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(54) Title: DIAGNOSTIC METHOD BASED ON LARGE SCALE IDENTIFICATION OF POST-TRANSLATIONAL MODIFICATION OF PROTEINS

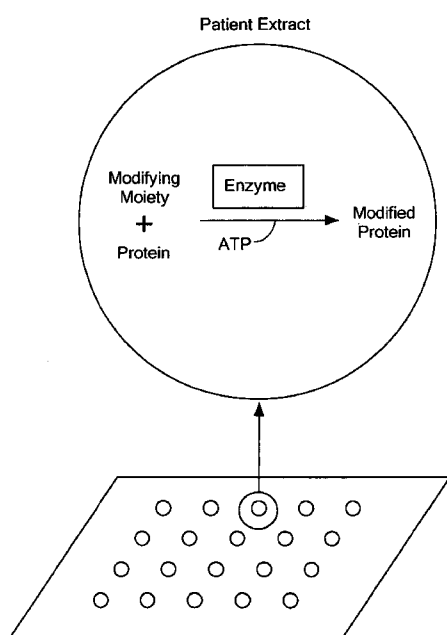


FIG. 1A

(57) Abstract: Methods for the large scale identification of post-translational modification states of proteins and enzyme activities for carrying out post-translational modification reactions involve the analysis of functional extracts using protein arrays. The methods and kits of the invention can be used to diagnose and characterize a wide variety of diseases and medical conditions, including cancer, neurodegenerative diseases, immune diseases, infectious diseases, genetic diseases, metabolic conditions, and drug effects using cells or body fluids of a patient.



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TITLE OF THE INVENTION

**DIAGNOSTIC METHOD BASED ON LARGE SCALE IDENTIFICATION OF POST-
TRANSLATIONAL MODIFICATION OF PROTEINS**

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Provisional Patent Application Ser. No. 61/196,461, filed October 17, 2008, which is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

Post-translational modification (PTM) of proteins has been studied largely using purified systems or whole cells. The analysis of protein PTM in cell extracts as well as extracellular fluids is both theoretically and empirically problematic. For example, both ubiquitination and phosphorylation, common examples of PTM, are very rapidly reversed, and this reversal requires no energy input or special conditions, aside from the actions of isopeptidases and phosphatases. Moreover, classical biochemical methods such as Western blot do not work well for concentrated mixtures of proteins, because the modified protein bands spread throughout the electrophoretic gel, and in complex samples, such as a cell extract or a blood plasma sample, many protein species would overlap, making protein identification difficult or impossible. Chemical methods such as mass spectrometry cannot distinguish ubiquitin and polyubiquitin chains, yet only the latter are critical for protein degradation.

In recent years, our understanding of posttranslational modifications and their implication for human diseases have greatly increased. In Alzheimer's disease (25) and Parkinson's disease (26-28) the ubiquitination of proteins has been shown to play a pivotal role in the regulation of cellular processes and human pathologies. Although the role that ubiquitination plays in tumorigenesis is still poorly understood, cases of ubiquitin ligases showing relationships with oncogenesis were recently described (29-31). Thus, systematic assays for the screening, including diagnostic screening, of ubiquitinated or other post-translationally modified proteins remain limited.

BRIEF SUMMARY OF THE INVENTION

The invention provides methods and kits for the systematic and large scale determination of protein PTMs and the enzyme activities that catalyze them. The methods entail incubating protein microarrays or another protein array format with cell extracts or fluids from a subject, performing specific PTM reactions on the microarrays, and detecting protein modification states of specific proteins. The methods according to the invention overcome obstacles associated with classical biochemical techniques by performing PTM reactions on protein microarrays with patient materials whose physiological state is preserved, appropriately supplemented with limiting PTM reaction components, and make it possible for the first time to rapidly screen patient samples for activities that modulate PTM states related to disease.

In one embodiment, the invention utilizes protein microarrays or other array formats of proteins together with appropriately supplemented functional cell extracts or body fluid samples to study the role of PTM in the presence and progression of many types of disease and many aspects of cellular function. Certain PTM states are mechanistically involved in cellular protein turnover, and consequently PTM states can be correlated with diseases related to protein turnover, such as, for example, Alzheimer's disease and other neurodegenerative diseases, and diseases related to regulation of the cell cycle, such as cancer.

In one aspect the invention provides a method of identifying an altered PTM state of a protein in a patient. The method includes contacting a functional extract of a sample from the patient with a microarray containing an ordered plurality of proteins that represent proteins in the patient, establishing conditions for a specific PTM reaction in the extract, and determining the level of PTM of one or more proteins in the microarray. The presence or absence, or the observed level, of PTM of proteins in the microarray is then compared with the level of PTM of the corresponding proteins in a control sample, so that altered PTM states of proteins are identified that are expected to be similarly altered in the patient.

Another aspect of the invention is a method of identifying a protein PTM enzyme activity in a patient. The method includes contacting a functional extract of a sample from the patient with an array comprising an ordered plurality of proteins that represent proteins in the patient, and identifying post-translationally modified proteins in the array. The presence or absence, or the relative amount, of a PTM enzyme activity in the patient can be inferred from the protein posttranslational modifications observed in the array. The presence or absence, or the relative amount, of a corresponding PTM state produced by the enzyme activity in the patient may also be inferred from the results obtained with this method.

Still another aspect of the invention is a method of diagnosing a disease or medical condition in a patient. The method includes contacting a functional extract of a sample from the patient with a microarray containing an ordered plurality of proteins that represent proteins in the patient and identifying post-translationally modified proteins in the microarray to obtain a PTM state data set. The data set can serve as a signature or profile of protein PTMs in the patient as well as of the enzymes producing them. The data set is then compared with a standard data set that includes PTM state data diagnostic for the disease or medical condition and, based on the comparison, the disease or medical condition is diagnosed in the patient.

Yet another aspect of the invention is a method of identifying a set of biomarkers for a disease or medical condition. The method includes comparing the PTM profile of one or more patients having the disease or medical condition with similar profiles from one or more control subjects who do not have the disease or medical condition. The profiles are obtained by separately contacting functional extracts from the patients and control subjects with an array containing an ordered plurality of proteins, such as proteins encoded by the human genome, and determining the level of PTM of one or more proteins in the array. The presence or absence, or the observed level, of PTM of proteins in the array for the patients is then compared with the presence or absence or level of PTM of the corresponding proteins for the control subjects. A set of biomarkers is formed from proteins of the patients whose level of PTM is altered compared to control levels.

In a further aspect, the invention provides a kit for the diagnosis of a disease or medical condition, or the characterization of the effects of a drug, by the analysis of a PTM state of a protein in a patient sample. The kit includes a standard containing one or more functional extracts capable of producing a known pattern of protein PTM states on a protein microarray or in another array format. The kit also is adapted for, and contains instructions for, carrying out one of the above described methods. Optionally, the kit further contains a protein microarray, or a reagent such as a substrate, an enzyme, an enzyme inhibitor, a drug, or one or more antibodies. When applied with a method according to the invention, the standard produces a pattern of protein PTM that is diagnostic for a disease or medical condition, or the effects of a drug.

BRIEF DESCRIPTION OF THE DRAWINGS

Other features and advantages of the invention will be apparent from the following description of the preferred embodiments thereof and from the claims, taken in conjunction with the accompanying drawings.

Fig. 1A presents a schematic illustration of a PTM reaction carried out on a protein microarray using a functional extract from a patient sample. Fig. 1B shows a schematic illustration of the use of a PTM reaction on a protein microarray to diagnose a disease in a patient sample. The inset shows a reaction scheme common to ubiquitin-like modifiers, and the inset at the right shows example E1 and E2 enzymes for several ubiquitin-like modifiers.

Fig. 2A shows the degradation of ^{35}S -labeled securin, added as a control to functional extracts, as a function of time at selected points during the cell cycle. The reactions were stopped at the indicated times by the addition of sample buffer and were then analyzed by SDS-PAGE and autoradiography. The star (*) labeled lanes reflect the state of the extracts at the time when incubation on the protein microarrays were stopped. Fig. 2B is a schematic illustration of the use of a protein microarray for the detection of posttranslational modifications. An example of one block/subarray out of the 48 on each chip is given (16 rows x 16 columns).

Fig. 3A shows the distribution of signal intensity minus background values of all the spots on a protein microarray after detection of polyubiquitinated proteins. Reactivities were divided into 100 equally-sized bins, and the number of spots (y-axis) at different intensity levels (x-axis) of CP-released (left) and APC-inhibited (right) cell extracts was plotted. The inset represents a 20X magnification of the positive signals where the y-axis ranges between 0 and 250 and the x-axis ranges between 0 and 45,000. In Fig. 3B the reactivity level of 13 known APC substrates (dots) was compared to the reactivity level of the 'buffer' spots located in the same subarray (stars). The reactivities were then compared using a two-sample t-test to determine their significance, and the p-values were labeled below each substrate. Fig. 3C shows scatter plots of the positive signal intensities on each chip. The plots show the variability between two biological replicates (black dots; x-axis: CP-released, y-axis: CP-released) vs the variability between signals from two different conditions (red dots; x-axis: APC-inhibited, y-axis: CP-released).

Fig. 4A shows analysis by SDS-PAGE (4–15% gels) and autoradiography of ^{35}S -labelled substrates (Nek9, Calm2, RPS6KA4 and cyclin G2) added to CP synchronized HeLa S3 extracts with and without the addition of the APC-inhibitor emi1. Fig. 4B shows a similar analysis in which ^{35}S -labelled p27 was added to CP synchronized HeLa S3 extracts with the addition of UbcH10, DN-UbcH10, or MG-132, or Emi1; the bottom panel shows the change in stability of p27 under this condition. The top panel is the same gel exposed for 4 days (long exposure) to detect p27-conjugated ubiquitin chains.

Figs. 5A and 5B show the results of experiments to test the recognition of polyubiquitinated proteins with FK1 antibody.

Fig. 6 shows the distribution of signal and background levels observed on four representative protein microarrays.

Fig. 7 shows the signal-to-noise ratio for all spots on a protein microarray chip.

Fig. 8 shows the signal - background values for the buffer spots on five representative protein microarrays.

Fig. 9 shows the levels of the indicated endogenous proteins in functional extracts as a function of time as detected by Western blotting.

Figs. 10A and 10B show the signal intensity distribution of all the spots on a protein microarray. Fig. 10A shows the results for a CP-released extract, and Fig. 10B shows the results for an APC-inhibited extract.

Fig. 11 shows human proteins that were significantly ubiquitinated by enzymes present in cerebrospinal fluid (CSF) from a patient with brain tumor.

Fig. 12 shows a Western blot of normal human CSF proteins that were polyubiquitinated using enzyme activity in CSF.

Fig. 13 shows the results of ubiquitination of a microarray of human proteins using normal human CSF. The number of ubiquitinated proteins detected is represented as a function of the fold increase of fluorescence over background.

Fig. 14 shows human proteins detected on a microarray as polyubiquitinated by enzymes present in two normal human CSF samples. The proteins shown revealed a fluorescence signal at least 50-fold over background.

Fig. 15 shows the fluorescence signal obtained for differentially modified proteins on a microarray after the indicated PTM reactions using extracts of mitotic checkpoint arrested and released HeLa S3 cells.

Fig. 16 presents a Venn diagram illustrating the relationships among protein targets found to be modified by different ubiquitin-like modifiers.

DETAILED DESCRIPTION OF THE INVENTION

The inventors have developed methods that permit the rapid and large-scale diagnostic screening of altered protein PTM states and related enzyme activities correlated with disease. The methods involve applying concentrated cell extracts or body fluid samples from a subject to protein microarrays and appropriately supplementing them to carry out one or more specific

PTM reactions. Specifically, modifications are then detected by labeling the modified proteins and scanning the array.

Patterns of post-translational changes in certain polypeptides are known to correlate with certain diseases, such as Alzheimer's disease and cancer (see Table 3). While the altered polypeptides themselves may be detectable in extracellular fluids or cell extracts, and could be useful in diagnosing disease and monitoring its progression, an easier alternative to looking for the modified proteins themselves is to assay for the activity of specialized enzymes that make the modifications and are present in such fluids or extracts. Such an assay is the focus of this invention. Assaying for such activities requires, in addition to the enzyme itself, which is supplied by the patient sample, the presence of relevant cofactors and appropriate substrates. A PTM activity assay can be used not only to diagnose a disease state, it can also be used to identify candidate biomarkers of diseases in body fluids and cell extracts prepared from patient samples. Knowledge of the modified target proteins in a disease provides intrinsically important information about the altered post-translational process that occurs in the disease and its role in the disease.

Covalently modified proteins, such as polyubiquitinated proteins, are hard to identify by the standard biochemical technique of gel electrophoresis, because the modified protein bands spread throughout the gel. In a complex sample like a functional cell extract or undiluted body fluid, many protein molecular species would overlap, making identification of specific modified proteins difficult or impossible. The high concentration and large number of different proteins in patient samples such as cell or tissue extracts, and body fluids such as blood plasma or CSF, generally require additional processing steps to separate the sample into different fractions or to purify certain molecular components prior to analysis. In contrast, with the present methods, a PTM reaction is performed directly on a protein microarray, or another array format wherein the location of each protein is known. The known physical location of the protein on the array, rather than its electrophoretic mobility in a gel, is used to identify the target. Combined with the use of antibodies that have binding specificity for particular PTM states, such as polyubiquitinated vs. monoubiquitinated proteins, or combined with the use of a labeled modifying moiety, the use of protein arrays greatly simplifies the problem of identifying specific PTM states on specific proteins, and the use of microarrays also makes possible the simultaneous analysis of thousands of proteins. Thus, the present invention overcomes previous obstacles to identifying altered PTM states and altered activity of enzymes that produce PTM in

a patient and brings PTM analysis into a realm where it is possible for the first time to diagnose disease in a clinical setting.

The method according to the invention detects changes both in PTM enzyme activity and its cognate protein targets in a patient through the analysis of a patient sample, such as plasma, CSF, or from an extract prepared from biopsy tissue. There is great need for a method that is capable of rapidly detecting biomarkers of diseases such as Alzheimer's disease or cancer in a patient sample, and to distinguish the disease from the normal state. Detecting PTMs of a large number of proteins provides a detailed fingerprint of the PTM enzymes released from tissues during disease.

Regarding extracellular fluids such as CSF or plasma, it is still unclear how certain intracellular proteins are deposited in such extracellular fluids, though they are expected to result from cellular turnover; nevertheless, many examples of intracellular proteins in such fluids are known. For example, it is known that cytoskeletal proteins such as tau and post-translationally modified forms thereof (phospho-tau) can be readily detected in CSF from patients suffering from Alzheimer's disease. Prior to the present invention, however, it was unknown whether functional PTM enzymes are present in extracellular fluid samples such as CSF and plasma and could be used to modify target proteins. Thus, the invention now provides a means to assay PTM enzyme activities in samples that were previously not used for such analysis.

As used herein, the term "post-translational modification" or "PTM" refers to a reaction wherein a chemical moiety is covalently added to a protein. Many proteins can be post-translationally modified through the covalent addition of a chemical moiety (also referred to herein as a "modifying moiety") after the initial synthesis (i.e., translation) of the polypeptide chain. Such chemical moieties usually are added by an enzyme to an amino acid side chain or to the carboxyl or amino terminal end of the polypeptide chain, and may be cleaved off by another enzyme. Single or multiple chemical moieties, either the same or different chemical moieties, can be added to a single protein molecule. PTM of a protein can alter its biological function, such as its enzyme activity, its binding to or activation of other proteins, or its turnover, and is important in cell signaling events, development of an organism, and disease. Examples of PTM covered by the method of the invention include, but are not limited to ubiquitination, phosphorylation, sumoylation, neddylation, ADP-ribosylation, and glycosylation. In some embodiments of the present invention, the PTM reaction is a modification of proteins with a ubiquitin-like modifier selected from the group consisting of ISG15, UCRP, FUB1, NEDD8, FAT10, SUMO-1, SUMO-2, SUMO-3, Apg8, Apg12, Urm1, UBL5, and Ufm1 (see Table 1 for

further description). In other embodiments of the present invention, the PTM reaction is one of ubiquitination, sumoylation, and neddylation.

One method of the invention involves detection and analysis of altered states of PTM in one or more proteins in a patient compared to a control patient, control data, or data obtained from the same patient at an earlier time. A state of PTM can be altered, for example, if there is a change in the average number of a given chemical group attached per protein molecule, if there is a change in the type of chemical group or groups attached per protein molecule, or if there is a different mixture of protein molecules having distinct modification patterns in a patient sample. Alteration of a PTM state of a protein includes going from an unmodified protein to a modified one and vice-versa, as well as changes in the number or type of chemical moieties added to the protein.

Thus, one embodiment of the invention is a method of identifying an altered PTM state of a protein in a patient. The method includes the steps of (i) contacting a functional extract of a sample from the patient with a protein microarray containing proteins that are representative of proteins in the patient; (ii) establishing a specific PTM reaction on the microarray, whereby the reaction results in a PTM of one or more proteins in the microarray through the activity of one or more enzymes present in the extract; (iii) determining the level of PTM of proteins in the microarray; and (iv) comparing the levels of PTM with PTM levels of corresponding proteins in a control sample to identify altered PTM states of one or more proteins in the patient.

A specific PTM reaction can be established on an array by adding a substrate (e.g., ubiquitin) to the extract or fluid sample that is required for a single PTM reaction. An assay also can be rendered specific for a single PTM reaction by the use of an antibody that detects only one specific PTM state. Methods according to the invention can be addressed to either a single specific PTM reaction at a time or more than one specific PTM reactions performed simultaneously in the same reaction mixture (multiplex format).

In order to take advantage of the large scale screening possible with microarrays in methods of the invention, it is necessary to apply a concentrated and biologically functional extract or a concentrated extracellular fluid to the surface of a microarray. Preferably, such an extract or fluid is essentially devoid of detergents or surfactants, as well as toxins or substances that could inhibit the biological function of components of the extract, e.g., enzymes and co-factors involved in PTM reactions, or that could denature or alter the protein targets in the microarray. Negligible amounts of detergents, toxins, or other factors that do not effect PTM activity may be present. Extracts of patient samples or body fluid samples are preferably

maintained at a protein concentration approaching that of in the body of the subject, so that protein-protein interactions that might affect activity are retained in the extract.

Highly concentrated cellular extracts have been shown to have demonstrable function. Such cellular extracts from *Xenopus* and from somatic cells that demonstrated a function specified for a particular phase of the cell cycle have allowed for the recapitulation of complex events, such as the ordered degradation of mitotic substrates (1). Also, in recent years, these systems have been employed for an in vitro expression cloning (IVEC) screening approach (2) and were used successfully to identify proteins that undergo mitosis-specific degradation (3,4), apoptotic protease substrates (5), protein kinase substrates (5), and other binding interactions (6).

As used herein, the term "functional extract" refers to the extract of a patient sample, either in its entirety or any unfractionated portion or volume portion thereof, or any dilution thereof. The term "functional extract" also includes an extracellular fluid sample obtained from a patient, applied either undiluted or diluted, in its entirety or as any mass portion or volume portion thereof. Preferably, the functional extract is not subjected to a protein purification process prior to use in a PTM reaction on a microarray. The extract as used for a PTM reaction can be supplemented with any reagent, including salts, buffers, gases, substrates, enzymes, inhibitors, etc., as desired or as appropriate for the particular PTM reaction performed.

An example of a method for preparing a functional extract is to use a gentle, minimally diluting method such as one or more cycles of freeze-thaw, optionally combined with mildly hypotonic lysis of cells that may be present in the sample. The amount of sample material used to prepare the extract will depend on the scale of the experiment, such as the number and size of the microarrays used, but generally at least one million cells or at least an amount of tissue or bodily fluid equivalent to 50 microliters of an undiluted lysed tissue sample or cell extract, or at least about 20 μ l of a bodily fluid such as plasma or cerebrospinal fluid is sufficient for preparing an extract to cover a single 1 x 3 inch microarray.

In order to prepare a functional extract, cells are first harvested using standard techniques for collecting cells, e.g., from culture or from a specimen obtained from a patient. Such techniques can include, for example, tissue homogenization, treatment of tissue or cell culture with trypsin, collagenase, or other enzymes, passage through a needle, sonication, or separation by centrifugation or passage through a column, such as an affinity column. Cells can be swelled in a buffer such as 25 mM HEPES, pH 7.5, containing 1.5 mM $MgCl_2$, 5 mM KCl, 1mM DTT, optionally containing a preferred mixture of protease inhibitors, such as CompleteTM protease inhibitors (Roche). The ratio of lysis or homogenization solution preferably is kept to a

minimum, e.g., similar to or less than the volume of cells being extracted, in order to minimize the dilution of extracted material. For example, a ratio of about 0.5 to 1 volume of lysis solution to cell volume can be used; preferably 0.8 volume or less of lysis solution is used for each volume of cells to be disrupted. After homogenization, the crude cell extract can be treated to remove membranes and whole or fragmented cells, such as by centrifugation. Alternatively, functional extracts can be made from different cellular compartments such as nuclear, cytoplasmic, or mitochondrial extracts according to published protocols.

Functional extracts can be prepared from any suitable source of cells or tissue that can be obtained from a patient or subject. The patient or subject can be a human or a non-human animal. Sources of cells or tissue for extraction can include, for example, a biopsy specimen, such as a tumor or suspected tumor, serum, plasma, cerebrospinal fluid, saliva, urine. Non-cellular (e.g., bodily fluid) samples usually contain intracellular content that is sufficient for analysis; such content may be derived, for example, from directed secretion from cells, from inflammation, or tissue damage.

A functional extract can be supplemented with one or more substances to aid in the analysis of a specific post-translational state or a specific PTM enzyme activity. For example, an extract can be supplemented with a reagent, a substrate, an enzyme, an enzyme inhibitor, a drug, an antibody, or any mixture thereof. Alternatively, an extract can be depleted using antibodies directed to a chosen protein, protein complex, or modified protein. An extract lacking a particular protein component also can be prepared from knockout or knockdown cells. Preferably, a biochemical energy source such as ATP plus an ATP regenerating system is added to the extract or fluid to establish a reaction on the microarray. A high concentration of creatine phosphate (e.g. 150 mM) is a suitable ATP-regenerating system. Creatine phosphokinase can also be added in addition to creatine phosphate, but may be omitted if sufficiently present in the extract or fluid. Preferably, a substrate for a PTM enzyme, such as ubiquitin, is also added to the extract or fluid to establish a specific PTM reaction.

For some PTM reactions (e.g., ubiquitination, requiring E1, E2, and E3 enzymes), more than one enzyme is necessary to carry out the reaction, and while one or more enzyme is supplied by the extract or fluid sample, one or more other enzymes required for optimal activity may be limited or missing. In such cases the missing or limited enzyme or enzymes can be added to the extract or fluid to establish an optimal PTM reaction. A further useful strategy is to add to the extract an inhibitor of an enzyme that inhibits a particular type of PTM. Examples include methyl-ubiquitin and dominant-negative E2 enzymes for ubiquitination or sumoylation. A list of enzymes that might be added to supplement a PTM reaction is provided in Table 1.

5

Table 1

Ubiquitin-Like Modifier	Ubiquitin Sequence Homology (%)	E1-E2-E3 Conjugating Enzymes Deconjugating Enzyme (DCE)	Substrates	Functions
ISG15 (UCRP) (2 ubiquitins)	29, 27	E1: UBE1L; E2: UBCH8	PLC γ 1, JAK1, STAT1, ERK1/2, serpin 2a	Positive regulator of IFN-related immune response, potentially involved in cell growth and differentiation
FUB1 (MNSF β)	37	NA	TCR- α -like protein, Bcl-G	Negative regulator of leukocyte activation and proliferation
NEDD8 (Rub1)	58	E1: APPBP1-UBA3; E2: UBC12; E3: Roc1, Mdm2; DCE: DEN1/NEDP1, UCH-L1, UCH-L3, USP21, COP9	cullins, p53, Mdm2, synphilin-1	Positive regulator of ubiquitin E3s; directs to proteasomal degradation
FAT10 (2 ubiquitins)	29, 36	NA	MAD2	Cell cycle checkpoint for spindle assembly, directs to proteasomal degradation
SUMO-1 (SMT3C, GMP1, UBL1)	18	E1: SAE-1/-2 (AOS1-UBA2); E2: UBC9; E3: RanBP2, Pc2, PIAS superfamily; DCE: SENP-1 and -2 (Ulp-1 and -2), SUSP4	Glut1, Glut4, c-Jun, I κ B α , p53, Mdm2, SOD-1, RXR α , NEMO, PML, Sam68, RanGAP1, RanBP2, ADAR1, PCNA, Drp1, STAT-1, Sp3, thymine-DNA glycosylase, topoisomerase II	Control of protein stability, function, and localization, antagonist to ubiquitin, overlap with SUMO-2/-3
SUMO-2 (SMT3B); SUMO-3	16	E1: SAE-1/-2; E2: UBC9; DCE: SENP-3 and -5	RanGAP1, C/EBP β 1, topoisomerase II, thymine-	Transcription regulation, cell cycle progression

Ubiquitin-Like Modifier	Ubiquitin Sequence Homology (%)	E1-E2-E3 Conjugating Enzymes Deconjugating Enzyme (DCE)	Substrates	Functions
(SMT3A)			DNA glycosylase	
Apg 8	10	E1: Apg7; E2: Apg3; DCE: Apg4	Phosphatidylethanolamine	Autophagy, cytoplasm-to-vacuole targeting
Apg 12	17	E1: Apg7; E2: Apg10	Apg 5	Autophagy, cytoplasm-to-vacuole targeting
Urm1	12	E1: Uba4	Ahp1	Potential role in oxidative stress response
UBL5 (Hub1)	25	NA	CLK4, Snu66, Sph1, Hbt1	Pre-mRNA splicing, appetite regulation
Ufm1	16	E1: Uba5; E2: Ufc1	NA	Potential role in endoplasmic stress response

Small molecule inhibitors may also be used in a PTM reaction. Additionally, adenosine 5'-(gamma-thio)triphosphate can be added as an inhibitor of ATP-dependent processes in an extract. Also, certain proteases can be inhibited, removed, or supplemented into the reaction in order to check their effect or to find specific targets.

