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**WO 02/27017 A2**

(54) Title: METHOD FOR QUANTIFYING PHOSPHOKINASE ACTIVITY ON PROTEINS

(57) Abstract: The invention involves a method for measuring phosphorylation of proteins and, as such, is an indicator of protein kinase activity. The method involves the *in vitro* phosphorylation of a target protein but subjecting that protein (non-phosphorylated) to reaction mixture containing all reagents, including phosphokinase which allow the creation of a phosphorylated form of protein. The phosphorylated protein is measured by contacting it with an antibody specific for the phosphorylation sites(s). The invention includes antibodies useful in practicing the methods of the invention. The invention particularly relates to phosphorylation of Tau, Rb and EGFR proteins and antibodies specific for the site of phosphorylation of the Tau, Rb or EGFR proteins.

## 5           METHOD FOR QUANTIFYING PHOSPHOKINASE ACTIVITY ON PROTEINS

BACKGROUND OF THE INVENTION

10           This application claims the priority of provisional application No. 60/235,620 filed on September 27, 2000.

FIELD OF THE INVENTION

15           This invention relates to assays and reagents for measuring protein kinase activity *in vitro*.

BACKGROUND OF THE ART

20           Drug development efforts involve a continuum of activities initiated by target selection of a molecule. Since all drugs work at the level of the cell, those targets are usually proteins that somehow are involved in cellular communication pathways. Signal transduction pathways are key to normal cell function. Aberrations in the expression of intracellular molecules and coordinated interactions of signal transduction pathways are

25           associated with a variety of diseases and, thus, are the focus of drug discovery efforts. Phosphorylation of proteins in signal transduction pathways is one of the key covalent modifications that occur in multicellular organisms. The enzymes that carry out this modification are the protein kinases, which catalyze the transfer of the phosphate from

30           ATP to tyrosine, serine or threonine residues on protein substrates. Phosphorylation of these amino acid residues modulates enzymatic activity and creates binding sites for the recruitment of downstream signaling proteins. Because protein kinases are critical components of cellular signaling pathways, their catalytic activity is strictly regulated. Abnormalities in protein kinase activity alter patterns of phosphorylation with

35           subsequent effects on the cell function. Many drug discovery efforts involve the identification of chemicals that selectively suppress protein kinase activity. This invention is designed to provide assays and reagents to monitor protein kinase activity.

5           The targeted residues for phosphorylation can be contained in a full-length, biologically active molecule of recombinant or natural origin. Most methods currently employed for measuring protein kinase activity use peptide substrates, which include the targeted phosphorylation residue. This art is taught in US 6, 066,462 (Quantitation of individual protein kinase activity) incorporated herein by reference. This method differs  
10 from the present invention in that the peptide substrate does not contain all possible phosphorylation sites that can be acted on by kinases and thus may not truly reflect activity on a natural protein. The invention described herein can be used with whole molecule or fragments, of natural or recombinant origin. Also, the delineation of activity at different residue sites requires in the invention, a different PSSA for detection as  
15 opposed to a different peptide in US 6,066,462.

          Another method for detection of kinase activity involves use of a generic antibody that binds to all phospho-tyrosine residues. This method is described in US 5,766,863 (Kinase receptor activation assay) incorporated herein by reference. This  
20 method suffers from an inability to discriminate among phosphorylated tyrosine residues on a molecule. This method is also incapable of detecting phospho-serine or phospho-threonine molecules since the antibody does not detect such phosphorylated residues. In contrast, the method described herein uses antibodies, which bind to the sequence specific residues surrounding the phosphorylated amino acid plus the  
25 phospho-residue itself. The reagents used in this invention are capable of detecting phosphorylated threonine, serine or tyrosine molecules.

          Three examples are employed; all of which involve important molecular targets of current interest in disease-oriented pharmaceutical study.

30           Currently, neurobiologists are focusing efforts on the proteins in the brain that can be associated with disease. One such protein is called Tau, a neuronal microtubule-associated protein found predominantly in axons. The function of Tau is to promote tubulin polymerization and stabilize microtubules, but it also serves to link certain  
35 signaling pathways to the cytoskeleton. Tau phosphorylation regulates both normal and pathological functions of this protein. Tau, in its hyper-phosphorylated form, is the

5 major component of paired helical filaments (PHF), the building block of neurofibrillary lesions in Alzheimer's disease (AD) brain. Hyperphosphorylation impairs the microtubule binding function of Tau, resulting in the destabilization of microtubules in AD brains, ultimately leading to neuronal degeneration. Hyperphosphorylated Tau is also found in a range of other central nervous system disorders. Numerous  
10 serine/threonine kinases, including GSK-3 $\beta$ , PKA, PKC, CDK5, MARK, JNK, p38MAPK and casein kinase II, can phosphorylate Tau.

Detection of *in vitro* kinase activity is critical for screening compounds that may be able to inhibit this activity and therefore could be useful in ameliorating various  
15 neurodegenerative diseases where Tau phosphorylation is abnormally high. Current efforts exist to identify drugs that might suppress kinase activity towards the Tau protein; however, these methods suffer from poor sensitivity and low specificity. Phosphorylation at individual Serine or Threonine residues within the Tau protein has been shown to correlate with disease. This invention overcomes both of these  
20 deficiencies in the described 'art'.

US Patent 5,601,985 relates to methods of detecting abnormally phosphorylated Tau Protein; US Patent 5,843,779 relates to monoclonal antibodies directed against the microtubule-associated protein, Tau, and hybridomas secreting  
25 these antibodies; US Patent 5,733,734 relates to methods of screening for Alzheimer's disease or disease associated with the accumulation of paired helical filaments and US Patent 6,066,462 relates to quantitation of individual protein kinase activity. These patents are incorporated herein by reference.

30 Other models exist to show the general applicability of this format for monitoring kinase activity. For the purposes of illustration, we have designed assays around an intranuclear molecule Retinoblastoma protein (Rb protein) important in cell cycle regulation and a cell surface receptor molecule (EGFR).

35 Retinoblastoma protein (Rb), the tumor suppressor product of the retinoblastoma susceptibility gene, is a 110 kDa protein which plays an important role in regulating cell

5 growth and differentiation. Loss of its function leads to uncontrolled cell growth and tumor development. Mutational inactivation of the Rb gene is found in all retinoblastomas and in a variety of other human malignancies including cancers of breast, lung, colon, prostate, osteosarcomas, soft tissue sarcomas, and leukemia. Central to the role of the Rb protein as a tumor suppressor is the ability of Rb to suppress  
10 inappropriate proliferation by arresting cells in the G1 phase of the cell cycle. Rb protein exerts its growth suppressive function by binding to transcription factors including E2F-1, PU.1, ATF-2, UBF, Elf-1, and c-Abl. The binding of Rb protein is governed by its phosphorylation state. Hypo- or under-phosphorylated Rb binds and sequesters transcription factors, most notably those of the E2F/DP family, inhibiting the  
15 transcription of genes required to traverse the G1 to S phase boundary. The cell cycle inhibitory function is abrogated when Rb undergoes phosphorylation catalyzed by the complex of cyclins/cyclin-dependent protein kinases (cdks).

Rb contains at least 16 consensus serine/threonine sequences for cdk phosphorylation, although the significance of all these sites is unclear. It has been demonstrated that phosphorylation of threonine 821 on Rb is catalyzed by cdk2/complex such as Cyclin E/cdk2 and Cyclin A/cdk2. The phosphorylation of threonine 821 disrupts the interaction of Rb with the proteins containing the sequence LXCXE. The dephosphorylation of Rb protein returns Rb to its active, growth  
20 suppressive state. Removal of phosphates on Rb appears to be carried out by a multimeric complex of protein phosphatase type 1 (PP1) and noncatalytic regulatory subunits at the completion of mitosis. The quantitation of Rb phosphorylated at specific amino acid residues gives important information regarding the activity of kinases as well as the functional state of activation of the Rb protein itself. For the purposes of  
25 illustration, we designed an assay to quantitate the amount of Rb protein that is specifically phosphorylated at threonine 821. This ELISA does not recognize Rb phosphorylated at sites other than [pT<sup>821</sup>] or non-phosphorylated Rb. Samples can be controlled for Rb content by parallel measurement of total Rb.

35 WO 01/11367 (Assay of the phosphorylation activity of cyclin/CDK complex on retinoblastoma (RB) protein for identifying compounds which modify this activity) describes a method for detecting kinase activity by ELISA using a synthetic peptide and

5 a monoclonal antibody that recognizes the phosphorylated form of the peptide. The basis of this method is the coating of a solid phase with a synthetic peptide containing the consensus sequence of a region upon which a kinase acts. The peptide is allowed to come in contact with a kinase that allows a specific residue on that peptide to become phosphorylated. The activity of the kinase is reflected in the by the binding of the  
10 monoclonal antibody. Our invention differs from WO 01/11367 by the ability to use natural protein as the substrate for kinase activity. This feature is superior to the use of peptides since all naturally occurring phosphorylation sites would be present. The use of a single monoclonal antibody recognizing phosphoserine (clone 2B9) does not allow any discrimination of specific phosphorylation sites among those on the naturally  
15 occurring protein. Our use of specific PSSAs allows that distinction as well as the detection of phosphothreonine and phosphotyrosine residues.

In another example, a cell surface receptor was studied and a kinase-dependent assay designed. Epidermal growth factor receptor (EGFR) belongs to the family of  
20 receptor tyrosine kinases (RTKs), which regulate cell growth, survival, proliferation and differentiation. EGFR is expressed at full length as a 170 kDa type I transmembrane glycoprotein which consists of an extracellular ligand-binding domain, a single hydrophobic transmembrane region, and an intracellular, highly conserved region involved with signal transduction. Several deletions in the extra- and intracellular  
25 domain of the EGFR have been found in number of tumors. For example, EGFRvIII is a 145 kDa protein with a deletion of exons 2-7 in EGFR mRNA. A 100 kDa truncated EGFR without the cytoplasmic domain is observed in the culture supernatant from A431 cells, a human epidermal carcinoma cell line.

30 EGFR is activated by binding of a number of ligands such as EGF, transforming growth factor  $\alpha$  (TGF $\alpha$ ), amphiregulin, betacellulin, heparin binding EGF-like growth factor (HB-EGF) and epiregulin. The binding causes EGFR homo- and heterodimerization and rapid activation of its intrinsic tyrosine kinase followed by autophosphorylation of multiple tyrosine residues in the cytoplasmic domain. The  
35 phosphorylation of tyrosine residues in the COOH-terminal tail of the molecule serve as binding sites for cytosolic signaling proteins containing Src homology 2 (SH2) domains.

5 Several sites of *in vivo* phosphorylation have been identified in the EGFR including  
Tyr<sup>845</sup>, Tyr<sup>992</sup>, Tyr<sup>1068</sup>, Tyr<sup>1086</sup>, and Tyr<sup>1173</sup>. These sites bind and activate a variety of  
downstream signaling protein which contain SH2 domains, including growth factor  
receptor-binding protein 2 (Grb2), Src homology and collagen domain protein (Shc) and  
phospholipase C- $\gamma$  (PLC $\gamma$ ). The binding of these or other signaling proteins to the  
10 receptor and/or their phosphorylation results in transmission of subsequent signaling  
events that culminate in DNA synthesis and cell division.

