+2.9 $\Delta$	+32 $\Delta$
22	$\nabla$	NC	+62 $\Delta$	-1.3 $\nabla$	+8.7 $\Delta$	+6.8 $\Delta$
23	$\nabla$	$\nabla$	-4.5 $\nabla$	+1.7 $\Delta$	+1.2 $\Delta$	NC
24	$\nabla$	NC	-4.0 $\nabla$	NC	+5.1 $\Delta$	+2.5 $\Delta$
25	$\nabla$	$\nabla$	-1.2 $\nabla$	+20 $\Delta$	+6.3 $\Delta$	+33 $\Delta$
26	$\nabla$	$\Delta$	NC	-1.8 $\Delta$	-1.8 $\nabla$	NC
27	$\nabla$	NC	-99 $\nabla$	-1.7 $\nabla$	+3.7 $\Delta$	+34 $\Delta$
28	$\nabla$	$\nabla$	-3.5 $\nabla$	+1.8 $\Delta$	+1.5 $\Delta$	+13 $\Delta$
29		NC	NC	+8.5 $\Delta$	NC	+8.1 $\Delta$
$\nabla$ 30	$\nabla$	$\nabla$	-3.7 $\nabla$	+2.1 $\Delta$	+2.0 $\Delta$	+6.5 $\Delta$

Example 21: The reduced polyp development in APC<sup>min/+</sup>ROR $\alpha$  transgenic mouse compared with those in APC<sup>min/+</sup> mouse

**[0054]** To examine whether tumor suppressive function of ROR $\alpha$  is applied to spontaneous intestinal tumorigenesis of mouse model, we generated APC<sup>min/+</sup> mice crossed with ROR $\alpha$  transgenic mice and analyzed sex- and age-matched mice. We generated transgenic mice expressing a human ROR $\alpha$  cDNA, and confirmed the increase of ROR $\alpha$  expression in colon and intestine tissues (data not shown). APC<sup>min/+</sup> mice die within 24 weeks of age, whereas mortality of APC<sup>min/+</sup> ROR $\alpha$  transgenic mice was decreased compared with APC<sup>min/+</sup> littermate controls (Figure 6B). We quantified the number

of polyps by stereoscopic microscopy, and found the decrease of the number of visible polyps (>1.0 mm in diameter) in the intestines or colon of APC<sup>min/+</sup> ROR $\alpha$  transgenic mice compared with that in APC<sup>min/+</sup> mice (Figure 6C). These data support the notion that ROR $\alpha$  influences the Wnt signaling mediated tumor formation and growth by suppressive function of Wnt signaling. Taken together, ROR $\alpha$  affects modulation of cell and tumor growth in APC<sup>min/+</sup> mouse model of intestinal tumorigenesis.

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## [0055]

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**Claims**

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1. A method for screening an anticancer agent, the method comprising the steps of:

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culturing cells;  
bringing a potential substance into contact with the cells;  
determining whether the phosphorylation level of ROR $\alpha$  in the cells increases as compared to that in control cells (not brought into contact with the potential substance); and  
selecting the potential substance as an anticancer agent if the phosphorylation level of ROR $\alpha$  in the cells increases.

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2. The method of claim 1, wherein the phosphorylation level of ROR $\alpha$  is measured by any one selected from the group consisting of electrophoresis, fluorescence spectrometry, mass spectrometry, an immunoassay or a PCR assay.

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3. The method of claim 2, wherein the immunoassay is an immunoblot assay for anti-phospho-ROR $\alpha$ S35IgG.  
4. The method of claim 1, wherein the phosphorylation level of ROR $\alpha$  is measured by analyzing the expression level of a Wnt target gene.

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5. The method of claim 4, wherein the expression level of the Wnt target gene is analyzed by an immunoblot assay.  
6. The method of claim 4, wherein the expression level of the Wnt target gene is analyzed by a RT-PCR assay.  
7. The method of claim 2, wherein the cells are colorectal cancer cells.

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8. A method of diagnosing cancer, comprising the steps of:  
collecting cells from a subject;  
measuring the phosphorylation level of ROR $\alpha$  in the cells collected from the subject; and  
determining that cancer is highly likely to develop if the phosphorylation level of ROR $\alpha$  in the cells is lower than in that in cells of a normal person.

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**A**

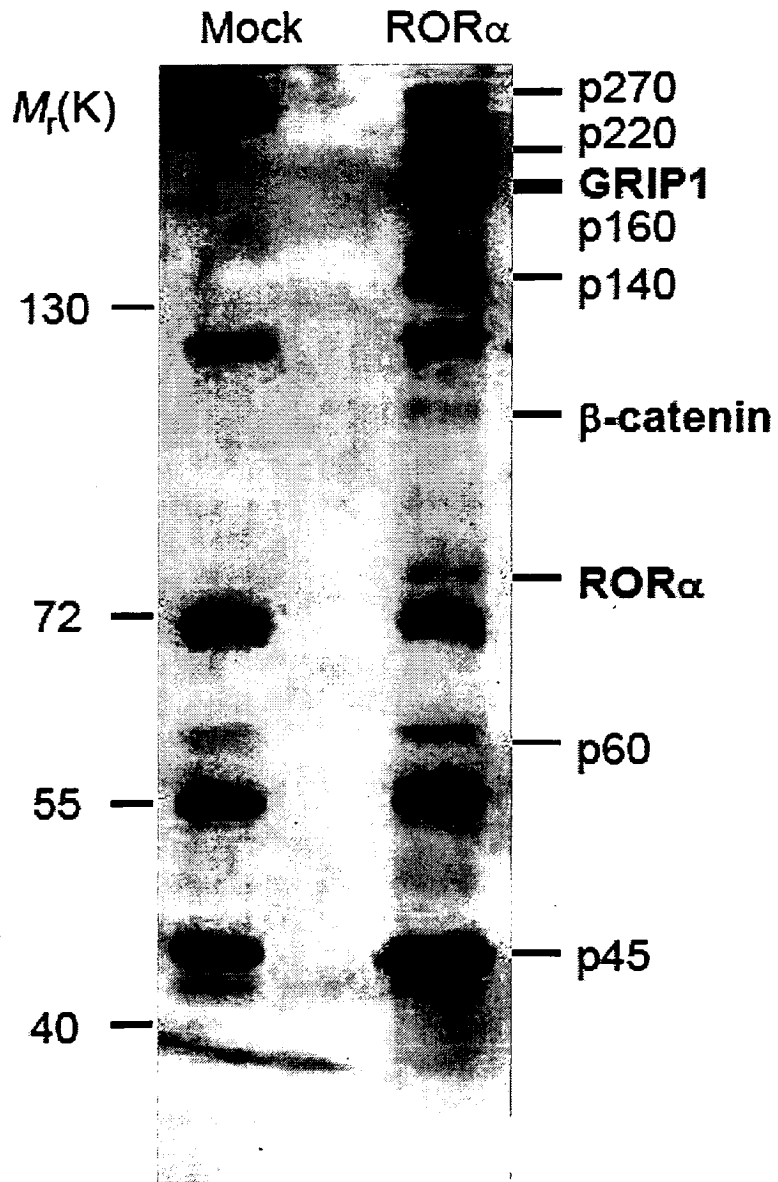


Fig. 1 A

**B**

Protein ID	Peptide sequence for ROR $\alpha$
GRIP1	PVLPSSSEFTTRTLMMR GQGLNMTPSMVAPSGMPATMSNPR NLLPKSIVNGGSWSGEP NSHTFNCRMLVK SIVNGGSWSGEP LHDSK
$\beta$ -catenin	SVENCVCIMR SLEGEKTGSRDVIPMDALGPDGYSTVDR YQEAEPGPLGSAVGSQR RRPECGR