5 A protein array for use in the invention can be selected from commercially available microarrays, which are preferred. An array for use in the invention also can be fabricated in any desired format or dimensions and with any desired number of target proteins, as long as the position of each target protein is known and the target can be identified by its position in the array. The array has a substrate upon which proteins are deposited in a two-dimensional array
10 (i.e., an ordered plurality of proteins), such that each position in the array contains a single type of known protein whose PTM can be investigated. The substrate of the array can be made of a material such as a glass slide, to which protein molecules are covalently or non-covalently bound. Optionally, glass can be coated with nitrocellulose or derivatized with epoxy or amino groups to provide desirable surface properties, to reduce non-specific binding, or to provide
15 attachment points for proteins. An example of a commercially available protein microarray suitable for use in the invention is the Proto-Array® Human Protein Microarray from Invitrogen, which contains over 8000 human proteins. Other commercially available or user prepared arrays or microarrays can be used as well. Selected proteins, for example recombinant proteins that are N-terminally or C-terminally tagged and purified, can be used to prepare any desired
20 protein microarray for use in the invention.

A protein array for use with the invention can have at least 2, 5, 10, 100, 1000, 8000, 10,000, 30,000, or 100,000 or more individual protein spots or wells in the array, in addition to which other locations can be added to the array for controls or background determination, or other purposes as desired. The individual proteins in the array can be all distinct, or the proteins
25 at some positions can be identical to proteins at other positions, or can be variants (e.g., sequence mutants or differently modified versions) of proteins at other positions.

An alternative to using a protein microarray for detection is to use an array constructed from a microtiter plate or any similar container having a plurality of wells. Individual target proteins can be added to individual wells at known locations for carrying out the PTM reaction
30 and detection. It is only necessary to retain the proteins at their respective locations throughout the reaction, washing, and detection steps. For example, recombinant proteins bearing a tag, such as a GST, FLAG, or myc tag, can be coupled to glass beads that are deposited at specific locations in a microtiter plate. The beads can be retained in the wells during solution exchange,

and offer the possibility to uncouple and release the modified proteins for further study, e.g., by mass spectrometry.

A functional extract is contacted with a protein microarray, usually by depositing an aliquot or portion of the extract, optionally after dilution or supplementation with a reagent or buffer, onto the surface of the microarray where proteins are deposited. Alternatively, supplements can be added after the extract is deposited onto the microarray. Once contacted with the microarray, the extract can be incubated under any desired conditions, such as at room temperature or another temperature (e.g., 30 or 37 °C), suitable to promote the protein-protein interactions and enzyme reactions necessary to allow a PTM state to be established. Generally, the incubation will last for a period ranging from several minutes to hours. The incubation conditions should be sufficient to permit a steady state level for the particular PTM reaction under consideration to be established.

The particular target proteins in the microarray can be selected so as to be representative of the proteins available in the patient. For example, the microarray can include a large number of human proteins if the patient is a human patient. In one embodiment, the proteins in the microarray are initially in an unmodified state, such as that obtained by expressing the proteins in a recombinant expression system that does not modify the proteins. In another embodiment, the proteins in the microarray have various states of PTM; such proteins can be further modified by a functional extract, providing differential modification signals. Alternatively, in another embodiment the target proteins in the array can be biochemically stripped of certain PTMs prior to exposure to the functional extract for analysis. During the step of contacting the functional extract with the microarray, one or more proteins in the array will become post-translationally modified by the enzymes, cofactors, and substrates in the extract.

Following an appropriate incubation period, the cell extract can be washed off the microarray by standard techniques, including spin drying, centrifugation, or blowing a stream of gas (e.g., air or nitrogen) over the surface of the microarray followed by application of a buffer solution to the microarray. The washing step can be repeated as needed to remove components from the cell extract from the microarray, leaving the modified target proteins attached to the microarray for subsequent detection. A suitable washing solution is a Tris buffered saline solution (TBS), optionally supplemented with one or more detergents (e.g., 0.05% Tween, or for more stringent conditions 0.5% SDS) to dissociate non-specifically bound proteins from the proteins in the array.

After the cell extract has been removed, the next step is to determine the level of PTM of individual proteins in the microarray. This can be accomplished, for example, using an antibody that specifically binds all proteins having a specific type of modification. Many such antibodies are commercially available, such as Anti-Polyubiquitin (BioMol), anti-ubiquitin (with specific linkages, Cell Signaling), anti-sumo1 (Cell Signaling, BioMol), anti-sumo2/3 (Cell Signaling, Biomol), anti-NEDD8 (Biomol, MBI, Sigma), anti-APG8 (Boston Biochem), anti-FAT10 (Boston Biochem), and anti-UFM1 (Boston Biochem). Examples of commercially available antibodies that can be used to specifically detect different PTM states are listed in Table 2.

Table 2

PTM Detected/Antibody	Catalog Number	Company
Ubiquitin monoclonal mouse monoclonal	AB-001	Cell Signaling
SUMO2 polyclonal mouse polyclonal	AB-S80	Cell Signaling
SUMO2 monoclonal mouse monoclonal	AB-S81	Cell Signaling
SUMO3 MaxPab polyclonal mouse polyclonal	AB-S90	Cell Signaling
SUMO3 polyclonal mouse polyclonal	AB-S91	Cell Signaling
SUMO3 monoclonal mouse monoclonal	AB-S92	Cell Signaling
SUMO3 monoclonal mouse monoclonal	AB-S93	Cell Signaling
SUMO4 MaxPab polyclonal mouse polyclonal	AB-S95	Cell Signaling
SUMO4 polyclonal rabbit polyclonal	AB-S96	Cell Signaling
SUMO4 polyclonal rabbit polyclonal	AB-S97	Cell Signaling
Anti-NEDD8 rabbit polyclonal	A-812	Cell Signaling
Anti-UBE1L (E1) rabbit polyclonal	A-306	Cell Signaling
Anti-ISG15 rabbit polyclonal	A-600	Cell Signaling
UBE2L6 (UbcH8) MaxPab polyclonal mouse polyclonal	AB-242	Cell Signaling
UBE2L6 polyclonal mouse polyclonal	AB-243	Cell Signaling
UBE2L6 (UbcH8) monoclonal mouse monoclonal	AB-244	Cell Signaling
ISG15 MaxPab polyclonal rabbit polyclonal	AB-I10	Cell Signaling
ISG15 monoclonal clonal mouse monoclonal	AB-I11	Cell Signaling

Anti-UFM1 rabbit polyclonal	A-500	Cell Signaling
APG3 polyclonal mouse recombinant	AB-A10APG3	Cell Signaling
APG3 monoclonal mouse monoclonal	AB-A11APG3	Cell Signaling
APG4B polyclonal rabbit polyclonal	AB-A20APG4B	Cell Signaling
APG4C MaxPab polyclonal mouse polyclonal	AB-A21APG4C	Cell Signaling
APG4C polyclonal rabbit polyclonal	AB-A22APG4C	Cell Signaling
APG5 monoclonal mouse monoclonal	AB-A25APG5	Cell Signaling
APG7 MaxPab polyclonal mouse polyclonal	AB-A30APG7	Cell Signaling
APG7 polyclonal rabbit polyclonal	AB-A31APG7	Cell Signaling
APG9A polyclonal rabbit polyclonal	AB-A40APG9	Cell Signaling
APG10 polyclonal rabbit polyclonal	AB-A50APG10	Cell Signaling
APG10 polyclonal rabbit polyclonal	AB-A51APG10	Cell Signaling
APG12 MaxPab polyclonal mouse polyclonal	AB-A64APG12	Cell Signaling
APG12 polyclonal rabbit polyclonal	AB-A65APG12	Cell Signaling
APG12 monoclonal mouse monoclonal	AB-A66APG12	Cell Signaling
URM1 polyclonal rabbit polyclonal	AB-O30	Cell Signaling
Anti Fat10 (Protein derived)	PW9680-002	Biomol
anti- Fat10 Polyclonal	PW9585-0025	Biomol
anti-URM1 polyclonal	PW9595-0025	Biomol
anti-FUB1 polyclonal	PW9615-0025	Biomol
Mouse Anti-O-GlcNAc Monoclonal Antibody	sc-81483	Santa Cruz
S-nitrosocysteine antibody	ab50185	Abcam
Acetylated-Lysine Antibody	#9441	Cell Signaling
acetyl Lysine antibody	ab76	Abcam
Citrulline polyclonal antibody	PAB0068	Abnova

In order to visualize the specifically bound antibody molecules on the microarray, the unbound first antibody is first washed away and a second antibody (e.g., an anti-immunoglobulin that specifically binds the first antibody) can be added to the microarray and allowed to bind with the first antibody. The second antibody can be labeled, e.g., by conjugation to a label moiety such as a fluorescent dye, so as to generate a signal permitting detection by a microarray scanner, such as a GenePix 4000B (Molecular Devices). Preferably, the signal emitted to detect post-translationally modified proteins in the microarray is a light signal, though

other signals such as radioactivity can be used as well. The scanner can detect both the amount of signal and its position within the microarray. Two or more PTMs can be detected simultaneously by using a selection of different first antibodies, each binding specifically to a different protein modification and each recognized by a different second antibody, with each second antibody conjugated to a different labeling moiety (e.g., different fluorescent dyes having excitation and emission wavelengths selected to enable simultaneous detection). An alternative method is to use labeled primary antibodies instead of using secondary antibodies. The data can be output as an image, or as an amount of signal detected in each spot of the microarray.

An alternative method for detecting PTM of proteins in the microarray is to add the modifying moiety (e.g., a protein such as ubiquitin or sumo that is added during the PTM reaction) in a tagged form, such as a His-, GST-, or Myc-tagged moiety, and to detect the tagged molecule using a specific antibody for the tag (e.g., anti-His, anti-GST, or anti-Myc antibody). In yet another alternative method of detection, a modification moiety can be labeled with a labeling moiety such as biotin or a ^{35}S -labeled or radioiodinated amino acid. Phosphorylation of proteins can be detected using an antibody specific for a phosphoprotein or by adding gamma- ^{32}P -ATP into the reaction. Many techniques, such as streptavidin binding or autoradiography, can be used to visualize such labeled modification moieties instead of using antibodies, or where an appropriate antibody is not available.

Yet another method of detecting modification of proteins in the microarray is to harvest the proteins from individual spots in the array and to perform biochemical analysis, e.g., by mass spectrometry, to identify the nature of the modification, such as the number and position of modified amino acids in the protein sequence. This can be accomplished, for example, by treating individual protein-containing spots with a proteolytic enzyme such as trypsin, or by using a specifically labile chemical linkage to the substrate of the array. Quantities of individual proteins in the pg to ng range can be recovered from microarray spots; such amounts are sufficient for a wide variety of biochemical analyses, including peptide mapping, amino acid sequencing, and mass spectroscopy.

Preferably, the microarray includes control spots (e.g., spotted with buffer but no protein or of GST spotted on the array) distributed across the array which can be used for background subtraction or normalization. Analysis of the distribution of background signal intensities as well as the distribution of control modified protein signal intensities, taking into account the signal-to-noise ratio, will suggest an appropriate threshold level of signal intensity considered to

be significant enough to represent a positive result (i.e., detection of a post-translationally modified protein).

After the level of the PTM state for one or more proteins in the microarray has been detected, alteration of this state can be identified by comparing the results for each individual protein to similar results obtained using a control sample. The control sample can be obtained from another patient, for example, or obtained from the same patient at an earlier date or from a control tissue sample obtained from another subject. A functional extract prepared from the control is used in the same method as for the test subject and applied to a second protein microarray, preferably an identical microarray to the first microarray used for the test subject, having the same proteins as the first microarray. Alternatively, comparison data can be used that have been generated using a set of patients, or data representing known or defined ratios of certain modifications. The level of a PTM state for a given protein in the first microarray (results for the test subject) is compared to the level obtained for the corresponding protein in the second microarray. Analysis of the change in state, e.g., the direction and extent of change, or the presence or absence of any change, optionally can be used to diagnose a disease or medical condition, to determine a physiological, metabolic, or developmental state, to assess the effectiveness of a drug in the patient, or to identify target proteins for treatment based on either different modification activity or different modification state.

The analysis of functional extracts using protein microarrays can also be applied to a method for identifying a PTM state of a protein. This method can be applied either to a patient sample, or to any specimen of cells or living tissue. A functional extract is prepared from the patient sample or cell or tissue specimen, as outlined above. The extract, or a portion or dilution of the extract, is contacted with a protein microarray as described earlier, and one or more proteins in the microarray becomes post-translationally modified, or a PTM becomes altered (e.g., degree of polyubiquitination) or is removed. Optionally, the extract is supplemented with one or more reagents, co-factors, substrates, enzymes, or antibodies either prior to or during the step of contacting the microarray. A signal is then detected from the modified proteins in the array, such as the fluorescence signal obtained from primary and labeled secondary antibodies as described previously. The signal, preferably background subtracted, is correlated with the identity of the protein in the respective position in the microarray, which results in identification of a PTM state of a particular protein.

A method of diagnosing a disease or medical condition related to a pattern of protein PTM can be carried out using the strategies outlined above. A functional extract is prepared

from a sample of a patient suspected of having a certain disease or medical condition. The extract, or a portion or dilution of the extract, optionally substituted with one or more reagents to promote and/or stabilize a particular PTM reaction, is contacted with a protein microarray. The microarray contains an ordered array of proteins corresponding to proteins in the patient. During the incubation of the extract on the microarray, one or more target proteins in the array become post-translationally modified. The extract is washed away and the modified proteins in the microarray are detected, using a strategy such as described earlier, for example, by detecting a fluorescence signal from a primary/secondary antibody pair. The pattern of signals from the microarray are measured and recorded to form a PTM data set for the patient sample. The patient data set is compared to a standard data set containing a pattern of PTM states that is characteristic or diagnostic for the disease or medical condition.

This type of diagnostic assay can be applied to a wide variety of diseases, medical conditions, and biological states. A number of diseases or conditions for which PTMs are known or suspected to play a role are summarized in Table 3. The methods of the present invention are particularly suited to diagnosing diseases or medical conditions including, but not limited to: cancer, such as breast cancer, ovarian cancer, uterine cancer, brain cancer, including astrocytoma, renal cell carcinoma, and vascular tumors of the central nervous system; neurodegenerative diseases, such as Alzheimer's disease, Parkinson's disease, Huntington's disease, amyotrophic lateral sclerosis, multiple sclerosis, prion diseases, neuronal intranuclear disease, Rett syndrome, and Rubenstein-Taybi syndrome; metabolic diseases, such as diabetes mellitus, diabetic ventricular dysfunction, and gout; immune diseases, including autoimmune diseases, rheumatoid arthritis, collagen-induced arthritis, systemic lupus erythematosus, celiac disease, encephalomyelitis, and IgA neuropathy; infectious diseases, such as viral diseases; cardiovascular diseases, such as cardiac dysfunction and atherosclerosis; and biological states such as cell cycle progression, DNA damage and repair, apoptosis, the NFkB pathway, Fanconi anemia, tumorigenesis, cellular, tissue, and embryonic differentiation, and aging. PTMs that may contribute to tumorigenesis include phosphorylation, acetylation, methylation, glycosylation, prolyl isomerization, hydroxylation, oxidation, glutathionylation, and ubiquitination.

Table 3

PTM	DISEASE	MODIFIED PROTEIN	REFERENCE	TITLE
Ubiquitination	Cancer/tumor	cMyc, HectH9 (E3 ligase)	33	The ubiquitin ligase HectH9 regulates transcriptional activation by Myc and is essential for tumor cell proliferation
Ubiquitination	Cancer/tumor, Breast and ovarian cancer	BRCA1 (E3 ligase)	34	Ubiquitination and proteasomal degradation of the BRCA1 tumor suppressor is regulated during cell cycle progression.
SUMOylation	Cancer/tumor	Ubc9 (E2 conjugating enzyme)	35	A role for Ubc9 in tumorigenesis
Ubiquitination	Alzheimers disease	Bcl-2	36	Inhibition of the ubiquitin-proteasome system in Alzheimer's Disease
Glycosylation	Alzheimers disease	tau	37	Glycosylation of microtubule-associated protein tau: an abnormal posttranslational modification in Alzheimer's disease
K48-linked and K63-linked ubiquitination	Parkinson's disease	synphilin-1, parkin, α -synuclein, UCHL1	38	Parkin mediated lysine 63-linked polyubiquitination: a link to protein inclusions formation in Parkinson's and other conformational diseases?

Ubiquitination	Parkinson's Disease, Autophagy	Parkin	39	Parkin-mediated K63-linked polyubiquitination: a signal for targeting misfolded proteins to the aggresome-autophagy pathway.
Ubiquitination	Neurodegenerative Diseases	P62	40	Lysine 63-linked polyubiquitin potentially partners with p62 to promote the clearance of protein inclusions by autophagy.
Acetylation, deacetylation, methylation	Neurologic and psychiatric disorders including Huntington's disease, Parkinson's disease, anxiety and mood disorders, Rubinstein-Taybi syndrome, and Rett syndrome	HDAC	41	Epigenetic targets of HDAC inhibition in neurodegenerative and psychiatric disorders.
Nedd8ylation	Neurodegenerative Diseases, Parkinson's disease and Rosenthal fibres in astrocytoma	NEDD8	42	Accumulation of NEDD8 in neuronal and glial inclusions of neurodegenerative disorders.
Ubiquitination	Neurodegenerative diseases	Mad2, BubR1 associated to cDc20	43	Inhibitory factors associated with anaphase-promoting complex/cylosome in mitotic checkpoint.
Ubiquitination	Cell Cycle progression		44	Ubiquitin dependence of selective protein degradation demonstrated in the mammalian cell cycle mutant ts85.

	Cell Cycle progression	cyclin	45	Cyclin: a protein specified by maternal mRNA in sea urchin eggs that is destroyed at each cleavage division.
	Cell Cycle progression	APC/C (cDc20, CDH1 and MAD2)	46	Control of mitotic transitions by the anaphase-promoting complex.
Conjugation	Cell Cycle progression	cyclin	47	Cyclin is degraded by the ubiquitin pathway.
Ubiquitination	Cell Cycle progression	Cdc34, CDK activity-by degrading CDK activators or inhibitors	48	How proteolysis drives the cell cycle
Ubiquitination	Cell Cycle progression	APC/C (cDc20, MAD2)	49	Ubiquitination by the anaphase-promoting complex drives spindle checkpoint inactivation.
Ubiquitination, phosphorylation, methylation DNA damage and repair	DNA damage and repair	ATR/MRN complex	50	Twists and turns in the function of DNA damage signaling and 5 repair proteins by PTMs.
Acetylation, methylation, phosphorylation, ubiquitination and SUMOylation	Huntington disease	Histone (H2A, H2B, H3 and H4)	51	Mechanisms of disease: Histone modifications in Huntington's disease.
SUMOylation	Huntington disease	Huntingtin (Httex1p)	52	SUMO modification of Huntingtin and Huntington's disease pathology.
Ubiquitination, SUMOylation, phosphorylation, acetylation and nitrosylation	NFkB pathway	IkappaB kinase (IKK) complex, the IkappaB proteins and the NF-kappaB	53	PTMs regulating the activity and function of the nuclear factor kappa B pathway.

SUMOylation	Neuronal Intranuclear Inclusion disease (NIID)	SUMOylation substrates: Promyelocytic leukaemia protein (PML) and RanGAP1.HDAC4	54	SUMOylation substrates in neuronal intranuclear inclusion disease.
SUMOylation	Type 1 diabetes	M55V substitution of SUMO4	55	SUMO wrestling with type 1 diabetes.
SUMOylation	Polyglutamine Diseases	ESCA1 and ESCA2	56	Enhanced SUMOylation in polyglutamine diseases
Ubiquitination	Kidney cancers	HIF- alpha	57	The role of von Hippel-Lindau tumor suppressor protein and hypoxia in renal clear cell carcinoma.
Neddylation, SUMOylation,	Renal cell carcinomas, pheochromocytomas, and vascular tumors of the central nervous system	pVHL, NEDD8 conjugation to Cul-2	58	The von Hippel-Lindau tumor suppressor gene product promotes, but is not essential for, NEDD8 conjugation to cullin-5 2.
SUMOylation	Diabetes mellitus, diabetic ventricular dysfunction	ERK5, Ubc9 (SUMO E2 conjugase) or PIAS1 (E3 ligase)	59	Effects of MEK5/ERK5 association on small ubiquitin-related modification of ERK5: implications for diabetic ventricular dysfunction after myocardial infarction.
Ubiquitination, SUMOylation	Parkinson's, Alzheimer's, Huntington's, Prion and amyotrophic lateral sclerosis	α SYN (PARK1), UCH-L1, DJ-1 binds to the SUMO E3 PIASx, A β and tau, UBB+1etc...	60	The ubiquitin proteasome system in neurodegenerative diseases: sometimes the chicken, sometimes the egg.
Methylation, deimination, and phosphorylation	Multiple Sclerosis	MBP	61	Multiple sclerosis: an important role for PTMs of myelin basic protein in pathogenesis.

Glycosylation	Autoimmunity, Rheumatoid arthritis and IgA nephropathy	IgG and IgA1	62	Plasma proteins glycosylation and its alteration in disease.
SUMOylation	Parkinson	DJ-1	63	Proper SUMO-1 conjugation is essential to DJ-1 to exert its full activities.
SUMOylation	Parkinson	DJ-1, and pyrimidine tract-binding protein-associated splicing factor (PSF)	64	DJ-1 transcriptionally up-regulates the human tyrosine hydroxylase by inhibiting the sumoylation of pyrimidine tract-binding protein-associated splicing factor.
Ubiquitination, phosphorylation and acetylation	Cancer	p53	65	Ubiquitination, phosphorylation and acetylation: the molecular basis for p53 regulation.
Phosphorylation	Cancer	Fra-1	66	Accumulation of Fra-1 in ras-transformed cells depends on both transcriptional autoregulation and MEK-dependent posttranslational stabilization.
Phosphorylation	Cancer	NF-kappa B	67	Inhibition of constitutive NF-kappa B activity by I kappa B alpha M suppresses tumorigenesis.
Ubiquitination, SUMOylation	Cancer	Smad4	68	Sumoylation of Smad4, the common Smad mediator of transforming growth factor-beta family signaling.
Phosphorylation	Uterine leiomyomas	Ref-1	69	Altered PTM of redox factor 1 protein in human uterine smooth muscle tumors.