Elevated expression and/or amplification of the EGFR have been found in  
breast, bladder, glioma, colon, lung, squamous cell, head and neck, ovarian, and  
15 pancreatic cancers. Selective compounds have been developed that target either the  
extracellular ligand-binding domain of EGFR or the intracellular tyrosine kinase region,  
resulting in interference with the signaling pathways that modulate mitogenic and other  
cancer-promoting responses. These potential anticancer agents include a number of  
small molecule, tyrosine kinase inhibitors.

#### 20 SUMMARY OF THE INVENTION

The invention describes assays and reagents for quantitating phosphorylation of  
proteins. The method involves subjecting a protein to a phosphokinase that will  
25 phosphorylate the protein and contacting the phosphorylated protein with an antibody  
specific for the phosphorylated site and detecting the antibody bound to the  
phosphorylated site. The invention includes antibodies useful in practicing the methods  
of the invention. The invention particularly relates to phosphorylation of Tau, Rb, and  
EGFR proteins and antibodies specific for the site of phosphorylation of the Tau, Rb,  
30 and EGFR proteins.

In each example system, the targeted protein (Tau, Rb or EGFR) is  
phosphorylated *in vitro* or *in vivo* and the specific phosphorylation event is detected  
using a highly selective phosphorylation site-specific antibody (PSSA). The appearance  
35 or disappearance of the targeted phosphorylation event can be quantified as a percentage  
of total protein that may be phosphorylated at each site.

5

The highly specific nature of the PSSAs allows parallel independent measurement of multiple phosphorylation sites on one protein. Moreover, different kinases can be measured simultaneously by using different PSSAs that selectively target different sites in the protein, thereby providing an avenue for generating phosphorylation site profiles. In contrast to existing methods that quantitate phosphorylated proteins as a diagnostic or prognostic indication of disease, this invention measures protein kinase enzymatic activity that results in the phosphorylation of proteins at a specific site(s). This method is also amenable to large-scale 'High Throughput Screening' formats currently being used by pharmaceutical and biotech companies to discover new drugs.

15

The term antibody used herein refers to monoclonal, polyclonal, Fab and F(ab)<sub>2</sub> fragments, genetically engineered antibodies or fragments thereof. Antibodies may be modified, for example, humanized to minimize cross species reaction. Pan antibodies as the term is used herein refers to antibodies that bind to phosphorylated and non-phosphorylated forms of the protein.

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5

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates specificity of the Anti-phospho Tau [pS<sup>199</sup>] phosphorylation site-specific antibody (PSSA).

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Figure 2 illustrates Anti-phospho Tau [pS<sup>214</sup>] PSSA specificity.

Figure 3a and 3b illustrate detection of total Tau vs. Tau phosphorylated at the PKA/serine 214 site by ELISA.

15

Figure 4a-b illustrate detection of Tau phosphorylated at GSK-3 $\beta$ /serine 199/202 (4a) vs. total Tau (4b) sites by ELISA.

Figure 5 illustrates a dose-response curve generated in an ELISA using the Tau serine 214 PSSA.

20

Figure 6 illustrates the specificity of the Tau PSSAs in an ELISA to detect Tau phosphorylation catalyzed by PKA vs. GSK-3 $\beta$  enzymes.

Figure 7 illustrates that multiple GSK-3 $\beta$  phosphorylation sites on Tau can be detected by ELISA using Tau PSSAs.

25

Figure 8 illustrates that a specific inhibitor of PKA activity selectively inhibits the phosphorylation on serine 214 of Tau but does not interfere with GSK enzyme activity as demonstrated using Tau [pS<sup>214</sup>] and Tau [pS<sup>199</sup>] PSSAs as detected by ELISA.

30

Figure 9 defines the specificity of the anti-Rb [pT<sup>821</sup>].

Figure 10 shows studies to determine the specificity of the Rb [pT<sup>821</sup>] ELISA.

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Figure 11 shows the specificity of the Rb [pT<sup>821</sup>] ELISA for threonine 821 as determined by peptide competition.

Figure 12 shows the application of the Rb [pT<sup>821</sup>] ELISA in evaluating kinase activity in Jurkat cells were grown in the presence of the kinase inhibitor, staurosporine.

40

Figure 13 illustrates the specificity of the EGFR PSSA [pY<sup>1173</sup>].

Figure 14 shows the specificity of the EGFR [pY<sup>1173</sup>] ELISA for tyrosine residue 1173 as determined by peptide competition.

45

Figure 15 demonstrates the response curve of phosphorylation of EGFR in A431 cells after treatment with EGF using the EGFR [pY<sup>1173</sup>] ELISA.

50

Figure 16 shows the application of the EGFR [pY<sup>845</sup>] ELISA in evaluating kinase activity in A431 cells were grown in the presence of the tyrosine kinase inhibitor, PD158780.

5

DETAILED DESCRIPTION OF THE INVENTION

**Tau System:** The Tau protein system demonstrates the utility of this invention on a protein that is found both intracellularly and extracellularly in normal and pathological conditions. The Tau protein has multiple phosphorylation sites acted upon by multiple protein kinases. Phosphoserine and phosphotyrosine residues exist. Both mono-phospho and dual-phosphoresidues are distinguishable in this model system.

**Tau Recombinant Protein:** Full length Tau-441 protein is purified recombinant protein derived through cloning of human Tau cDNA and expressed in *E.coli*. The protein is purified via standard methods. This protein is commercially available from multiple vendors.

**Tau pS<sup>199</sup> PSSA:** Rabbits were immunized with a chemically synthesized and KLH conjugated phosphopeptide corresponding to the region of the longest isoform of the Tau protein that includes serine 199. The chemically synthesized phosphopeptides (RSGYS(pS)PGSPG) is sequence ID #1. The Tau pS<sup>199</sup> PSSA was purified from rabbit serum by sequential epitope-specific chromatography. The antibody was negatively preadsorbed using a non-phosphopeptide corresponding to the site of phosphorylation to remove antibody that is reactive with non-phosphorylated Tau. The final product was generated by affinity chromatography using the peptide that is phosphorylated at serine 199. This antibody recognizes specifically the Tau protein when phosphorylated on serine 199, as demonstrated by peptide competition analysis in a western blotting assay. Serine 199 is phosphorylated *in vitro* and *in vivo* by glycogen synthase kinase-3 $\beta$  (GSK-3 $\beta$ ). This reagent is commercially available.

PSSA Tau specificity is shown in figure 1. Cell extracts from African green monkey kidney (CV-1) cells, stably expressing human four repeat tau and a protein phosphatase inhibitor, were resolved by SDS-PAGE on a 10% Tris-glycine gel. The proteins were transferred to nitrocellulose. Membranes were incubated with 0.50  $\mu$ g/mL anti-phosphoTau [pS<sup>199</sup>], following prior incubation in the absence (a) or presence of the peptide immunogen (b), or the non-phosphopeptide corresponding to the tau phosphopeptide (c). After washing, membranes were incubated with goat F(ab')<sub>2</sub> anti-rabbit IgG alkaline phosphatase and

5 bands were detected using the Tropix WesternStar™ detection method. The data in Figure 1 show that only the phosphopeptide corresponding to this site blocks the antibody signal, illustrating the specificity of the anti-tau [pS<sup>199</sup>] antibody for this phosphorylation site.

10 Tau [pS<sup>214</sup>] PSSA. The procedures for generating this antibody were similar to those described above for the Tau pS<sup>199</sup> PSSA. The chemically synthesized phosphopeptide was derived from the region of the longest isoform of Tau protein that includes serine 214 (GSRSRTP(pS)LPTPP) sequence ID#2. This antibody recognizes specifically the Tau protein when phosphorylated on serine 214, as demonstrated by peptide competition analysis in a western blotting assay. Serine 214 is phosphorylated *in vitro* and *in vivo* by  
15 cAMP-dependent protein kinase (PKA). This reagent is commercially available Biosource International.

Tau pS<sup>214</sup> PSSA specificity is show in Figure 2. SF-9 cell extracts, expressing human four repeat tau, were resolved by SDS PAGE on a 10% Tris-glycine gel. The proteins were  
20 transferred to nitrocellulose. Membranes were incubated with 0.50 µg/mL anti-phospho tau [pS<sup>214</sup>], following prior incubation in the absence (a) or presence of the peptide immunogen (b), or the non-phosphopeptide corresponding to the tau phosphopeptide (c). After washing, membranes were incubated with goat F(ab')<sub>2</sub> anti-rabbit IgG alkaline phosphatase and bands were detected using the Tropix WesternStar™ detection method. The data in Figure 2  
25 show that only the phosphopeptide corresponding to this site blocks the antibody signal, illustrating the specificity of the anti-Tau [pS<sup>214</sup>] antibody for this phosphorylation site. PSSAs to other Tau sites [pS<sup>202</sup>, pS<sup>396</sup>, pT<sup>181</sup>, pS<sup>199</sup>/pS<sup>202</sup>, pS<sup>404</sup>] are characterized using similar methods.

### 30 Pan-Tau polyclonal Antibody

Rabbits were immunized with the recombinant Tau protein. The antibody was purified from the rabbit serum using a protein-A affinity column. This antibody recognizes multiple antigenic sites on Tau protein. This antibody will bind to both non-phosphorylated and phosphorylated forms of Tau protein.

35

### Tau-5 monoclonal Antibody (mAb)

5           The mouse mAb to Tau was raised using purified bovine microtubule-associated proteins (MAPs) as the immunogen. The resulting hybridoma was produced by fusing immunized BALB/c mouse splenocytes and mouse myeloma Sp2/0-Ag14 cells. It shows no cross-reaction with other MAPs or tubulin. It reacts with the non-phosphorylated as well as the phosphorylated forms of Tau and the reactive epitope maps to residues 210-230. This reagent is commercially available from Biosource International.

#### Total Tau ELISA and Phospho-Tau ELISA

A concentration of 2.5  $\mu\text{g/mL}$  of Tau-5 monoclonal antibody in carbonate buffer, pH 9.4, was incubated at 100  $\mu\text{L/well}$  in microtiter plates at 4°C overnight. The wells were washed with a PBS/Tween-20 solution three times followed by blocking on other sites on the plastic surface with a buffered solution containing unrelated proteins such as BSA for 2 hours at room temperature. GSK-3 $\beta$  phosphorylated Tau, PKA phosphorylated Tau, and non-phosphorylated Tau were added to the wells at various concentrations and incubated for 1 hour at room temperature. After three washings with Washing Buffer, the wells were incubated respectively with Tau pS<sup>214</sup> PSSA, Tau pS<sup>199</sup> PSSA and Pan-Tau antibodies at the optimized concentrations (ranging from 0.1 to 1  $\mu\text{g/mL}$ ) for 1 hour at room temperature. The plates then were washed three times with Washing Buffer, followed by the addition of an HRP conjugated anti-rabbit IgG secondary antibody at 1:5000 dilution for 1 hour at room temperature. After washing, 100  $\mu\text{L}$  of Stabilized Chromogen was added to each well and then incubated for 20 minutes at room temperature in the dark. The O.D. values at 450 nm were measured following the addition of stop solution to each well.