Fig. 1B

**C**

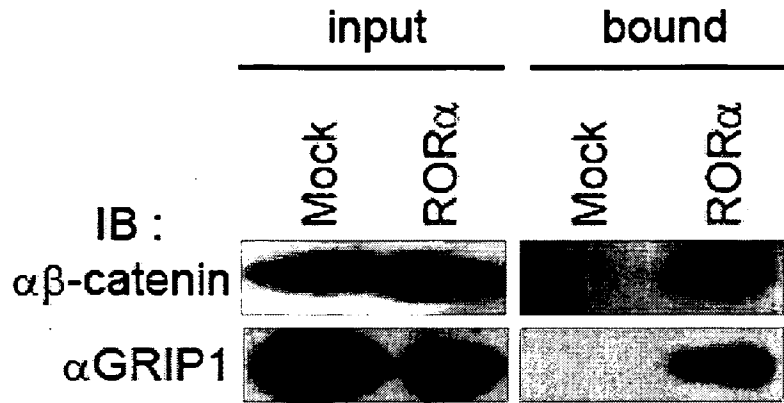


Fig. 1C

**D**

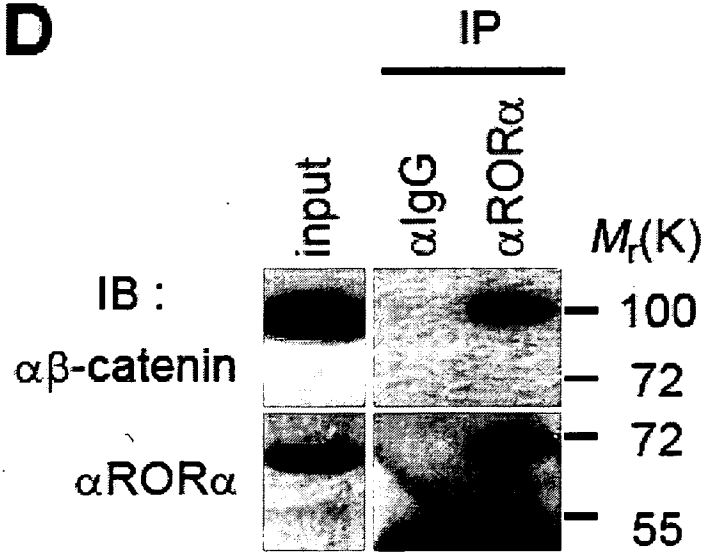


Fig. 1D

**E**

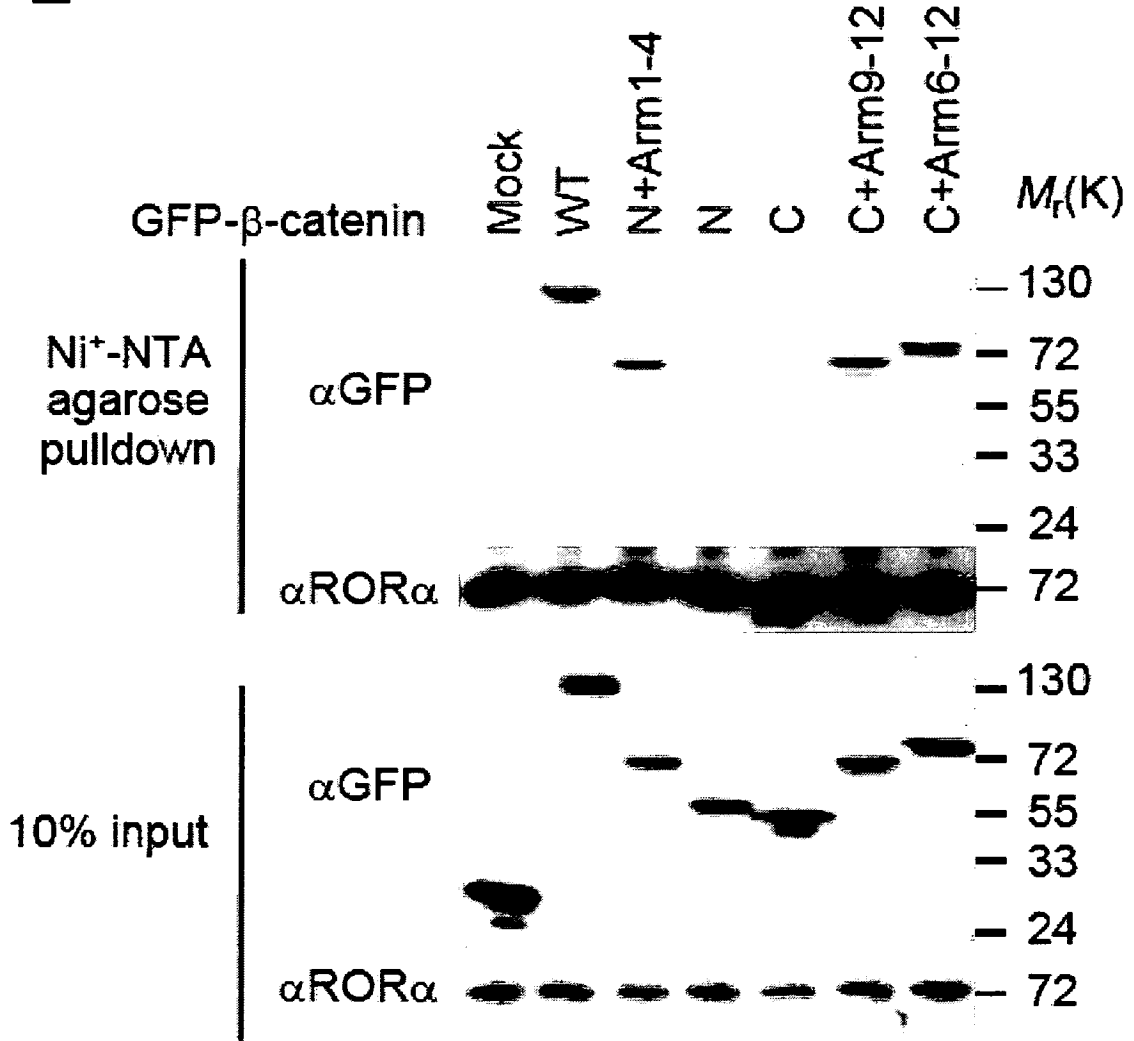


Fig. 1E

**F**

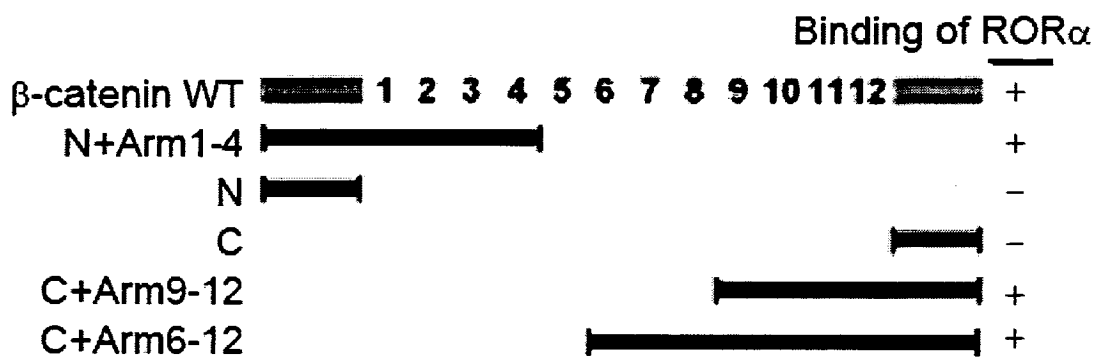


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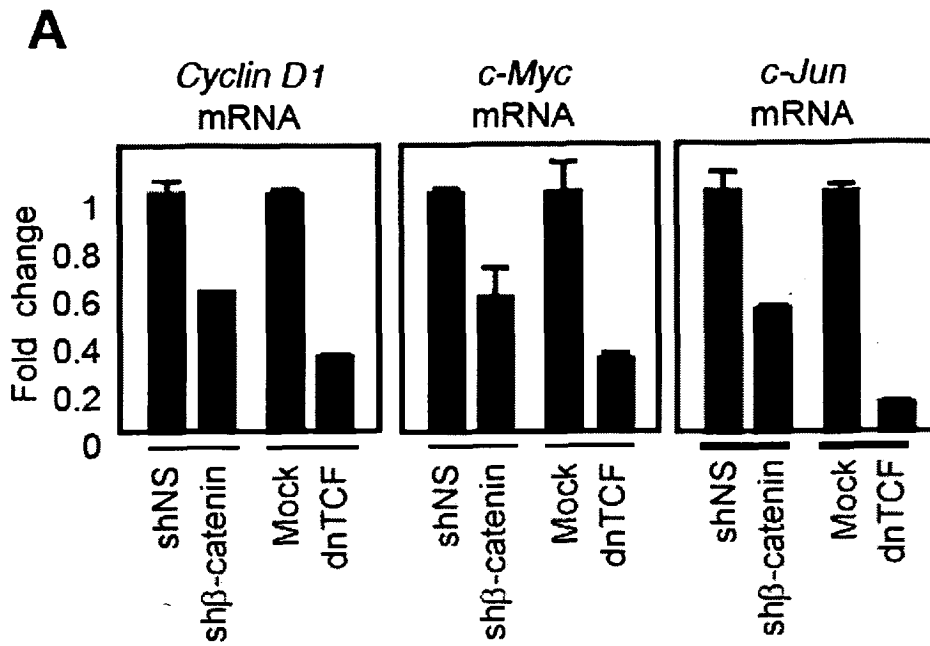


Fig. 2A

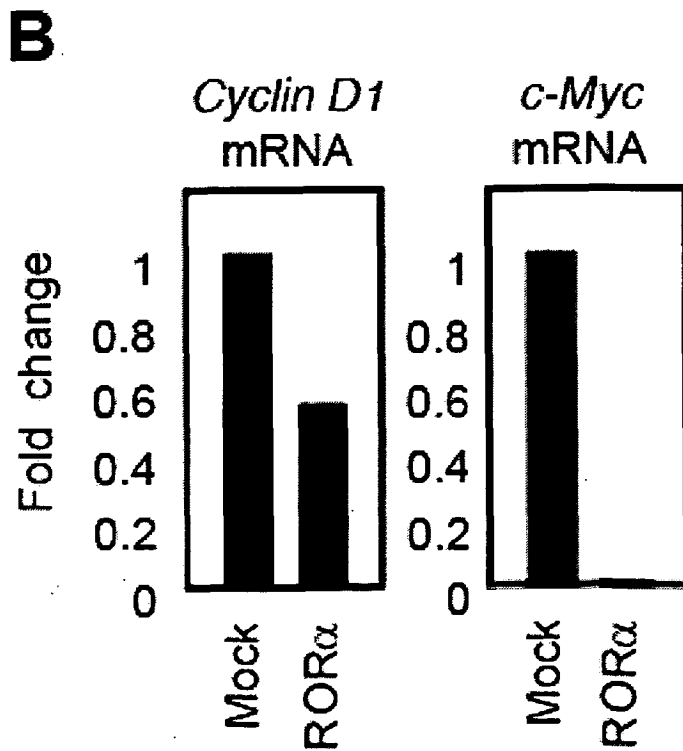


Fig. 2B

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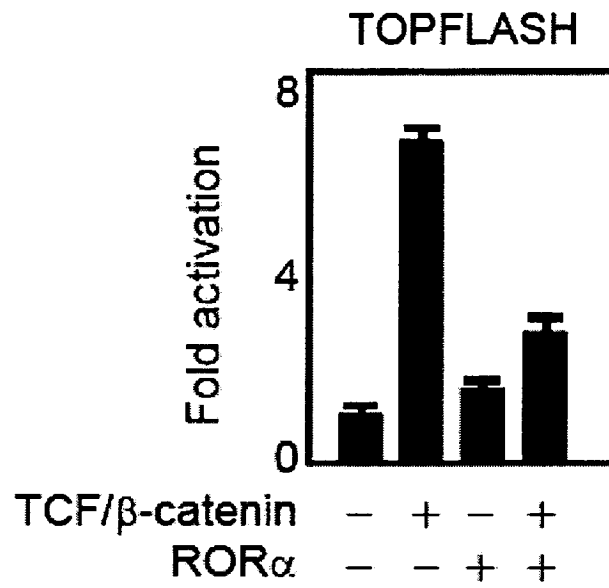


Fig. 2C

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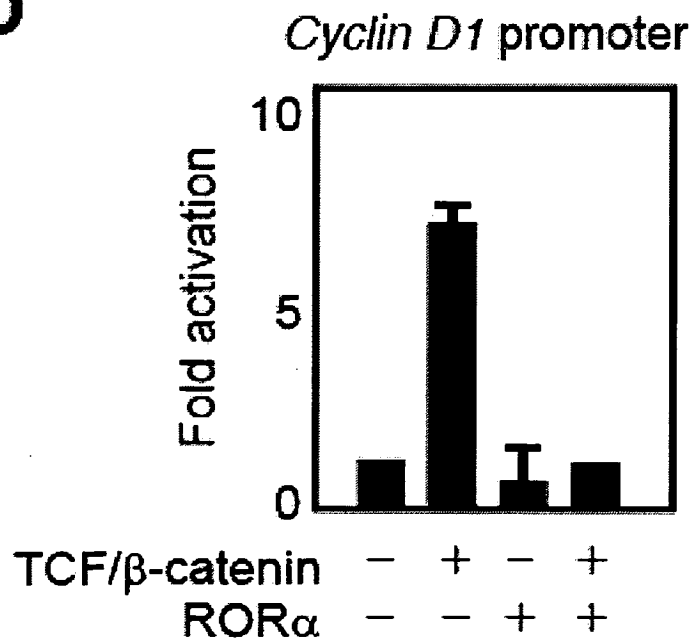


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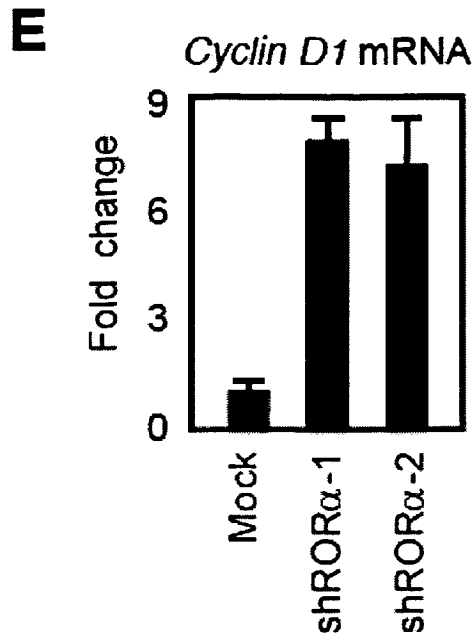


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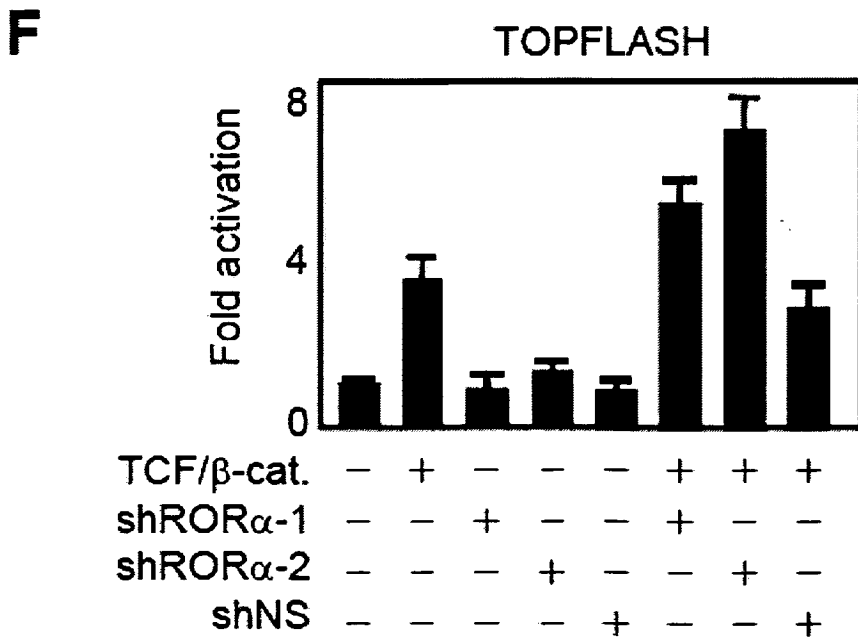