Phosphorylation	tumorigenesis, differentiation and apoptosis	p53, GSK3beta	70	Glycogen synthase kinase3 beta phosphorylates serine 33 of p53 and activates p53's transcriptional activity.
Phosphorylation	tumorigenesis	pp60c-src	71	pp60c-src in human melanocytes and melanoma 30 cells exhibits elevated specific activity and reduced tyrosine 530 phosphorylation compared to human fibroblast pp60c-src.
Phosphorylation	tumorigenesis	P120	72	Abelson murine leukemia virus transformation defective mutants with impaired P120 associated protein kinase activity.
Glycosylation	Prion Disease	PrP	73	Asparagine-linked glycosylation of the scrapie and cellular prion proteins.
Ubiquitination	Fanconi anemia	FANCD2	74	Fanconi anemia: causes and consequences of genetic instability.
Ubiquitination	Fanconi anemia	FANCD2, catalytic subunit PHF9(FANCL)	75	A novel ubiquitin ligase is deficient in Fanconi anemia.
Ubiquitination	Aging	BRCA1; PCNA; NFkB; p27; SNEV ^{Prp19Pso4}	76	Aging and the ubiquitinome: traditional and non-traditional functions of ubiquitin in aging cells and tissues.
Ubiquitination, SUMOylation, Oxydation	Aging		77	Aging and dietary restriction effects on ubiquitination, sumoylation, and the proteasome in the heart.
Ubiquitination	Aging	DAF-16, RLE-1 (E3 ligase)	78	RLE-1, an E3 ubiquitin ligase, regulates C. elegans aging by

SUMOylation	Aging	POMP-1	79	catalyzing DAF-16 polyubiquitination. Effects of aging and dietary restriction on ubiquitination, sumoylation, and the proteasome in the spleen. Caretakeer or undertaker? The role of the proteasome in aging
	Aging	Decrease of expressed Proteasome proteins:S9:Rpn6 (p44.5), Rpn5 (p55), a2 (HC3), a7(HC8), S7:Rpt1 (MSS1) and S10b:Rpt4 (p42) parkin	80	
S-nitrosylation, Ubiquitination	Parkinson's disease		81	Nitrosative stress linked to sporadic Parkinson's disease: S-nitrosylation of parkin regulates its E3 ubiquitin ligase activity.
Glycosylation	Virus related diseases	penv9,penv14	82	Glycosylation inhibitors block the expression of LAV/HTLV-III (HIV) glycoproteins.
Glycosylation	Virus related diseases	gp46	83	Immunogenicity and conformational properties of an N-linked glycosylated peptide epitope of human T-lymphotropic virus type 1 (HTLV-I).
Glycosylation	Virus related diseases	peroxiredoxin 1 and HTLV-1-p24-(gag)	84	Posttranslational glycosylation of target proteins implicate molecular mimicry in the pathogenesis of HTLV-1 associated neurological disease.
Glycosylation	Virus related diseases	gp 100	85	A glycopolypeptide (gp 100) is the main antigen detected by

Citrullination/deimination	Multiple Sclerosis, Diabetes, Alzheimer's	Myelin basic protein (MBP)	86	HTLV-III antisera. A tale of two citrullines-- structural and functional aspects of myelin basic protein deimination in health and 5 disease.
OGlcNAc	Cardiac dysfunction	SP1, eNOS,	87	O-GlcNAc modification of nucleocytoplasmic proteins and diabetes.
OGlcNAc	Diabetes, Alzheimer's disease	tau,β-amyloid precursor, AP-3, synapsin-I, Neurofilament H, L, M, IRS, GS, PDX-1, eNOS, SP1	88	O-GlcNAc modification in diabetes and Alzheimer's disease.
OGlcNAc	Diabetes		89	A bittersweet modification: O-GlcNAc and cardiac dysfunction.
OGlcNAc	Diabetes	Sp1(but also metionned the serum response factor, c-myc, estrogen receptors and RNA pol II)	90	PTM by O15 GlcNAc: another way to change protein function.
Various PTMs	Atherosclerosis; celiac disease; autoimmune encephalomyelitis; multiple sclerosis; systemic lupus erythematosus; collagen-induced arthritis;rheumatoid arthritis	αB-crystallin, MBP, Fibrin, Type II collagen, MBP Ac1-1, Sm D1, D3, Wheat gliadin, LDL, SnRNP D	91	Posttranslational protein modifications: new flavors in the menu of autoantigens.

Various PTMs	Multiple sclerosis/EAE, Collagen-induced arthritis, Rheumatoid arthritis, systemic lupus erythematosus.	Fillagrin, Vimentin, H2B	92	Posttranslational modifications of self-antigens.
Various PTMs	Rheumatoid arthritis; Multiple sclerosis; Systemic lupus erythematosus	trichohyalin, filaggrin and keratin, myelin basic protein(MBP), fibrin, vimentin and nucleophosmin/B23, histones, Sm-D1, Sm-D3, Sm-ByB9, LSm4 Fibrin	93	Modifications of arginines and their role in autoimmunity.
Citrullination	Rheumatoid arthritis		94	Autoantigenic posttranslational modifications of proteins: does it apply to rheumatoid arthritis?

The methods of the invention can be applied to identify a set of biomarkers for a disease or medical condition. The set of biomarkers can include information such as the identity of two or more proteins whose level of a given PTM is altered (i.e., either increased, decreased, or modified in terms of the number or position of attached modifying moieties) in the disease or medical condition. The set can be established, for example, by comparing the protein PTM profile of one or more patients having the disease or medical condition with similar profiles from one or more control subjects who do not have the disease or medical condition. The profiles are obtained by separately contacting functional extracts from the patients and control subjects with a microarray containing an ordered plurality of proteins, such as proteins encoded by the human genome, and determining the level of PTM of one or more proteins in the microarray. The presence or absence, or the observed level, of PTM of proteins in the microarray for the patients is then compared with the presence or absence or level of PTM of the corresponding proteins for the control subjects. A set of biomarkers is formed from proteins of the patients whose level of PTM is altered compared to control levels. The biomarker set in some cases can be specific for a certain type of patient sample (e.g., plasma, cerebrospinal fluid, tissue, or cell type). Biomarker sets so identified can be used in any of the methods according to the invention, e.g., in a method of diagnosis.

Methods of the invention can be used to screen for and identify substrates of protein modifying enzymes. For example, a protein microarray containing a set of proteins that include candidate proteins for one or more selected types of PTM can be incubated with a solution containing one or more enzymes that catalyze PTM reactions. The methods described above can be employed to label and identify proteins in the array that serve as substrates for the enzyme(s). Optionally, the array can include variations of one or more protein substrates, e.g., sequence variants or proteins having one or more known modifications at different sites. The array can include only a single protein and its variants, or it can include proteins representative of an entire genome, or proteins expressed by a given cell or tissue, or any subset thereof. Such screening methods can be used to define the specificity of a protein modifying enzyme with respect to protein substrates or with respect to the enzyme recognition sequence, for example, or to analyze signaling pathways.

A further use for the methods of the invention is to characterize the activity of one or more protein modifying enzymes in a functional extract. A functional extract can be analyzed using methods described earlier, while supplementing only with chemical compounds that supply energy for the PTM reaction carried out by a particular enzyme or which serve as

cofactors. The protein substrates for the enzyme are supplied in the protein microarray. Further characterization of the functional extract can then be obtained by supplementing it with one or more protein modifying enzymes. Depending on the nature of the signaling pathway, the functional extract can be supplemented with additional enzymes in different combinations in parallel assays. For example, in the case of polyubiquitination, one assay can be performed with the functional extract alone (i.e., no supplementation with exogenous enzymes), another assay can involve the supplementation of the functional extract with an E1 enzyme, and additional assays can involve supplementation with an E1 enzyme plus different combinations of E2 enzymes. In this way a full signaling pathway or any portion thereof can be characterized for a given functional extract using a large number of potential protein substrates by performing only a few reactions.

The invention also includes kits that are useful in practicing the methods presented here, e.g., diagnostic kits. A kit for the diagnosis of a disease or medical condition by the analysis of a PTM state of a protein in a patient sample contains a standard set of one or more functional extracts capable of producing a known pattern of protein PTM states on a protein microarray. Optionally, the kit also contains instructions for carrying out one or more of the methods outlined above. The kit can also optionally contain one or more reagents, such as substrates, cofactors, biochemical agents, buffers, enzymes, enzyme inhibitors, antibodies, or labeling moieties such as fluorophores or radiolabeled compounds. The kit also can include computer software for analysis, one or more protein microarrays, blocking reagents for such microarrays, and packaging material for any of the kit components.

Previous protein-based diagnostic tests typically have assayed the abundance of a protein, and in certain cases its activity. However, the present invention is unique in utilizing functional samples from patients to determine global PTMs for diagnostics purposes. These methods may serve both for diagnosis of different diseases as described herein, and as a tool for the discovery of new biomarkers and drug targets.

There are many assays available to detect binding interactions, but up to now they have used either dilute protein solutions or detergent-containing cell lysates. The number and strength of the interactions detected are therefore distorted by the change in relative concentration of ligand and target, or by the presence of detergents. In addition, the modification profile can be affected by a change in the relative amounts of, for example, kinase/phosphatase pairs. In the methods according to the present invention, however, undiluted extract (functional extract) can be used without adding detergent, preserving the original

physiological state. In addition to examining cytoplasmic fractions, nuclear fractions and smaller organelles can be applied to the microarray as well.

The present methods have far greater dynamic range than available mass spectrometry methods, since thousands of proteins can be spotted on an individual chip in pure form and at high concentration, removing the effect of their relative abundance. Proteins can also be attached to the microarray in different orientations to ensure that binding to different parts of the protein can be detected. The present methods are more straightforward compared to mass spectrometry, and considerably less time-consuming than SDS gels and similar techniques.

The following examples are presented to illustrate the advantages of the present invention and to assist one of ordinary skill in making and using the invention. These examples are not intended in any way otherwise to limit the scope of the disclosure.

EXAMPLE I

Protein Ubiquitination Patterns Upon Escape From The Spindle Assembly Checkpoint In Mammalian Cells

Protein microarrays were used to identify the polyubiquitination state of proteins under specific cellular conditions. Highly concentrated cellular extracts that have demonstrable function specific for a particular phase of the cell cycle were used to modify the polyubiquitination state of human proteins on a microarray.

Specifically, the degradation of proteins involved in mitosis was examined by determining the polyubiquitination state of certain proteins at specific stages of the cell cycle. During mitosis, rapid degradation of the mitotic cyclins (11,12) causes abrupt shut-down of mitotic kinase activity, allowing the cell to enter anaphase. The Anaphase Promoting Complex (APC), a multi-subunit E3 ligase, targets cyclins and other mitotic substrates for proteasomal degradation (13,14) which in turn leads to the metaphase to anaphase transition. Thus, cell division is highly controlled by the degradation of polyubiquitinated proteins (15).

The experimental strategy was to use nocodazole arrested HeLa S3 functional cytoplasmic extracts and to follow protein polyubiquitination during release from the checkpoint by incubation on protein microarrays by assaying reactivity with labeled antibodies against polyubiquitin chains. Differentially modified proteins were examined in APC-inhibited versus APC-active extracts. The polyubiquitin signature of G1 extracts was also examined.

Tissue Culture And Cell Synchronization

HeLa S3 cells were synchronized in prometaphase by treatment with nocodazole, or in G1 by a release from nocodazole arrest. Cells were incubated in thymidine-containing (2 mM) medium, then released into fresh medium, followed by a nocodazole arrest (0.1 g/ml). For G1 cells, nocodazole-arrested cells were released into fresh medium for 4 h. Cells were harvested, washed with phosphate buffered saline (PBS), and processed for extraction as described below.

Extract Preparation

HeLa S3 cells were synchronized with thymidine for 20 hours, released for 3 hours, and then arrested in mitosis by the addition of nocodazole for an additional 11 hours. Synchronized cells (CP-extracts) were then harvested, washed with PBS, lysed in Swelling Buffer (25 mM HEPES pH 7.5, 1.5 mM MgCl₂, 5 mM KCl, 1 mM dithiothreitol, 1 tablet of Complete protease inhibitors (Roche)), and homogenized by freeze-thawing and passage through a needle. G1-extracts were prepared in the same manner with an additional 4 hour release from nocodazole arrest. Extracts were cleared by subsequent centrifugation (5 min at 5,000 r.p.m. followed by 60 min at 14,000 r.p.m.). Extract (20 µl) was supplemented with Degradation Cocktail (1 µL) containing 1.5 mg/ml ubiquitin (Boston Biochem), 150mM creatine phosphate, 20 mM ATP (pH 7.4), 2 mM EGTA (pH 7.7), 20 mM MgCl₂.

Incubation Of Extracts With Microarrays

Human ProtoArray® microarrays (Invitrogen) were washed three times (10 min each) with TBS containing 0.05% Tween 20 (TBS-T) and then blocked for 4 hours at 4°C with microarray blocking solution (ArrayIt® brand BlockIt™ (TeleChem International, Inc.)). Extracts were pre-incubated with either Emi1 (1 mg/ml) or H₂O for 30 minutes. 100 µl of CP or G1 extracts (~25 mg/ml) were then supplemented with UbcH10 (5 µl, 1 mg/ml; Boston Biochem) and incubated under a coverslip on the microarrays for 1 hour at RT. The arrays were then washed and incubated overnight with anti-polyubiquitin antibody (FK1, 1mg/ml; Biomol) diluted 1:250. To label modified (polyubiquitinated) proteins, an anti-mouse Cy3-conjugated secondary antibody (3 µl; 1 mg/ml, Jackson ImmunoResearch Laboratories) was incubated for 1 hour at RT. The arrays were washed again, spin-dried (200g, 5 min) and scanned with a GenePix 4000B scanner.

Images and Data Processing

Results were recorded as TIFF files and images were quantified using Gene Pix Pro 5 feature extraction software (version 4000B). Scanning parameters were set so that none of the spots showed saturation: PMT gain value = 400; laser power = 30% (see Fig. 10). For each spot, the local background intensity was subtracted from the median spot intensity.

Data Filtering And Normalization

The processed data set was organized in a matrix where each column contains the reactivities measured for a given array and each row contains the reactivities measured for a given protein over all arrays. The negative values were set to zero and the data was then normalized using the quantile normalization algorithm (32).

Data Analysis

To determine subsets of proteins that were differentially modified on the different microarrays a two-sample t-test was used. Each protein was tested separately by comparing its signal intensity values in two different conditions (2 replicates per chip; 2 chips for each tested condition). Thus four signal intensities were measured for each protein and each condition. 1000 permutations were performed (within rows, i.e., all values for each protein were shuffled) and permutation-based p-values were calculated based on the new t-scores. P-values lower than 0.01 were considered significant.

Degradation Assays

Coupled in vitro transcription and translation were performed from pCS2+ constructs using a rabbit reticulocyte lysate system (TnT SP6, Promega) or wheat germ extracts. ³⁵S-labelled substrates were added to G1 or CP extracts of synchronized HeLa S3 cells (see extract preparation). Aliquots were removed at 0, 30, 60, and 90 min and analyzed by SDS-PAGE (4–15%) and autoradiography. Additionally, endogenous protein levels (actin (Sigma), securin (Mbl), calmodulin (Upstate), and p27 (Upstate)) were determined in the extracts by Western blotting at the indicated times.

Results

The E2-conjugating enzyme, UbcH10, has been shown to overcome the metaphase-anaphase transition (16). After arresting cells in nocodazole, concentrated extracts (apprx

25mg/ml) were made and these retain the checkpoint state (CP extracts). It is known that addition of UbcH10 to a concentration of 5 uM (approx. 25 mg protein/ml) to nocodazole-arrested, concentrated cell extracts inactivates the metaphase state and leads to APC-dependant substrate degradation (17).

5 Extracts were prepared from synchronized HeLa S3 cells arrested in mitosis or in G1. CP extracts were divided into three aliquots; one was retained, one was supplemented with UbcH10, and the third received UbcH10 and an inhibitor of APC, emi1. The samples were placed on the protein microarray for 60 minutes at room temperature (Fig. 2B). In order to control for the activity of the extracts, an aliquot of each sample was removed and ³⁵S labeled-securin, a well-characterized APC substrate, was added to record its degradation (Fig. 2A). 10 Securin remained stable in CP extracts even after 60 minutes at room temperature (Fig. 2A, right panel) which is consistent with the inhibition of APC by the spindle checkpoint. CP extract supplemented with UbcH10 (CP-released) degraded securin rapidly while the addition of the APC inhibitor Emi1 (APC-inhibited) stabilized securin for at least sixty minutes. To label 15 modified proteins on the arrays, an anti-polyubiquitin antibody (FK1) was used (Fig. 5) with a Cy3-conjugated secondary antibody. Microarrays were then scanned and the median signal intensity and local background of each spot was measured. Fig. 2B illustrates the process and depicts one representative scanned subarray (out of 48 on each chip) and its reactivity.

20 Most of the spots in the microarray revealed a signal of low intensity or similar to the background level. Only 9-11% of the spots on each chip gave a positive signal after subtracting the local background intensity. Fig. 3A shows the distribution of the data of two representative chips under the CP-released (left panel) and APC-inhibited condition (right panel); the inset depicts the positive signal reactivity that was detected. A commonly accepted criterion for determining minimum signal (threshold) that can be accurately quantified is the measure of 25 Signal to Noise Ratio (SNR) where a higher SNR indicates higher signal over background noise; a signal-to-noise ratio of 3 is commonly considered the lower limit for accurate detection. Thus, the SNR ratio for every spot on the chip was calculated as follows: $SNR = (\text{signal mean} - \text{background mean}) / (\text{standard deviation of the background})$ (18). Even though the background signal within each microarray was variable (Fig. 6), the SNR per spot revealed a clear signal 30 (SNR>3) even for spots with a low signal intensity of about 1500 units (Fig. 7).

 The threshold level defining a significant polyubiquitination signal was determined using the signal from 96 'buffer' spots on each microarray. When subtracting the local background from the signal, 99% of the buffer spots on each chip gave a negative value (mean value of -

1130; see Fig. 8). The signal of thirteen known APC substrates was determined on each chip was compared with the signal of the 'buffer' spots located adjacent to them (i.e., in the same subarray). As shown in Fig. 3B, nine of these substrates appeared to have a signal that was significantly higher than the buffer spots ($p < 0.05$) but only five of them gave a positive signal. In order to reduce the potential false positive rate, only positive values were considered as reflecting real modification signals in this study.

To test the reproducibility of the assay and its ability to detect differential PTMs between different conditions, microarrays that were incubated with different extract preparations (biological replicates) were compared, and microarrays with extracts under different conditions (CP released vs. APC-inhibited) were also compared. Figure 3C depicts the scatter plots of the positive spot reactivities in each comparison (log scale). Visually the two different conditions (red dots) produced a signal that was more spread and variable compared to the biological replicates (black dots), which are closer to the diagonal. These distributions differ very significantly by statistical tests. Two microarrays were compared from each condition, and the p-value of the differences between corresponding proteins (each comprised of 4 spots) was calculated using a two-sample t-test. To control for the multiple hypothesis testing, the p-value determination was based on 1000 permutations (per protein) of the data. More than a hundred proteins yielded a significant p-value ($p < 0.01$); these proteins are listed in Table 4. While these proteins varied greatly in their attributed functions and cellular processes, several known APC substrates are among the significantly detected proteins, including all three aurora kinases. Given the state of knowledge of APC substrates it was to be expected that some new substrates should have been detected by this approach. Five proteins (Nek9, Calm2, RPS6KA4, cyclin G2 and p27) that were detected as differentially modified in these microarrays had previously been reported to play a role in mitosis. These five proteins, together with two proteins (Zap-70 and MAP3K11) that were not previously shown to be involved in mitosis, were selected for a biochemical assay to test their ability to serve as APC substrates. Zap-70 and MAP3K11 showed no detectable ubiquitination or degradation in the biochemical assay for mitosis dependent degradation. It should be noted that not all substrates would be expected to score in such an assay, due to lack of cofactors, poor folding, lack of posttranslational modification, or other factors, and therefore a negative result is not dispositive. However, Nek9, Calm2, RPS6KA4 and cyclin G2 proteins were found to be degraded in the CP extracts, and their degradation was inhibited by the addition of emi1 (Fig. 4A). Interestingly, p27 appeared to be degraded in the CP-released extracts as well; however, a longer exposure (Fig. 4B) revealed that the protein

accumulated polyubiquitin chains (causing a gel shift) and was not rapidly degraded (compare with the addition of the proteasome inhibitor MG-132). While the addition of emi1 did not inhibit completely the formation of ubiquitin chains, it appeared to yield a lower signal then seen in the CP-released extract; this conjugation might have occurred during the pre-incubation of the emi1 with the extracts. The endogenous level of calm2 and p27 in CP-released and APC-inhibited extracts was examined by Western blot. Both p27 and calm2 were degraded in the extracts from cells released into an anaphase-like state, and their degradation was inhibited by the addition of emi1.

5

Table 4

Protein Name	Accession	p-value
histone UNFRAC. WHOLE HISTONE - known Autoantigen		0.0002
ring finger protein 128 (RNF128) transcript variant 1	NM_194463.1	0.0004
erythrocyte membrane protein band 4.1 like 5	BC054508.1	0.0004
BC013173 Homo sapiens, clone MGC:17340	BC013173.1	0.0004
Clmodulin 2	NM_001743	0.0005
HTGN29 protein (HTGN29)	NM_020199.1	0.0006
ankyrin repeat domain 13	BC032833.2	0.0006
ribosomal protein S6 kinase 90kDa polypeptide 4 (RPS6KA4) transcript variant 2	NM_001006944.1	0.0007
macrophage stimulating 1 receptor (c-met-related tyrosine kinase) (MST1R)	NM_002447.1	0.0008
hypothetical protein FLJ11184	BC011842.2	0.0008
PCTAIRE protein kinase 2	BC033005.1	0.0008
aurora kinase A (AURKA) transcript variant 2	NM_003600.2	0.0009
dolichyl-phosphate mannosyltransferase polypeptide 2 regulatory subunit (DPM2) transcript variant 2	NM_152690.1	0.0009
ems1 sequence (mammary tumor and squamous cell carcinoma-associated (p80/85 src substrate) (EMS1)	NM_138565.1	0.0009
cytochrome P450 family 26 subfamily A polypeptide 1 (CYP26A1) transcript variant 2	NM_057157.1	0.0010
KIAA0157 protein (KIAA0157)	NM_032182.2	0.0010
solute carrier family 23 (nucleobase transporters) member 2	BC013112.2	0.0011
ring finger protein 111	BC060862.1	0.0011
additional sex combs like 1 (Drosophila)	BC064984.1	0.0012
cDNA clone MGC:39273 IMAGE:5440834	BC024289.1	0.0012
PAS domain containing serine/threonine kinase (PASK)	NM_015148.1	0.0013
YY1 transcription factor (YY1)	NM_003403.3	0.0013
proteasome (prosome macropain) 26S subunit non-ATPase 4 (PSMD4) transcript variant 1	NM_002810.1	0.0014
hypothetical protein LOC143458 (LOC143458)	NM_174902.2	0.0014

selectin ligand interactor cytoplasmic-1 (SLIC1) transcript variant 1	NM_153337.1	0.0015
MAX interacting protein 1 (MXI1) transcript variant 2	NM_130439.1	0.0015
neural precursor cell expressed developmentally down-regulated 8 (NEDD8)	NM_006156.1	0.0016
aurora kinase B (AURKB)	NM_004217.2	0.0016
src homology three (SH3) and cysteine rich domain	BC020221.1	0.0016
hypothetical protein DKFZp762O076 (DKFZp762O076)	NM_018710.1	0.0016
Nedd4 family interacting protein 1 (NDFIP1)	NM_030571.2	0.0016
hypothetical protein FLJ36175	BC029520.1	0.0017
EGF-like repeats and discoidin I-like domains 3	BC053656.1	0.0018
hypothetical protein MGC4618 (MGC4618)	NM_032326.1	0.0019
zeta-chain (TCR) associated protein kinase 70kDa (ZAP70) transcript variant 1	NM_001079.3	0.0019
ribosomal protein L30 (RPL30)	NM_000989.2	0.0019
feline sarcoma oncogene (FES)	NM_002005.2	0.0019
met proto-oncogene (hepatocyte growth factor receptor) (MET)	NM_000245.2	0.0021
ADP-ribosylation factor-like 7 (ARL7)	NM_005737.3	0.0022
Histone F2a2 H2a(f2a2) - known Autoantigen		0.0022
likely ortholog of mouse gene trap locus 3 (GTL3)	NM_013242.1	0.0022
immediate early response 3 (IER3) transcript variant short	NM_003897.2	0.0023
potassium voltage-gated channel shaker-related subfamily beta member 2 (KCNAB2)	NM_003636.1	0.0023
immunoglobulin heavy constant gamma 1 (G1m marker)	BC014667.1	0.0024
ring finger protein 4 (RNF4)	NM_002938.2	0.0025
proteasome (prosome macropain) 26S subunit non-ATPase 4 (PSMD4) transcript variant 2	NM_153822.1	0.0026
chromosome 6 open reading frame 145 (C6orf145)	NM_183373.2	0.0027
neurotrophic tyrosine kinase receptor type 1 (NTRK1) transcript variant 3	NM_001007792.1	0.0028
pleckstrin homology domain containing family G member 5 (PLEKHG5) transcript variant 1	NM_020631.2	0.0028
Sjogren syndrome antigen A1 (52kDa ribonucleoprotein autoantigen SS-A/Ro) (SSA1)	NM_003141.2	0.0028

interferon stimulated gene 20kDa (ISG20)	NM_002201.3	0.0028
WD repeat domain 45 (WDR45) transcript variant 1	NM_007075.3	0.0029
TANK-binding kinase 1 (TBK1)	NM_013254.2	0.0029
chromosome 16 open reading frame 5	BC002882.1	0.0030
insulin-like growth factor 1 receptor (IGF1R)	NM_000875.2	0.0030
ring finger protein 111	BC010369.1	0.0031
G protein-coupled receptor kinase 4 (GRK4) transcript variant 2	NM_001004056.1	0.0032
v-yes-1 Yamaguchi sarcoma viral related oncogene homolog (LYN)	NM_002350.1	0.0033
RAS-like family 10 member B	BC041133.1	0.0034
hypothetical protein MGC11257 (MGC11257)	NM_032350.3	0.0035
chromosome 7 open reading frame 2 (C7orf2)	NM_022458.2	0.0035
expressed in T-cells and eosinophils in atopic dermatitis (ETEA)	NM_014613.1	0.0036
mitogen-activated protein kinase kinase 11 (MAP3K11)	NM_002419.2	0.0036
casein kinase 1 alpha 1 (CSNK1A1) transcript variant 1	NM_001025105.1	0.0038
zeta-chain (TCR) associated protein kinase 70kDa transcript variant 1	BC053878.1	0.0038
hypothetical gene LOC128439 (LOC128439)	NM_139016.2	0.0038
hypothetical protein MGC17403 (MGC17403)	NM_152634.1	0.0039
N-glycanase 1 (NGLY1)	NM_018297.2	0.0039
signal recognition particle 19kDa	BC010947.1	0.0040
DNA fragmentation factor 40kDa beta polypeptide (caspase-activated DNase) (DFFB) transcript variant 3	NM_001004285.1	0.0040
casein kinase 1 delta (CSNK1D) transcript variant 1 Not full-length.	NM_001893.3	0.0042
dendritic cell-derived ubiquitin-like protein (DC-UbP)	NM_152277.1	0.0043
cDNA clone MGC:3432 IMAGE:2959461	BC013957.1	0.0043
DnaJ (Hsp40) homolog subfamily B member 12 (DNAJB12) transcript variant 1	NM_001002762.1	0.0043
solute carrier family 36 (proton/amino acid symporter) member 4	BC047374.1	0.0044
SMT3 suppressor of mif two 3 homolog 1 (yeast) (SUMO1) transcript variant 1	NM_003352.4	0.0044
similar to hypothetical protein FLJ25555	BC044239.1	0.0049
lysosomal-associated protein transmembrane 4 alpha (LAPTM4A)	NM_014713.2	0.0050
KIAA1458 protein	BC031691.2	0.0051

interleukin 17E (IL17E) transcript variant 1	NM_022789.2	0.0053
serum/glucocorticoid regulated kinase (SGK)	NM_005627.1	0.0053
hypothetical protein FLJ10156	BC005004.1	0.0054
thousand and one amino acid protein kinase (TAO1)	NM_004783.1	0.0054
ADP-ribosylation-like factor 6 interacting protein 4 (ARL6IP4)	NM_016638.1	0.0054
zinc finger protein 313 (ZNF313)	NM_018683.2	0.0055
solute carrier family 6 (neurotransmitter transporter) member 15	BC022253.1	0.0055
XM_378350.2	XM_378350.2	0.0057
low density lipoprotein receptor-related protein 10 (LRP10)	NM_014045.1	0.0060
arrestin domain containing 3 (ARRDC3)	NM_020801.1	0.0062
cyclin-dependent kinase inhibitor 1B (p27 Kip1) (CDKN1B)	NM_004064.2	0.0062
p53-regulated DDA3 (DDA3)	NM_032636.2	0.0065
calcium/calmodulin-dependent protein kinase IV (CAMK4)	NM_001744.2	0.0066
BC015569 Homo sapiens, Similar to SRp25 nuclear protein	BC015569.1	0.0066
chromosome 6 open reading frame 201 (C6orf201)	NM_206834.1	0.0067
tripartite motif-containing 52 (TRIM52)	NM_032765.1	0.0067
hypothetical protein FLJ38628 (FLJ38628)	NM_152267.2	0.0071
vasopressin-induced transcript	BC000877.1	0.0074
Ro-52 Ro-52 - known Autoantigen		0.0074
cyclin G2	BC032518.1	0.0076
mitogen-activated protein kinase kinase 6 (MAP2K6) transcript variant 2 ; mutant protein: MAP2K6 mutant	NM_031988.1	0.0077
conserved helix-loop-helix ubiquitous kinase (CHUK)	NM_001278.3	0.0078
aurora kinase C (AURKC) transcript variant 1	NM_001015878.1	0.0079
dual-specificity tyrosine-(Y)-phosphorylation regulated kinase 3 (DYRK3) transcript variant 2	NM_001004023.1	0.0080
cullin 3 (CUL3)	NM_003590.2	0.0080
hepatocyte growth factor-regulated tyrosine kinase substrate (HGS)	NM_004712.3	0.0084
B lymphoid tyrosine kinase (BLK)	NM_001715.2	0.0084
hypothetical protein MGC40579 (MGC40579)	NM_152776.1	0.0086