#### Kinase Reactions

Phosphorylation of Tau using PKA occurred as follows. PKA was purchased from New England Biolabs. Recombinant Tau protein (1  $\mu\text{g}$ ) was incubated with various concentrations of PKA enzyme in buffer containing 50 mM Tris-HCl (pH 7.5), 10 mM MgCl<sub>2</sub> and 100  $\mu\text{M}$  ATP for 1 hour at 30°C.

#### Phosphorylation of Tau using GSK-3 $\beta$

GSK-3 $\beta$  was purchased from Upstate Biotechnology Inc. Recombinant Tau protein (1  $\mu\text{g}$ ) was incubated with various concentrations of the enzyme in buffer containing 40 mM

5 HEPES (pH 7.2), 5 mM MgCl<sub>2</sub>, 5 mM EDTA, 100 μM ATP, and 50 μg/mL heparin for 1 hour at 30°C.

10 Figures 3a and 3b show the assessment of total Tau and selective Tau phosphorylation at the PKA/ Ser<sup>214</sup> site by ELISA. In figure 3a, phosphorylated Tau was placed into an ELISA with detection either by PSSA specific for Tau pS<sup>214</sup> or by pan-Tau antibody. Both detection antibodies detected the phosphorylated Tau with equal signals. In figure 3b, non-phosphorylated Tau was placed into the same assay. As expected, the Tau pS<sup>214</sup> failed to detect the Tau protein without the phosphate group whereas the pan-Tau detector did quantitate the protein

15 Figures 4a and 4b show the assessment of total Tau and selective Tau phosphorylation at the GSK-3β/ Ser<sup>199/202</sup> sites by ELISA. Figure 4a uses either non-phosphorylated Tau or GSK-3β- phosphorylated Tau in the ELISA with a detector of Tau pS<sup>199/202</sup>. Non-phosphorylated Tau does not react positively in the ELISA whereas the phosphorylated Tau shows strong results. If pan-Tau is used as the detector, both proteins are readily detected (figure 4b).

25 Figure 5 shows the direct relationship between the amount of phosphoTau detected by ELISA as a relationship of the quantity of kinase activity added to the *in vitro* reaction. Various amounts of PKA enzyme were used to phosphorylate the Tau protein. Starting with the highest concentration of PKA, 5 units, (PKA tau 1), the PKA enzyme was then serially diluted 1:2 as shown, followed by a 1:1000 dilution and then applied to each well of the ELISA assay. Detection of phosphoTau was performed using a PSSA to Tau that is phosphorylated at Ser<sup>214</sup> (a PKA site). These data indicate that the lower the amount of kinase in the reaction, the lower the amount of phosphoprotein produced is detected in the ELISA. Thus, the ELISA is indirectly a measure of phosphokinase activity.

35 Figures 6a and 6b shows the specificity in detecting Tau protein phosphorylation catalyzed by PKA vs. GSK3β enzymes using the Tau PSSAs and ELISA. The results demonstrate that the Tau pS<sup>214</sup> PSSA ELISA only detects Tau when phosphorylated by PKA and the Tau pS<sup>199</sup> PSSA ELISA only detects Tau when phosphorylated by GSK3β.

5

Figure 7 shows that GSK3 $\beta$  enzyme can phosphorylate multiple sites on Tau protein and PSSAs can independently detect the phosphorylated sites at Tau pT<sup>181</sup>, Tau pS<sup>202</sup>, Tau pS<sup>199</sup>/pS<sup>202</sup>, Tau pS<sup>396</sup>, and Tau pS<sup>404</sup>. This provides evidence that the ELISA is useful in creating a profile of phosphorylation events on the protein subjected to kinase enzyme activity.

10

Figure 8 shows the specificity of kinase reaction when tested as a profile with two antibodies, one specific for a PKA phosphorylation site (pS<sup>214</sup>) and the other for a GSK site (pS<sup>199</sup>) on Tau protein. A PKA-specific inhibitor, PKI (heat-stable inhibitor of c-AMP-dependent protein kinase; New England Biolab), was mixed at various ratios of inhibitor to enzyme (either PKA or GSK) and the resultant mixture analyzed by ELISA using the Tau PSSAs. The PKA-specific inhibitor altered the kinase activity of the pS<sup>214</sup> site alone. These data again attest to the specificity of the ELISA and the ability to independently monitor kinase activities on the same protein at different sites. These data also show the capability of screening for drug interference of kinase activity.

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Antibodies to other tau sites shown in Table II are also representative of the invention. Som of the phosphorylated sites are known to be associated with disease as further indicated in Table II.

TABLE II

Phospho Site	Disease Linked (Y/N/?)	Notes (NGD = Neurodegenerative disease; FTD = )
T39	?	Phosphorylated by Casein kinase II
T181, hu	?	Involved in pretangle process?
S184	Y	Phosphorylated by GSK-3b; disrupts microtubule network
S195	Y	Phosphorylated by GSK-3b; disrupts microtubule network
S198	Y	Phosphorylated by GSK-3b; disrupts microtubule network
S199	Y	Phosphorylated by GSK-3b; linked to hereditary FTD
S202	Y	Microtubule-dependent phosphorylation by CDK 5 and GSK-3b; linked to hereditary NGD
T205	?	Microtubule-dependent phosphorylation by CDK 5 and GSK-3b
T212	Y	Specific for NGD processes; phosphorylated by GSK-3b and PKA
S214	Y	Specific for NGD processes; may block aggregation; phos'd by PKA
2T17	?	
T231	Y	Involved in pretangle process?; phos'd by GSK-3b and cdc2/CDK1
S235	?	Microtubule-independent phosphorylation by GSK-3b
S262	Y	May block aggregation; phosphorylated by CAM K II and GSK-3b; major site in AD brain
S320	?	
S324	?	
S356	Y	Involved in pretangle process?; AD pathway; major site in AD brain; phosphorylated by GSK-3b
S361	?	
S396	N	Phos'd by GSK-3b
S400	?	Phos'd by GSK-3b
T403	?	
S404	?	Involved in pretangle process?; microtubule-independent phosphorylation; phosphorylated by GSK-3b
S409	Y	AD pathway; phosphorylated by PKA
S412	?	AD pathway
S413	Y	AD pathway; phosphorylated by GSK-3b
S416	?	Phosphorylated by CAM K II
S422	Y	Linked with several NGD's; phosphorylated by MAPK

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**Rb System:** This model system presents an intra-nuclear protein that is large with multiple phosphorylation sites acted upon by multiple protein kinases. Phosphoserine and phosphotyrosine residues exist. Both mono-phospho and dual-phosphoresidues are distinguishable in this model system.

15

5 Rb protein: Full length Rb protein is purified recombinant protein derived through cloning of human Rb cDNA and expressed in *E. coli*. The protein is purified via standard methods. This protein is commercially available from multiple vendors.

10 Rb [pT<sup>821</sup>] PSSA: The rabbit antiserum was produced against a chemically synthesized phosphopeptide derived from a region of human Rb that contains threonine 821. Antibody was purified from rabbit serum by sequential epitope-specific chromatography. The antibody has been negatively preadsorbed using a non-phosphopeptide corresponding to the site of phosphorylation to remove antibody that is reactive with non-phosphorylated pRb. The final product is generated by affinity chromatography using a pRb-derived peptide that  
15 is phosphorylated at threonine 821. Figure 9 defines the specificity of the anti-Rb [pT<sup>821</sup>]. SDS-PAGE on a 7.5% Tris-glycine gel resolved cell extracts, prepared from MCF-7 cells. The proteins were then transferred to PVDF. Membranes were incubated with 0.5 µg/mL anti-RB [pT<sup>821</sup>], following prior incubation in the absence (a) or presence of the peptide immunogen (b), the non-phosphopeptide corresponding to the RB phosphopeptide (c), the  
20 phosphopeptides corresponding to threonine 356 (d), serine 807/811 (e), serine 249/threonine 252 (f), and serine 751 (g) on phospho-RB. After washing, membranes were incubated with goat F(ab')<sub>2</sub> anti-rabbit IgG alkaline phosphatase and bands were detected using the Tropix WesternStar™ detection method. The data show that only the phosphopeptide corresponding to this site blocks the antibody signal, therefore  
25 demonstrating the specificity of the anti-Rb [pT<sup>821</sup>] antibody for this phosphorylated residue.

Total Rb [pan] Detection Antibody: the detection antibody is a monoclonal, clone G3-245, available commercially from BD/Pharmingen (San Diego, CA). It recognizes an epitope  
30 between amino acids 332-344 of Rb protein. This antibody will bind to both non-phosphorylated and phosphorylated forms of Rb protein.

Rb monoclonal antibody: the capture antibody [linked to the solid phase] is a monoclonal, clone 3C8, available commercially from QED Biosciences (San Diego, CA). It reacts with  
35 epitope on near the C-terminal end of the Rb protein (aa886-aa905). This antibody will bind to both non-phosphorylated and phosphorylated forms of Rb protein.

5

Total Rb and Rb [pT<sup>821</sup>] ELISA: A concentration of 1.25 µg/mL of Rb monoclonal antibody in carbonate buffer, pH 9.4, was incubated at 100 µL/well in microtiter plates at 4°C overnight. The wells were washed with a PBS/Tween-20 solution three times followed by blocking on other sites on the plastic surface with a buffered solution containing unrelated proteins such as BSA for 2 hours at room temperature. Jurkat cell lysate containing phosphorylated Rb or non-phosphorylated recombinant Rb were added to the wells at various concentrations and incubated for 2 hour at room temperature. After three washings with Washing Buffer, the wells were incubated, respectively, with Rb [pT<sup>821</sup>] PSSA and biotinylated Pan-Rb antibodies at the optimized concentrations (ranging from 0.1 to 1 µg/mL) for 1 hour at room temperature. The plates then were washed three times with Washing Buffer, followed by the addition of an HRP conjugated anti-rabbit IgG secondary antibody at 1:5000 dilution or 0.25 µg/mL of streptavidin-HRP for 1 hour at room temperature. After washing, 100 µL of Stabilized Chromogen was added to each well and then incubated for 20 minutes at room temperature in the dark. The OD values at 450 nm were measured following the addition of stop solution to each well.

Figure 10 shows studies to determine the specificity of the Rb [pT<sup>821</sup>] ELISA. In the first study, solutions containing Rb protein at a concentration of 20 ng/mL from Jurkat, U2OS, and Colo205 were analyzed with the Rb [pT<sup>821</sup>] ELISA kit, along with a solution containing 20 ng/mL purified full length Rb protein expressed in *E. coli* (non-phosphorylated). Figure 11 shows that the Rb protein isolated from the cell lines was strongly recognized. These data provide evidence that appropriate phosphorylation of the Rb protein is requisite for reactivity in this assay.

In the second study, specificity for threonine 821 was determined by peptide competition. The data presented in Figure 11 show that only the peptide corresponding to the region surrounding threonine 821, containing the phospho-threonine, could block the ELISA signal.