Fig. 2F

**G**

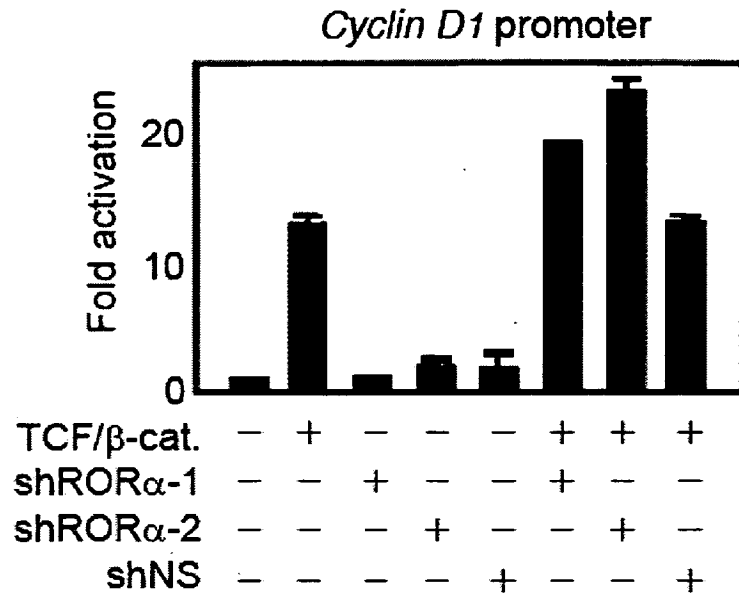


Fig. 2G

**H**

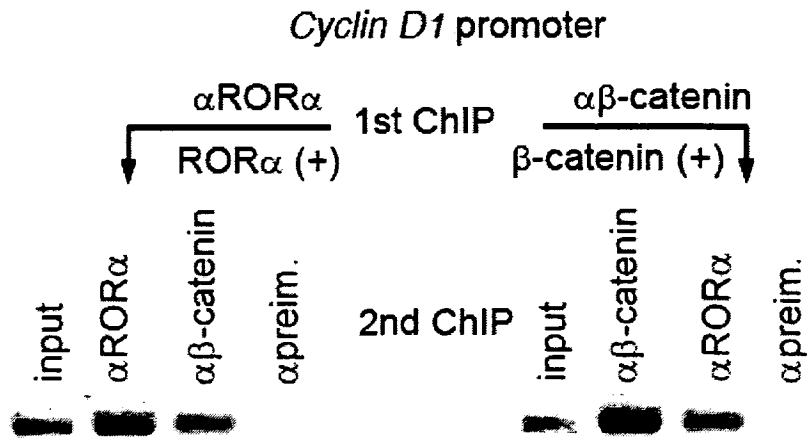


Fig. 2H

I

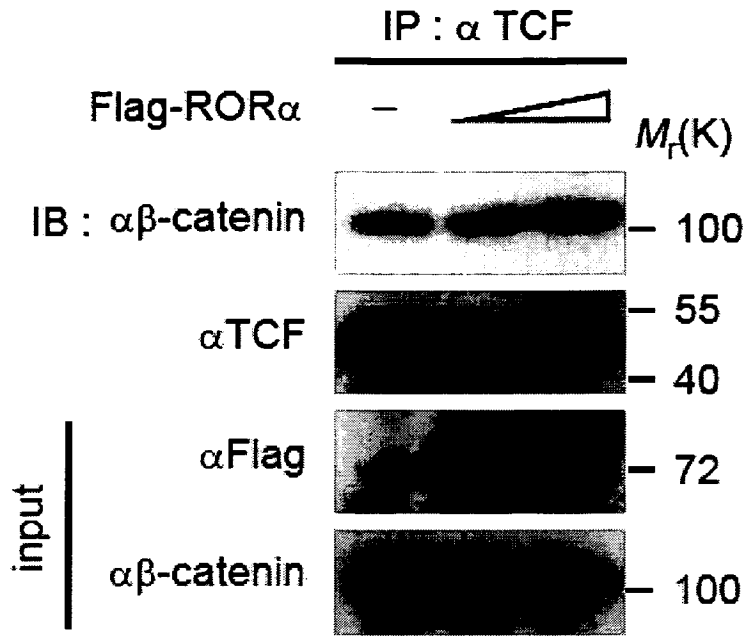


Fig. 2I

J

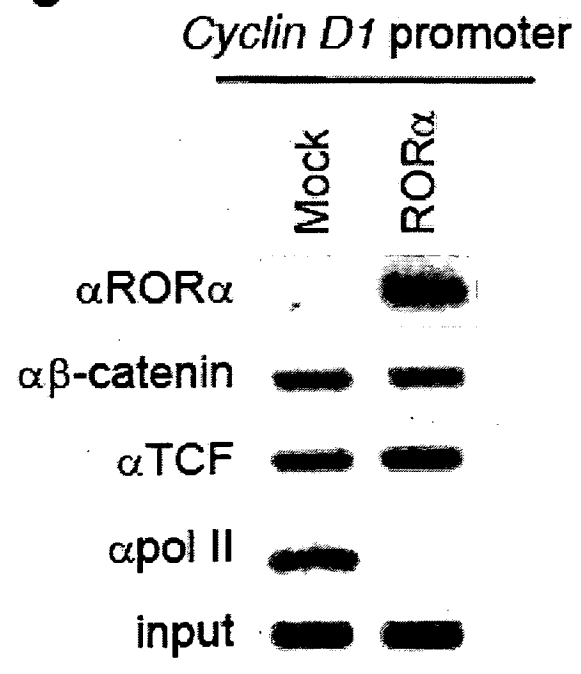


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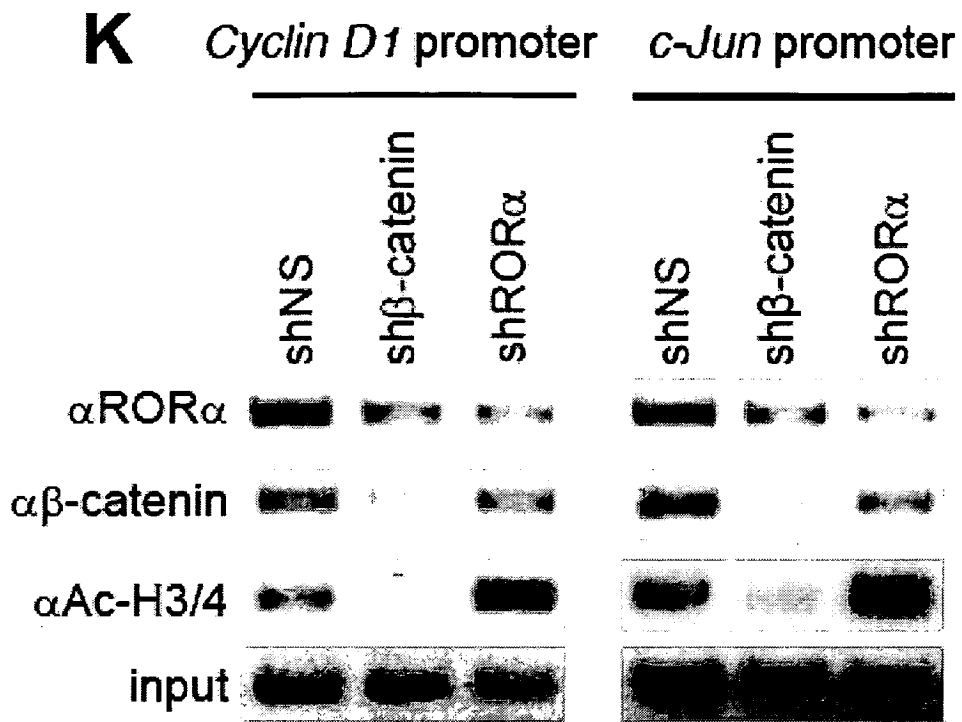


Fig. 2K

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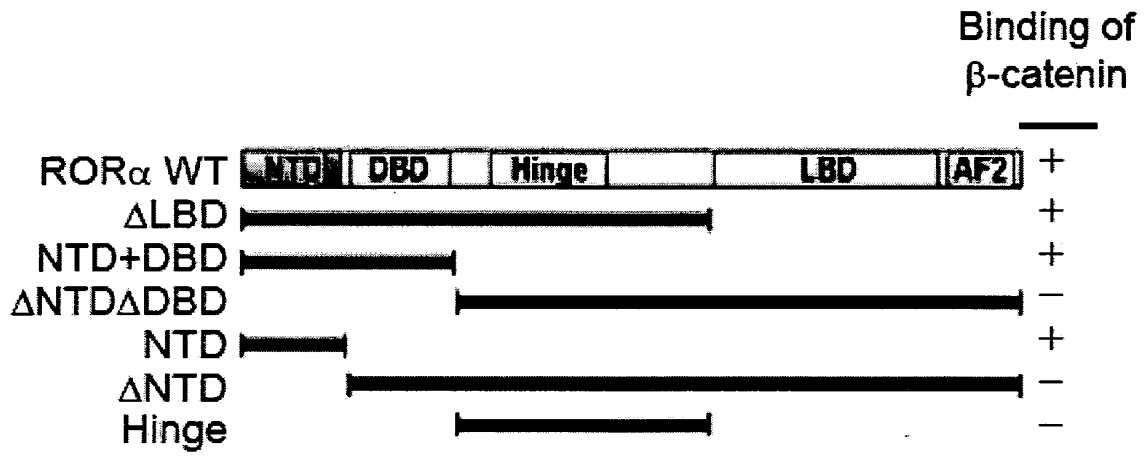


Fig. 3A

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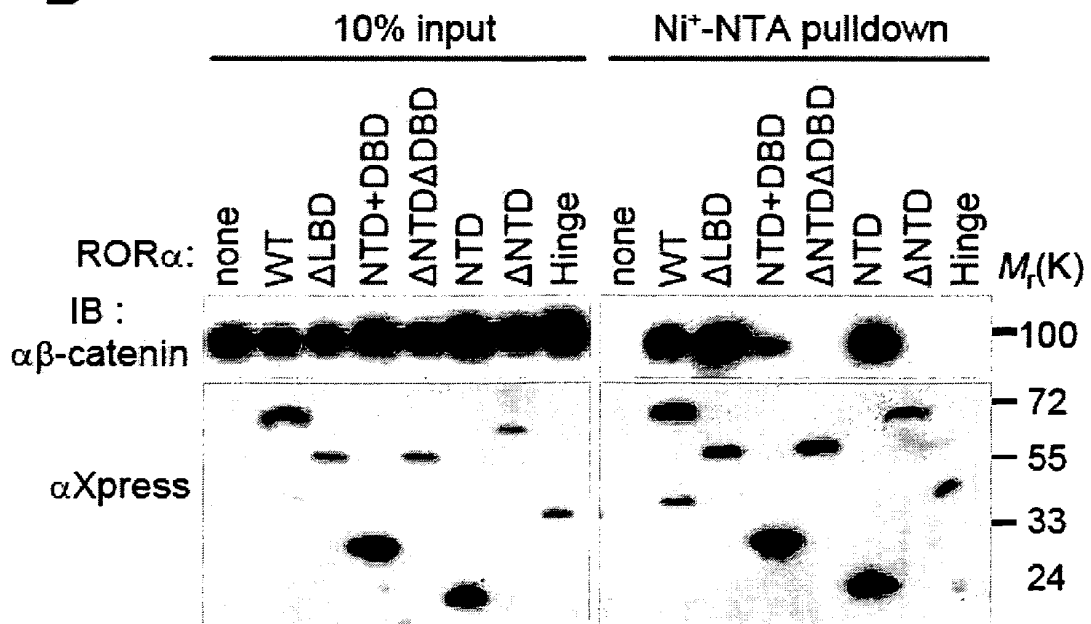