NIMA (never in mitosis gene a)- related kinase 9 (NEK9)	NM_033116.2	0.0086
solute carrier family 1 member 1 (SLC1A1) nuclear gene encoding mitochondrial protein	NM_004170.2	0.0086
Homo sapiens, SWI/SNF related, matrix associated, actin dependent regulator of chromatin, subfamily d, member 2	BC018953.1	0.0086
calcium binding protein 4	BC033167.1	0.0088
chromosome 19 open reading frame 28 (C19orf28)	NM_174983.2	0.0088
ubiquitin-activating enzyme E1-like (UBE1L)	NM_003335.2	0.0090
regenerating islet-derived 1 alpha (pancreatic stone protein pancreatic thread protein)	BC005350.1	0.0090
DnaJ (Hsp40) homolog subfamily B member 6 transcript variant 2	BC000177.2	0.0091
calcium/calmodulin-dependent protein kinase (CaM kinase) II beta (CAMK2B) transcript variant1	NM_001220.3	0.0093
ubiquitin-conjugating enzyme E2-like	BC064566.1	0.0094
melanoma antigen family B 1 (MAGEB1)	NM_002363.1	0.0097
secretory carrier membrane protein 3 (SCAMP3) transcript variant 1	NM_005698.2	0.0097
hypothetical protein LOC255330	BC042038.1	0.0099

EXAMPLE II

Ubiquitination of Human Brain Proteins in Alzheimer's Disease

Human brain specimens are collected from deceased human subjects at autopsy after
5 obtaining informed consent from the next of kin under protocols approved by the Partners
Human Research Committee at Brigham and Women's Hospital. Weighed frozen human
temporal or frontal cortices containing white and gray matter are added to freshly prepared, ice-
cold TBS (20 mM Tris-HCl, 150 mM NaCl, pH 7.4) at a ratio of 4:1 (TBS volume / brain wet
weight) and homogenized with 25 strokes at a setting of 10 on a mechanical Dounce
10 homogenizer. The homogenate is centrifuged at 175,000 x g in a TLA100.2 rotor on a Beckman
TL 100 centrifuge, and then the supernatant is aliquoted and stored at -80°C.

For analysis of ubiquitination, samples are thawed on ice, supplemented with 5 µM
ubiquitin, 2 mM ATP, and 150 mM creatine phosphate, and then incubated on a microarray to
carry out the ubiquitination reaction. Optionally, E1 and/or E2 enzymes can be added to the
15 extract, to determine if they are limiting the ubiquitination reaction.

EXAMPLE III

Protein Ubiquitination in Cerebrospinal Fluid (CSF) from a Patient with Brain Tumor

20 Undiluted CSF from a patient with brain tumor was analyzed for enzyme activity
responsible for PTM (ubiquitination) of human proteins. Conditions were similar to conditions
used for cellular extracts. An ATP regenerating system and ubiquitin were added to the CSF
sample, and the mixture was reacted with a protein microarray containing 8000 human proteins.
25 A control reaction contained the same CSF sample but was not supplemented with ubiquitin or
the energy mix.

A specific subset of proteins that are disproportionately expressed in brain (compared to
a background of all the proteins that were on the chip) were found to be ubiquitinated (i.e.,
showed at least 2.5-fold higher signal than in the control), as shown in Fig. 11. The proteins that
underwent CSF-mediated ubiquitination were distinct from background modification seen under
30 control conditions. The functional annotation categories (gene ontology ('GO') terms) of these
proteins were analyzed using the FatiGO online tool. List #1 shown in Fig. 11 holds the
accession numbers for proteins that were highly ubiquitinated in comparison to the control (i.e.

predicted list). List #2 holds the accession numbers of all the proteins on the microarray (i.e. background list). The 'GO' terms that are labeled with an asterisk (*) were shown to be enriched in this analysis, and the percentages of their appearance in the predicted list and in the background list is given in the third column. For comparison, terms associated with stress response (second row) showed no difference percentage of appearance in the ubiquitinated list when compared to the background list.

EXAMPLE IV

Analysis of Protein Ubiquitination in Normal Human Cerebrospinal Fluid (CSF) Sample

The ubiquitinating activity in a normal human CSF sample was tested by Western blotting. The ubiquitination reaction was started by adding an ATP regenerating system (2 mM ATP and 150 mM creatine phosphate) and ubiquitin (5 μ M) to an aliquot of the CSF sample, and the reaction was run for 1 hour at 30°C. After the reaction was completed, the reaction mixture was subjected to SDS-PAGE and detection was performed with an anti-polyubiquitin antibody (FK1, Biomol). The results are shown in Fig. 12. There was a high molecular weight smear of ubiquitinated proteins in the reaction that included CSF and added ubiquitin, as compared to negative controls (CSF treated at 95°C for 5 min or ubiquitin omitted).

Next, the ubiquitinating activity of CSF was tested by allowing it to ubiquitinate proteins in a human protein microarray. The CSF sample was supplemented with 2 mM ATP and 150 mM creatine phosphate and ubiquitin (5 μ M). The sample was then incubated on a Human ProtoArray® (Invitrogen) protein microarray in order to identify the basal ubiquitination activity in the sample. After incubation of the samples on the arrays for 60 min at 25°C, the activity was stopped by washing the microarrays with TBS containing 0.05% Tween-20, and the modified proteins were identified using a first antibody specific for the polyubiquitinated state, and a second antibody (DyLight 649-conjugated goat anti-mouse IgM with minimal cross-reactivity to human, (catalog # 115-495-075), Jackson ImmunoResearch) directed to the first antibody. The second antibody carried a fluorescent label (DyLight 649) for detection. The signal intensity of each spot in the microarray (reflecting the ubiquitination of the protein on that spot) was used to statistically identify ubiquitinated proteins (i.e., those spots having signal statistically significant over background fluorescence or a control spot). Ubiquitinated proteins in the array showed a difference of between 2- and 50-fold compared to a control reaction without added CSF (Fig.

13). The number of proteins that met the criteria ranged from 12 to 485 proteins in one CSF sample (lower line, ●) and from 10 to 265 in the other (upper line, +). Fig. 14 presents a list of proteins that showed increased modification signal in each of the two CSF samples at a level of more than 50-fold when compared to the control (non-CSF) reaction, together with the fluorescence intensity of four spots for each protein. The scale indicates the value (log transformed) of each of the 4 duplicate spots of these proteins (2 microarrays; 2 spots per microarray, lanes 1-4) compared to the values on the control array on the right (lanes 5-6). A colorbar is given on the right (blue (bottom of the scale), low reactivity; red (top of the scale), high reactivity). A list of proteins that showed at least a 50-fold increase in their level of ubiquitination by the CSF (vs. no CSF) is presented in Table 5.

Table 5

Accession	Protein Description
NM_006259	S100 calcium binding protein A14 (S100A14), mRNA
NM_020672	Williams Beuren syndrome chromosome region 22, mRNA (cDNA clone MGC:2022 IMAGE:3544156)
BC001780	zinc finger CCCH-type containing 10 (ZC3H10), mRNA
NM_032786	chemokine (C-X-C motif) ligand 11 (CXCL11), mRNA
NM_032357	ankyrin repeat and BTB (POZ) domain containing 1 (ABTB1), transcript variant 1, mRNA
NM_006597	interleukin 1, alpha (IL1A), mRNA
NM_032548	v-akt murine thymoma viral oncogene homolog 3 (protein kinase B, gamma) (AKT3), transcript variant 1, mRNA
NM_174902	serine carboxypeptidase 1, mRNA (cDNA clone IMAGE:4328599), partial cds
NM_000961	v-raf murine sarcoma 3611 viral oncogene homolog (ARAF), mRNA
NM_002609	tec protein tyrosine kinase (TEC), mRNA
NM_025160	myotilin (MYOT), transcript variant 1, mRNA
NM_017881	platelet-derived growth factor receptor, beta polypeptide (PDGFRB), mRNA
NM_033505	SEI1 selenoprotein I (SLE1)

EXAMPLE V

Proteins Modified With Ubiquitin-Like Modifiers Upon Mitotic Release

The PTM of human proteins in a microarray was studied using functional cell extracts from HeLa S3 cells obtained after release from the mitotic checkpoint (CP). Growth, cell cycle modulation, preparation of extracts of the cells, and microarray measurements were as described in Example 1. Separate reactions were performed using each of the following modifying moieties (ubiquitin-like modifiers): ubiquitin, sumo1, sumo2/3, FAT10, UFM1, and ISG15.

Table 1 describes further details of selected ubiquitin-like modifiers. In each case, the cell extract was supplemented with energy mix plus 5 μ M of the respective modifying moiety.

Checkpoint extracts from HeLa S3 cells arrested with nocodazole were divided into two aliquots, one was denoted as the checkpoint-arrested extract (CP-arrested), and one was supplemented with UbcH10 to relieve the checkpoint arrest (CP-released). Microarrays were incubated with these extracts to allow the proteins on the array to be modified. Each microarray contained approximately 8000 proteins spotted in duplicates at a reported level of around 10 pg per spot (median diameter approximately 150 μ m). After washing the reaction off the microarray, an antibody specific to the modifying moiety used in the reaction was added to detect modified proteins on the microarray. Microarrays were scanned, and the median signal intensity and local background of each spot was measured. Then, the anti-modifier antibody was detected by adding a fluorescently-labeled secondary antibody. Microarrays were scanned and the median signal intensity and local background of each spot was measured. The data were then organized in a matrix where each column contains the reactivity measured for a given array, and each row contains the reactivity measured for a given protein over all arrays. The negative values were set to zero, and the data were then normalized using a quantile normalization algorithm. Table 6 summarizes the proteins that were either differentially modified in anaphase over metaphase or were highly modified. The highly modified (but not differentially modified) proteins are indicated with an asterisk, and the remaining proteins were differentially modified.

TABLE 6		
Ubiquitin		
GenBank Accession	Gene Symbol	Name
BC001396	C9ORF32	CHROMOSOME 9 OPEN READING FRAME 32
BC004967	UBAC1	UBIQUITIN ASSOCIATED DOMAIN CONTAINING 1
BC007581	ALDH4A1	ALDEHYDE DEHYDROGENASE 4 FAMILY, MEMBER A1
BC008720	CRELD1	DKFZP566D213 PROTEIN
BC010369	RNF111	RING FINGER PROTEIN 111
BC011399	SYK	SPLEEN TYROSINE KINASE
BC013173	RSPRY1	RING FINGER AND SPRY DOMAIN CONTAINING 1
BC015219	RBCK1	CHROMOSOME 20 OPEN READING FRAME 18
BC020221	STAC	SH3 AND CYSTEINE RICH DOMAIN
BC021988	NDFIP2	NEDD4 FAMILY INTERACTING PROTEIN 2
BC032518	CCNG2	CYCLIN G2
BC036540	LOC400120	HYPOTHETICAL LOC400120
BC041133	RASL10B	RAS-LIKE, FAMILY 10, MEMBER B
BC044239	ANKRD13D	ANKYRIN REPEAT DOMAIN 13 FAMILY, MEMBER D
BC046151	TOM1	TARGET OF MYB1 (CHICKEN)
BC048970	TTLL7	TUBULIN TYROSINE LIGASE-LIKE FAMILY, MEMBER 7
BC056240	SPRR1B	SMALL PROLINE-RICH PROTEIN 1B (CORNIFIN)
BC066340	BLOC1S1	BIOGENESIS OF LYSOSOME-RELATED ORGANELLES COMPLEX-1, SUBUNIT 1
NM_000875	IGF1R	INSULIN-LIKE GROWTH FACTOR 1 RECEPTOR
NM_001004056	GRK4	G PROTEIN-COUPLED RECEPTOR KINASE 4
NM_001220	CAMK2B	CALCIUM/CALMODULIN-DEPENDENT PROTEIN KINASE (CAM KINASE) II BETA
NM_002103	GYS1	GLYCOGEN SYNTHASE 1 (MUSCLE)
NM_002378	MATK	MEGAKARYOCYTE-ASSOCIATED TYROSINE KINASE
NM_002648	PIM1	PIM-1 ONCOGENE
NM_002810	PSMD4	PROTEASOME (PROSOME, MACROPAIN) 26S SUBUNIT, NON-ATPASE, 4
NM_003045	SLC7A1	SOLUTE CARRIER FAMILY 7 (CATIONIC AMINO ACID TRANSPORTER, Y+

		SYSTEM), MEMBER 1
NM_003403	YY1	YY1 TRANSCRIPTION FACTOR
NM_004438	EPHA4	EPH RECEPTOR A4
NM_004712	HGS	HEPATOCYTE GROWTH FACTOR-REGULATED TYROSINE KINASE SUBSTRATE
NM_004783	TAOK2	TAO KINASE 2
NM_005030	PLK1	POLO-LIKE KINASE 1 (DROSOPHILA)
NM_005727	TSPAN1	TETRASPANIN 1
NM_005737	ARL4C	ADP-RIBOSYLATION FACTOR-LIKE 4C
NM_006007	ZFAND5	ZINC FINGER, A20 DOMAIN CONTAINING 2
NM_006293	TYRO3	TYRO3 PROTEIN TYROSINE KINASE
NM_013242	C16ORF80	GENE TRAP LOCUS 3 (MOUSE)
NM_018215	FLJ10781	HYPOTHETICAL PROTEIN FLJ10781
NM_018384	GIMAP5	GTPASE, IMAP FAMILY MEMBER 5
NM_022905	TTC23	TETRATRICOPEPTIDE REPEAT DOMAIN 23
NM_032182	KIAA0157	KIAA0157
NM_032765	TRIM52	TRIPARTITE MOTIF-CONTAINING 52
NM_080823	SRMS	SRC-RELATED KINASE LACKING C-TERMINAL REGULATORY TYROSINE AND N-TERMINAL MYRISTYLATION SITES
NM_130439	MXI1	MAX INTERACTOR 1
NM_152285	ARRDC1	ARRESTIN DOMAIN CONTAINING 1
NM_153217	TMEM174	HYPOTHETICAL PROTEIN MGC13034
NM_153822	PSMD4	PROTEASOME (PROSOME, MACROPAIN) 26S SUBUNIT, NON-ATPASE, 4
NM_173541	C10ORF91	CHROMOSOME 10 OPEN READING FRAME 91
NM_194271	RNF34	RING FINGER PROTEIN 34
BC016381	NA	NA
BC004967*	UBAC1	UBIQUITIN ASSOCIATED DOMAIN CONTAINING 1
BC010369*	RNF111	RING FINGER PROTEIN 111
BC014475*	BIRC7	LIVIN INHIBITOR-OF-APOTOSIS
BC015569*	ARL6IP4	ADP-RIBOSYLATION-LIKE FACTOR 6 INTERACTING PROTEIN 4
BC021988*	NDFIP2	NEDD4 FAMILY INTERACTING PROTEIN 2
BC023982*	C5ORF32	PUTATIVE NUCLEAR PROTEIN ORF1-FL49
BC025700*	AFF4	AF4/FMR2 FAMILY, MEMBER 4
BC044239*	ANKRD13D	ANKYRIN REPEAT DOMAIN 13 FAMILY, MEMBER D
BC053895*	IRS1	INSULIN RECEPTOR SUBSTRATE 1
BC054049*	ZNF364	ZINC FINGER PROTEIN 364
BC060833*	PRRG1	PROLINE RICH GLA (G-CARBOXYGLUTAMIC ACID) 1
NM_001033551*	TOM1L2	TARGET OF MYB1-LIKE 2 (CHICKEN)
NM_002019*	FLT1	FMS-RELATED TYROSINE KINASE 1 (VASCULAR ENDOTHELIAL GROWTH

		FACTOR/VASCULAR PERMEABILITY FACTOR RECEPTOR)
NM_002110*	HCK	HEMOPOIETIC CELL KINASE
NM_002253*	KDR	KINASE INSERT DOMAIN RECEPTOR (A TYPE III RECEPTOR TYROSINE KINASE)
NM_002938*	RNF4	RING FINGER PROTEIN 4
NM_002944*	ROS1	V-ROS UR2 SARCOMA VIRUS ONCOGENE HOMOLOG 1 (AVIAN)
NM_002946*	RPA2	REPLICATION PROTEIN A2, 32KDA
NM_005053*	RAD23A	RAD23 HOMOLOG A (S. CEREVISIAE)
NM_005228*	EGFR	EPIDERMAL GROWTH FACTOR RECEPTOR (ERYTHROBLASTIC LEUKEMIA VIRAL (V- ERB-B) ONCOGENE HOMOLOG, AVIAN)
NM_012478*	WBP2	WW DOMAIN BINDING PROTEIN 2
NM_017949*	CUEDC1	CUE DOMAIN CONTAINING 1
NM_020182*	TMEPAI	TRANSMEMBRANE, PROSTATE ANDROGEN INDUCED RNA
NM_020630*	RET	RET PROTO-ONCOGENE (MULTIPLE ENDOCRINE NEOPLASIA AND MEDULLARY THYROID CARCINOMA 1, HIRSCHSPRUNG DISEASE)
NM_030636*	EEPD1	KIAA1706 PROTEIN
NM_130465*	TSPAN17	TETRASPANIN 17
NM_152267*	RNF185	RING FINGER PROTEIN 185
NM_153229*	TMEM92	TRANSMEMBRANE PROTEIN 92
NM_153345*	TMEM139	HYPOTHETICAL PROTEIN FLJ90586
NM_194271*	RNF34	RING FINGER PROTEIN 34
Sumo2/3		
GenBank Accession	Gene Symbol	Name
NM_014805	EPM2AIP1	EPM2A (LAFORIN) INTERACTING PROTEIN 1
NM_177974	CASC4	CANCER SUSCEPTIBILITY CANDIDATE 4
BC017789	CHORDC1	CYSTEINE AND HISTIDINE-RICH DOMAIN (CHORD) -CONTAINING 1
NM_018393	TCP11L1	T-COMPLEX 11 (MOUSE) LIKE 1
NM_017588	WDR5	WD REPEAT DOMAIN 5
BC056402	LOC144097	HYPOTHETICAL PROTEIN BC007540
NM_003697	OR5F1	OLFACTORY RECEPTOR, FAMILY 5, SUBFAMILY F, MEMBER 1
NM_014868	RNF10	RING FINGER PROTEIN 10
NM_016269	LEF1	LYMPHOID ENHANCER-BINDING FACTOR 1
BC014475	BIRC7	LIVIN INHIBITOR-OF-APOTOSIS
BC009207	HIC2	HYPERMETHYLATED IN CANCER 2
NM_031845	MAP2	MICROTUBULE-ASSOCIATED PROTEIN 2
BC020523	INTS7	CHROMOSOME 1 OPEN READING FRAME 73
NM_018679	TCP11	T-COMPLEX 11 (MOUSE)
NM_019087	ARL15	ADP-RIBOSYLATION FACTOR-LIKE 15

BC043247	TLE3	TRANSDUCIN-LIKE ENHANCER OF SPLIT 3 (E(SP1) HOMOLOG, DROSOPHILA)
BC002677	AHDC1	AT HOOK, DNA BINDING MOTIF, CONTAINING 1
NM_003403	YY1	YY1 TRANSCRIPTION FACTOR
BC039583	MGEA5	MENINGIOMA EXPRESSED ANTIGEN 5 (HYALURONIDASE)
NM_015148	PASK	PAS DOMAIN CONTAINING SERINE/THREONINE KINASE
BC010125	C3ORF37	CHROMOSOME 3 OPEN READING FRAME 37
NM_001786	CDC2	CELL DIVISION CYCLE 2, G1 TO S AND G2 TO M
BC005008	CEACAM6	CARCINOEMBRYONIC ANTIGEN-RELATED CELL ADHESION MOLECULE 6 (NON-SPECIFIC CROSS REACTING ANTIGEN)
NM_144706	C2ORF15	CHROMOSOME 2 OPEN READING FRAME 15
NM_007277	EXOC3	EXOCYST COMPLEX COMPONENT 3
NM_002648	PIM1	PIM-1 ONCOGENE
NM_002019	FLT1	FMS-RELATED TYROSINE KINASE 1 (VASCULAR ENDOTHELIAL GROWTH FACTOR/VASCULAR PERMEABILITY FACTOR RECEPTOR)
NM_152619	DCLK2	DOUBLECORTIN AND CAM KINASE-LIKE 2
BC022253	SLC6A15	SOLUTE CARRIER FAMILY 6, MEMBER 15
NM_017949	CUEDC1	CUE DOMAIN CONTAINING 1
NM_006002	UCHL3	UBIQUITIN CARBOXYL-TERMINAL ESTERASE L3 (UBIQUITIN THIOLESTERASE)
NM_001278	CHUK	CONSERVED HELIX-LOOP-HELIX UBIQUITOUS KINASE
NM_001219	CALU	CALUMENIN
BC050645	BYSL	BYSTIN-LIKE
BC040272	IL16	INTERLEUKIN 16 (LYMPHOCYTE CHEMOATTRACTANT FACTOR)
BC023152	GYG2	GLYCOGENIN 2
NM_002011	FGFR4	FIBROBLAST GROWTH FACTOR RECEPTOR 4
BC024725	ANKRD50	ANKYRIN REPEAT DOMAIN 50
NM_138353	LOC90379	HYPOTHETICAL PROTEIN BC002926
BC061697	C3ORF62	CHROMOSOME 3 OPEN READING FRAME 62
NM_015417	SPEF1	CHROMOSOME 20 OPEN READING FRAME 28
NM_181707	C17ORF64	CHROMOSOME 17 OPEN READING FRAME 64
NM_199334	THRA	THYROID HORMONE RECEPTOR, ALPHA (ERYTHROBLASTIC LEUKEMIA VIRAL (V-ERB-A) ONCOGENE HOMOLOG, AVIAN)
BC060760	GIMAP6	IMMUNE ASSOCIATED NUCLEOTIDE 2
NM_002738	PRKCB1	PROTEIN KINASE C, BETA 1