Kinase reactions for Rb: Natural sources for Rb were obtained for these studies from exponentially growing cells. Endogenous cellular kinases provided the phosphorylation of the natural Rb protein. Figure 12 shows the application of this ELISA to study kinase

5 reactions. Jurkat cells were grown in the presence of the kinase inhibitor, staurosporine, at various concentrations for 36 hours prior to lysis. Lysates were normalized for total Rb content using the BioSource Total Rb ELISA (catalog #KHO0011). Levels of Rb phosphorylation at threonine 821 were determined. These data show that staurosporine inhibits the phosphorylation of Rb at threonine 821, possibly through the inhibition of cdk.

10

**EGFR System:** This model system presents a cell surface receptor protein. This protein is large with multiple phosphorylation sites consisting of phospho-threonine, phospho-serine and phospho-tyrosine residues.

15 **EGFR protein:** Human EGFR protein was purified from human carcinoma A431 cells by affinity purification. The product is purchased from Sigma (St. Louis, MO cat # E-2645).

**EGFR [pY<sup>1173</sup>] PSSA:** Rabbit antiserum was produced against a chemically synthesized phosphopeptide derived from the region of EGFR that contains tyrosine 1173. The sequence is conserved in human, mouse, and rat. Antibody was purified from serum by sequential epitope-specific chromatography. The antibody has been negatively preadsorbed using (i) a non-phosphopeptide corresponding to the site of phosphorylation to remove antibody that is reactive with non-phosphorylated EGFR enzyme, and (ii) a generic tyrosine phosphorylated peptide to remove antibody that is reactive with phospho-tyrosine (irrespective of the sequence). The final product is generated by affinity chromatography using an EGFR-derived peptide that is phosphorylated at tyrosine 1173. Figure 13 illustrates the specificity of the EGFR PSSA [pY<sup>1173</sup>]. Cell extracts prepared from NIH3T3 cells expressing EGFR were starved for 30 hours, then stimulated for 10 minutes with 30 ng/mL EGF (+), or left unstimulated (-), then resolved by SDS-PAGE on a 6% Tris-glycine gel, and transferred to nitrocellulose. Membranes were incubated with 0.50 µg/mL anti-EGFR [pY<sup>1173</sup>] antibody, following prior incubation in the absence (lanes 1 & 2), or presence of the peptide immunogen (lanes 3 & 4), or the non-phosphopeptide corresponding to the EGFR phosphopeptide (lanes 5 & 6). After washing, membranes were incubated with goat F(ab')<sub>2</sub> anti-rabbit IgG alkaline phosphatase and bands were detected using the Tropix WesternStar™ detection method. The data show that only the phosphopeptide

35

5 corresponding to this site blocks the antibody signal, demonstrating the specificity of the anti-EGFR [pY<sup>1173</sup>] antibody for this phosphorylated residue.

EGFR [pY<sup>845</sup>] PSSA: Prepared essentially as EGFR [pY<sup>1173</sup>] PSSA but using chemically synthesized phosphopeptides from the region that contains tyrosine 845.

10

EGFR [Pan] monoclonal antibody: The capture antibody is a mouse monoclonal antibody, clone 199.12, available commercially from Neomarkers, Inc. (Union City, CA). It is specific for human EGFR and does not react with HER2/neu, HER3 and HER4. This antibody will bind to both non-phosphorylated and phosphorylated forms of EGFR protein.

15

EGFR [Pan] Detection Antibody: This rabbit antibody was prepared by immunization with a synthetic peptide corresponding to C-terminus of human EGFR. The antibody was purified using protein A affinity column. It shows no cross-reactivity with HER2/neu, HER3 and HER4.

20

EGFR PSSA and Full Length ELISA: A concentration of 2.5 µg/mL of pan-EGFR monoclonal antibody in carbonate buffer, pH 9.4, was incubated at 100 µL/well in microtiter plates at 4°C overnight. The wells were washed with a PBS/Tween-20 solution three times followed by blocking on other sites on the plastic surface with a buffered solution containing unrelated proteins such as BSA for 2 hours at room temperature. Autophosphorylated EGFR or non-phosphorylated EGFR were added to the wells at various concentrations and incubated for 1 hour at room temperature. After three washings with Washing Buffer, the wells were incubated, respectively, with EGFR [pY<sup>845</sup>] PSSA, EGFR [pY<sup>1173</sup>] PSSA, and Pan-EGFR antibodies at the optimized concentrations (ranging from 0.1 to 1 µg/mL) for 1 hour at room temperature. The plates then were washed three times with Washing Buffer, followed by the addition of an HRP conjugated anti-rabbit IgG secondary antibody at 1:2000 dilution for 1 hour at room temperature. After washing, 100 µL of Stabilized Chromogen was added to each well and then incubated for 20 minutes at room temperature in the dark. The OD values at 450 nm were measured following the addition of stop solution to each well.

35

5 The specificity of the EGFR [pY<sup>1173</sup>] ELISA for tyrosine residue 1173 was determined by peptide competition. The data presented in Figure 14 show that only the peptide corresponding to the region surrounding tyrosine residue 1173, containing the phospho-threonine, could block the ELISA

10 Kinase Reactions: (autophosphorylation)

EGFR was incubated (auto-phosphorylated) in the buffer of 15 mM HEPES (pH7.4), 6 mM MnCl<sub>2</sub> and 15 mM MgCl<sub>2</sub> containing 1uM ATP for 30 minutes at 30oC.

15 Figure 15 demonstrates the response curve of phosphorylation of EGFR in A431 cells after treatment with EGF at 1-500 ng/mL for 10 minutes. The phosphorylation of EGFR tyrosine was detected with EGFR [pY<sup>1173</sup>] ELISA.

20 Figure 16 demonstrates use of the described invention to detect protein kinase activity associated with EGFR at residue pY845 and inhibition of that activity by a protein kinase inhibitor. 2 ng/ vial of purified human EGFR was incubated (auto-phosphorylated) in the buffer of 15 mM HEPES (pH7.4), 6 mM MnCl<sub>2</sub> and 15 mM MgCl<sub>2</sub> containing 1uM ATP for 30 minutes at 30oC. For phosphorylation inhibition of EGFR [pY<sup>845</sup>], tyrosine kinase inhibitor PD158780 (Calbiochem, cat #. 513035) was added to the vials at indicated concentration. EGFR [pY<sup>845</sup>] phosphorylation was measured at 4ng/mL using EGFR  
25 [pY<sup>845</sup>] phosphorylation site specific ELISA.

5

Table 1: List signal transduction proteins the phosphorylation of which can be determined by methods of the present invention.

**TABLE 1**

10

Examples of Signal Transduction Proteins

**Protein**

15

**A**

alpha-actinin  
 alpha-synuclein  
 ABL/c-Abl (Abelson nonreceptor protein tyrosine kinase)  
 Acetylcholine Receptor  
 Ack nonreceptor protein tyrosine kinase;  
 Akt/PKB serine/threonine protein kinase  
 AP-1 (Activator protein-1 jun/fos dimeric transcription factors  
 AP-2 (Activator protein-2 transcription factor  
 Apaf-1 (Apoptosis protease-activating factor-1)  
 25 Apaf-2 (Apoptosis protease-activating factor-2/cytochrome C)  
 Apaf-3 (Apoptosis protease-activating factor-3/caspase-9  
 Arp2/3 (Actin related protein)  
 Atf-1 (Activating transcription factor-1)  
 Atf-2 (Activating transcription factor-2)  
 30 Atf-3 (Activating transcription factor-3)  
 Atf-4 (Activating transcription factor-4)  
 ATM (Ataxia Telangiectasia Mutated. Protein)

**B**

35 B-ATF nuclear basic leucine zipper protein/transcription factors  
 Bad  
 Bak  
 Bax  
 Bcl-2 (B-cell chronic lymphocytic leukemia 2)  
 40 Bcl-xL  
 Bcl-xS  
 BCR/ABL protein tyrosine kinase  
 beta-Catenin  
 BID (BH-3 Interacting Death Domain)  
 45 Blk (B Lymphocyte Src non-receptor protein tyrosine kinase family member)  
 BMK-1 (Big Map Kinase/ERK5)  
 Btk (Bruton's Tyrosine Kinase)

**C**

50 Cadherin  
 CADTK (calcium activated protein tyrosine kinase/Cakbeta/Pyk2/FAK2/RAFTK)  
 CAK (Cdk-Activating Kinase)  
 Cak-beta (Cell adhesion kinase beta/ CADTK/Pyk2/FAK2/RAFTK)  
 caldesmon  
 55 calmodulin  
 calpain cysteine proteases  
 CaM kinase II (Calmodulin-dependent protein kinase II)  
 CB1 (Cannabinoid Receptor 1)

- 5 CB2 (Cannabinoid Receptor 2)  
 caspase-2 (Cysteine Aspartyl Protease-2/ ICH-1/NEDD-2)  
 caspase-3 (Cysteine Aspartyl Protease-3/LICE/PPP32/YAMA/apopain/SCA-1)  
 caspase-8 (Cysteine Aspartyl Protease-8/MACH/FLICE/Mch5)  
 caspase-9 (Cysteine Aspartyl Protease-9/ICE-LAP6/Mch6/APAF-3)
- 10 Caveolin 1, 2, and 3)  
 CD45 transmembrane tyrosine phosphatase  
 CD45AP (CD45-associated protein)  
 c-fos transcription factor  
 CDK1/cdc2 (Cyclin-dependent kinase-1)
- 15 CDK2 (Cyclin dependent kinase-2)  
 CDK4 (Cyclin dependent kinase-4)  
 CDK5 (Cyclin dependent kinase-5)  
 c-Jun transcription factor  
 c-myc transcription factor
- 20 Cortactin  
 COX-2 (Cyclooxygenase-2/prostaglandin-endoperoxide synthase-2)  
 c-kit receptor protein  
 c-raf protein serine/threonine kinase  
 CREB transcription factor
- 25 Crk SH2 and SH3 domain-containing adaptor protein  
 CSK (Carboxyl-terminal Src Kinase)  
 cytochrome-c
- D**
- 30 DAPK (Death Associated Protein Kinase)  
 desmin  
 DNA-PK (DNA dependent protein kinase)
- E**
- 35 E2F-1 DNA binding protein  
 EGF-R (Epidermal Growth Factor Receptor)  
 eIF-2alpha (Eukaryotic translation Initiation Factor 2alpha)  
 ERK1/MAPK (Extracellular signal-Regulated/Mitogen-Activated Protein Kinase 1)
- 40 ERK2/MAPK (Extracellular signal-Regulated/Mitogen-Activated Protein Kinase 2)  
 ERK3 (Extracellular signal-Regulated/p62 Mitogen-Activated Protein Kinase 3)  
 ERK4 (Extracellular signal-Regulated Protein Kinase 4)  
 ERK5 (Extracellular signal-Regulated Protein Kinase 5/Big MAP Kinase 1)  
 ERK6 (Extracellular signal-Regulated Protein Kinase 6/p38gamma)
- 45 ERK7 (Extracellular signal-Regulated Protein Kinase 7)  
 ERK5 (Extracellular signal-Regulated Protein Kinase 8)
- F**
- F-actin
- 50 FADD (Fas-associated Death Domain)  
 FAK (Focal Adhesion Kinase/pp125FAK)  
 FAS (FAS-Ligand Receptor)  
 Fgr non-receptor Src family tyrosine kinase  
 Fos B
- 55 Fra-1 (Fos-related antigen-1)  
 Fra-2 (Fos-related Antigen-2)  
 FRK (Fos-Regulating Kinase)  
 FYB (Fyn binding protein)  
 Fyn non-receptor Src family tyrosine kinase
- 60