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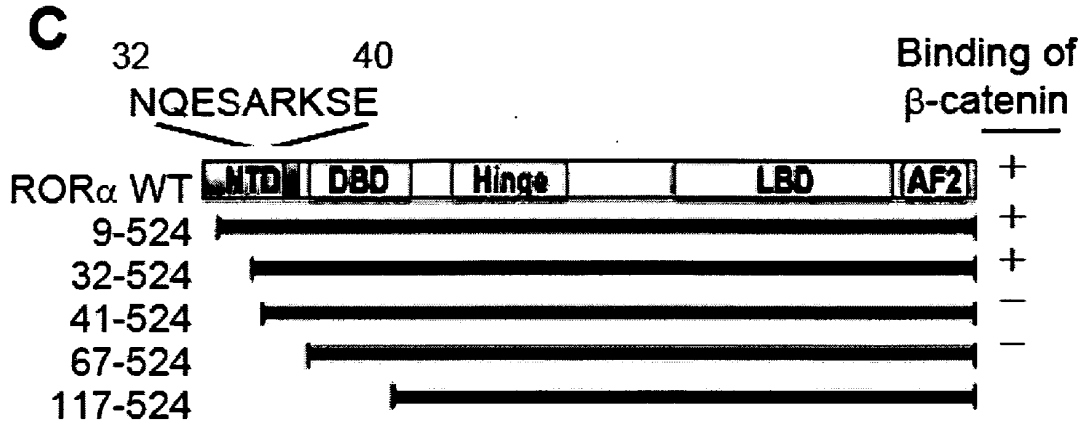


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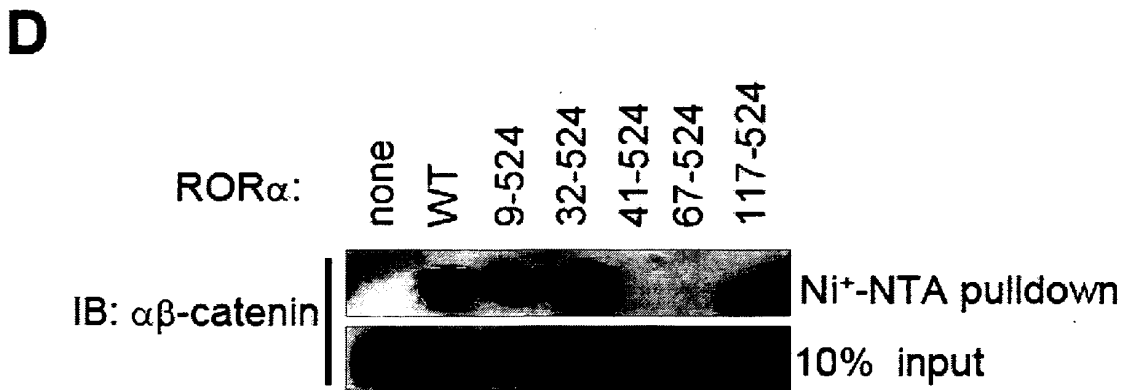


Fig. 3D

**E**



Fig. 3E

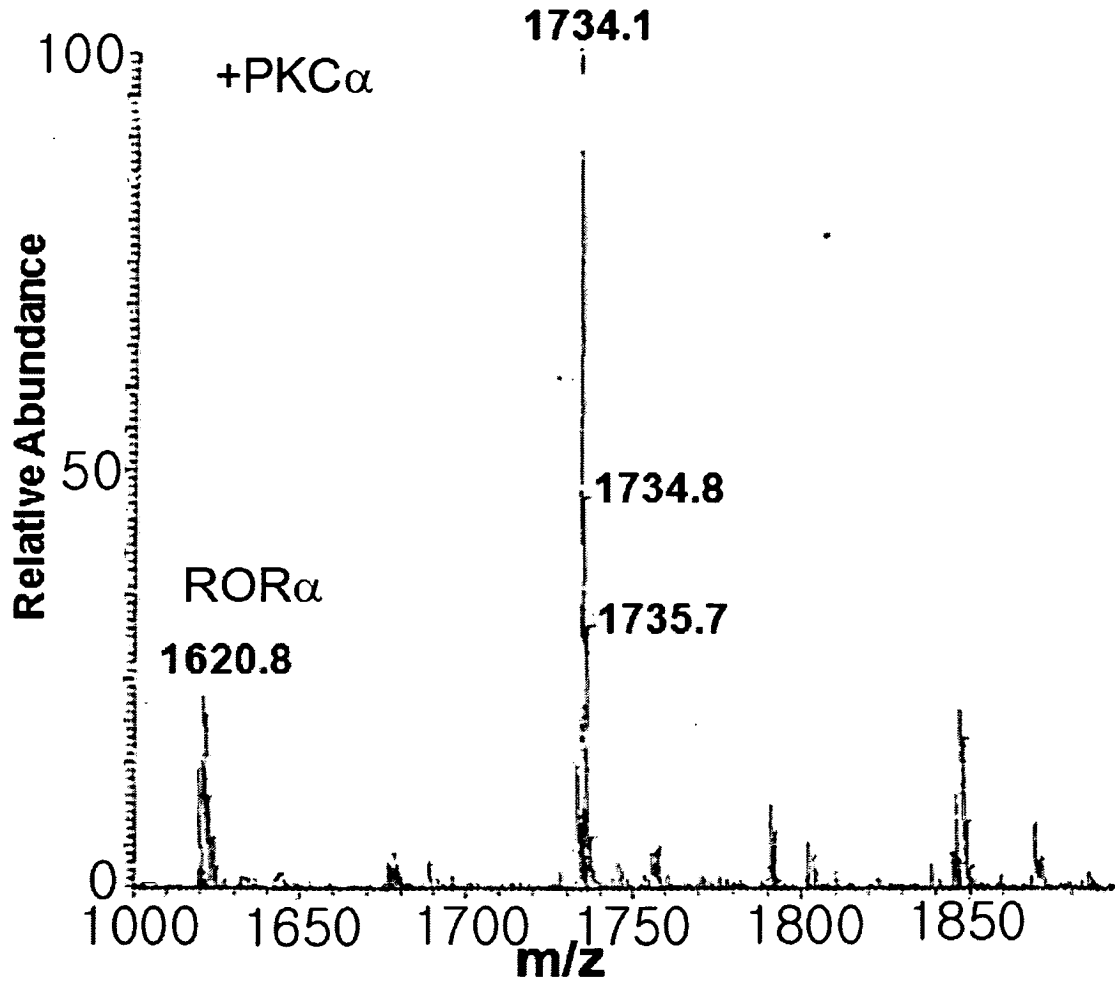


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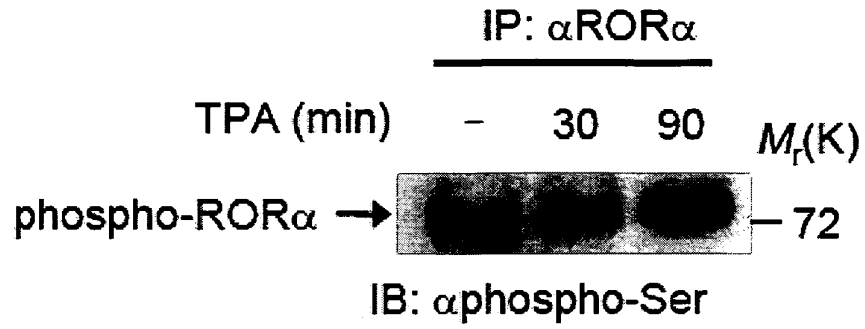


Fig. 3G

**H**

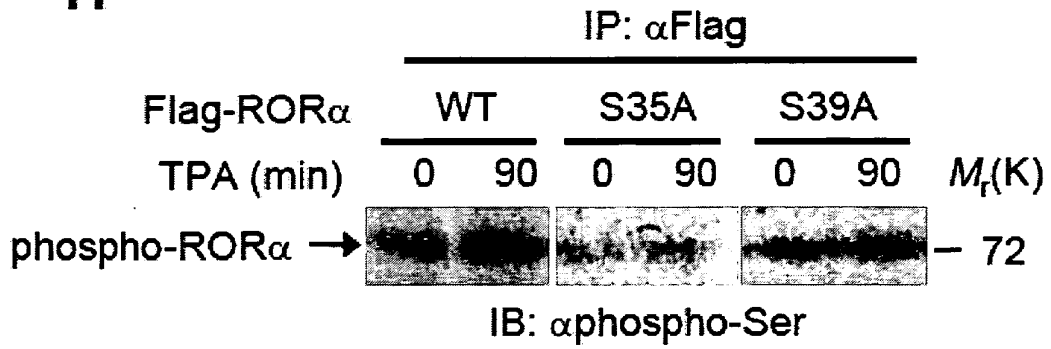


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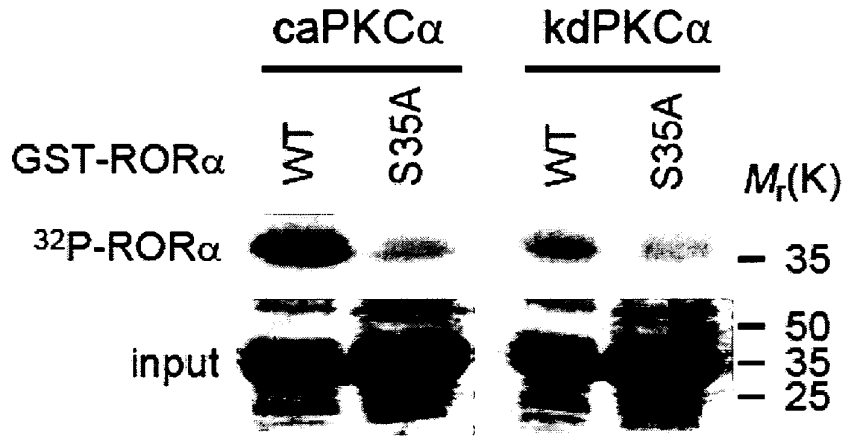


Fig. 3I

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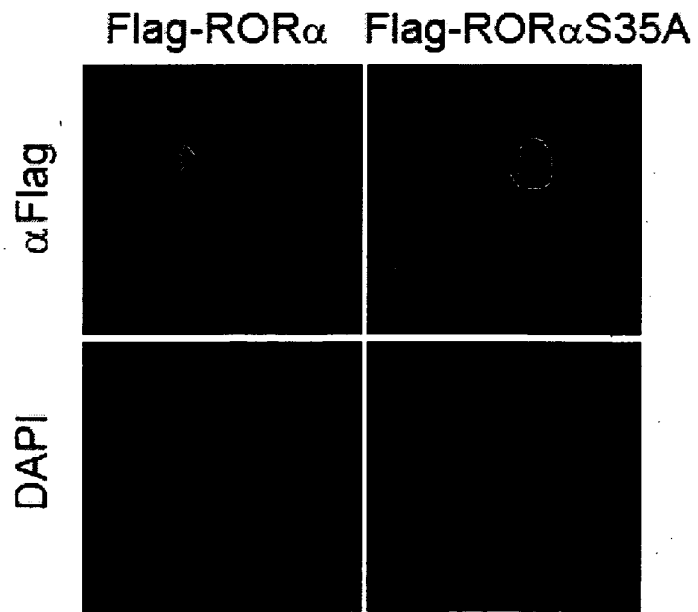


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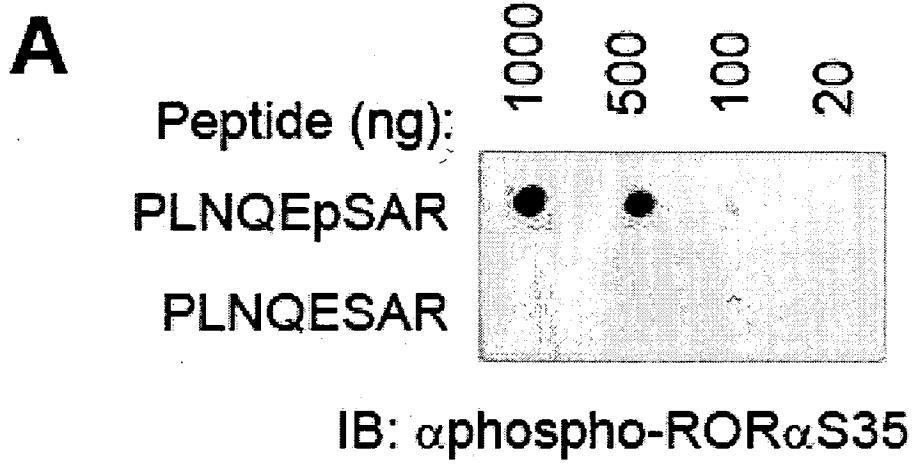