BC000247	THAP4	THAP DOMAIN CONTAINING 4
BC013567	USP48	HYPOTHETICAL PROTEIN FLJ11328
NM_198498	C11ORF53	CHROMOSOME 11 OPEN READING FRAME 53
BC012289	KIAA0515	KIAA0515 PROTEIN
BC004219	AGPAT3	1-ACYLGLYCEROL-3-PHOSPHATE O-ACYLTRANSFERASE 3
NM_130766	SKIP	SKELETAL MUSCLE AND KIDNEY ENRICHED INOSITOL PHOSPHATASE
NM_001328	CTBP1	C-TERMINAL BINDING PROTEIN 1
BC058861	SULT1C4	SULFOTRANSFERASE FAMILY, CYTOSOLIC, 1C, MEMBER 2
BC046117	DNALI1	DYNEIN, AXONEMAL, LIGHT INTERMEDIATE POLYPEPTIDE 1
NM_032017	STK40	SERINE/THREONINE KINASE 40
NM_173822	FAM126B	HYPOTHETICAL PROTEIN MGC39518
BC032120	C20ORF11	CHROMOSOME 20 OPEN READING FRAME 11
NM_001556	IKBKB	INHIBITOR OF KAPPA LIGHT POLYPEPTIDE GENE ENHANCER IN B-CELLS, KINASE BETA
NM_032014	MRPS24	MITOCHONDRIAL RIBOSOMAL PROTEIN S24
NM_145796	POGZ	POGO TRANSPOSABLE ELEMENT WITH ZNF DOMAIN
NM_001042599	ERBB4	
NM_017629	EIF2C4	ARGONAUTE 4
NM_032846	RAB2B	RAB2B, MEMBER RAS ONCOGENE FAMILY
BC011234	SMNDC1	SURVIVAL MOTOR NEURON DOMAIN CONTAINING 1
NM_017583	TRIM44	TRIPARTITE MOTIF-CONTAINING 44
NM_005639	SYT1	SYNAPTOTAGMIN I
NM_016954	TBX22	T-BOX 22
NM_002796	PSMB4	PROTEASOME (PROSOME, MACROPAIN) SUBUNIT, BETA TYPE, 4
NM_000666	ACY1	AMINOACYLASE 1
NM_032326	TMEM175	HYPOTHETICAL PROTEIN MGC4618
NM_001197	BIK	BCL2-INTERACTING KILLER (APOPTOSIS-INDUCING)
NM_170672	RASGRP3	RAS GUANYL RELEASING PROTEIN 3 (CALCIUM AND DAG-REGULATED)
BC017357	ZNF765	HYPOTHETICAL PROTEIN BC001610
BC020233	IGLC2	IMMUNOGLOBULIN LAMBDA CONSTANT 1 (MCG MARKER)
BC059374	STK31	SERINE/THREONINE KINASE 31
NM_014248	RBX1	RING-BOX 1
NM_005158	ABL2	V-ABL ABELSON MURINE LEUKEMIA VIRAL ONCOGENE HOMOLOG 2 (ARG, ABELSON-RELATED GENE)

NM_018668	VPS33B	VACUOLAR PROTEIN SORTING 33B (YEAST)
BC063451	TCP10L2	T-COMPLEX 10 (MOUSE)
NM_002623	PFDN4	PREFOLDIN SUBUNIT 4
BC016652	BMX	BMX NON-RECEPTOR TYROSINE KINASE
NM_153486	LDHD	LACTATE DEHYDROGENASE D
NM_033307	CASP4	CASPASE 4, APOPTOSIS-RELATED CYSTEINE PEPTIDASE
NM_004113	FGF12	FIBROBLAST GROWTH FACTOR 12
NM_005148	UNC119	UNC-119 HOMOLOG (C. ELEGANS)
NM_004838	HOMER3	HOMER HOMOLOG 3 (DROSOPHILA)
NM_016355	DDX47	DEAD (ASP-GLU-ALA-ASP) BOX POLYPEPTIDE 47
NM_014548	TMOD2	TROPOMODULIN 2 (NEURONAL)
BC016964	MRGPRF	MAS-RELATED GPR, MEMBER F
BC029220	SOX5	SRY (SEX DETERMINING REGION Y) -BOX 5
BC030711	C2ORF13	CHROMOSOME 2 OPEN READING FRAME 13
NM_001571	IRF3	INTERFERON REGULATORY FACTOR 3
BC031830	KLHL32	KIAA1900
NM_153498	CAMK1D	CALCIUM/CALMODULIN-DEPENDENT PROTEIN KINASE ID
NM_144602	C16ORF78	HYPOTHETICAL PROTEIN MGC32905
NM_012325	MAPRE1	MICROTUBULE-ASSOCIATED PROTEIN, RP/EB FAMILY, MEMBER 1
BC057840	PSMB5	PROTEASOME (PROSOME, MACROPAIN) SUBUNIT, BETA TYPE, 5
NM_079422	MYL1	MYOSIN, LIGHT POLYPEPTIDE 1, ALKALI; SKELETAL, FAST
BC029267	MUC20	MUCIN 20
NM_020830	WDFY1	WD REPEAT AND FYVE DOMAIN CONTAINING 1
NM_033003	GTF2I	
BC009571	STRA13	STIMULATED BY RETINOIC ACID 13 HOMOLOG (MOUSE)
NM_005030	PLK1	POLO-LIKE KINASE 1 (DROSOPHILA)
NM_022754	SFXN1	LIKELY ORTHOLOG OF MOUSE SIDEROFLEXIN 1
BC012997	SULF1	SULFATASE 1
NM_001221	CAMK2D	CALCIUM/CALMODULIN-DEPENDENT PROTEIN KINASE (CAM KINASE) II DELTA
BC031691	SLAIN2	KIAA1458 PROTEIN
NM_014840	NUAK1	NUAK FAMILY, SNF1-LIKE KINASE, 1
BC001772	QARS	GLUTAMINYL-TRNA SYNTHETASE
NM_032693	ARD1B	
BC025314	IGHG1	IMMUNOGLOBULIN HEAVY CONSTANT GAMMA 1 (G1M MARKER)
BC033491	ADAD2	TESTIS NUCLEAR RNA-BINDING

		PROTEIN-LIKE
BC009650	PDS5A	SCC-112 PROTEIN
NM_018326	GIMAP4	GTPASE, IMAP FAMILY MEMBER 4
NM_005239	ETS2	V-ETS ERYTHROBLASTOSIS VIRUS E26 ONCOGENE HOMOLOG 2 (AVIAN)
NM_006257	PRKCQ	PROTEIN KINASE C, THETA
NM_152667	NANP	N-ACETYLNEURAMINIC ACID PHOSPHATASE
BC001728*	TFPT	TCF3 (E2A) FUSION PARTNER (IN CHILDHOOD LEUKEMIA)
BC001772*	QARS	GLUTAMINYL-TRNA SYNTHETASE
BC007048*	ZMYM5	ZINC FINGER, MYM-TYPE 5
BC010125*	C3ORF37	CHROMOSOME 3 OPEN READING FRAME 37
BC017314*	ETS1	V-ETS ERYTHROBLASTOSIS VIRUS E26 ONCOGENE HOMOLOG 1 (AVIAN)
BC020985*	COASY	COENZYME A SYNTHASE
BC036572*	ZCCHC12	ZINC FINGER, CCHC DOMAIN CONTAINING 12
BC040949*	MEF2D	MADS BOX TRANSCRIPTION ENHANCER FACTOR 2, POLYPEPTIDE D (MYOCYTE ENHANCER FACTOR 2D)
BC056402*	LOC144097	HYPOTHETICAL PROTEIN BC007540
BC056415*	RPAP3	HYPOTHETICAL PROTEIN FLJ21908
NM_001014796*	DDR2	DISCOIDIN DOMAIN RECEPTOR FAMILY, MEMBER 2
NM_001039468*	MARK2	MAP/MICROTUBULE AFFINITY- REGULATING KINASE 2
NM_001786*	CDC2	CELL DIVISION CYCLE 2, G1 TO S AND G2 TO M
NM_001910*	CTSE	CATHEPSIN E
NM_002378*	MATK	MEGAKARYOCYTE-ASSOCIATED TYROSINE KINASE
NM_002497*	NEK2	NIMA (NEVER IN MITOSIS GENE A) - RELATED KINASE 2
NM_002938*	RNF4	RING FINGER PROTEIN 4
NM_003141*	TRIM21	TRIPARTITE MOTIF-CONTAINING 21
NM_006257*	PRKCQ	PROTEIN KINASE C, THETA
NM_006259*	PRKG2	PROTEIN KINASE, CGMP-DEPENDENT, TYPE II
NM_006937*	SUMO2	SMT3 SUPPRESSOR OF MIF TWO 3 HOMOLOG 2 (YEAST)
NM_015981*	CAMK2A	CALCIUM/CALMODULIN-DEPENDENT PROTEIN KINASE (CAM KINASE) II ALPHA
NM_016058*	TPRKB	TP53RK BINDING PROTEIN
NM_017838*	NOLA2	NUCLEOLAR PROTEIN FAMILY A, MEMBER 2 (H/ACA SMALL NUCLEOLAR RNPS)
NM_021709*	SIVA1	CD27-BINDING (SIVA) PROTEIN
NM_032752*	ZNF496	ZINC FINGER PROTEIN 496

NM_130807*	MOBK12A	MOB1, MPS ONE BINDER KINASE ACTIVATOR-LIKE 2A (YEAST)
NM_145173*	DIRAS1	DIRAS FAMILY, GTP-BINDING RAS-LIKE 1
NM_175907*	ZADH2	HYPOTHETICAL PROTEIN BC010734
NM_033003*	NA	NA
Nedd8		
GenBank Accession	Gene Symbol	Name
BC000178	KCMF1	POTASSIUM CHANNEL MODULATORY FACTOR 1
BC000395	LETMD1	LETM1 DOMAIN CONTAINING 1
BC001852	THG1L	INTERPHASE CYCTOPLASMIC FOCI PROTEIN 45
BC002526	HSPA4	HEAT SHOCK 70KDA PROTEIN 4
BC007312	KIRREL2	KIN OF IRRE LIKE 2 (DROSOPHILA)
BC009074	C8ORF70	CHROMOSOME 8 OPEN READING FRAME 70
BC009485	C4ORF16	CHROMOSOME 4 OPEN READING FRAME 16
BC012945	C19ORF57	HYPOTHETICAL PROTEIN MGC11271
BC018953	SMARCD2	SWI/SNF RELATED, MATRIX ASSOCIATED, ACTIN DEPENDENT REGULATOR OF CHROMATIN, SUBFAMILY D, MEMBER 2
BC020658	TMEM40	TRANSMEMBRANE PROTEIN 40
BC038504	SNF1LK	SNF1-LIKE KINASE
BC050696	C12ORF48	CHROMOSOME 12 OPEN READING FRAME 48
BC051849	RPAIN	RPA INTERACTING PROTEIN
BC062736	CTD-2090I13.4	BASIC TRANSCRIPTION FACTOR 3, PSEUDOGENE 9
NM_004235	KLF4	KRUPPEL-LIKE FACTOR 4 (GUT)
NM_004391	CYP8B1	CYTOCHROME P450, FAMILY 8, SUBFAMILY B, POLYPEPTIDE 1
NM_005206	CRK	V-CRK SARCOMA VIRUS CT10 ONCOGENE HOMOLOG (AVIAN)
NM_005651	TDO2	TRYPTOPHAN 2,3-DIOXYGENASE
NM_006251	PRKAA1	PROTEIN KINASE, AMP-ACTIVATED, ALPHA 1 CATALYTIC SUBUNIT
NM_012328	DNAJB9	DNAJ (HSP40) HOMOLOG, SUBFAMILY B, MEMBER 9
NM_013442	STOML2	STOMATIN (EPB72)-LIKE 2
NM_014878	KIAA0020	KIAA0020
NM_018014	BCL11A	B-CELL CLL/LYMPHOMA 11A (ZINC FINGER PROTEIN)
NM_019895	CLNS1A	CHLORIDE CHANNEL, NUCLEOTIDE-SENSITIVE, 1A
NM_021803	IL21	INTERLEUKIN 21
NM_152443	RDH12	RETINOL DEHYDROGENASE 12 (ALL-TRANS AND 9-CIS)

BC051366	NA	NA
BC005008*	CEACAM6	CARCINOEMBRYONIC ANTIGEN-RELATED CELL ADHESION MOLECULE 6 (NON-SPECIFIC CROSS REACTING ANTIGEN)
BC006323*	ABCB7	ATP-BINDING CASSETTE, SUB-FAMILY B (MDR/TAP), MEMBER 7
BC011707*	NRBF2	NUCLEAR RECEPTOR BINDING FACTOR 2
BC012109*	HOMER2	HOMER HOMOLOG 2 (DROSOPHILA)
BC020985*	COASY	COENZYME A SYNTHASE
BC021906*	FMNL1	FORMIN-LIKE 1
BC053895*	IRS1	INSULIN RECEPTOR SUBSTRATE 1
BC056669*	DCUN1D2	DCN1, DEFECTIVE IN CULLIN NEDDYLLATION 1, DOMAIN CONTAINING 2 (S. CEREVISIAE)
BC058924*	UBE2M	UBIQUITIN-CONJUGATING ENZYME E2M (UBC12 HOMOLOG, YEAST)
NM_001004105*	GRK6	G PROTEIN-COUPLED RECEPTOR KINASE 6
NM_001039468*	MARK2	MAP/MICROTUBULE AFFINITY-REGULATING KINASE 2
NM_001798*	CDK2	CYCLIN-DEPENDENT KINASE 2
NM_001895*	CSNK2A1	CASEIN KINASE 2, ALPHA 1 POLYPEPTIDE
NM_003141*	TRIM21	TRIPARTITE MOTIF-CONTAINING 21
NM_003668*	MAPKAPK5	MITOGEN-ACTIVATED PROTEIN KINASE-ACTIVATED PROTEIN KINASE 5
NM_005019*	PDE1A	PHOSPHODIESTERASE 1A, CALMODULIN-DEPENDENT
NM_005038*	PPID	PEPTIDYLPROLYL ISOMERASE D (CYCLOPHILIN D)
NM_006156*	NEDD8	NEURAL PRECURSOR CELL EXPRESSED, DEVELOPMENTALLY DOWN-REGULATED 8
NM_012247*	SEPHS1	SELENOPHOSPHATE SYNTHETASE 1
NM_012325*	MAPRE1	MICROTUBULE-ASSOCIATED PROTEIN, RP/EB FAMILY, MEMBER 1
NM_015417*	SPEF1	CHROMOSOME 20 OPEN READING FRAME 28
NM_016058*	TPRKB	TP53RK BINDING PROTEIN
NM_018014*	BCL11A	B-CELL CLL/LYMPHOMA 11A (ZINC FINGER PROTEIN)
NM_022754*	SFXN1	LIKELY ORTHOLOG OF MOUSE SIDEROFLEXIN 1
NM_030662*	MAP2K2	MITOGEN-ACTIVATED PROTEIN KINASE KINASE 2
NM_032141*	CCDC55	COILED-COIL DOMAIN CONTAINING 55
NM_130439*	MXI1	MAX INTERACTOR 1
NM_138559*	BCL11A	B-CELL CLL/LYMPHOMA 11A (ZINC FINGER PROTEIN)
NM_175907*	ZADH2	HYPOTHETICAL PROTEIN BC010734

NM_212535*	PRKCB1	PROTEIN KINASE C, BETA 1
FAT10		
GenBank Accession	Gene Symbol	Full Name
NM_005737	ARL4C	ADP-RIBOSYLATION FACTOR-LIKE 4C
BC013648	EFHD2	EF-HAND DOMAIN FAMILY, MEMBER D2
BC031247	CCDC67	COILED-COIL DOMAIN CONTAINING 67
NM_015621	CCDC69	COILED-COIL DOMAIN CONTAINING 69
NM_024099	C11ORF48	CHROMOSOME 11 OPEN READING FRAME 48
NM_016951	CKLF	CHEMOKINE-LIKE FACTOR
BC008919	TBC1D9B	KIAA0676 PROTEIN
NM_032855	HSH2D	HEMATOPOIETIC SH2 DOMAIN CONTAINING
NM_152788	ANKS1B	ANKYRIN REPEAT AND STERILE ALPHA MOTIF DOMAIN CONTAINING 1B
NM_001277	CHKA	CHOLINE KINASE ALPHA
NM_152434	CWF19L2	CWF19-LIKE 2, CELL CYCLE CONTROL (S. POMBE)
NM_004811	LPXN	LEUPAXIN
NM_182739	NDUFB6	NADH DEHYDROGENASE (UBIQUINONE) 1 BETA SUBCOMPLEX, 6, 17KDA
BC053602	C15ORF38	HYPOTHETICAL PROTEIN FLJ35955
NM_018976	SLC38A2	SOLUTE CARRIER FAMILY 38, MEMBER 2
BC004967	UBAC1	UBIQUITIN ASSOCIATED DOMAIN CONTAINING 1
BC010360	LMBRD1	LMBR1 DOMAIN CONTAINING 1
BC016381	NA	HYPOTHETICAL PROTEIN
BC017101	POMZP3	POM (POM121 HOMOLOG, RAT) AND ZP3 FUSION
BC026175	ATF2	ACTIVATING TRANSCRIPTION FACTOR 2
BC062359	C8ORF47	CHROMOSOME 8 OPEN READING FRAME 47
NM_000301	PLG	PLASMINOGEN
NM_002815	PSMD11	PROTEASOME (PROSOME, MACROPAIN) 26S SUBUNIT, NON-ATPASE, 11
NM_002854	PVALB	PARVALBUMIN
NM_012198	GCA	GRANCALCIN, EF-HAND CALCIUM BINDING PROTEIN
NM_017727	FLJ20254	HYPOTHETICAL PROTEIN FLJ20254
NM_021925	C2ORF43	HYPOTHETICAL PROTEIN FLJ21820
NM_138785	C6ORF72	CHROMOSOME 6 OPEN READING FRAME 72
NM_144686	TMC4	TRANSMEMBRANE CHANNEL-LIKE 4
NM_012416	RANBP6	RAN BINDING PROTEIN 6
NM_006899	IDH3B	ISOCITRATE DEHYDROGENASE 3 (NAD+) BETA
BC001726	NOL11	NUCLEOLAR PROTEIN 11
BC015219	RBCK1	CHROMOSOME 20 OPEN READING FRAME 18

BC034801	ZDHC19	ZINC FINGER, DHHC-TYPE CONTAINING 19
BC022244	PYCR1	PYRROLINE-5-CARBOXYLATE REDUCTASE 1
NM_006399	BATF	BASIC LEUCINE ZIPPER TRANSCRIPTION FACTOR, ATF-LIKE
BC014949	DHX58	LIKELY ORTHOLOG OF MOUSE D11LGP2
NM_014182	ORMDL2	ORM1-LIKE 2 (S. CEREVISIAE)
NM_024114	TRIM48	TRIPARTITE MOTIF-CONTAINING 48
NM_006607	PTTG2	PITUITARY TUMOR-TRANSFORMING 2
NM_004357	CD151	CD151 ANTIGEN (RAPH BLOOD GROUP)
NM_005513	GTF2E1	GENERAL TRANSCRIPTION FACTOR IIE, POLYPEPTIDE 1, ALPHA 56KDA
NM_016231	NLK	NEMO-LIKE KINASE
NM_054033	FKBP1B	FK506 BINDING PROTEIN 1B, 12.6 KDA
NM_152646		hypothetical protein MGC23270
NM_173518	C8ORF45	CHROMOSOME 8 OPEN READING FRAME 45
NM_177951	PPM1A	PROTEIN PHOSPHATASE 1A (FORMERLY 2C), MAGNESIUM-DEPENDENT, ALPHA ISOFORM
NM_020990	CKMT1B	CREATINE KINASE, MITOCHONDRIAL 1B
NM_001258	CDK3	CYCLIN-DEPENDENT KINASE 3
NM_138565	CTTN	CORTACTIN
NM_018189	DPPA4	DEVELOPMENTAL PLURIPOTENCY ASSOCIATED 4
NM_001330	CTF1	CARDIOTROPHIN 1
BC029541	LETM2	LEUCINE ZIPPER-EF-HAND CONTAINING TRANSMEMBRANE PROTEIN 2
NM_144594	GTSF1	FAMILY WITH SEQUENCE SIMILARITY 112, MEMBER B
NM_173192	KCNIP2	KV CHANNEL INTERACTING PROTEIN 2
BC034468	FLJ11171	HYPOTHETICAL PROTEIN FLJ11171
NM_033306	CASP4	CASPASE 4, APOPTOSIS-RELATED CYSTEINE PEPTIDASE
BC041132	KIFC3	KINESIN FAMILY MEMBER C3
BC011461	MITF	MICROPHthalmia-ASSOCIATED TRANSCRIPTION FACTOR
BC046214	MPHOSPH8	M-PHASE PHOSPHOPROTEIN, MPP8
BC057774	RG9MTD3	RNA (GUANINE-9-) METHYLTRANSFERASE DOMAIN CONTAINING 3
NM_016606	REEP2	RECEPTOR ACCESSORY PROTEIN 2
NM_145265	CCDC127	SIMILAR TO RIKEN CDNA 0610011N22
BC015056	ACAD10	ACYL-COENZYME A DEHYDROGENASE FAMILY, MEMBER 10
BC007224	GALNT10	UDP-N-ACETYL-ALPHA-D-GALACTOSAMINE:POLYPEPTIDE N-ACETYL GALACTOSAMINYLTRANSFERASE 10 (GALNAC-T10)
BC009289	ACSBG1	ACYL-COA SYNTHETASE BUBBLEGUM

		FAMILY MEMBER 1
BC011786	NA	CHROMOSOME 11 OPEN READING FRAME 43
NM_000559	HBG2	HEMOGLOBIN, GAMMA A
NM_024680	E2F8	E2F TRANSCRIPTION FACTOR 8
BC000557	PEMT	PHOSPHATIDYLETHANOLAMINE N-METHYLTRANSFERASE
BC005974	VAMP4	VESICLE-ASSOCIATED MEMBRANE PROTEIN 4
BC009771	BCCIP	CDK INHIBITOR P21 BINDING PROTEIN
BC053508	ARL6IP2	ADP-RIBOSYLATION FACTOR-LIKE 6 INTERACTING PROTEIN 2
NM_001307	CLDN7	CLAUDIN 7
NM_002688	12:00 AM	SEPTIN 5
NM_004123	GIP	GASTRIC INHIBITORY POLYPEPTIDE
NM_004545	NDUFB1	NADH DEHYDROGENASE (UBIQUINONE) 1 BETA SUBCOMPLEX, 1, 7KDA
NM_004712	HGS	HEPATOCYTE GROWTH FACTOR-REGULATED TYROSINE KINASE SUBSTRATE
NM_005621	S100A12	S100 CALCIUM BINDING PROTEIN A12 (CALGRANULIN C)
NM_016388	TRAT1	T CELL RECEPTOR ASSOCIATED TRANSMEMBRANE ADAPTOR 1
NM_138998	DDX39	DEAD (ASP-GLU-ALA-ASP) BOX POLYPEPTIDE 39
NM_144673	CMTM2	CKLF-LIKE MARVEL TRANSMEMBRANE DOMAIN CONTAINING 2
NM_182597	C7ORF53	HYPOTHETICAL PROTEIN FLJ39575
BC035601	WWC3	KIAA1280 PROTEIN
BC036365	C10ORF81	HYPOTHETICAL PROTEIN LOC338564
NM_002103	GYS1	GLYCOGEN SYNTHASE 1 (MUSCLE)
NM_145252	LOC124220	SIMILAR TO COMMON SALIVARY PROTEIN 1
NM_139280	ORMDL3	HYPOTHETICAL PROTEIN LOC51242
NM_022372	GBL	G PROTEIN BETA SUBUNIT-LIKE
BC052805	EPB49	ERYTHROCYTE MEMBRANE PROTEIN BAND 4.9 (DEMATEIN)
NM_014551	NCAPH2	KLEISIN BETA
NM_017848	FAM120C	CHROMOSOME X OPEN READING FRAME 17
BC008141	UCHL5IP	THREE PRIME REPAIR EXONUCLEASE 2
NM_005832	KCNMB2	POTASSIUM LARGE CONDUCTANCE CALCIUM-ACTIVATED CHANNEL, SUBFAMILY M, BETA MEMBER 2
NM_173517	VKORC1L1	VITAMIN K EPOXIDE REDUCTASE COMPLEX, SUBUNIT 1-LIKE 1
NM_173473	C10ORF104	CHROMOSOME 10 OPEN READING FRAME 104
NM_030650	KIAA1715	KIAA1715
NM_014570	ARFGAP3	ADP-RIBOSYLATION FACTOR GTPASE