- 5    **G**  
 Gab 1 (Grb2-associated binder 1)  
 Gab 2 (Grb2-associated binder 2)  
 GCK (Germinal Center Kinase)  
 GEF (Guanine nucleotide Exchange Factor)  
 10    G $\alpha$  inhibitory guanine nucleotide regulatory protein  
 G $\beta$  inhibitory guanine nucleotide regulatory protein  
 G $\gamma$  inhibitory guanine nucleotide regulatory protein  
 Gq/11 guanine nucleotide-binding protein  
 Gq/11 $\beta$  guanine nucleotide-binding protein  
 15    Gq/11 $\gamma$  guanine nucleotide-binding protein  
 Grb2 (Growth factor Receptor Binding protein-2)  
 Grk2 (G protein-coupled Receptor Kinase)  
 GSK-3 $\alpha$  (Glycogen Synthase Kinase 3alpha)  
 GSK-3 $\beta$  (Glycogen Synthase Kinase 3beta)  
 20
- H**  
 Hck (Hematopoietic cell kinase)  
 HGF-R (Hepatocyte growth factor receptor)  
 Hrk (3-Hydroxy-3-methyl glutaryl-coenzyme A Reductase Kinase)  
 25
- I**  
 IkappaB alpha NFkB inhibitory protein  
 IkappaB beta NFkB inhibitory protein  
 IKKalpha (IkB kinase alpha)  
 30    IKKbeta (IkB kinase beta)  
 IKKgamma (IkB kinase gamma/NEMO)  
 IGF-1 receptor (Insulin-like growth factor-I receptor)  
 Insulin receptor  
 Integrins  
 35    Integrin-Associated Protein (IAP/CD47)  
 IRAK (Interleukin-1 Receptor-Associated Kinase)  
 IRK (Insulin Receptor Kinase)  
 IRS-1 (Insulin Receptor Substrate 1)  
 IRS-2 (Insulin Receptor Substrate 2)  
 40
- J**  
 JAB1 (Jun-Activation domain Binding protein 1)  
 JAK1 (Janus Activating Kinase 1)  
 JAK2 (Janus Activating Kinase 2)  
 45    JAK3 (Janus Activating Kinase 3)  
 JNK1/SAPK $\gamma$  (c-Jun amino-terminal kinase 1/Stress-Activated Protein Kinase  $\gamma$ )  
 JNK2/SAPK $\beta$  (c-Jun amino-terminal kinase 2/Stress-Activated Protein Kinase  $\beta$ )  
 JNK3/SAPK $\alpha$  (c-Jun amino-terminal kinase 3/Stress-Activated Protein Kinase  $\alpha$ )
- 50    **L**  
 LAT (Linker for Activation of T cells)  
 Lck non-receptor Src family protein tyrosine kinase  
 Lyn non-receptor Src family protein tyrosine kinase
- 55    **M**  
 MEF2c transcription factor  
 MEK1 (Mitogen-activated ERK-activating Kinase 1)  
 MEK2 (Mitogen-activated ERK-activating Kinase 2)  
 MEK3 (Mitogen-activated ERK-activating Kinase 3)  
 60    MEK4 (Mitogen-activated ERK-activating Kinase 4)

- 5 MEK5 (Mitogen-activated ERK-activating Kinase 5)  
 MEKK1 (MEK kinase 1)  
 Met (c-met/HGF-receptor)  
 MKP 1 (MAP Kinase Phosphatase 1)  
 MKP 2 (MAP Kinase Phosphatase 2)  
 10 MKP 3 (MAP Kinase Phosphatase 3)  
 MKP 4 (MAP Kinase Phosphatase 4)  
 MKP 5 (MAP Kinase Phosphatase 5)  
 MKP 6 (MAP Kinase Phosphatase 6)  
 MLCK (Myosin light chain kinase)  
 15 MuSK (Muscle specific serine/threonine kinase)  
 Myosin  
 MLCK PPase (Myosin Light Chain Kinase Phosphatase)

**N**

- 20 Beta-NAP (Beta-Neuron Adaptor Protein/AP-3)  
 NAT1/DAP-5 (Novel APOBEC-1 Target no.1/Death-Associated Protein-5)  
 NCK SH2 and SH3 domains-containing transforming protein  
 Nek2 (Nima-related Kinase2)  
 NFAT-1 (Nuclear Factor of Activated T-cells)  
 25 NfkapppaB (Nuclear Factor Kappa B transcription factor)  
 NIK (NFkappaB Inducing Kinase)  
 NTK (Nervous Tissue and T cell Kinase)

**P**

- 30 p130cas  
 p190RhoGAP GTPase  
 P2Y2 purinoceptor  
 p36 CAK assembly/activation factor  
 p38 (ERK6 MAPK/SAPK)  
 35 p38d (SAPK4)  
 p53 Tumor suppressor gene.  
 p58 IPK (Inhibitor of the interferon-induced double-stranded RNA-activated Protein Kinase, PKR)  
 p62dok GAP-associated protein  
 p62 lck ligand/ZIP  
 40 p68 kinase  
 p96  
 PAK1 (p21-Activated protein Kinase 1)  
 PAK2 (p21-Activated protein Kinase 2)  
 PAK3 (p21-Activated protein Kinase 3)  
 45 PARP (Poly(ADP-Ribose) Polymerase)  
 Paxillin  
 PCNA (Proliferating Cell Nuclear Antigen)  
 PDGF Receptor (Platelet Derived Growth Factor Receptor)  
 PDK1 (Phosphoinositide-Dependent Kinase-1)  
 50 PDK-2 (Phosphoinositide-Dependent Kinase-2/ Integrin-linked kinase)  
 PECAM-1 (Platelet-Endothelial Cell Adhesion Molecule-1)  
 PI3K (Phosphatidyl Inositol-3-Kinase)  
 PIAS (Protein Inhibitors of Activated STATs)  
 PITP alpha (Phosphatidylinositol Transfer Protein alpha)  
 55 PKA alpha/cAMP-dependent protein kinase  
 PKB (Protein kinase B)  
 PKC alpha (Protein Kinase C alpha)  
 PKC beta (Protein Kinase C beta)  
 PKC delta (Protein Kinase C delta)  
 60 PKC gamma (Protein Kinase C gamma)  
 PKD (Protein Kinase D)  
 PKR (Protein Kinase R or double-stranded RNA-activated protein kinase)

- 5 PLC-gamma1 (Phospholipase C-gamma1)  
 PRK (Proliferation Related Kinase)  
 PTEN (MMAC1 tumor suppressor gene/protein phosphatase)  
 Pyk2 (CAKbeta/FAK2/RAFTK) Protein tyrosine Kinase
- 10 **R**  
 Rac/cdc42 GTPase  
 Raf1 (C-raf) serine/threonine protein kinase  
 A-Raf serine/threonine protein kinase  
 B-raf serine/threonine kinase
- 15 V-Raf viral serine/threonine protein kinase  
 RAFTK (Related Adhesion Focal Tyrosine Kinase)  
 RAIDD (RIP-Associated ICH-1/CED-3 homologous protein with a Death Domain)  
 Rap2 GTPase  
 Rap1-GAP (C3G) inactivator of Rap-1
- 20 Rapsyn  
 Ras GTPase  
 Rb (Retinoblastoma tumor suppressor protein)  
 Rho Small molecular weight GTPase  
 RIP (Receptor Interacting Protein)
- 25 ROCK (Rho-activated kinase)
- S**  
 S6k (S6 Kinase)  
 Shc
- 30 SHIP (SH2 domain containing inositol phosphatase)  
 SH-PTP1 Protein Tyrosine Phosphatase  
 SH-PTP2 Protein Tyrosine Phosphatase  
 SIRPalpha1 (Signal Related Protein Alpha)  
 SIP1 (Smad Interacting Protein 1)
- 35 Smad2 (Sma and Mad-related 2)  
 Smad3 (Sma and Mad-related 3)  
 Smad5 (Sma and Mad-related 5)  
 Smad7 (Sma and Mad-related 7)  
 SOCS-1 (Suppressor of Cytokine Signaling-1)
- 40 SOCS-2 (Suppressor of Cytokine Signaling-2)  
 SOCS-3 (Suppressor of Cytokine Signaling-3)  
 SOS (Son of Sevenless)  
 Src non-receptor tyrosine kinase  
 SRF (Serum Response Factor)
- 45 SRPK1 (SR protein-specific Kinase1)  
 SRPK2 (SR protein-specific Kinase2)  
 STAT1alpha (Signal Transducer and Activator of Transcription 1)  
 STAT2 (Signal Transducer and Activator of Transcription 2)  
 STAT3 (Signal Transducer and Activator of Transcription 3)
- 50 STAT4 (Signal Transducer and Activator of Transcription 4)  
 STAT5alpha (Signal Transducer and Activator of Transcription 5alpha)  
 STAT5beta (Signal Transducer and Activator of Transcription 5 beta)  
 STAT6 (Signal Transducer and Activator of Transcription 6)  
 Syk (Spleen tyrosine kinase)
- 55 Syndecans transmembrane proteoglycan
- T**  
 Tak1 (TGF-b1 activated kinase)  
 Talin
- 60 TANK/I-TRAF (TNF Receptor Activating Factor)  
 Tau microtubule-associated protein  
 TBK-1/T2K (TANK Binding Kinase 1)

- 5 Tensin  
TNF-RI (Tumor Necrosis Factor Receptor I)  
TRADD (TNF-Receptor Associated Death Domain protein)  
TRAF1 (TNF-Receptor Associated Factor 1)  
TRAF2 (TNF-Receptor Associated Factor 2)  
10 TRAF3 (TNF-Receptor Associated Factor 3)  
TRAF4 (TNF-Receptor Associated Factor 4)  
TRAF5 (TNF-Receptor Associated Factor 5)  
TRAF6 (TNF-Receptor Associated Factor 6)
- 15 TrkA protein tyrosine receptor kinase A  
TrkB protein tyrosine receptor kinase B  
TrkC protein tyrosine receptor kinase C
- V**  
20 VEGF-receptor (vascular endothelial growth factor receptor, types 1, 2, 3)  
Vinculin
- W**  
25 WASP (Wiskott-Aldrich Syndrome Protein)
- Z**  
ZIP (Zeta Interacting Protein)  
ZIP kinase (zipper serine/threonine kinase)  
ZRP-1 (Zyxin Related Protein)  
30 Zyxin

Antibodies of the present invention are also useful for inactivating phosphorylated polypeptides for therapeutic purposes. The examples illustrate the present invention and are not intended to limit the invention in spirit or scope. Similarly, the description of these reagents and methods can be used in an inverse function to analyze the activity of protein specific phosphatases, enzymes that remove phosphate groups from specific amino acid residues.