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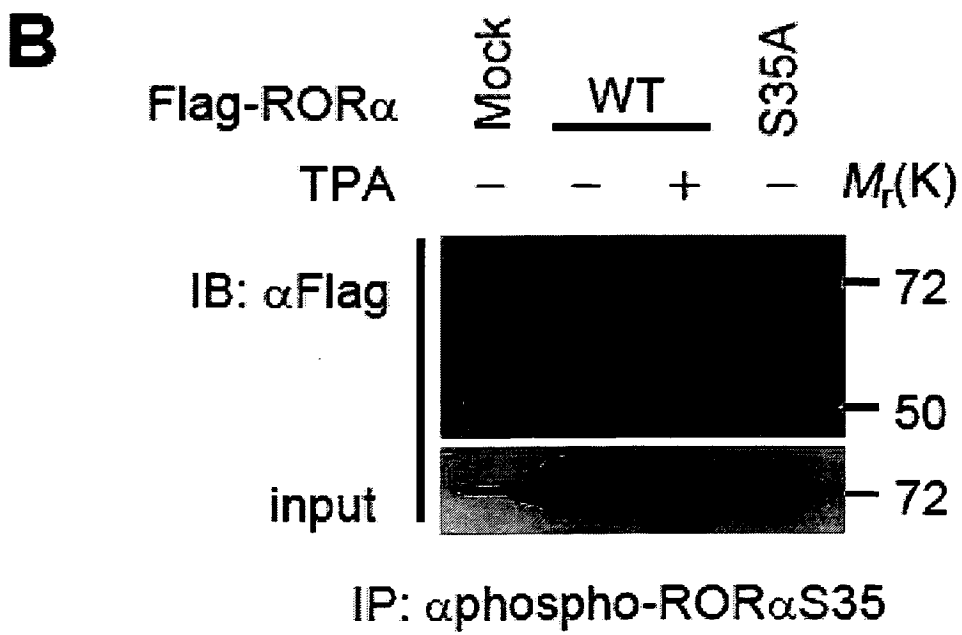


Fig. 4B

**C**

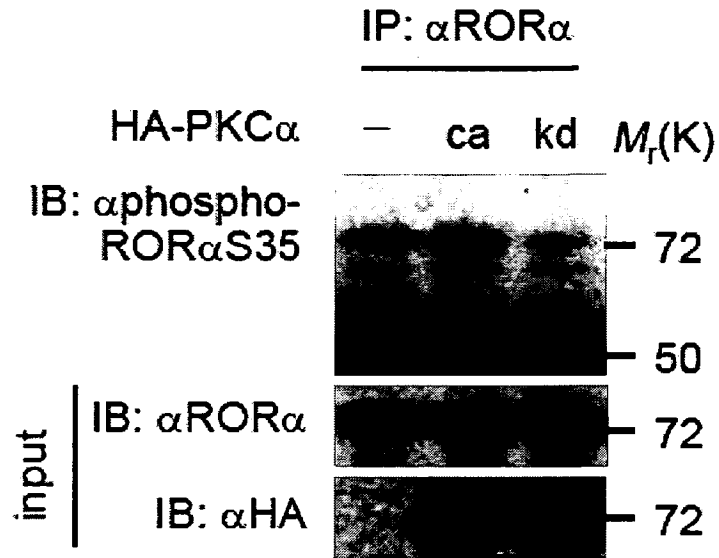


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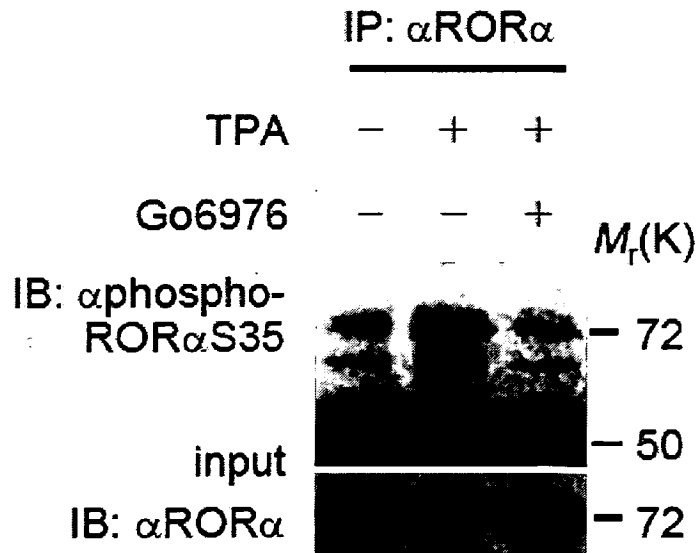


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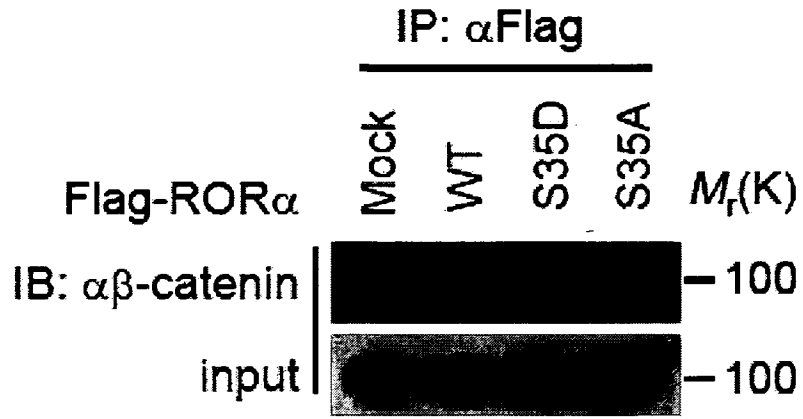


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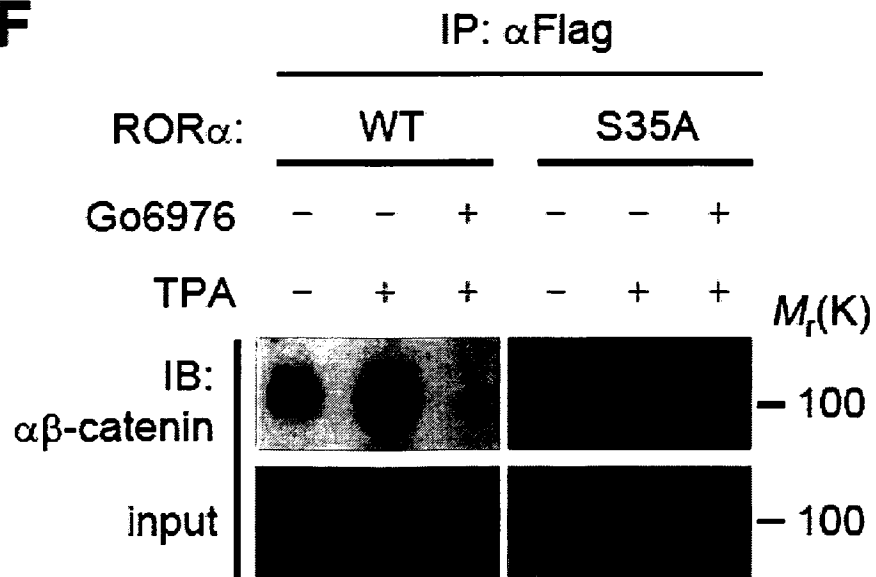


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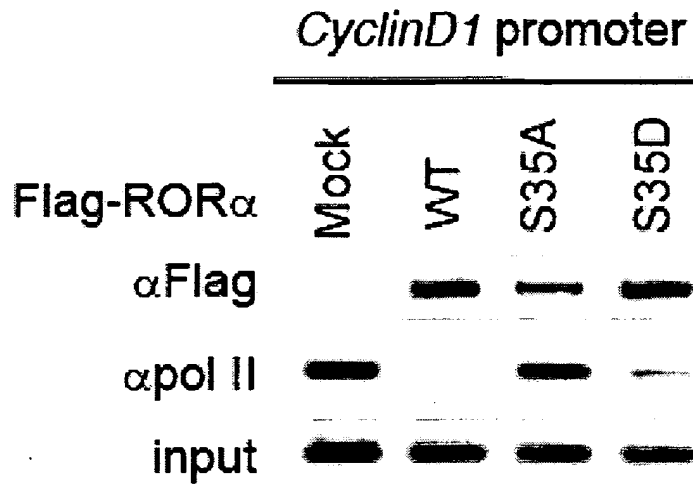


Fig. 4G

**H**

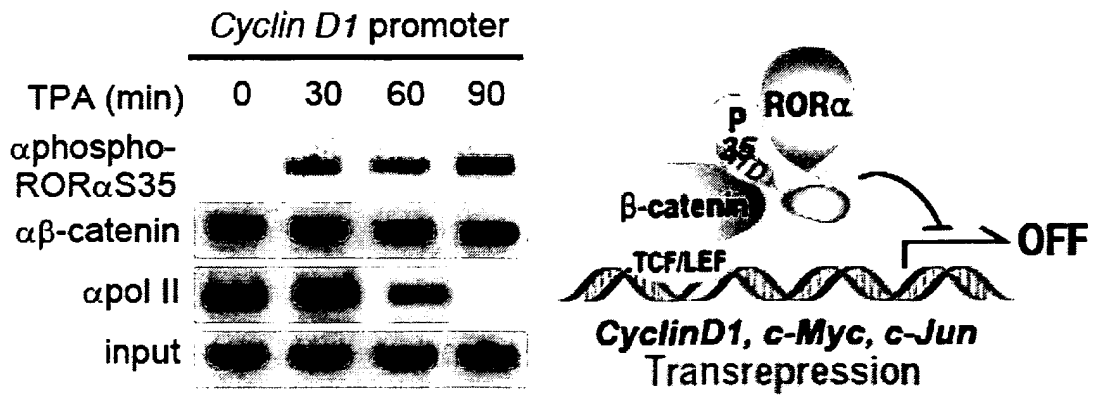


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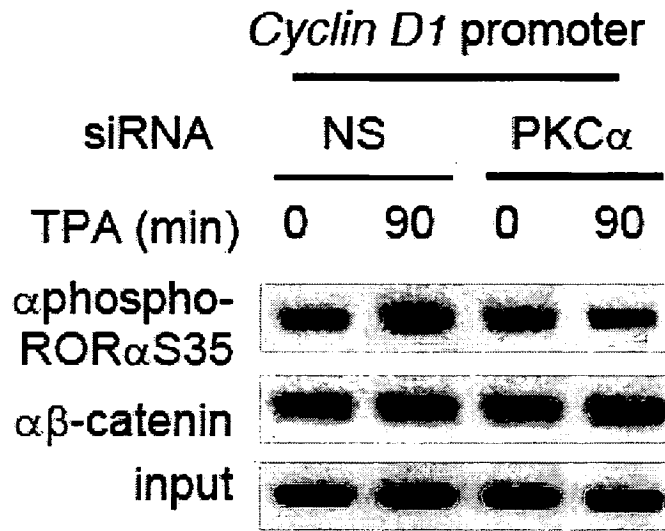


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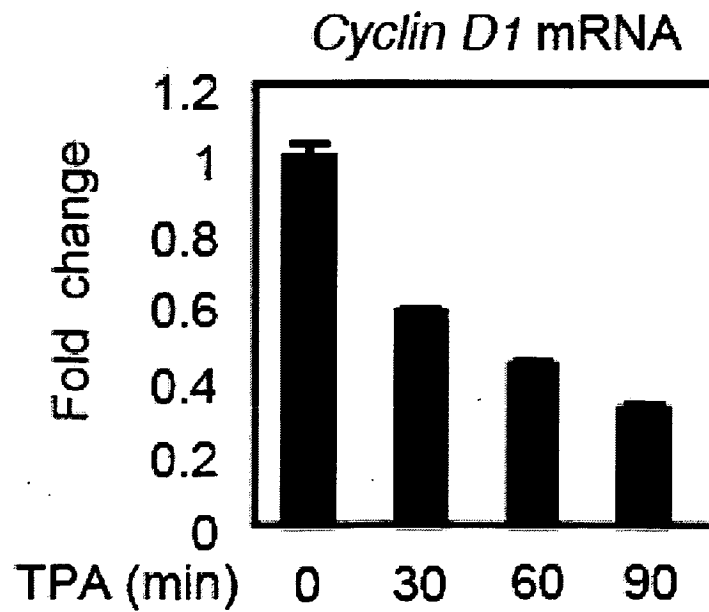