		ACTIVATING PROTEIN 3
NM_021159	RAP1GDS1	RAP1, GTP-GDP DISSOCIATION STIMULATOR 1
BC017066	PRRC1	HYPOTHETICAL PROTEIN MGC12103
NM_014805	EPM2AIP1	EPM2A (LAFORIN) INTERACTING PROTEIN 1
BC033734	C17ORF66	CHROMOSOME 17 OPEN READING FRAME 66
NM_021644	HNRPH3	HETEROGENEOUS NUCLEAR RIBONUCLEOPROTEIN H3 (2H9)
BC021987	NMI	N-MYC (AND STAT) INTERACTOR
NM_002489	NDUFA4	NADH DEHYDROGENASE (UBIQUINONE) 1 ALPHA SUBCOMPLEX, 4, 9KDA
NM_033542	DBNDD2	CHROMOSOME 20 OPEN READING FRAME 35
BC015754	CADPS	CA2+-DEPENDENT SECRETION ACTIVATOR
NM_032357	CCDC115	HYPOTHETICAL PROTEIN MGC12981
XM_291436		
BC012266	ATG12	ATG12 AUTOPHAGY RELATED 12 HOMOLOG (S. CEREVISIAE)
BC012377	EGFL7	EGF-LIKE-DOMAIN, MULTIPLE 7
BC017943	PPP1R1C	PROTEIN PHOSPHATASE 1, REGULATORY (INHIBITOR) SUBUNIT 1C
BC058031	HP	HAPTOGLOBIN
BC060828	ARID3A	AT RICH INTERACTIVE DOMAIN 3A (BRIGHT- LIKE)
NM_144586	LYPD1	LY6/PLAUR DOMAIN CONTAINING 1
BC009106	SEC16B	LEUCINE ZIPPER TRANSCRIPTION REGULATOR 2
NM_018990	CXORF9	CHROMOSOME X OPEN READING FRAME 9
NM_004935	CDK5	CYCLIN-DEPENDENT KINASE 5
BC014484	TOR1A	TORSIN FAMILY 1, MEMBER A (TORSIN A)
BC063111	GGT6	GAMMA-GLUTAMYLTRANSFERASE 6 HOMOLOG (RAT)
NM_023937	MRPL34	MITOCHONDRIAL RIBOSOMAL PROTEIN L34
NM_030810	TXNDC5	THIOREDOXIN DOMAIN CONTAINING 5
NM_138463	TLCD1	TLC DOMAIN CONTAINING 1
BC007919	STARD10	START DOMAIN CONTAINING 10
BC016703	ACSM5	HYPOTHETICAL PROTEIN FLJ20581
NM_001004354	NRARP	SIMILAR TO ANKYRIN-REPEAT PROTEIN NRARP
NM_002436	MPP1	MEMBRANE PROTEIN, PALMITOYLATED 1, 55KDA
NM_004013	DMD	DYSTROPHIN (MUSCULAR DYSTROPHY, DUCHENNE AND BECKER TYPES)
NM_018335	C14ORF131	CHROMOSOME 14 OPEN READING FRAME 131

NM_138385	TMEM129	TRANSMEMBRANE PROTEIN 129
NM_001823	CKB	CREATINE KINASE, BRAIN
NM_004440	EPHA7	EPH RECEPTOR A7
NM_006779	CDC42EP2	CDC42 EFFECTOR PROTEIN (RHO GTPASE BINDING) 2
NM_007162	TFEB	TRANSCRIPTION FACTOR EB
NM_014248	RBX1	RING-BOX 1
NM_016267	VGLL1	VESTIGIAL LIKE 1 (DROSOPHILA)
NM_181656	C17ORF58	CHROMOSOME 17 OPEN READING FRAME 58
NM_138482		hypothetical protein BC009264
BC026345	KIAA1189	KIAA1189
NM_032315	SLC25A33	PNC1 PROTEIN
NM_002944	ROS1	V-ROS UR2 SARCOMA VIRUS ONCOGENE HOMOLOG 1 (AVIAN)
BC017048	GJB2	GAP JUNCTION PROTEIN, BETA 2, 26KDA (CONNEXIN 26)
BC039814	ZRANB2	ZINC FINGER PROTEIN 265
NM_001044	SLC6A3	SOLUTE CARRIER FAMILY 6 (NEUROTRANSMITTER TRANSPORTER, DOPAMINE), MEMBER 3
NM_138470		hypothetical protein BC008131
NM_005084	PLA2G7	PHOSPHOLIPASE A2, GROUP VII (PLATELET-ACTIVATING FACTOR ACETYLHYDROLASE, PLASMA)
BC012499	SIRT1	SIRTIIN (SILENT MATING TYPE INFORMATION REGULATION 2 HOMOLOG) 1 (S. CEREVISIAE)
BC045532	LSM8	LSM8 HOMOLOG, U6 SMALL NUCLEAR RNA ASSOCIATED (S. CEREVISIAE)
NM_003295	TPT1	TUMOR PROTEIN, TRANSLATIONALLY-CONTROLLED 1
NM_006912	RIT1	RAS-LIKE WITHOUT CAAX 1
NM_014184	CNIH4	CORNICHON HOMOLOG 4 (DROSOPHILA)
BC003065	CDK2	CYCLIN-DEPENDENT KINASE 2
BC009793	ERCC8	EXCISION REPAIR CROSS-COMPLEMENTING RODENT REPAIR DEFICIENCY, COMPLEMENTATION GROUP 8
NM_005114	HS3ST1	HEPARAN SULFATE (GLUCOSAMINE) 3-O-SULFOTRANSFERASE 1
NM_018129	PNPO	PYRIDOXINE 5'-PHOSPHATE OXIDASE
NM_152285	ARRDC1	ARRESTIN DOMAIN CONTAINING 1
BC009710	GOSR2	GOLGI SNAP RECEPTOR COMPLEX MEMBER 2
NM_015966	ERGIC3	ERGIC AND GOLGI 3
NM_020370	GPR84	G PROTEIN-COUPLED RECEPTOR 84
NM_130398	EXO1	EXONUCLEASE 1
NM_145865	ANKS4B	ANKYRIN REPEAT AND STERILE ALPHA

		MOTIF DOMAIN CONTAINING 4B
BC001234	LOH11CR2A	LOSS OF HETEROZYGOSITY, 11, CHROMOSOMAL REGION 2, GENE A
BC062625	SLC39A4	SOLUTE CARRIER FAMILY 39 (ZINC TRANSPORTER), MEMBER 4
BC001889	NAPG	N-ETHYLMALEIMIDE-SENSITIVE FACTOR ATTACHMENT PROTEIN, GAMMA
BC013768	PCCB	PROPIONYL COENZYME A CARBOXYLASE, BETA POLYPEPTIDE
BC020651	MRPL35	MITOCHONDRIAL RIBOSOMAL PROTEIN L35
BC051291	RDH11	RETINOL DEHYDROGENASE 11 (ALL-TRANS AND 9-CIS)
BC069328	BMF	BCL2 MODIFYING FACTOR
NM_006426	DPYSL4	DIHYDROPYRIMIDINASE-LIKE 4
NM_178863	KCTD13	POTASSIUM CHANNEL TETRAMERISATION DOMAIN CONTAINING 13
BC004176	SSH3	SLINGSHOT HOMOLOG 3 (DROSOPHILA)
BC008790	GSTM3	GLUTATHIONE S-TRANSFERASE M3 (BRAIN)
BC010176	NY-SAR-48	SARCOMA ANTIGEN NY-SAR-48
BC020885	C12ORF65	HYPOTHETICAL PROTEIN FLJ38663
BC034554	SERPINA3	SERPIN PEPTIDASE INHIBITOR, CLADE A (ALPHA-1 ANTIPROTEINASE, ANTITRYPSIN), MEMBER 3
NM_000394	CRYAA	CRYSTALLIN, ALPHA A
NM_078476	BTN2A1	BUTYROPHILIN, SUBFAMILY 2, MEMBER A1
BC015904	MRPL10	MITOCHONDRIAL RIBOSOMAL PROTEIN L10
BC019039	RGS3	REGULATOR OF G-PROTEIN SIGNALLING 3
BC067445	DAB1	DISABLED HOMOLOG 1 (DROSOPHILA)
NM_003221	TFAP2B	TRANSCRIPTION FACTOR AP-2 BETA (ACTIVATING ENHANCER BINDING PROTEIN 2 BETA)
NM_015959	TXNDC14	THIOREDOXIN DOMAIN CONTAINING 14
BC010033	QPRT	QUINOLINATE PHOSPHORIBOSYLTRANSFERASE (NICOTINATE-NUCLEOTIDE PYROPHOSPHORYLASE (CARBOXYLATING))
NM_152522	ARL6IP6	ADP-RIBOSYLATION-LIKE FACTOR 6 INTERACTING PROTEIN 6
BC019254	ENOX2	CYTOSOLIC OVARIAN CARCINOMA ANTIGEN 1
NM_012148	DUX3	DOUBLE HOMEBOX, 3
NM_025004	CCDC15	COILED-COIL DOMAIN CONTAINING 15
BC017475	TTC15	TETRATRICOPEPTIDE REPEAT DOMAIN 15
NM_172211	CSF1	COLONY STIMULATING FACTOR 1

		(MACROPHAGE)
BC007862	GPR108	G PROTEIN-COUPLED RECEPTOR 108
BC010850	HEATR2	HYPOTHETICAL PROTEIN FLJ20397
NM_016009	SH3GLB1	SH3-DOMAIN GRB2-LIKE ENDOPHILIN B1
NM_152328	ADSSL1	ADENYLOSUCCINATE SYNTHASE LIKE 1
BC020867	SLC6A13	SOLUTE CARRIER FAMILY 6 (NEUROTRANSMITTER TRANSPORTER, GABA), MEMBER 13
NM_178126	FAM134C	HYPOTHETICAL PROTEIN LOC162427
NM_007241	SNF8	SNF8, ESCRT-II COMPLEX SUBUNIT, HOMOLOG (S. CEREVISIAE)
NM_016440	VRK3	VACCINIA RELATED KINASE 3
BC035314	BXDC1	BRIX DOMAIN CONTAINING 1
NM_030881	DDX17	DEAD (ASP-GLU-ALA-ASP) BOX POLYPEPTIDE 17
NM_001033578	SGK3	SERUM/GLUCOCORTICOID REGULATED KINASE FAMILY, MEMBER 3
BC010155	FDX1L	SIMILAR TO RIKEN CDNA B230118G17 GENE
NM_018667	SMPD3	SPHINGOMYELIN PHOSPHODIESTERASE 3, NEUTRAL MEMBRANE (NEUTRAL SPHINGOMYELINASE II)
NM_017812	CHCHD3	COILED-COIL-HELIX-COILED-COIL- HELIX DOMAIN CONTAINING 3
NM_001613	ACTG2	ACTIN, ALPHA 2, SMOOTH MUSCLE, AORTA
BC031329	TMEM149	U2(RNU2) SMALL NUCLEAR RNA AUXILIARY FACTOR 1-LIKE 4
BC039256	PDS5B	ANDROGEN-INDUCED PROLIFERATION INHIBITOR
NM_017634	KCTD9	POTASSIUM CHANNEL TETRAMERISATION DOMAIN CONTAINING 9
NM_001017980	LOC203547	HYPOTHETICAL PROTEIN LOC203547
BC053320	CTBP1	C-TERMINAL BINDING PROTEIN 1
NM_152619	DCLK2	DOUBLECORTIN AND CAM KINASE-LIKE 2
BC033668	ARHGAP28	KIAA1314 PROTEIN
BC059396	FAM92A3	FAMILY WITH SEQUENCE SIMILARITY 92, MEMBER A3
NM_080660	ZC3HAV1L	SIMILAR TO RIKEN CDNA 1200014N16 GENE
BC003551	TGM2	TRANSGLUTAMINASE 2 (C POLYPEPTIDE, PROTEIN-GLUTAMINE-GAMMA- GLUTAMYLTRANSFERASE)
NM_172341	LIN37	PRESENILIN ENHANCER 2 HOMOLOG (C. ELEGANS)
NM_005158	ABL2	V-ABL ABELSON MURINE LEUKEMIA VIRAL ONCOGENE HOMOLOG 2 (ARG, ABELSON-RELATED GENE)
NM_005558	LAD1	LADININ 1

NM_000624	SERPINA5	SERPIN PEPTIDASE INHIBITOR, CLADE A (ALPHA-1 ANTIPROTEINASE, ANTITRYPSIN), MEMBER 5
NM_173799	VSTM3	V-SET AND IMMUNOGLOBULIN DOMAIN CONTAINING 9
NM_003592	CUL1	CULLIN 1
BC017594	APIP	APAF1 INTERACTING PROTEIN
NM_032498	RHOXF2	PEPP SUBFAMILY GENE 2
BC008730	HK1	HEXOKINASE 1
BC016276	DLG7	DISCS, LARGE HOMOLOG 7 (DROSOPHILA)
BC033708	RALGPS1	RAL GEF WITH PH DOMAIN AND SH3 BINDING MOTIF 1
BC051000	TCL1B	T-CELL LEUKEMIA/LYMPHOMA 1B
BC066974	NA	HYPOTHETICAL PROTEIN
BC022983	LNK1	LIGAND OF NUMB-PROTEIN X 1
NM_003256	TIMP4	TIMP METALLOPEPTIDASE INHIBITOR 4
NM_003674	CDK10	CYCLIN-DEPENDENT KINASE (CDC2-LIKE) 10
BC004549	DUS3L	DIHYDROURIDINE SYNTHASE 3-LIKE (S. CEREVISIAE)
BC015596*	C21ORF51	CHROMOSOME 21 OPEN READING FRAME 51
BC018206*	FAM128B	HYPOTHETICAL PROTEIN FLJ14346
BC018722*	ASPSR1	ALVEOLAR SOFT PART SARCOMA CHROMOSOME REGION, CANDIDATE 1
BC022357*	RPL17	RIBOSOMAL PROTEIN L17
BC023152*	GYG2	GLYCOGENIN 2
BC025700*	AFF4	AF4/FMR2 FAMILY, MEMBER 4
BC032825*	SH3GL2	SH3-DOMAIN GRB2-LIKE 2
BC038838*	PRR16	MESENCHYMAL STEM CELL PROTEIN DSC54
BC052805*	EPB49	ERYTHROCYTE MEMBRANE PROTEIN BAND 4.9 (DEMATEIN)
BC056415*	RPAP3	HYPOTHETICAL PROTEIN FLJ21908
BC065370*	C20ORF112	CHROMOSOME 20 OPEN READING FRAME 112
NM_001032296*	STK24	SERINE/THREONINE KINASE 24 (STE20 HOMOLOG, YEAST)
NM_002498*	NEK3	NIMA (NEVER IN MITOSIS GENE A) - RELATED KINASE 3
NM_002624*	PFDN5	PREFOLDIN SUBUNIT 5
NM_004329*	BMPT1A	BONE MORPHOGENETIC PROTEIN RECEPTOR, TYPE 1A
NM_014245*	RNF7	RING FINGER PROTEIN 7
NM_014548*	TMOD2	TROPOMODULIN 2 (NEURONAL)
NM_015646*	RAP1B	RAP1B, MEMBER OF RAS ONCOGENE FAMILY
NM_017949*	CUEDC1	CUE DOMAIN CONTAINING 1

NM_018393*	TCP11L1	T-COMPLEX 11 (MOUSE) LIKE 1
NM_018679*	TCP11	T-COMPLEX 11 (MOUSE)
NM_024591*	CHMP6	CHROMATIN MODIFYING PROTEIN 6
NM_032368*	LZIC	LEUCINE ZIPPER AND CTNNBIP1 DOMAIN CONTAINING
NM_033118*	MYLK2	MYOSIN LIGHT CHAIN KINASE 2, SKELETAL MUSCLE
NM_130807*	MOBK2A	MOB1, MPS ONE BINDER KINASE ACTIVATOR-LIKE 2A (YEAST)
NM_145173*	DIRAS1	DIRAS FAMILY, GTP-BINDING RAS-LIKE 1
NM_152376*	UBXD3	UBX DOMAIN CONTAINING 3
NM_182493*	MLCK	MLCK PROTEIN
BC056907*	NA	NA
SUMO1		
GenBank Accession	Gene Symbol	Protein Name
BC033766	NDUFV3	NADH DEHYDROGENASE (UBIQUINONE) FLAVOPROTEIN 3, 10KDA
NM_001312	CRIP2	CYSTEINE-RICH PROTEIN 2
NM_004111	FEN1	FLAP STRUCTURE-SPECIFIC ENDONUCLEASE 1
NM_000805	GAST	GASTRIN
NM_030645	SH3BP5L	SH3-BINDING DOMAIN PROTEIN 5-LIKE
BC019337	IGHG1	IMMUNOGLOBULIN HEAVY CONSTANT GAMMA 1 (G1M MARKER)
BC056673	PPP1R2P9	PROTEIN PHOSPHATASE 1, REGULATORY (INHIBITOR) SUBUNIT 2 PSEUDOGENE 9
BC054520	MEF2D	MADS BOX TRANSCRIPTION ENHANCER FACTOR 2, POLYPEPTIDE D (MYOCYTE ENHANCER FACTOR 2D)
NM_006902	PRRX1	PAIRED RELATED HOMEBOX 1
NM_004436	ENSA	ENDOSULFINE ALPHA
NM_006255	PRKCH	PROTEIN KINASE C, ETA
NM_007080	LSM6	LSM6 HOMOLOG, U6 SMALL NUCLEAR RNA ASSOCIATED (S. CEREVISIAE)
NM_000860	HPGD	HYDROXYPROSTAGLANDIN DEHYDROGENASE 15- (NAD)
NM_144679	C17ORF56	CHROMOSOME 17 OPEN READING FRAME 56
NM_017431	PRKAG3	PROTEIN KINASE, AMP-ACTIVATED, GAMMA 3 NON-CATALYTIC SUBUNIT
NM_031473	IFT81	INTRAFLAGELLAR TRANSPORT 81 HOMOLOG (CHLAMYDOMONAS)
BC064593	DCP2	DCP2 DECAPPING ENZYME HOMOLOG (S. CEREVISIAE)
BC007347	CHD2	CHROMODOMAIN HELICASE DNA BINDING PROTEIN 2
BC003690	IPO4	IMPORTIN 4

BC016327	NUP62CL	HYPOTHETICAL PROTEIN FLJ20130
NM_080600	MAG	MYELIN ASSOCIATED GLYCOPROTEIN
BC017258	MCM2	MCM2 MINICHROMOSOME MAINTENANCE DEFICIENT 2, MITOTIN (S. CEREVISIAE)
NM_017785	CCDC99	HYPOTHETICAL PROTEIN FLJ20364
BC000809	TCEAL1	TRANSCRIPTION ELONGATION FACTOR A (SII)-LIKE 1
NM_000485	APRT	ADENINE PHOSPHORIBOSYLTRANSFERASE
NM_138820	HIGD2A	HIG1 DOMAIN FAMILY, MEMBER 2A
BC009415	KIF26A	KINESIN FAMILY MEMBER 26A
BC017440	TRAPPC2L	HEMATOPOIETIC STEM/PROGENITOR CELLS 176
NM_001092	ABR	ACTIVE BCR-RELATED GENE
BC013352	HTF9C	HPAII TINY FRAGMENTS LOCUS 9C
NM_021947	SRR	SERINE RACEMASE
BC011585	PRKCDBP	PROTEIN KINASE C, DELTA BINDING PROTEIN
BC052600	ZNF718	ZINC FINGER PROTEIN 718
BC004518	SYT17	SYNAPTOTAGMIN XVII
NM_178509	STXBP4	SYNTAXIN BINDING PROTEIN 4
BC017770	NA	NA
BC066938	DDX43	DEAD (ASP-GLU-ALA-ASP) BOX POLYPEPTIDE 43
BC000393	FAM127B	DKFZP564B147 PROTEIN
BC025787	ALKBH1	ALKB, ALKYLATION REPAIR HOMOLOG 1 (E. COLI)
BC015944	TIA1	TIA1 CYTOTOXIC GRANULE-ASSOCIATED RNA BINDING PROTEIN
NM_017988	SCYL2	SCY1-LIKE 2 (S. CEREVISIAE)
NM_002020	FLT4	FMS-RELATED TYROSINE KINASE 4
NM_031472	TRPT1	TRNA PHOSPHOTRANSFERASE 1
BC001728*	TFPT	TCF3 (E2A) FUSION PARTNER (IN CHILDHOOD LEUKEMIA)
BC003566*	ZNF24	ZINC FINGER PROTEIN 24 (KOX 17)
BC005383*	CETN3	CENTRIN, EF-HAND PROTEIN, 3 (CDC31 HOMOLOG, YEAST)
BC007048*	ZMYM5	ZINC FINGER, MYM-TYPE 5
BC010125*	C3ORF37	CHROMOSOME 3 OPEN READING FRAME 37
BC011804*	C1ORF165	CHROMOSOME 1 OPEN READING FRAME 165
BC015803*	IRF2	INTERFERON REGULATORY FACTOR 2
BC017314*	ETS1	V-ETS ERYTHROBLASTOSIS VIRUS E26 ONCOGENE HOMOLOG 1 (AVIAN)
BC036335*	BTBD12	BTB (POZ) DOMAIN CONTAINING 12
BC036572*	ZCCHC12	ZINC FINGER, CCHC DOMAIN CONTAINING 12
BC051688*	FLJ10781	HYPOTHETICAL PROTEIN FLJ10781
BC056402*	LOC144097	HYPOTHETICAL PROTEIN BC007540

BC067299*	MDM4	MDM4, TRANSFORMED 3T3 CELL DOUBLE MINUTE 4, P53 BINDING PROTEIN (MOUSE)
NM_000176*	NR3C1	NUCLEAR RECEPTOR SUBFAMILY 3, GROUP C, MEMBER 1 (GLUCOCORTICOID RECEPTOR)
NM_001008239*	C18ORF25	CHROMOSOME 18 OPEN READING FRAME 25
NM_001722*	POLR3D	POLYMERASE (RNA) III (DNA DIRECTED) POLYPEPTIDE D, 44KDA
NM_001895*	CSNK2A1	CASEIN KINASE 2, ALPHA 1 POLYPEPTIDE
NM_002739*	PRKCG	PROTEIN KINASE C, GAMMA
NM_002938*	RNF4	RING FINGER PROTEIN 4
NM_003141*	TRIM21	TRIPARTITE MOTIF-CONTAINING 21
NM_003345*	UBE2I	UBIQUITIN-CONJUGATING ENZYME E2I (UBC9 HOMOLOG, YEAST)
NM_003352*	SUMO1	SMT3 SUPPRESSOR OF MIF TWO 3 HOMOLOG 1 (YEAST)
NM_004454*	ETV5	ETS VARIANT GENE 5 (ETS-RELATED MOLECULE)
NM_006977*	ZBTB25	ZINC FINGER AND BTB DOMAIN CONTAINING 25
NM_014720*	SLK	STE20-LIKE KINASE (YEAST)
NM_032141*	CCDC55	COILED-COIL DOMAIN CONTAINING 55
NM_145796*	POGZ	POGO TRANSPOSABLE ELEMENT WITH ZNF DOMAIN
NM_175907*	ZADH2	HYPOTHETICAL PROTEIN BC010734
NM_212540*	E2F6	E2F TRANSCRIPTION FACTOR 6
UFM1		
GenBank Accession	Gene Symbol	Name
NM_005879	TRAIP	TRAF INTERACTING PROTEIN
NM_001018	RPS15	RIBOSOMAL PROTEIN S15
NM_013974	DDAH2	DIMETHYLARGININE DIMETHYLAMINOHYDROLASE 2
NM_001278	CHUK	CONSERVED HELIX-LOOP-HELIX UBIQUITOUS KINASE
BC012611	EIF4E	EUKARYOTIC TRANSLATION INITIATION FACTOR 4E
NM_006819	STIP1	STRESS-INDUCED-PHOSPHOPROTEIN 1 (HSP70/HSP90-ORGANIZING PROTEIN)
NM_024647	NUP43	NUCLEOPORIN 43KDA
NM_007045	FGFR1OP	FGFR1 ONCOGENE PARTNER
NM_014460	CSDC2	COLD SHOCK DOMAIN CONTAINING C2, RNA BINDING
NM_021260	ZFYVE1	ZINC FINGER, FYVE DOMAIN CONTAINING 1
NM_017437	CPSF2	CLEAVAGE AND POLYADENYLATION