5

What is claimed:

1. A method for measuring phosphokinase activity on a protein comprising:
  - 10 (a) subjecting a protein to a phosphokinase to phosphorylate a phosphorylation site on the protein
  - (b) providing an antibody specific to a phosphorylated phosphorylation site on the protein;
  - 15 (c) contacting the protein from (a) with the antibody of (b); and
  - (d) detecting the antibody bound to the phosphorylation site.
- 20 2. A method according to claim 1 wherein the protein is the Tau protein.
- 25 3. A method according to claim 2 wherein the phosphokinase is GSK-3 $\beta$ , PKA, PKC, CDK-5, MARK, JNK, p38MAPK, or casein kinase II.
- 30 4. The method according to claim 2 wherein the antibody is specific to a phosphorylated site at a specific location in the Tau protein, selected from the sites shown in Table II.
- 35 5. A method according to claim 1 wherein the protein is selected from the proteins in Table 1.
- 40 6. The method of claim 1 wherein the protein is EGFR.
7. The method of claim 1 wherein the protein is Rb.
8. An antibody prepared from a polypeptide immunogen having a phosphorylated serine.
- 45 9. An antibody raised to a polypeptide immunogen having a phosphorylated threonine.
10. An antibody raised to a polypeptide immunogen having a phosphorylated tyrosine.
- 50 11. An antibody specific for sequence ID #1.
12. An antibody specific for sequence ID #2.

5

13. An antibody to EGFR phosphorylated tyrosine 1173 or tyrosine 845 site.

14. An antibody to phosphorylated threonine 821 site.

10

15. A kit for the measurement of phosphokinase activity on a protein comprising

- (a) a first pan antibody specific and that binds to both phosphorylated and non-phosphorylated forms of the protein ;
- (b) a second pan antibody that binds to an independent site on the protein from the first pan antibody, wherein the second pan antibody is labeled;
- (c) non-phosphorylated and phosphorylated protein standards;
- (d) a phosphorylation site-specific antibody (PSSA) which binds to the protein only when the target site on the protein is phosphorylated and wherein the PSSA antibody is labeled; and
- (e) buffers.

15

20

16. A kit according to claim 11 where the protein is Tau.

25

17. A kit according to claim 11 where the protein is selected from the proteins listed in Table I.

30

18. A kit for the measurement of different kinase activities on a protein by quantitating phosphorylation site profiles comprising:

- (a) a first pan antibody that binds to both phosphorylated and non-phosphorylated forms of the protein;
- (b) a second pan antibody that binds to an independent site on the protein from the first pan antibody and wherein the second pan antibody is labeled;
- (c) protein standards for the non-phosphorylated and phosphorylated forms of the protein;
- (d) two or more PSSAs which bind to the protein only when the target sites on the protein which are phosphorylated wherein antibody is labeled so as to be ; and
- (e) buffers.

35

40

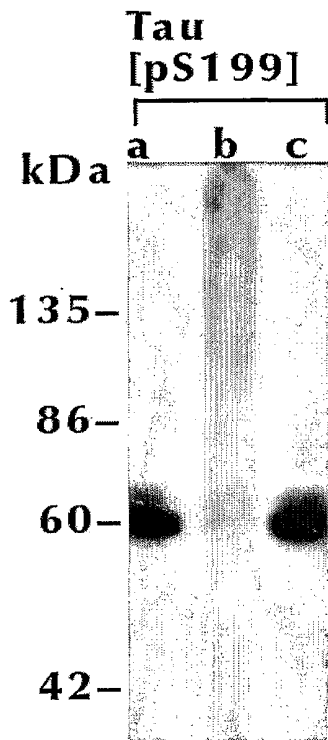
19. A kit according to claim 14 where the protein is Tau.