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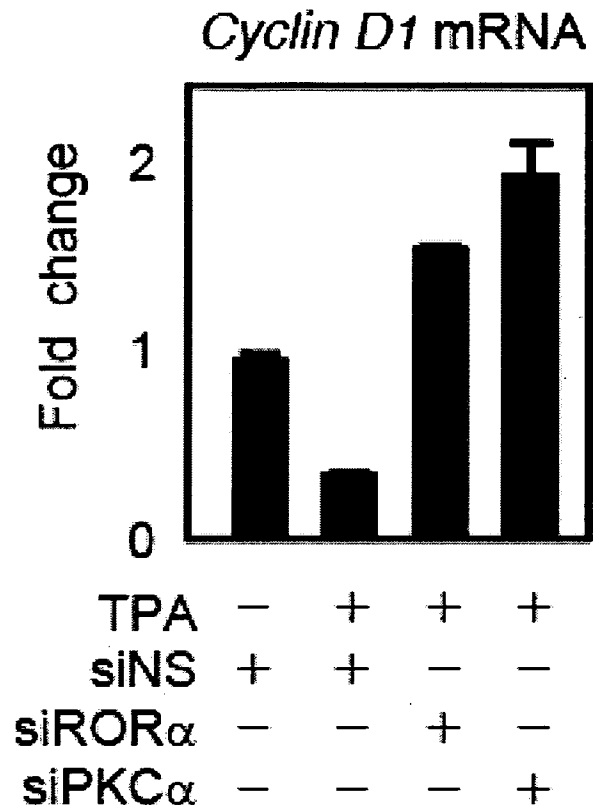
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Fig. 4K

**A**

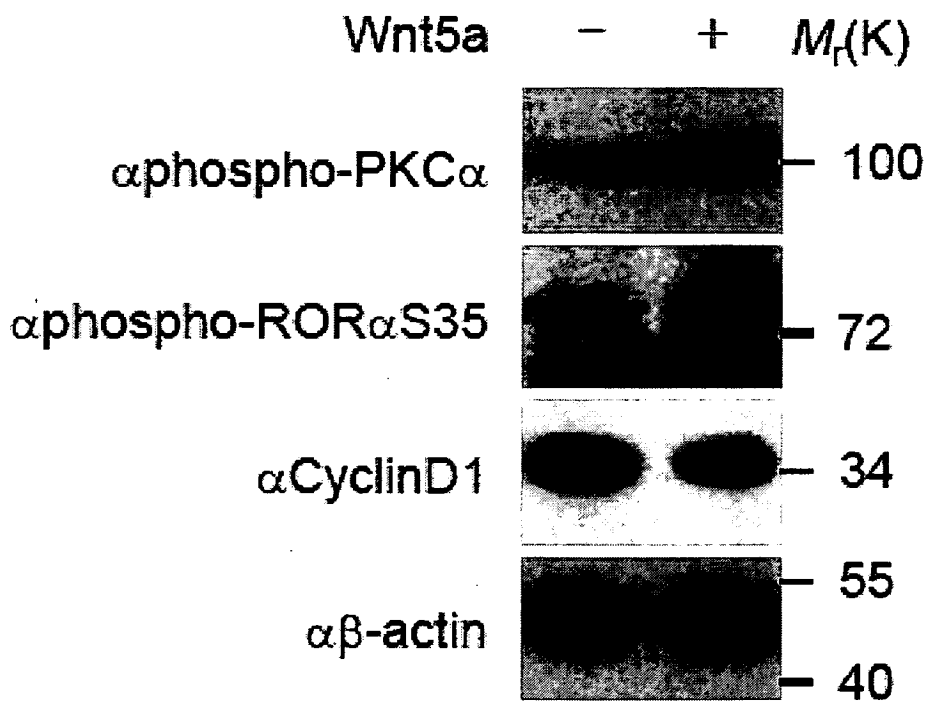


Fig. 5A

**B**

*Cyclin D1 mRNA*

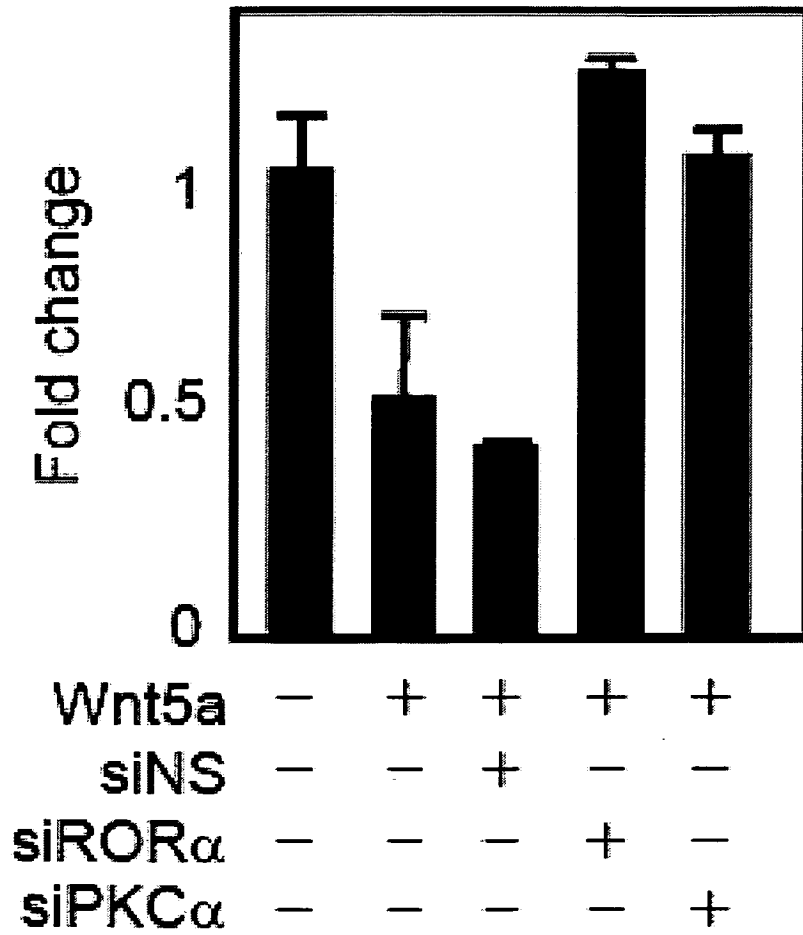


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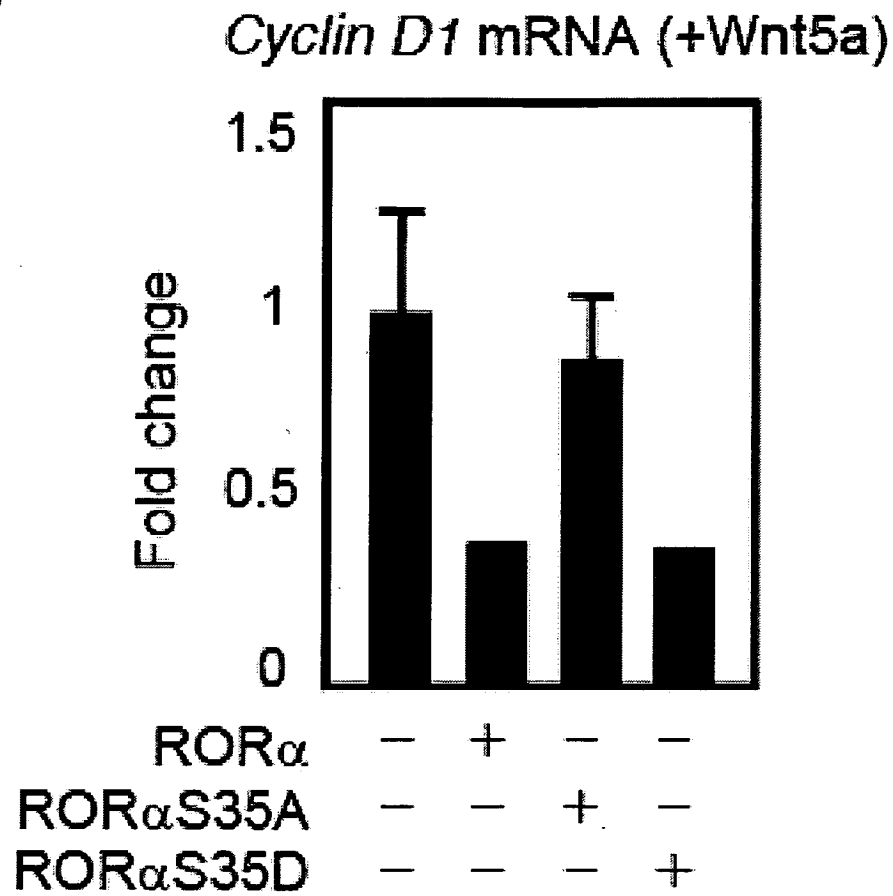
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Fig. 5C

**D**

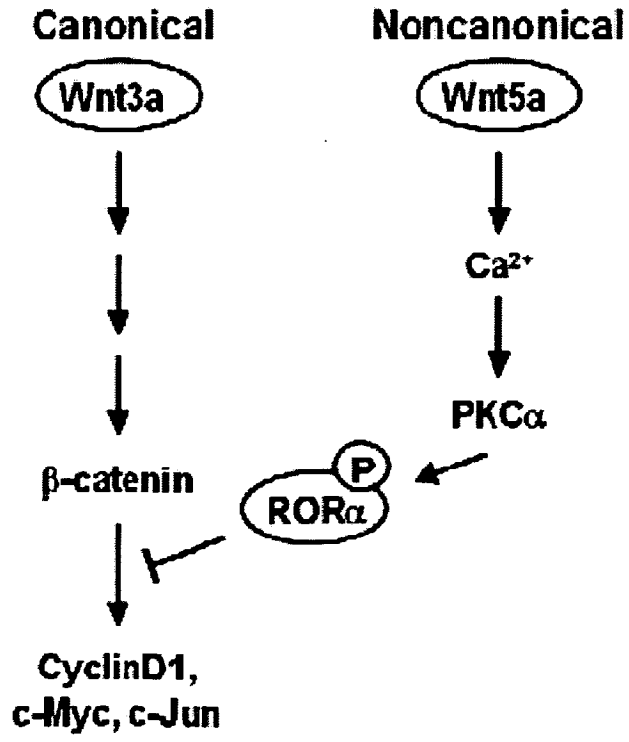
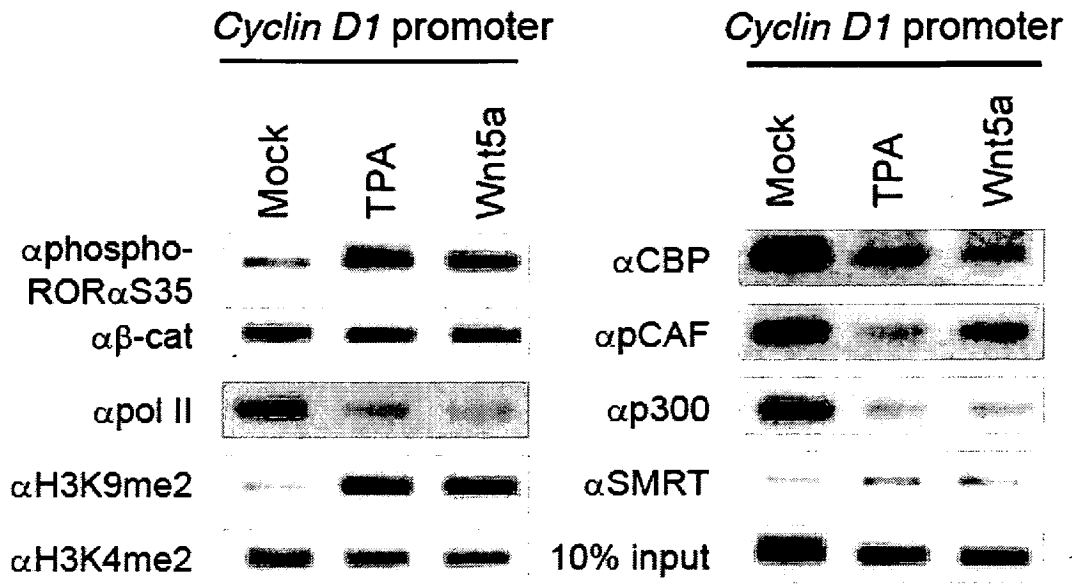