		SPECIFIC FACTOR 2, 100KDA
NM_138722	BCL2L14	BCL2-LIKE 14 (APOPTOSIS FACILITATOR)
NM_016059	PPIL1	PEPTIDYLPROLYL ISOMERASE (CYCLOPHILIN)-LIKE 1
NM_020139	BDH2	3-HYDROXYBUTYRATE DEHYDROGENASE, TYPE 2
NM_182493	MLCK	MLCK PROTEIN
BC000578	HPRT1	HYPOXANTHINE PHOSPHORIBOSYLTRANSFERASE 1 (LESCH-NYHAN SYNDROME)
BC060785	TRIM40	TRIPARTITE MOTIF-CONTAINING 40
BC003132	NUDC	NUCLEAR DISTRIBUTION GENE C HOMOLOG (A. NIDULANS)
NM_031219	HDHD3	HALOACID DEHALOGENASE-LIKE HYDROLASE DOMAIN CONTAINING 3
NM_002358	MAD2L1	MAD2 MITOTIC ARREST DEFICIENT-LIKE 1 (YEAST)
NM_006578	GNB5	GUANINE NUCLEOTIDE BINDING PROTEIN (G PROTEIN), BETA 5
NM_004064	CDKN1B	CYCLIN-DEPENDENT KINASE INHIBITOR 1B (P27, KIP1)
BC030280	KIAA0513	KIAA0513
NM_005338	HIP1	HUNTINGTIN INTERACTING PROTEIN 1
NM_004881	TP53I3	TUMOR PROTEIN P53 INDUCIBLE PROTEIN 3
BC015395	CCDC148	HYPOTHETICAL PROTEIN BC015395
NM_000394	CRYAA	CRYSTALLIN, ALPHA A
BC005955	C8ORF53	CHROMOSOME 8 OPEN READING FRAME 53
BC001327	IFRD2	INTERFERON-RELATED DEVELOPMENTAL REGULATOR 2
BC021551	NFATC2IP	NUCLEAR FACTOR OF ACTIVATED T-CELLS, CYTOPLASMIC, CALCINEURIN-DEPENDENT 2 INTERACTING PROTEIN
BC050537	FLJ20160	FLJ20160 PROTEIN
BC058862	TSKS	TESTIS-SPECIFIC KINASE SUBSTRATE
NM_005235	ERBB4	V-ERB-A ERYTHROBLASTIC LEUKEMIA VIRAL ONCOGENE HOMOLOG 4 (AVIAN)
NM_014012	REM1	RAS (RAD AND GEM)-LIKE GTP-BINDING 1
NM_022110	FKBPL	FK506 BINDING PROTEIN LIKE
NM_006147	IRF6	INTERFERON REGULATORY FACTOR 6
NM_001349	DARS	ASPARTYL-TRNA SYNTHETASE
BC064945	SCYL1BP1	SCY1-LIKE 1 BINDING PROTEIN 1
NM_032385	C5ORF4	CHROMOSOME 5 OPEN READING FRAME 4
NM_172037	RDH10	RETINOL DEHYDROGENASE 10 (ALL-TRANS)
NM_173621	C17ORF44	CHROMOSOME 17 OPEN READING FRAME 44

NM_004074	COX8A	CYTOCHROME C OXIDASE SUBUNIT 8A (UBIQUITOUS)
NM_022156	DUS1L	DIHYDROURIDINE SYNTHASE 1-LIKE (S. CEREVISIAE)
NM_016401	C11ORF73	HYPOTHETICAL PROTEIN HSPC138
NM_019617	GKN1	GASTROKINE 1
BC054501	DNM2	DYNAMIN 2
NM_058173	MUCL1	SMALL BREAST EPITHELIAL MUCIN
BC032307	CCDC123	HYPOTHETICAL PROTEIN FLJ14640
BC034028	SHARPIN	SHANK-ASSOCIATED RH DOMAIN INTERACTOR
BC015202	CENPT	CHROMOSOME 16 OPEN READING FRAME 56
BC013957	FAM62B	FAMILY WITH SEQUENCE SIMILARITY 62 (C2 DOMAIN CONTAINING) MEMBER B
BC015569	ARL6IP4	ADP-RIBOSYLATION-LIKE FACTOR 6 INTERACTING PROTEIN 4
BC020221	STAC	SH3 AND CYSTEINE RICH DOMAIN
BC053895	IRS1	INSULIN RECEPTOR SUBSTRATE 1
NM_002748	MAPK6	MITOGEN-ACTIVATED PROTEIN KINASE 6
NM_198086	JUB	JUB, AJUBA HOMOLOG (XENOPUS LAEVIS)
NM_006621	AHCYL1	S-ADENOSYLHOMOCYSTEINE HYDROLASE-LIKE 1
NM_018698	NXT2	NUCLEAR TRANSPORT FACTOR 2-LIKE EXPORT FACTOR 2
NM_005034	POLR2K	POLYMERASE (RNA) II (DNA DIRECTED) POLYPEPTIDE K, 7.0KDA
NM_018438	FBXO6	F-BOX PROTEIN 6
NM_033547	INTS4	INTEGRATOR COMPLEX SUBUNIT 4
NM_153212	GJB4	GAP JUNCTION PROTEIN, BETA 4 (CONNEXIN 30.3)
NM_175738	RAB37	RAB37, MEMBER RAS ONCOGENE FAMILY
BC013031	PHLDB1	PLECKSTRIN HOMOLOGY-LIKE DOMAIN, FAMILY B, MEMBER 1
NM_001005465	OR10G3	OLFACTORY RECEPTOR, FAMILY 10, SUBFAMILY G, MEMBER 3
NM_001899	CST4	CYSTATIN S
NM_004753	DHRS3	DEHYDROGENASE/REDUCTASE (SDR FAMILY) MEMBER 3
NM_021992	TMSL8	THYMOSIN-LIKE 8
NM_197970	BOLL	BOL, BOULE-LIKE (DROSOPHILA)
NM_139246	C9ORF97	CHROMOSOME 9 OPEN READING FRAME 97
NM_005586	MDFI	MYOD FAMILY INHIBITOR
BC041831	TLE3	TRANSDUCIN-LIKE ENHANCER OF SPLIT 3 (E(SP1) HOMOLOG, DROSOPHILA)
NM_003130	SRI	SORCIN
BC030237	SLC22A18AS	SOLUTE CARRIER FAMILY 22 (ORGANIC CATION TRANSPORTER), MEMBER 18

		ANTISENSE
BC053351	DLX1	DISTAL-LESS HOMEBOX 1
BC022034	LDHAL6B	LACTATE DEHYDROGENASE A-LIKE 6B
BC031964	GLUL	GLUTAMATE-AMMONIA LIGASE (GLUTAMINE SYNTHETASE)
NM_032350	C7ORF50	HYPOTHETICAL PROTEIN MGC11257
NM_152646		hypothetical protein MGC23270
BC024245	SALL2	SAL-LIKE 2 (DROSOPHILA)
NM_001004300	ZNF720	ZINC FINGER PROTEIN 720
NM_079422	MYL1	MYOSIN, LIGHT POLYPEPTIDE 1, ALKALI; SKELETAL, FAST
NM_024295	DERL1	DER1-LIKE DOMAIN FAMILY, MEMBER 1
BC026241	UBE3C	UBIQUITIN PROTEIN LIGASE E3C
BC064144	NA	NA
NM_152266	C19ORF40	HYPOTHETICAL PROTEIN MGC32020
NM_017722	TRMT1	TRM1 TRNA METHYLTRANSFERASE 1 HOMOLOG (S. CEREVISIAE)
NM_000905	NPY	NEUROPEPTIDE Y
BC001553	CHMP2B	CHROMATIN MODIFYING PROTEIN 2B
NM_006438	COLEC10	COLLECTIN SUB-FAMILY MEMBER 10 (C- TYPE LECTIN)
NM_014424	HSPB7	HEAT SHOCK 27KDA PROTEIN FAMILY, MEMBER 7 (CARDIOVASCULAR)
NM_001179	ART3	ADP-RIBOSYLTRANSFERASE 3
NM_020348	CNNM1	CYCLIN M1
NM_006928	SILV	SILVER HOMOLOG (MOUSE)
NM_022568	ALDH8A1	ALDEHYDE DEHYDROGENASE 8 FAMILY, MEMBER A1
NM_178152	DCX	DOUBLECORTEX; LISSENCEPHALY, X- LINKED (DOUBLECORTIN)
NM_153822	PSMD4	PROTEASOME (PROSOME, MACROPAIN) 26S SUBUNIT, NON-ATPASE, 4
NM_001699	AXL	AXL RECEPTOR TYROSINE KINASE
BC006195	ACLY	ATP CITRATE LYASE
NM_020397	CAMK1D	CALCIUM/CALMODULIN-DEPENDENT PROTEIN KINASE ID
BC017249	ENO3	ENOLASE 1, (ALPHA)
BC001600	CDC123	CHROMOSOME 10 OPEN READING FRAME 7
NM_024770	METTL8	HYPOTHETICAL PROTEIN FLJ13984
NM_194270	MORN2	MORN REPEAT CONTAINING 2
NM_022650	RASA1	RAS P21 PROTEIN ACTIVATOR (GTPASE ACTIVATING PROTEIN) 1
BC005830	ANXA9	ANNEXIN A9
NM_014065	ASTE1	ASTEROID HOMOLOG 1 (DROSOPHILA)
BC014244	RTN2	RETICULON 2
BC024002	FNDC8	FIBRONECTIN TYPE III DOMAIN CONTAINING 8
NM_178034	PLA2G4D	PHOSPHOLIPASE A2, GROUP IVD

		(CYTOSOLIC)
BC025266	TASP1	TASPASE, THREONINE ASPARTASE, 1
NM_003928	FAM127A	CAAX BOX 1
NM_017819	LOC131909	RNA (GUANINE-9-) METHYLTRANSFERASE DOMAIN CONTAINING 1
NM_018158	SLC4A1AP	SOLUTE CARRIER FAMILY 4 (ANION EXCHANGER), MEMBER 1, ADAPTOR PROTEIN
NM_175571	GIMAP8	GTPASE, IMAP FAMILY MEMBER 8
BC000453	PCM1	PERICENTRIOLAR MATERIAL 1
NM_000910	NPY2R	NEUROPEPTIDE Y RECEPTOR Y2
NM_018679	TCP11	T-COMPLEX 11 (MOUSE)
NM_022559	GH1	CHORIONIC SOMATOMAMMOTROPIN HORMONE 1 (PLACENTAL LACTOGEN)
BC030957	ANK1	ANKYRIN 1, ERYTHROCYTIC
NM_003168	SUPT4H1	SUPPRESSOR OF TY 4 HOMOLOG 1 (S. CEREVISIAE)
BC012095	BST1	BONE MARROW STROMAL CELL ANTIGEN 1
BC013740	SLC2A6	SOLUTE CARRIER FAMILY 2 (FACILITATED GLUCOSE TRANSPORTER), MEMBER 6
NM_016505	ZCCHC17	ZINC FINGER, CCHC DOMAIN CONTAINING 17
NM_018697	LANCL2	LANC LANTIBIOTIC SYNTHETASE COMPONENT C-LIKE 2 (BACTERIAL)
NM_152619	DCLK2	DOUBLECORTIN AND CAM KINASE-LIKE 2
NM_152770	C4ORF22	HYPOTHETICAL PROTEIN MGC35043
NM_004401	DFFA	DNA FRAGMENTATION FACTOR, 45KDA, ALPHA POLYPEPTIDE
NM_030636	EEPD1	KIAA1706 PROTEIN
BC014260	PARP3	POLY (ADP-RIBOSE) POLYMERASE FAMILY, MEMBER 3
BC009010	C6ORF142	CHROMOSOME 6 OPEN READING FRAME 142
BC047722	C2ORF64	HYPOTHETICAL PROTEIN MGC52110
NM_080873	ASB11	ANKYRIN REPEAT AND SOCS BOX-CONTAINING 11
NM_173547	TRIM65	TRIPARTITE MOTIF-CONTAINING 65
BC041668	RIPK3	RECEPTOR-INTERACTING SERINE-THREONINE KINASE 3
BC033728	NA	NA
BC048217	SPATA5	SPERMATOGENESIS ASSOCIATED 5
NM_001001852	PIM3	PIM-3 ONCOGENE
NM_002904	RDBP	RD RNA BINDING PROTEIN
BC030608	PODN	PODOCAN
BC023982	C5ORF32	PUTATIVE NUCLEAR PROTEIN ORF1-FL49
NM_133332	WHSC1	WOLF-HIRSCHHORN SYNDROME CANDIDATE 1
NM_004040	RHOB	RAS HOMOLOG GENE FAMILY, MEMBER B

BC033708	RALGPS1	RAL GEF WITH PH DOMAIN AND SH3 BINDING MOTIF 1
NM_002491	NDUFB3	NADH DEHYDROGENASE (UBIQUINONE) 1 BETA SUBCOMPLEX, 3, 12KDA
BC015944	TIA1	TIA1 CYTOTOXIC GRANULE-ASSOCIATED RNA BINDING PROTEIN
BC050688	RPSA	RIBOSOMAL PROTEIN SA
NM_002443	MSMB	MICROSEMINOPROTEIN, BETA-
NM_172314	IL25	INTERLEUKIN 17E
NM_019845	RPRM	REPRIMO, TP53 DEPENDENT G2 ARREST MEDIATOR CANDIDATE
BC013163	DCUN1D1	DCN1, DEFECTIVE IN CULLIN NEDDYLATION 1, DOMAIN CONTAINING 1 (S. CEREVISIAE)
BC017741	GTDC1	PRO0159 PROTEIN
BC023152	GYG2	GLYCOGENIN 2
NM_005663	WHSC2	WOLF-HIRSCHHORN SYNDROME CANDIDATE 2
NM_000214	JAG1	JAGGED 1 (ALAGILLE SYNDROME)
NM_004403	DFNA5	DEAFNESS, AUTOSOMAL DOMINANT 5
NM_022073	EGLN3	HYPOTHETICAL PROTEIN FLJ21620
NM_030571	NDFIP1	NEDD4 FAMILY INTERACTING PROTEIN 1
NM_145252	LOC124220	SIMILAR TO COMMON SALIVARY PROTEIN 1
BC000772	SIPA1L3	SIGNAL-INDUCED PROLIFERATION-ASSOCIATED 1 LIKE 3
NM_006579	EBP	EMOPAMIL BINDING PROTEIN (STEROL ISOMERASE)
BC014441	NSUN4	NOL1/NOP2/SUN DOMAIN FAMILY, MEMBER 4
BC019902	CCDC21	COILED-COIL DOMAIN CONTAINING 21
BC036827	LILRB2	LEUKOCYTE IMMUNOGLOBULIN-LIKE RECEPTOR, SUBFAMILY B (WITH TM AND ITIM DOMAINS), MEMBER 2
NM_001680	FXD2	FXD DOMAIN CONTAINING ION TRANSPORT REGULATOR 2
NM_006439	MAB21L2	MAB-21-LIKE 2 (C. ELEGANS)
NM_032786	ZC3H10	ZINC FINGER CCCH-TYPE CONTAINING 10
NM_024613	PLEKHF2	PLECKSTRIN HOMOLOGY DOMAIN CONTAINING, FAMILY F (WITH FYVE DOMAIN) MEMBER 2
NM_001752	CAT	CATALASE
NM_152471		hypothetical protein MGC17515
NM_152716	PATL1	FLJ36874 PROTEIN
BC004243	BCAT2	BRANCHED CHAIN AMINOTRANSFERASE 2, MITOCHONDRIAL
BC056246	GALNT3	UDP-N-ACETYL-ALPHA-D-GALACTOSAMINE:POLYPEPTIDE N-

		ACETYL GALACTOSAMINYLTRANSFERASE 3 (GALNAC-T3)
NM_022133	SNX16	SORTING NEXIN 16
NM_025221	KCNIP4	KV CHANNEL INTERACTING PROTEIN 4
NM_025234	WDR61	WD REPEAT DOMAIN 61
BC014649	GAL3ST1	GALACTOSE-3-O-SULFOTRANSFERASE 1
NM_002734	PRKAR1A	PROTEIN KINASE, CAMP-DEPENDENT, REGULATORY, TYPE I, ALPHA (TISSUE SPECIFIC EXTINGUISHER 1)
NM_023934	FUNDC2	FUN14 DOMAIN CONTAINING 2
NM_145173	DIRAS1	DIRAS FAMILY, GTP-BINDING RAS-LIKE 1
NM_020142	NDUFA4L2	NADH:UBIQUINONE OXIDOREDUCTASE MLRQ SUBUNIT HOMOLOG
NM_016485	VTAL	CHROMOSOME 6 OPEN READING FRAME 55
NM_000345	SNCA	SYNUCLEIN, ALPHA (NON A4 COMPONENT OF AMYLOID PRECURSOR)
BC067447	DAB1	DISABLED HOMOLOG 1 (DROSOPHILA)
NM_001010971	SAMD13	STERILE ALPHA MOTIF DOMAIN CONTAINING 13
BC022043	C7ORF36	CHROMOSOME 7 OPEN READING FRAME 36
BC004233*	TTYH2	TWEETY HOMOLOG 2 (DROSOPHILA)
BC017504*	DEF6	DIFFERENTIALLY EXPRESSED IN FDCP 6 HOMOLOG (MOUSE)
BC018206*	FAM128B	HYPOTHETICAL PROTEIN FLJ14346
BC018404*	FGF21	FIBROBLAST GROWTH FACTOR 21
BC020985*	COASY	COENZYME A SYNTHASE
BC031469*	LOC554207	HYPOTHETICAL LOC554207
BC058924*	UBE2M	UBIQUITIN-CONJUGATING ENZYME E2M (UBC12 HOMOLOG, YEAST)
NM_000020*	ACVRL1	ACTIVIN A RECEPTOR TYPE II-LIKE 1
NM_000154*	GALK1	GALACTOKINASE 1
NM_001014796*	DDR2	DISCOIDIN DOMAIN RECEPTOR FAMILY, MEMBER 2
NM_001105*	ACVR1	ACTIVIN A RECEPTOR, TYPE I
NM_001752*	CAT	CATALASE
NM_002227*	JAK1	JANUS KINASE 1 (A PROTEIN TYROSINE KINASE)
NM_002498*	NEK3	NIMA (NEVER IN MITOSIS GENE A) - RELATED KINASE 3
NM_002964*	S100A8	S100 CALCIUM BINDING PROTEIN A8 (CALGRANULIN A)
NM_003063*	SLN	SARCOLIPIN
NM_004972*	JAK2	JANUS KINASE 2 (A PROTEIN TYROSINE KINASE)
NM_005036*	PPARA	PEROXISOME PROLIFERATIVE ACTIVATED RECEPTOR, ALPHA
NM_005122*	NR1I3	NUCLEAR RECEPTOR SUBFAMILY 1, GROUP I, MEMBER 3

NM_005123*	NR1H4	NUCLEAR RECEPTOR SUBFAMILY 1, GROUP H, MEMBER 4
NM_014583*	LMCD1	LIM AND CYSTEINE-RICH DOMAINS 1
NM_015646*	RAP1B	RAP1B, MEMBER OF RAS ONCOGENE FAMILY
NM_016495*	TBC1D7	TBC1 DOMAIN FAMILY, MEMBER 7
NM_021709*	SIVA1	CD27-BINDING (SIVA) PROTEIN
NM_030572*	C12ORF39	CHROMOSOME 12 OPEN READING FRAME 39
NM_033360*	KRAS	V-HA-RAS HARVEY RAT SARCOMA VIRAL ONCOGENE HOMOLOG
NM_130807*	MOBK12A	MOB1, MPS ONE BINDER KINASE ACTIVATOR-LIKE 2A (YEAST)
NM_145173*	DIRAS1	DIRAS FAMILY, GTP-BINDING RAS-LIKE 1
NM_173541*	C10ORF91	CHROMOSOME 10 OPEN READING FRAME 91
BC004233*	NA	NA
BC008624*	NA	NA
ISG15		
GenBank Accession	Gene Symbol	Name
BC013366*	URP2	UNC-112 RELATED PROTEIN 2
BC017314*	ETS1	V-ETS ERYTHROBLASTOSIS VIRUS E26 ONCOGENE HOMOLOG 1 (AVIAN)
BC018404*	FGF21	FIBROBLAST GROWTH FACTOR 21
BC022363*	VPS37A	VACUOLAR PROTEIN SORTING 37A (YEAST)
BC024725*	ANKRD50	ANKYRIN REPEAT DOMAIN 50
BC025307*	PRKD2	PROTEIN KINASE D2
BC029112*	SAMSN1	SAM DOMAIN, SH3 DOMAIN AND NUCLEAR LOCALISATION SIGNALS, 1
BC029480*	LOC554203	HYPOTHETICAL LOC554203
BC035636*	APBB1IP	AMYLOID BETA (A4) PRECURSOR PROTEIN-BINDING, FAMILY B, MEMBER 1 INTERACTING PROTEIN
BC038838*	PRR16	MESENCHYMAL STEM CELL PROTEIN DSC54
BC039244*	NFYA	NUCLEAR TRANSCRIPTION FACTOR Y, ALPHA
BC042999*	ASXL2	ADDITIONAL SEX COMBS LIKE 2 (DROSOPHILA)
BC062423*	C7ORF41	HYPOTHETICAL PROTEIN ELLS1
NM_001571*	IRF3	INTERFERON REGULATORY FACTOR 3
NM_001926*	DEFA6	DEFENSIN, ALPHA 6, PANETH CELL-SPECIFIC
NM_002505*	NFYA	NUCLEAR TRANSCRIPTION FACTOR Y, ALPHA
NM_003141*	TRIM21	TRIPARTITE MOTIF-CONTAINING 21

NM_004304*	ALK	ANAPLASTIC LYMPHOMA KINASE (KI-1)
NM_005214*	CTLA4	CYTOTOXIC T-LYMPHOCYTE-ASSOCIATED PROTEIN 4
NM_005902*	SMAD3	SMAD, MOTHERS AGAINST DPP HOMOLOG 3 (DROSOPHILA)
NM_006324*	CFDP1	CRANIOFACIAL DEVELOPMENT PROTEIN 1
NM_007242*	DDX19B	DEAD (ASP-GLU-ALA-AS) BOX POLYPEPTIDE 19B
NM_012472*	LRRC6	LEUCINE RICH REPEAT CONTAINING 6
NM_015927*	TGFB1I1	TRANSFORMING GROWTH FACTOR BETA 1 INDUCED TRANSCRIPT 1
NM_017724*	LRRFIP2	LEUCINE RICH REPEAT (IN FLII) INTERACTING PROTEIN 2
NM_017855*	ODAM	APIN PROTEIN
NM_023112*	OTUB2	OTU DOMAIN, UBIQUITIN ALDEHYDE BINDING 2
NM_025241*	UBXD1	UBX DOMAIN CONTAINING 1
NM_053283*	DCD	DERMCIDIN
NM_172160*	KCNAB1	POTASSIUM VOLTAGE-GATED CHANNEL, SHAKER-RELATED SUBFAMILY, BETA MEMBER 1
NM_175907*	ZADH2	HYPOTHETICAL PROTEIN BC010734

The protein targets showing the highest reactivity in a sumo1 PTM assay were the RANBP2 protein, which was previously identified as a sumo1 E3 ligase, and TGFII. In the sumo2/3 PTM profile, one of the top reactivities was UbcH9, the only known E2 characterized to date for sumo conjugation. Additionally, among the highest reactivities (top 7) of neddylation proteins were the E2 and E3 enzymes that are known to be involved in the neddylation pathway. The other reactive proteins did not appear to be relevant to the neddylation pathway. Thus, among the top reacting proteins for each of these modifications were the enzymes that are involved in catalysis of the relevant PTM itself. In the case of FAT10, many of the highly reactive proteins were mitotic regulators or cytoskeleton related. To date only one substrate, Mad2, has been described for modification with FAT10, and indeed Mad2 was highly FATtenylated in this assay. FAT10 is known to be highly expressed in certain kinds of cancers, and its overexpression may lead to chromosomal aberrations as well as mitotic arrest. For UFM1 there are no previously known substrates, and therefore all of the identified UFM1 substrates are newly discovered.

For each of the modifying moieties, signals from the CP-arrested and the CP-released extracts were compared. Two microarrays from each condition were examined, and a two-tailed t-test was used to identify differentially modified proteins. To determine significance, a permutation-based p-value calculation was used, and corrected for false discovery rate (FDR) either using Storey's method or using the Hochberg-Benjamini correction. For each modifying moiety tested (i.e. ubiquitin, sumo1, sumo2/3, nedd8, FA10, UFM1, ISG15) the proteins showing significant change in their modification state upon release from the mitotic CP were identified. For each PTM, two biological replicates and two different mitotic conditions (CP-arrested and CP-released) were examined. A subset of the microarray proteins showed a marked difference under the two different conditions but were similar in the biological replicates. These were identified as differentially modified proteins. The data were then clustered based on the differentially modified proteins (Fig. 15). Each row in Fig. 15 represents a different protein that was found to be differentially modified under the two different mitotic conditions. The list of differentially modified proteins was compared for each of the modifications (see Table 7), and the results showed that the proteins were differentially targeted by each of the modifying moieties, and the sets of proteins modified by the different modifying moieties were not overlapping more than would be expected by chance. This is shown in a Venn diagram in Fig. 16, and suggests specialized roles for each different modification in regulating a unique set of target proteins.

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While the present invention has been described in conjunction with a preferred embodiment, one of ordinary skill, after reading the foregoing specification, will be able to effect various changes, substitutions of equivalents, and other alterations to the compositions and methods set forth herein. It is therefore intended that the protection granted by Letters Patent hereon be limited only by the definitions contained in the appended claims and equivalents thereof.

CLAIMS

What is claimed is:

1. A method of identifying an altered post-translational modification (PTM) state of a protein in a patient, the method comprising:

contacting a functional extract of a sample from the patient with an array comprising an ordered plurality of proteins that are representative of proteins in the patient;

establishing a specific PTM reaction on the array, whereby the reaction results in a PTM of one or more proteins in the array through the activity of one or more enzymes present in the extract;

determining a level of the PTM of said one or more proteins by detecting a signal from the array; and

comparing the level of PTM of said one or more proteins in the array with the level of PTM of the corresponding one or more proteins in a control sample to identify an altered PTM state of a protein in the patient.

2. The method of claim 1, wherein the PTM is selected from the group consisting of ubiquitination, phosphorylation, sumoylation, and neddylation.

3. The method of claim 1, wherein the patient sample is obtained from a source selected from the group consisting of plasma, cerebrospinal fluid, saliva, urine, and a biopsy specimen comprising cells or tissues of the patient.