45

20. A kit according to claim 14 where the proteins are as defined in Table I.

50

Figure 1



Tau pS214



FIGURE 2

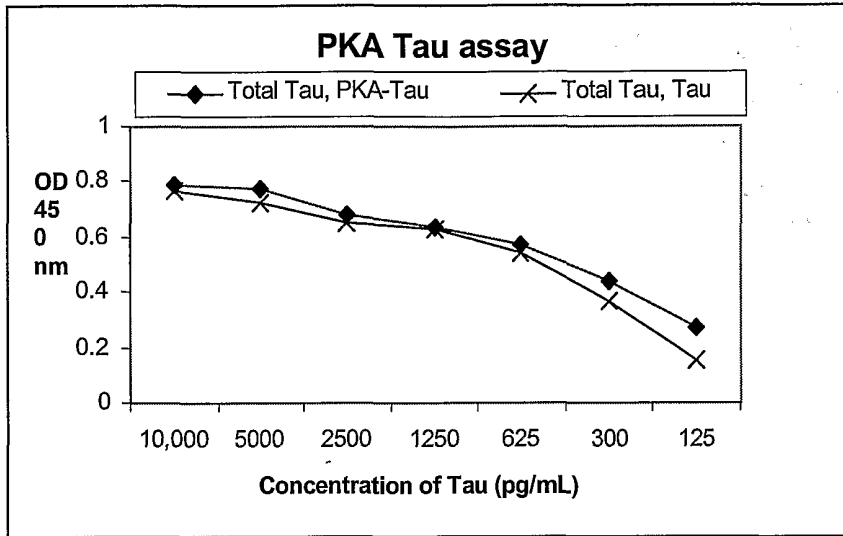


FIGURE 3a

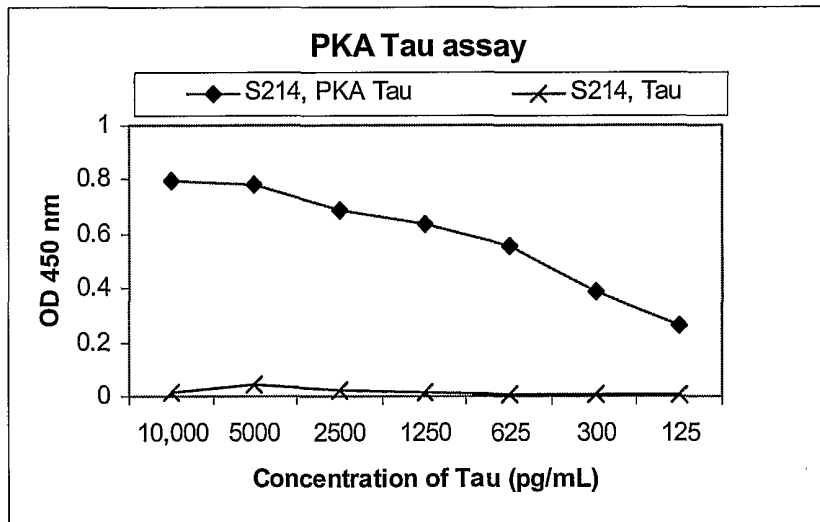


FIGURE 3b

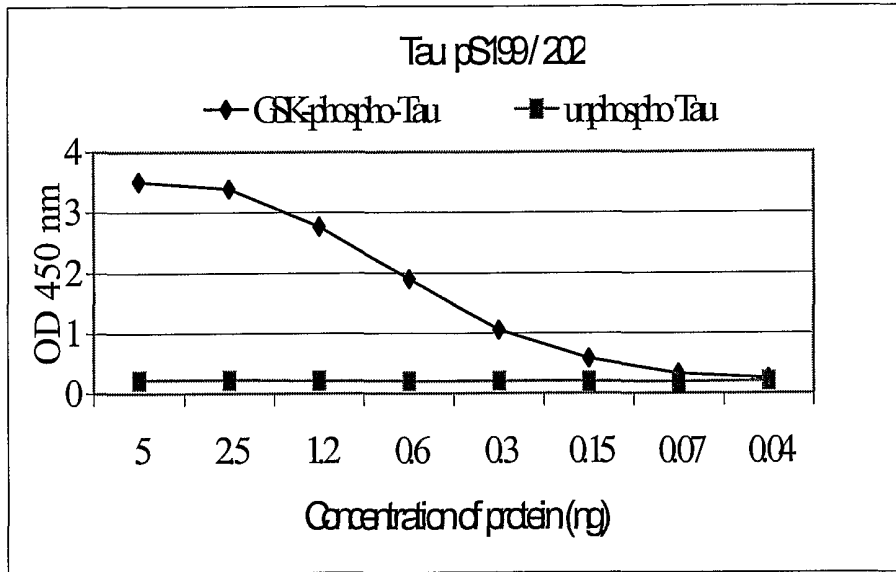


Figure 4a

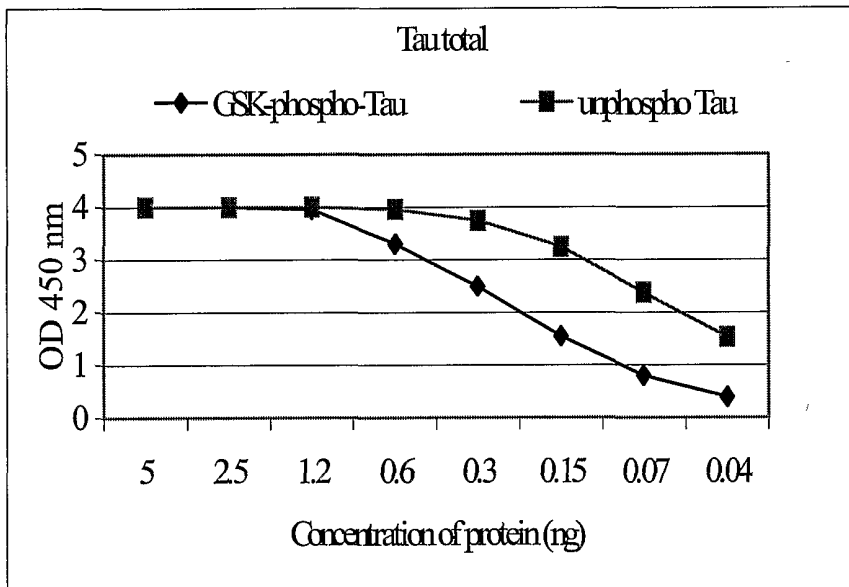


Figure 4b

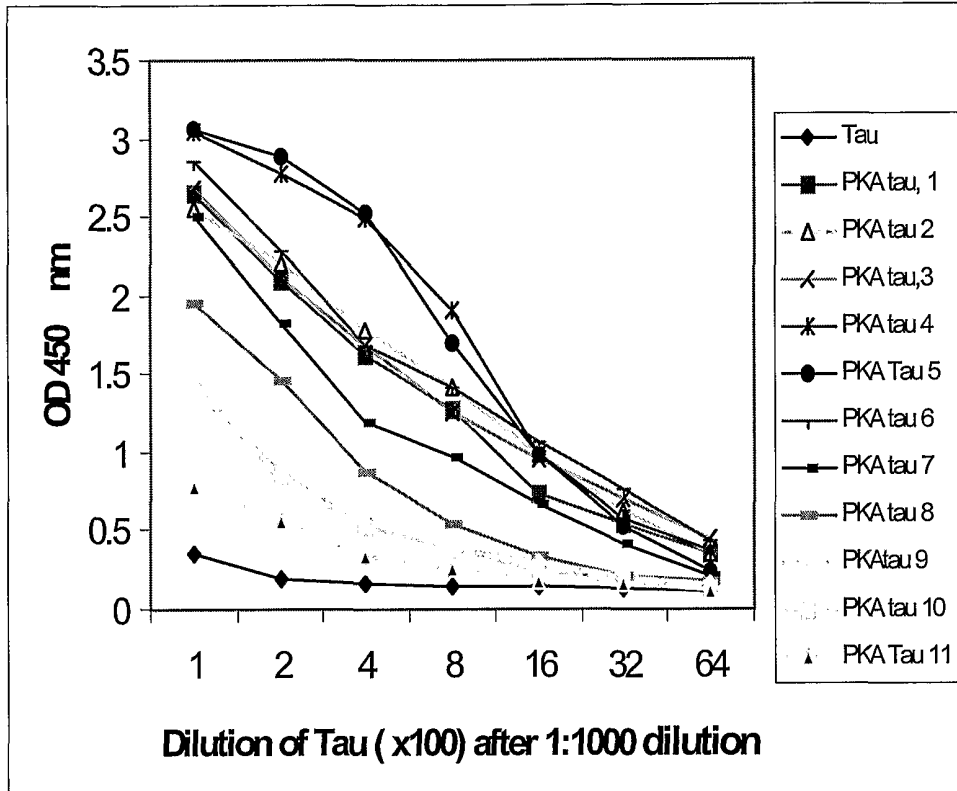


Figure 5

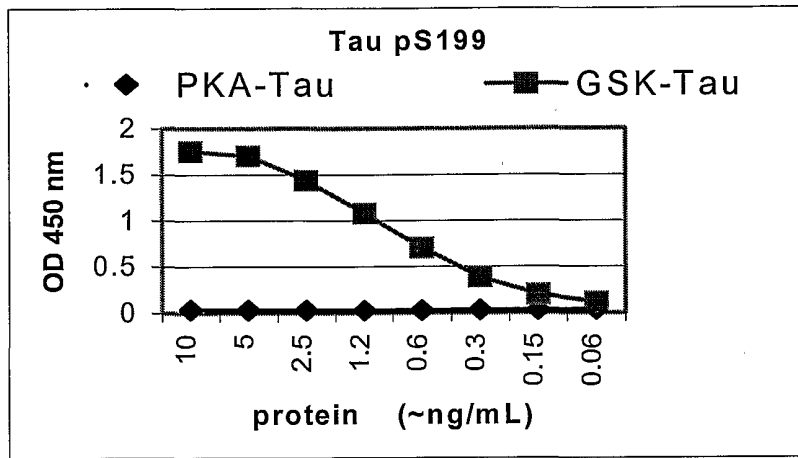


Figure 6a

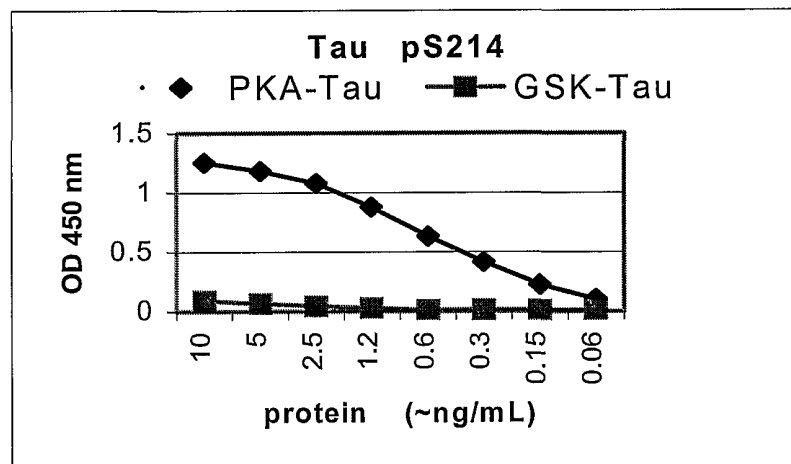


Figure 6b

Figure 7