Fig. 5D

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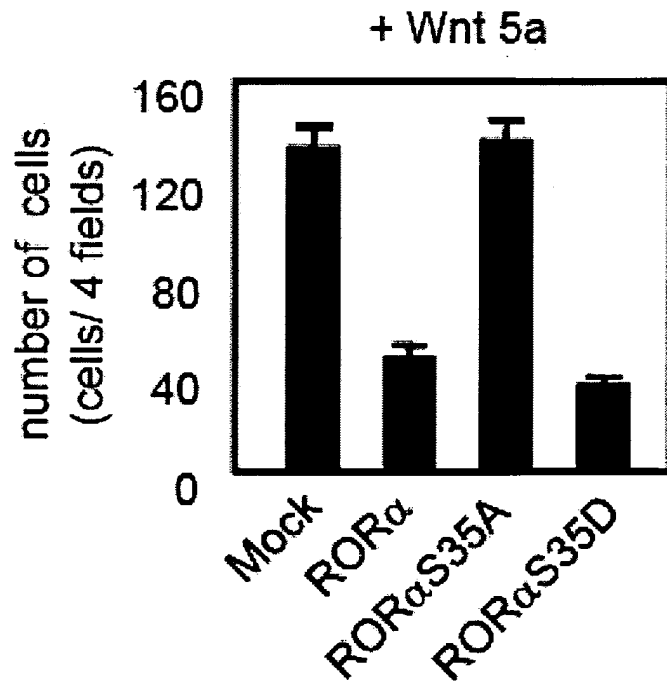


Fig. 5E

F

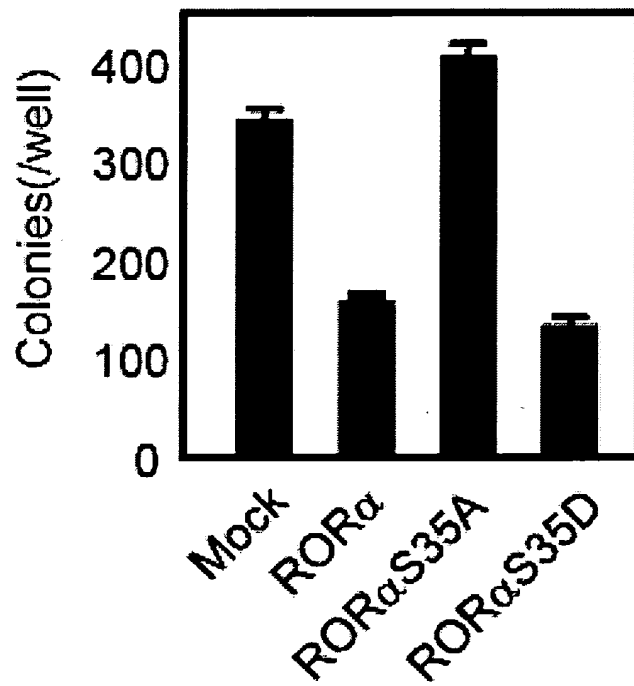
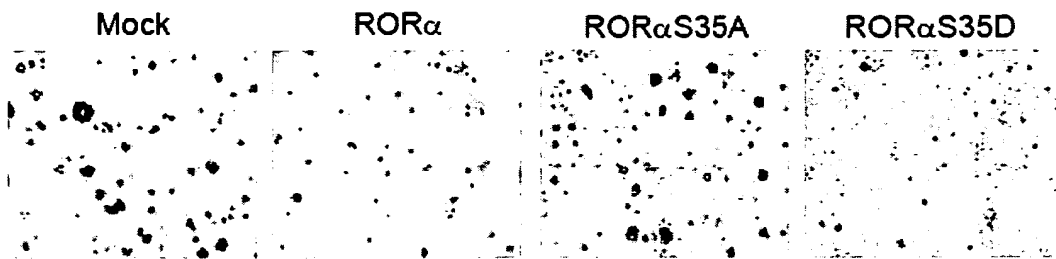