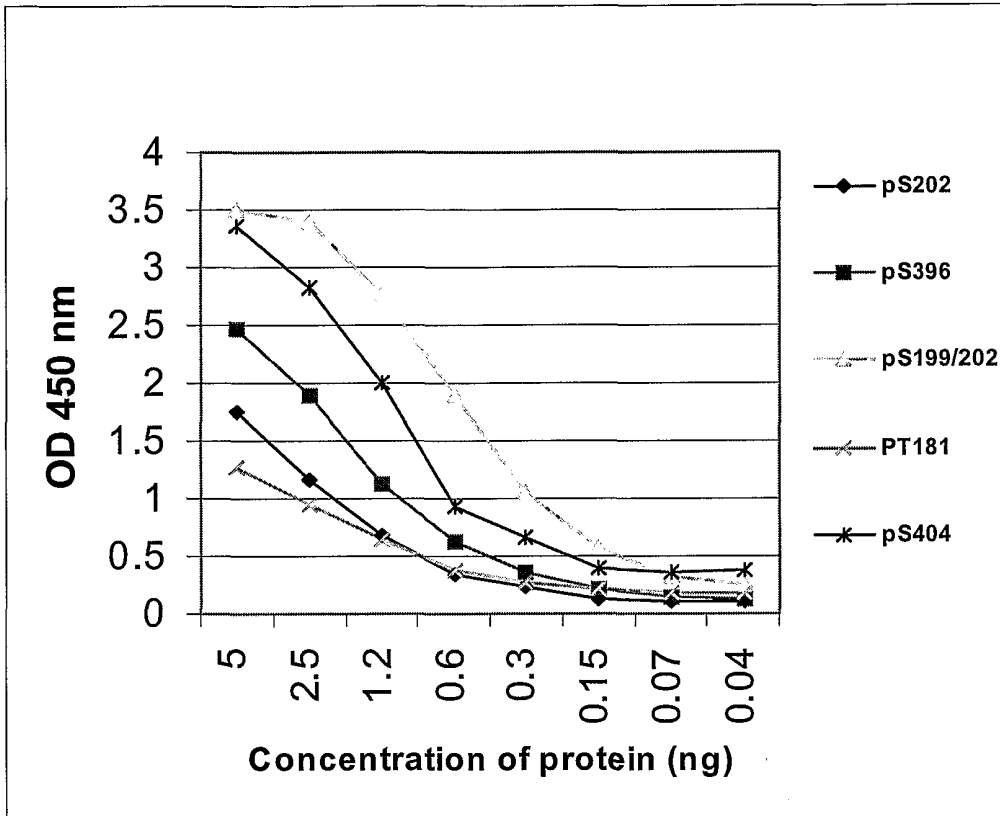


Figure 8

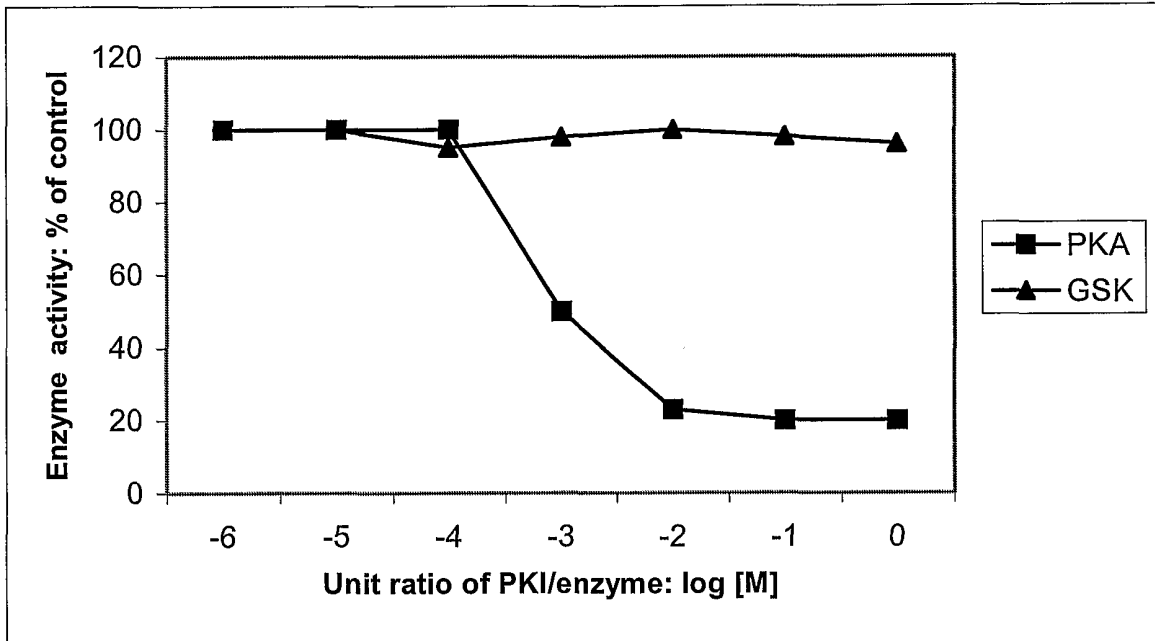


Figure 9

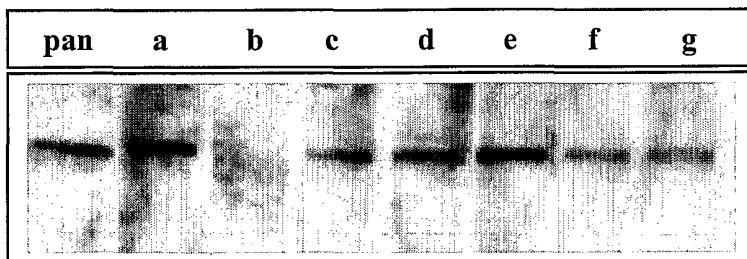


Figure 10

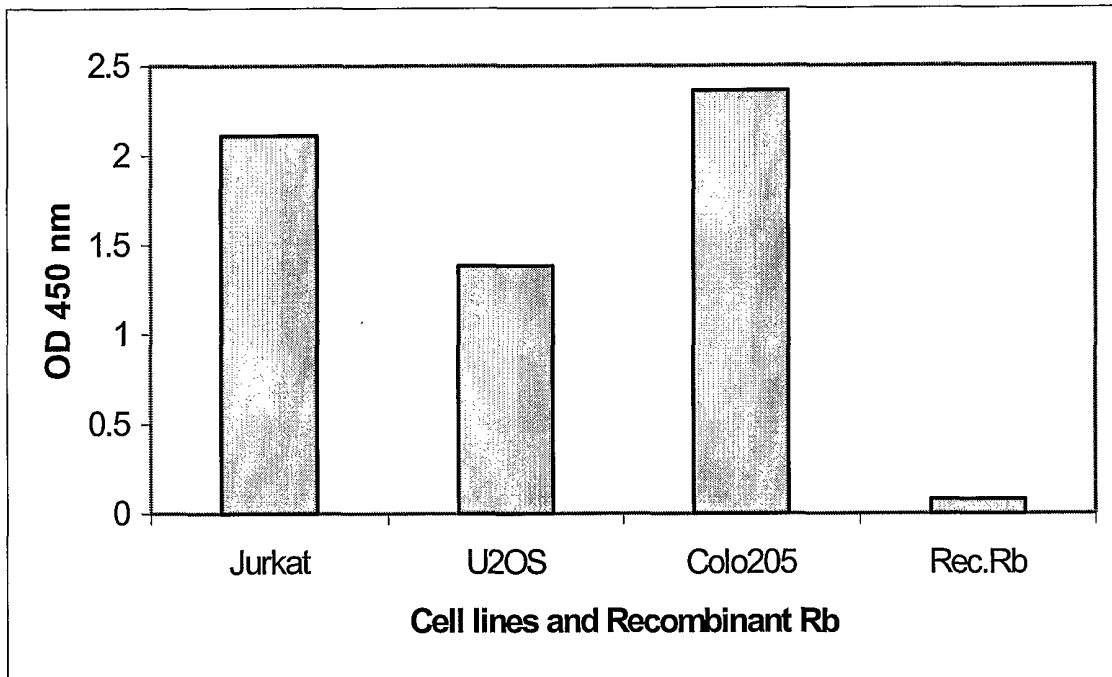


Figure 11

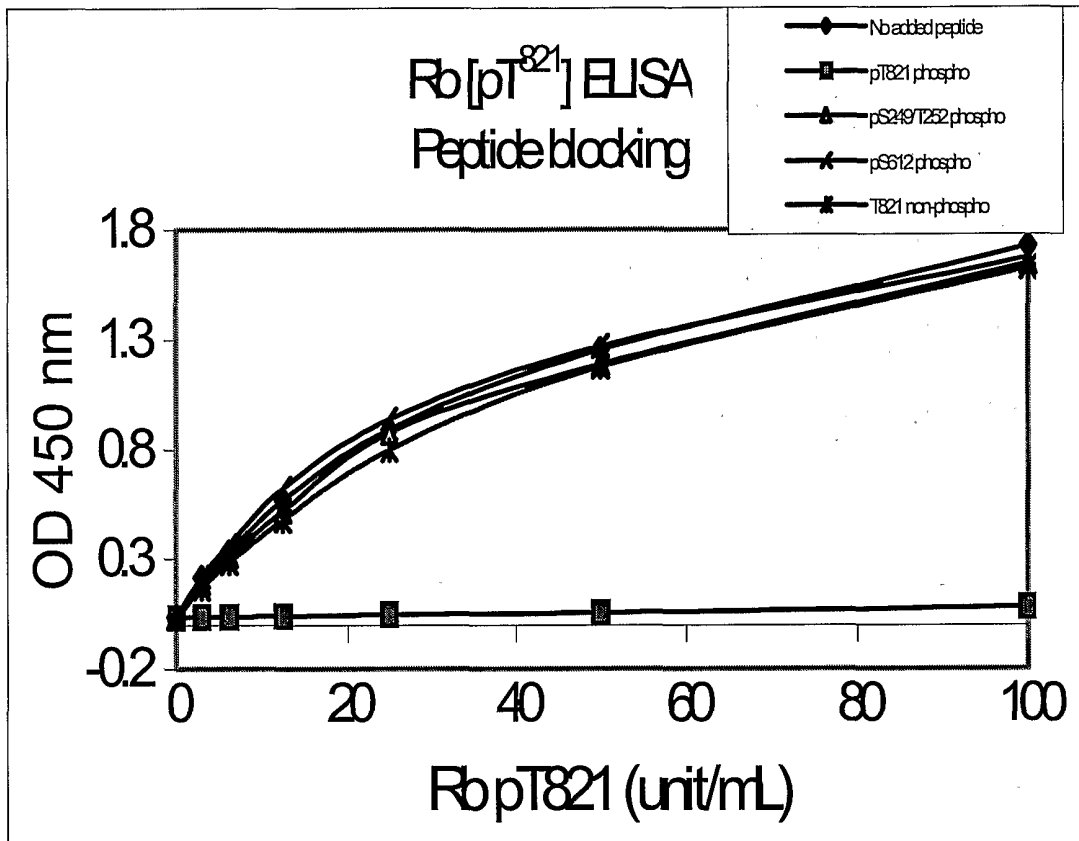


Figure 12

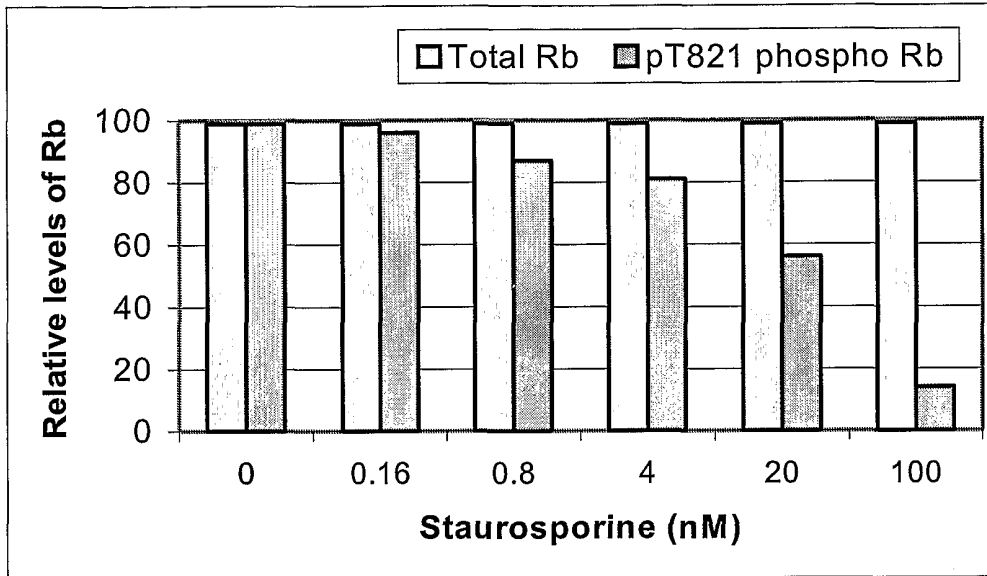
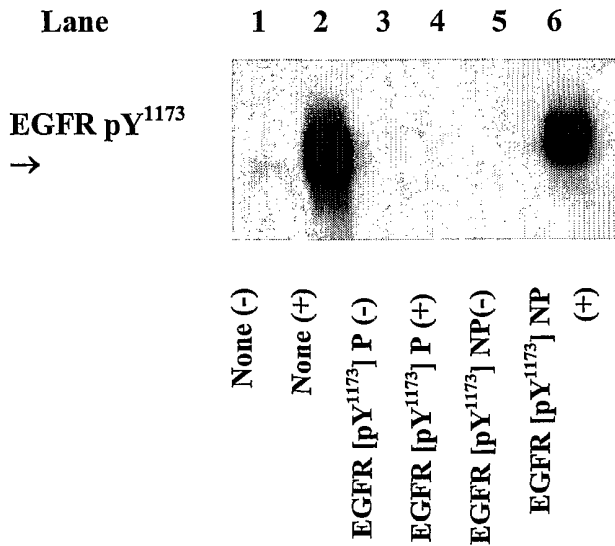


Figure 13



Peptide Used in Competition

Figure 14

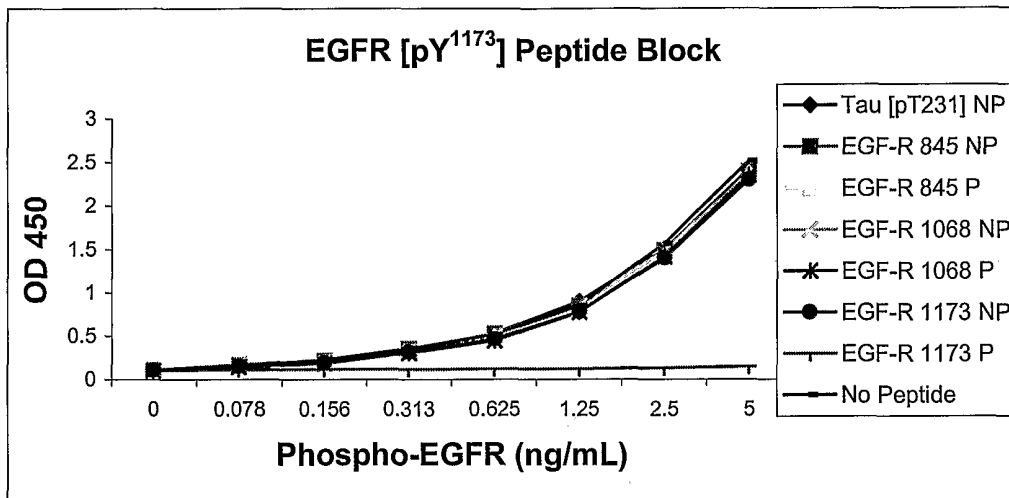


Figure 15

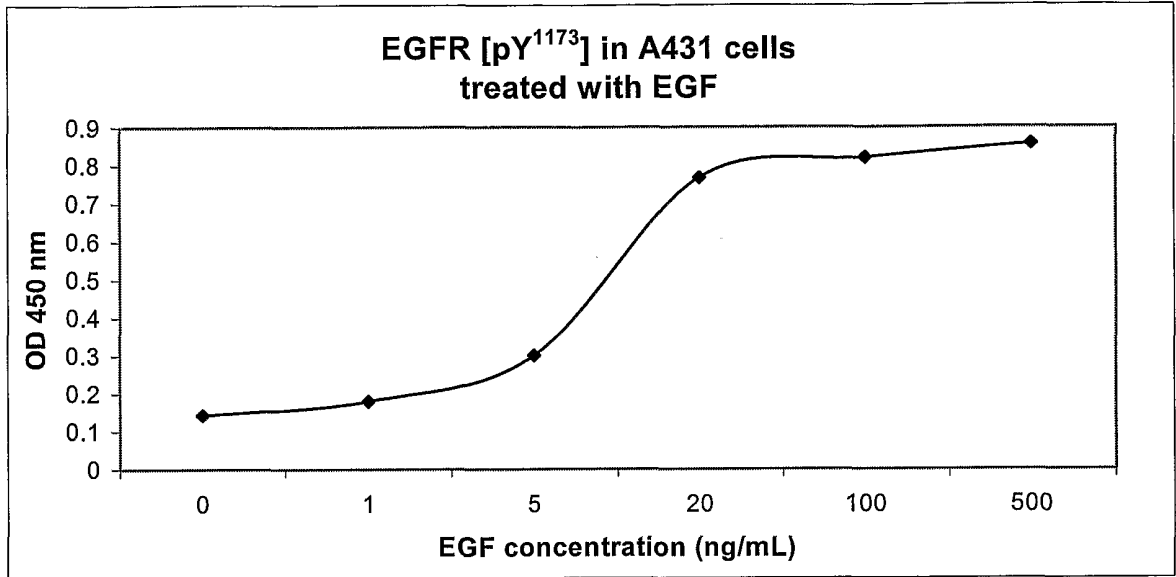


Figure 16