Fig. 5F

**A**

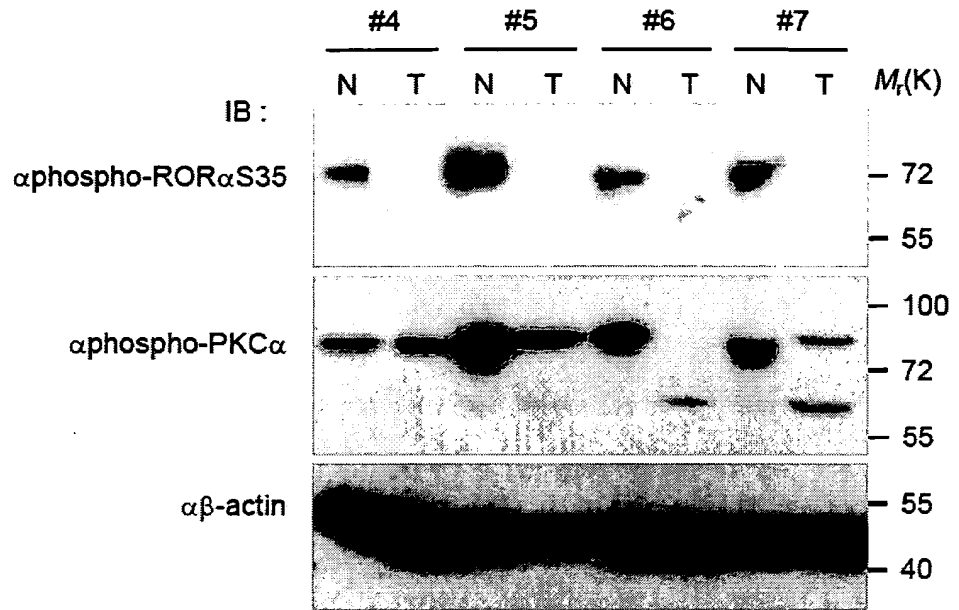


Fig. 6A

**B**

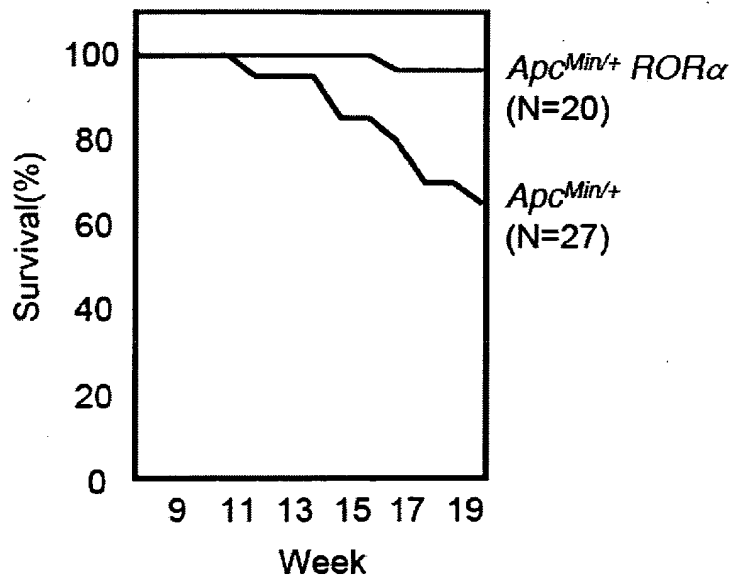


Fig. 6B

**C**

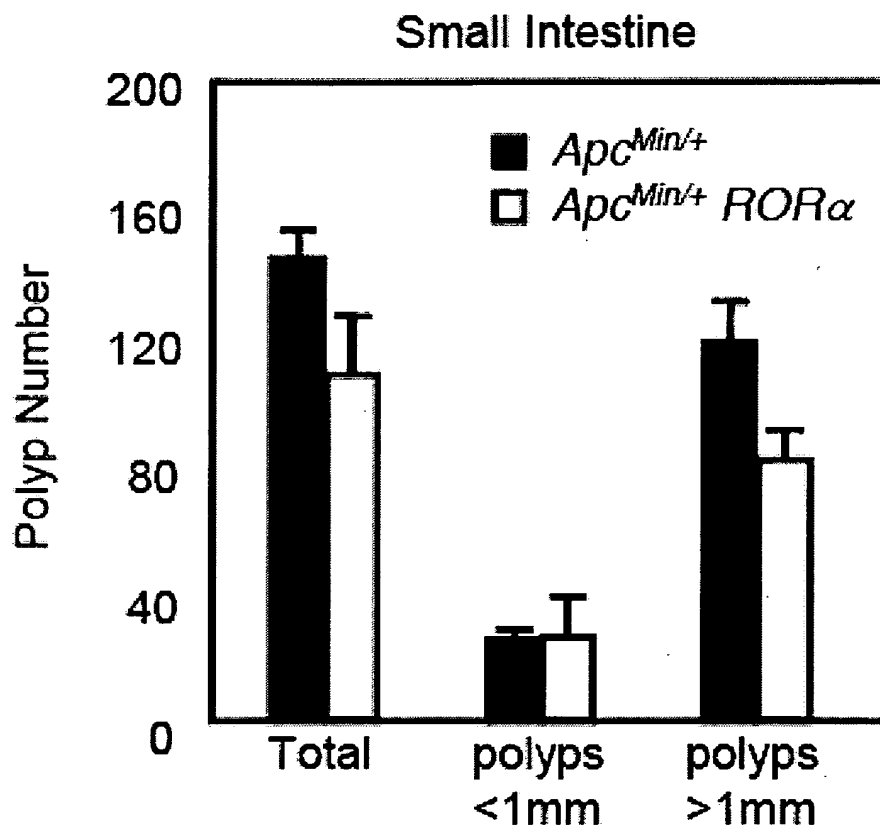


Fig. 6C

D

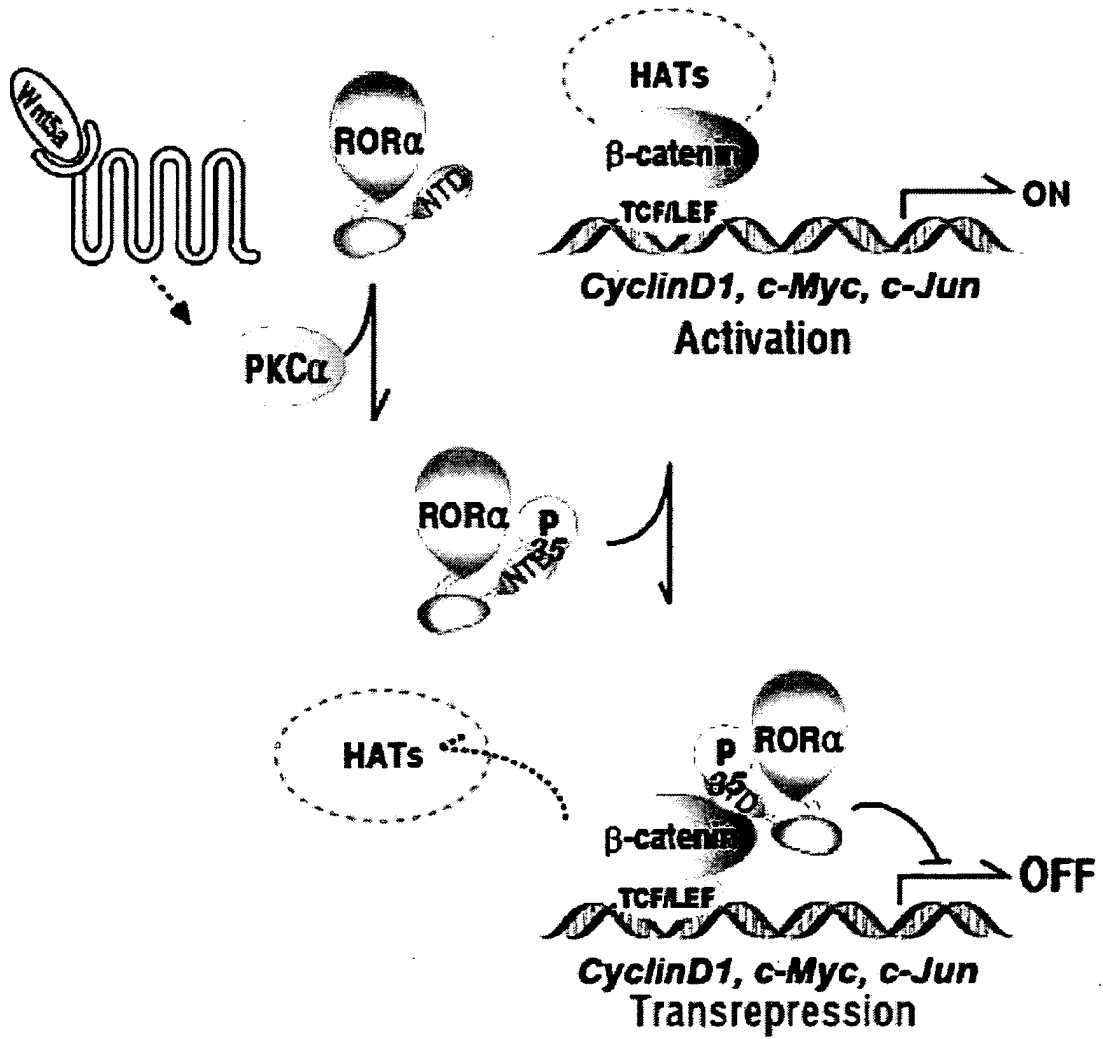


Fig. 6D

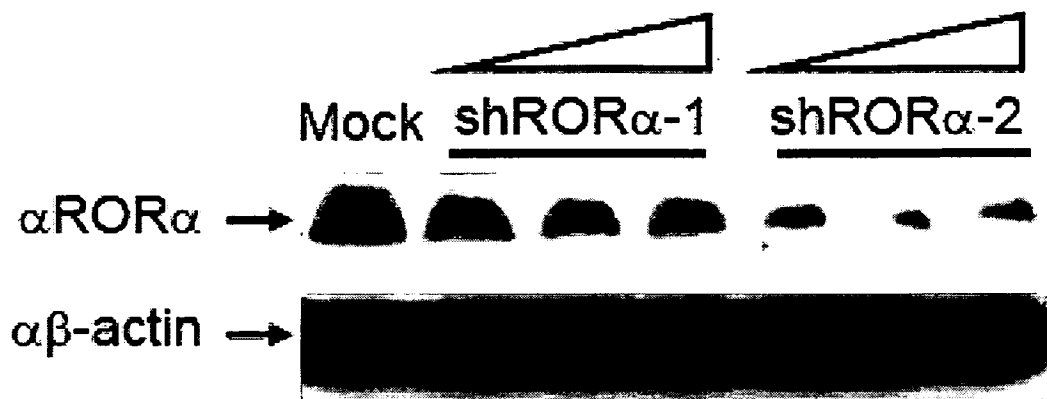


Fig. 7

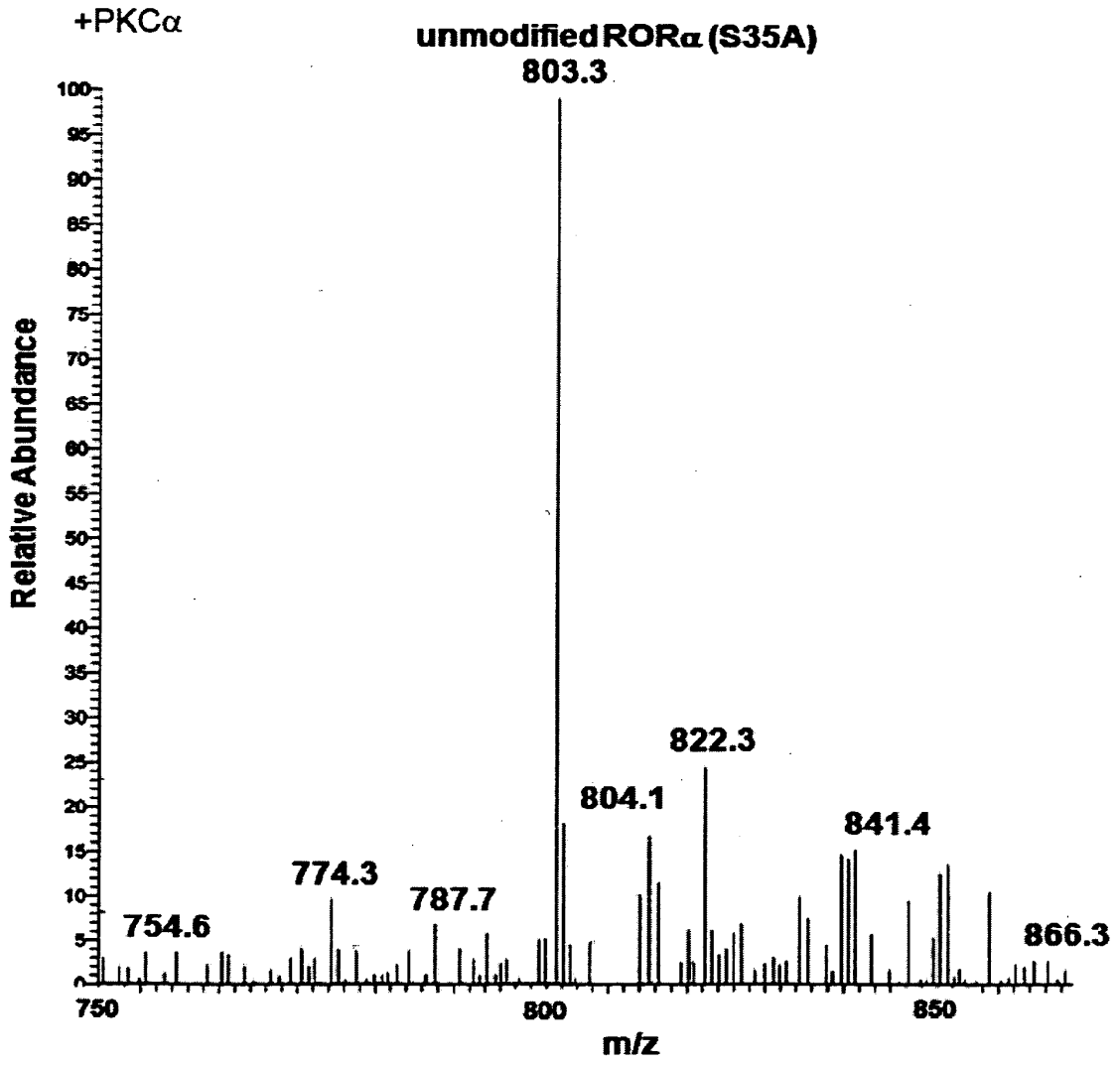


Fig. 8

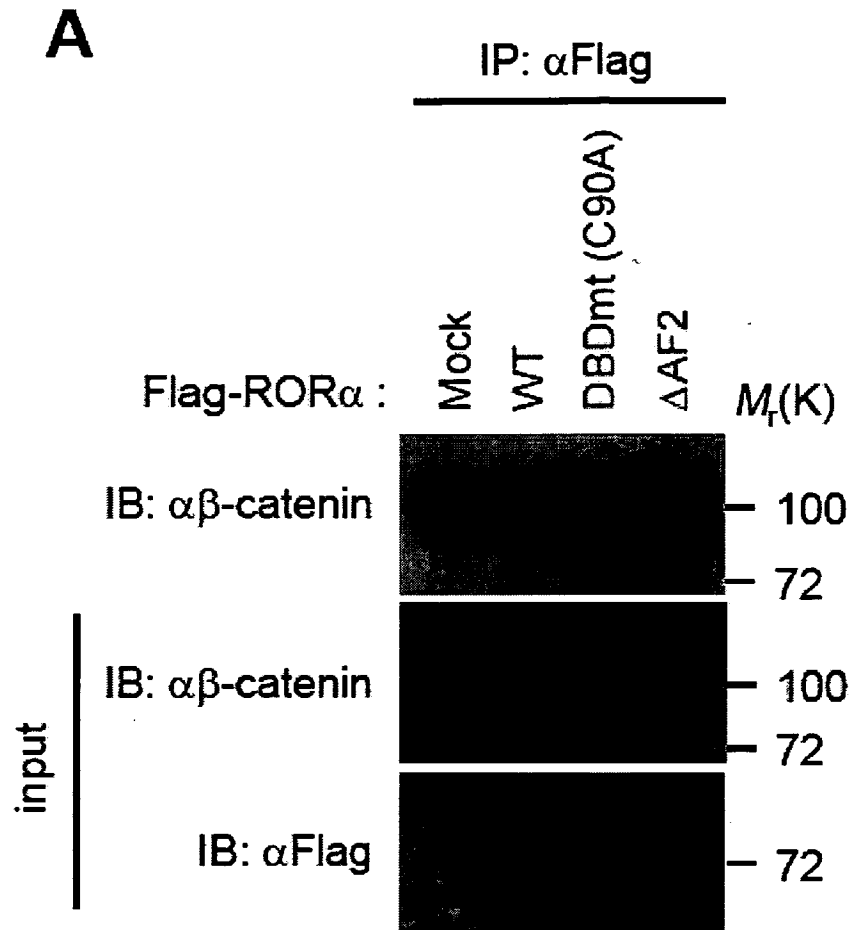


Fig. 9A

**B**

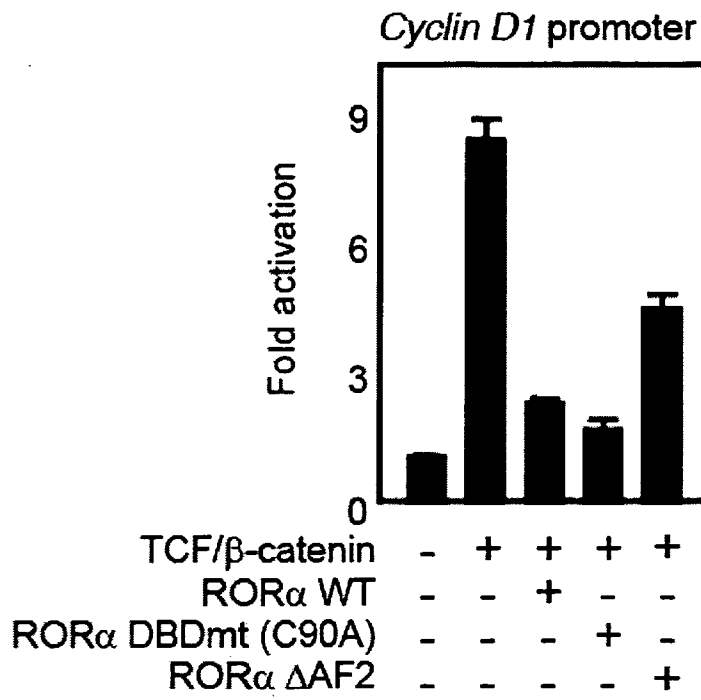


Fig. 9B

## REFERENCES CITED IN THE DESCRIPTION

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专利名称(译)	使用ror的抗癌药物筛选方法		
公开(公告)号	<a href="#">EP2431482A2</a>	公开(公告)日	2012-03-21
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[标]申请(专利权)人(译)	首尔大学校产学协力团		
申请(专利权)人(译)	首尔国立大学的产业基础		
当前申请(专利权)人(译)	首尔国立大学的产业基础		
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发明人	KIM, KEUN IL LEE, JI MIN BAEK, SUNG HEE		
IPC分类号	C12Q1/68 G01N33/574 G01N33/53 C12N5/071 G01N33/50 G01N33/573		
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摘要(译)

本发明涉及使用ROR $\alpha$ 筛选抗癌剂的方法，该方法包括以下步骤：培养细胞；使潜在的物质与细胞接触；确定细胞中ROR $\alpha$ 的磷酸化水平是否与对照细胞（未与潜在物质接触）相比增加；如果细胞中ROR $\alpha$ 的磷酸化水平增加，则选择潜在物质作为抗癌剂。