4. The method of claim 3, wherein the source is a biopsy specimen which is a tumor.

5. The method of claim 1, wherein the patient is suspected of having cancer, a neurodegenerative disease, a metabolic disease, an immune disease, or an infectious disease.

6. The method of claim 5, wherein the patient is suspected of having a neurodegenerative disease and the neurodegenerative disease is Alzheimer's disease or Huntington's disease.

7. The method of claim 1 wherein, prior to or during the step of establishing a specific PTM reaction, the extract is supplemented with a reagent, a substrate, an enzyme, an enzyme inhibitor, ATP, creatine phosphate, a drug, an antibody, or a combination thereof.
8. The method of claim 7, wherein the extract is supplemented with a substrate of an enzyme that carries out said specific PTM reaction.
9. The method of claim 7, wherein the extract is supplemented with an inhibitor of an enzyme that reverses said specific PTM reaction.
10. The method of claim 1, wherein the functional extract is prepared by a method comprising hypotonic lysis or freeze-thawing of cells in the patient sample.
11. The method of claim 10, wherein the extract is prepared by adding lysis buffer in an amount no more than 0.8 times the volume of cells.
12. The method of claim 1, wherein the functional extract is essentially detergent-free.
13. The method of claim 1, wherein the signal is a light signal.
14. The method of claim 13, wherein, in the step of determining, the position and intensity of the light signal are measured.
15. The method of claim 1 further comprising, following the step of establishing a specific PTM reaction, washing the reaction components off the array and incubating the array with a first antibody that specifically binds proteins in the array bearing said specific PTM.
16. The method of claim 15, further comprising washing unbound first antibody off the array and contacting the array with a second antibody that specifically binds the first antibody, wherein the second antibody is attached to a label moiety.
17. The method of claim 1 further comprising, prior to the step of comparing, performing the steps of establishing and determining using a control sample instead of the patient sample and a

second array comprising said ordered plurality of proteins, wherein the results obtained from the step of determining using the control sample are compared with the results obtained from the step of determining using the patient sample in the step of comparing.

18. The method of claim 1 further comprising, prior to the step of contacting, preparing the functional extract.

19. The method of claim 1, wherein two or more specific PTM reactions are established simultaneously.

20. The method of claim 1, wherein the step of establishing a specific PTM reaction includes adding a biochemical energy source to the extract.

21. The method of claim 20, wherein the biochemical energy source is a mixture of ATP and creatine phosphate.

22. The method of claim 1, wherein the step of establishing a specific PTM reaction includes adding a protein modifying moiety to the extract.

23. The method of claim 22, wherein the modifying moiety is a ubiquitin-like modifying moiety selected from the group consisting of ISG15, UCRP, FUB1, NEDD8, FAT10, SUMO-1, SUMO-2, SUMO-3, Apg8, Apg12, Urm1, UBL5, and Ufm1.

24. A method of identifying a protein PTM enzyme activity in a patient, the method comprising:

contacting a functional extract of a sample from the patient with an array comprising an ordered plurality of proteins that are representative of proteins in the patient;

establishing a specific PTM reaction on the array, whereby the reaction results in a PTM of one or more proteins in the array through said enzyme activity present in the extract;

determining a level of the PTM of said protein by detecting a signal from the array; and

comparing the results of the step of determining with results obtained for a control reaction lacking said functional extract, wherein a PTM enzyme activity in the patient is

identified when the level of the PTM of said protein is higher than the level of the PTM for said protein in the control.

25. The method of claim 24, wherein the PTM is selected from the group consisting of ubiquitination, phosphorylation, sumoylation, and neddylation.

26. The method of claim 24, wherein the patient sample is obtained from a source selected from the group consisting of plasma, cerebrospinal fluid, saliva, urine, and a biopsy specimen comprising cells or tissues of the patient.

27. The method of claim 26, wherein the source is a tumor.

28. The method of claim 24, wherein the patient is suspected of having cancer, a neurodegenerative disease, a metabolic disease, an immune disease, or an infectious disease.

29. The method of claim 28, wherein the patient is suspected of having a neurodegenerative disease and the neurodegenerative disease is Alzheimer's disease or Huntington's disease.

30. The method of claim 24, wherein prior to or during the step of contacting, the extract is mixed with a reagent, a substrate, an enzyme, an enzyme inhibitor, ATP, creatine phosphate, a drug, an antibody, or a combination thereof.

31. The method of claim 30, wherein the extract is supplemented with a substrate for said PTM enzyme.

32. The method of claim 30, wherein the extract is supplemented with an inhibitor of said PTM enzyme.

33. The method of claim 24, wherein the functional extract is prepared by a method comprising hypotonic lysis or freeze-thawing of cells in the patient sample.

34. The method of claim 33, wherein the extract is prepared by adding lysis buffer in an amount no more than 0.8 times the volume of cells.

35. The method of claim 24, wherein the functional extract is essentially detergent-free.
36. The method of claim 24, wherein the signal is a light signal.
37. The method of claim 36 wherein, in the step of determining, the position and intensity of the light signal are measured.
38. The method of claim 24 further comprising, following the step of establishing a specific PTM reaction, washing the reaction components off the array and incubating the array with a first antibody that specifically binds proteins in the array bearing said specific PTM.
39. The method of claim 38, further comprising washing unbound first antibody off the microarray and contacting the array with a second antibody that specifically binds the first antibody, wherein the second antibody is attached to a label moiety.
40. The method of claim 24 further comprising, prior to the step of contacting, preparing the functional extract.
41. The method of claim 24, wherein two or more specific PTM reactions are established simultaneously.
42. The method of claim 24, wherein the step of establishing a specific PTM reaction includes adding a biochemical energy source to the extract.
43. The method of claim 42, wherein the biochemical energy source is a mixture of ATP and creatine phosphate.
44. The method of claim 24, wherein the step of establishing a specific PTM reaction includes adding a protein modifying moiety to the extract.

45. The method of claim 44, wherein the modifying moiety is a ubiquitin-like modifying moiety selected from the group consisting of ISG15, UCRP, FUB1, NEDD8, FAT10, SUMO-1, SUMO-2, SUMO-3, Apg8, Apg12, Urm1, UBL5, and Ufm1.

46. A method of diagnosing a disease or medical condition in a patient, the method comprising:
contacting a functional extract of a sample from the patient with an array comprising an ordered plurality of proteins that are representative of proteins in the patient;

establishing a specific PTM reaction on the array, whereby the reaction results in a PTM of one or more proteins in the array through the activity of one or more enzymes present in the extract;

identifying one or more post-translationally modified proteins in the array by detecting a signal from the array to yield a PTM state data set for the patient sample; and

comparing the PTM state data set with a standard data set comprising PTM state data that are diagnostic for the disease or medical condition, so as to diagnose the disease or medical condition in the patient.

47. The method of claim 46, wherein the signal generated on the array indicates a PTM state selected from the group consisting of ubiquitination, phosphorylation, sumoylation, and neddylation.

48. The method of claim 46, wherein the patient sample is obtained from a source selected from the group consisting of plasma, cerebrospinal fluid, saliva, urine, and a biopsy specimen comprising cells or tissues of the patient.

49. The method of claim 48, wherein the source is a tumor.

50. The method of claim 46, wherein the patient is suspected of having cancer, a neurodegenerative disease, a metabolic disease, an immune disease, or an infectious disease.

51. The method of claim 48, wherein the patient is suspected of having a neurodegenerative disease and the neurodegenerative disease is Alzheimer's disease or Huntington's disease.

52. The method of claim 46 further comprising, following the step of contacting, washing the reaction components off the array and incubating the array with a first antibody that specifically binds proteins in the array bearing said specific PTM.

53. The method of claim 52, further comprising washing unbound first antibody off the microarray and contacting the array with a second antibody that specifically binds the first antibody, wherein the second antibody is attached to a label moiety.

54. The method of claim 46 further comprising, prior to the step of contacting, preparing the functional extract.

55. The method of claim 46, wherein two or more specific PTM reactions are established simultaneously.

56. The method of claim 46, wherein the step of establishing a specific PTM reaction includes adding a biochemical energy source to the extract.

57. The method of claim 56, wherein the biochemical energy source is a mixture of ATP and creatine phosphate.

58. The method of claim 46, wherein the step of establishing a specific PTM reaction includes adding a protein modifying moiety to the extract.

59. The method of claim 58, wherein the modifying moiety is a ubiquitin-like modifying moiety selected from the group consisting of ISG15, UCRP, FUB1, NEDD8, FAT10, SUMO-1, SUMO-2, SUMO-3, Apg8, Apg12, Urm1, UBL5, and Ufm1.

60. A kit for the diagnosis of a disease or medical condition or the detection of a biological state by the analysis of a PTM state of a protein in a patient sample, the kit comprising:

a standard comprising one or more functional extracts capable of producing a known pattern of protein PTM states on a protein microarray, wherein the pattern is diagnostic for the disease, medical condition, or biological state; and

instructions for carrying out the method of any one of claims 1, 24, and 46.

61. The kit of claim 60, further comprising a reagent selected from the group consisting of a substrate, an enzyme, an enzyme inhibitor, a drug, an antibody, ATP, creatine phosphate, and a protein modifying moiety.

63. The kit of claim 60, further comprising a protein microarray.

64. A method of identifying a set of biomarkers for a disease, medical condition, or biological state, comprising:

comparing a protein PTM profile from one or more patients having the disease, medical condition, or biological state with a protein PTM profile from one or more control subjects who do not have the disease, medical condition, or biological state, wherein the profiles are obtained by analyzing functional extracts from the patients and control subjects with a microarray containing an ordered plurality of proteins according to the method of any one of claims 1, 24, and 46; and

determining one or more differences in a PTM state of one or more proteins between the patient and control profiles, wherein said one or more differences are identified as a set of biomarkers for the disease, medical condition, or biological state.

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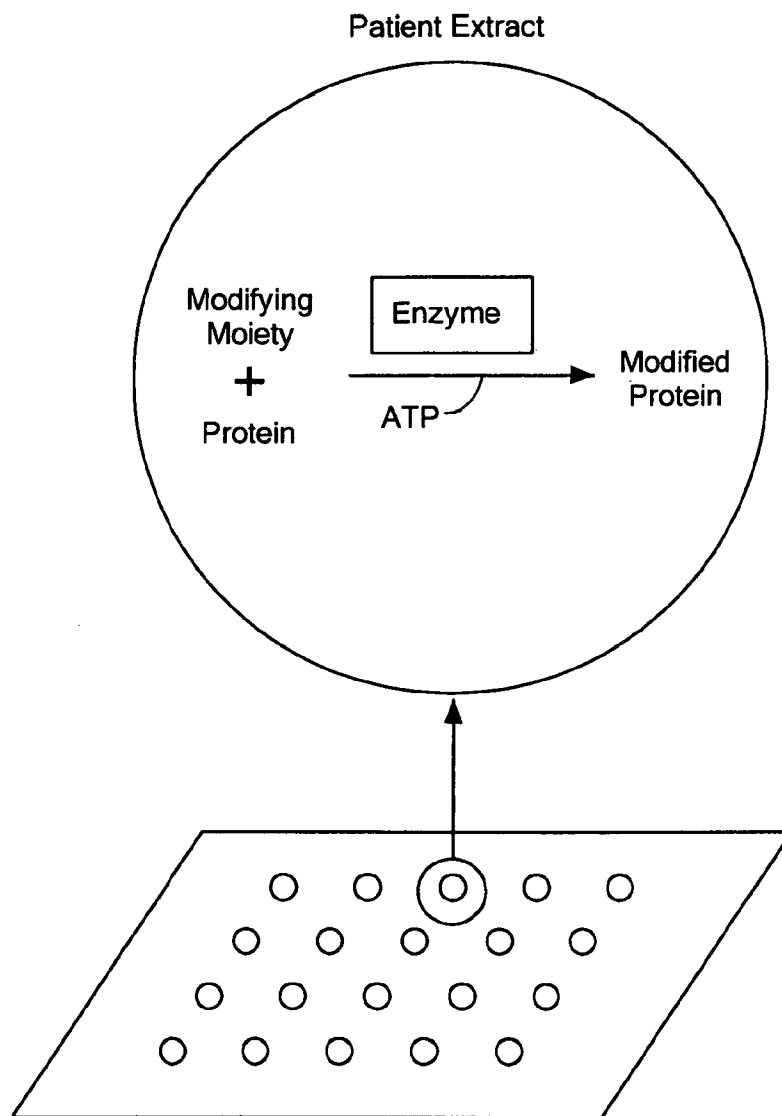
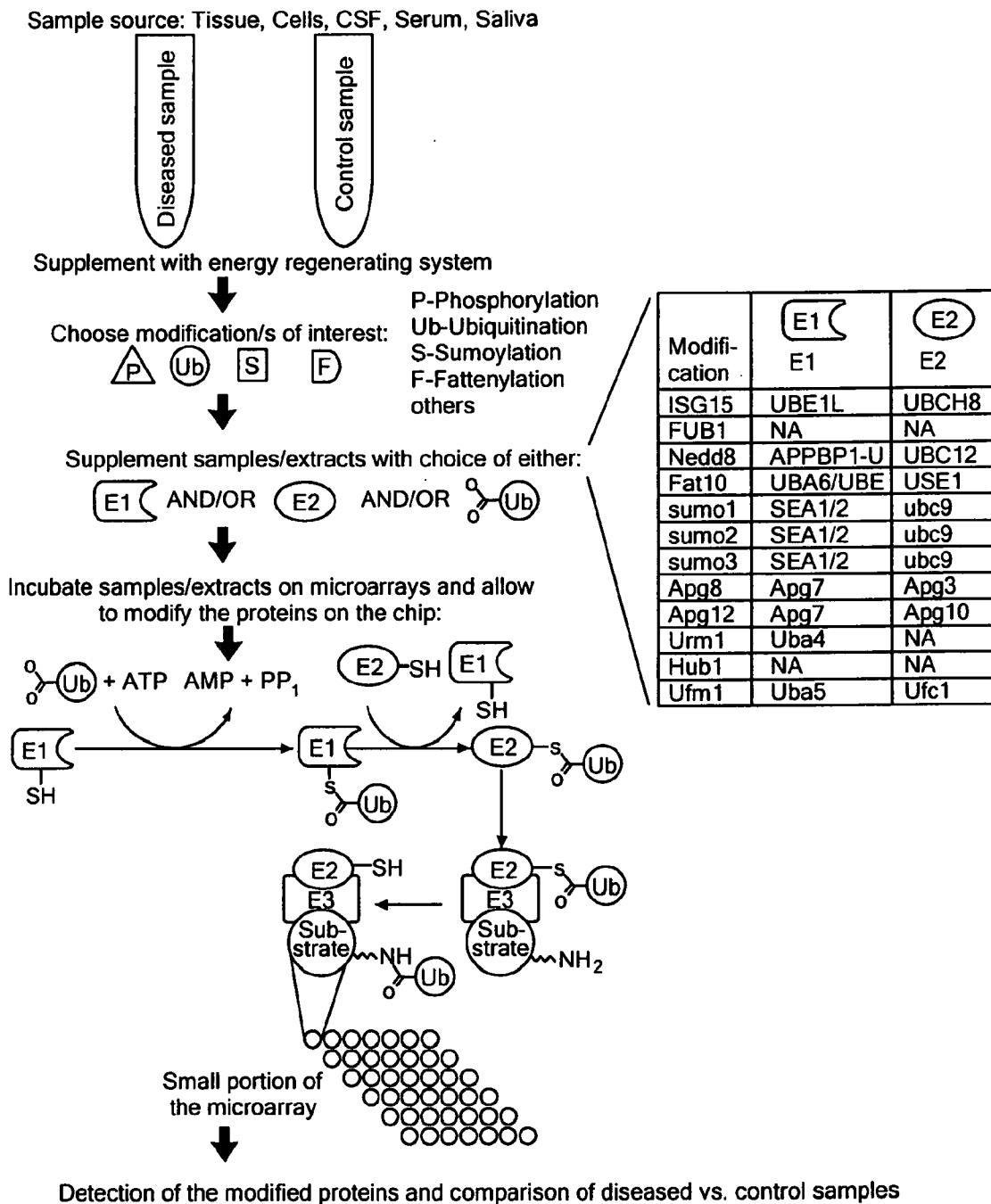
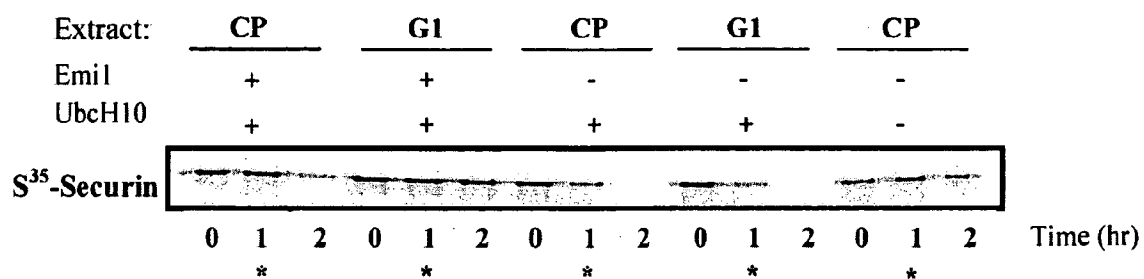
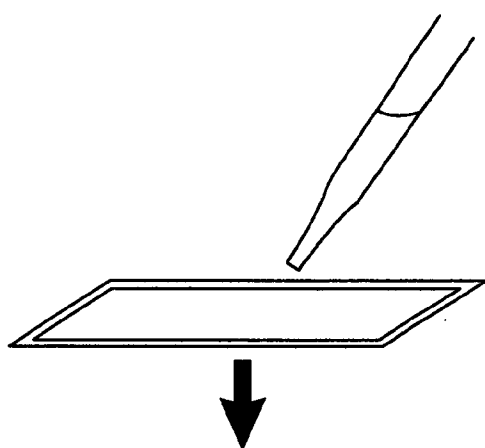


FIG. 1A

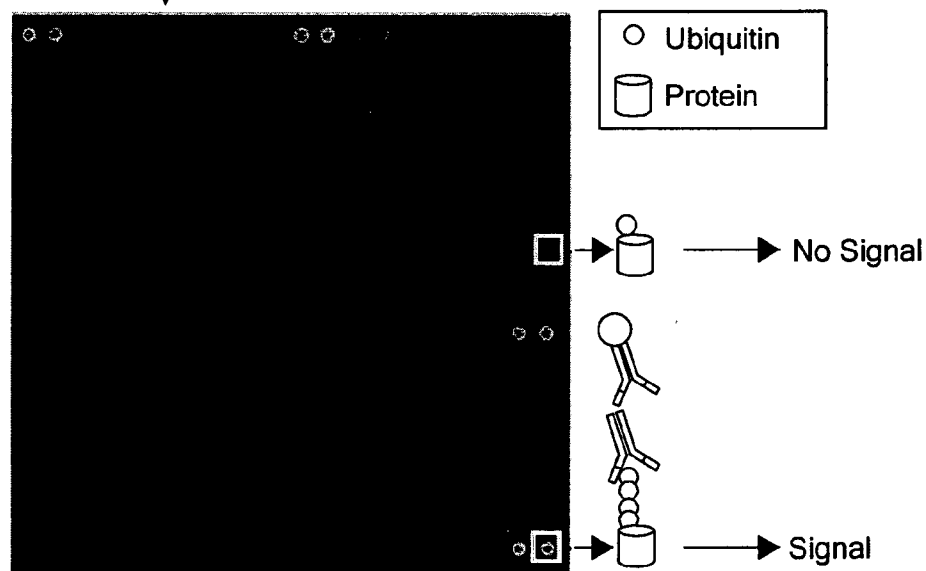
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**FIG. 1B**

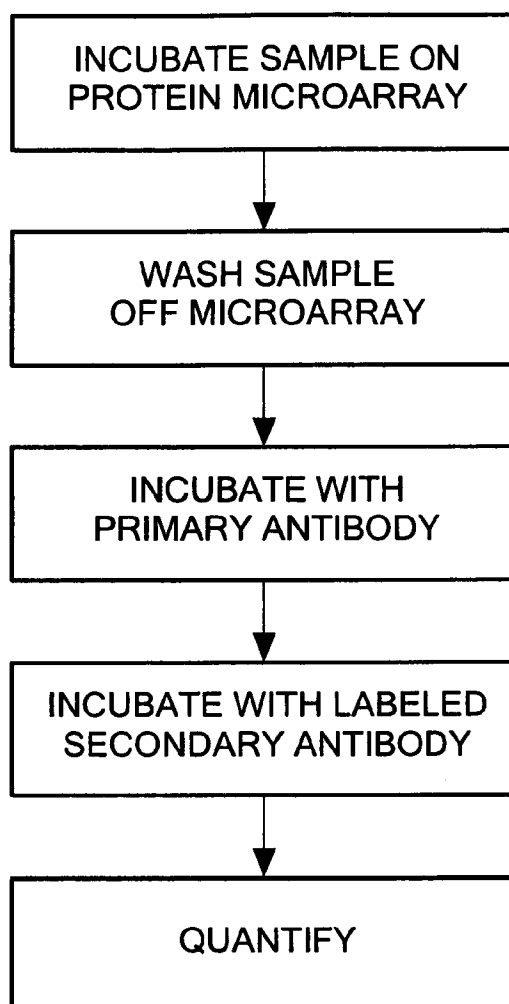
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**FIG. 2A**

- Incubation of extracts +/- E3 (or other enzyme) inhibitor on protein microarrays
- Washing extracts off the microarrays
- Incubation with primary antibody (against modification)
- Incubation with labeled secondary antibody
- Quantitation

**FIG. 2B**

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***FIG. 2C***

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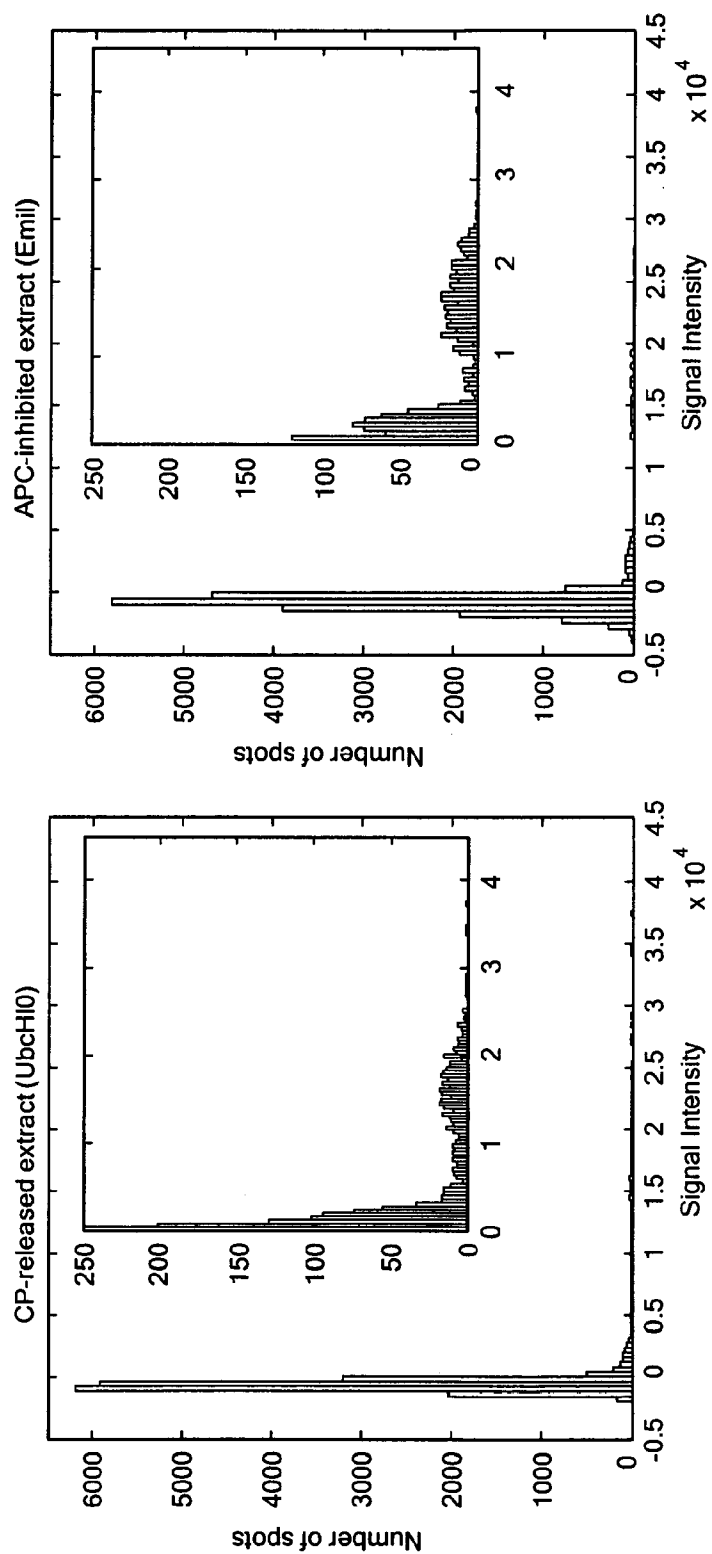
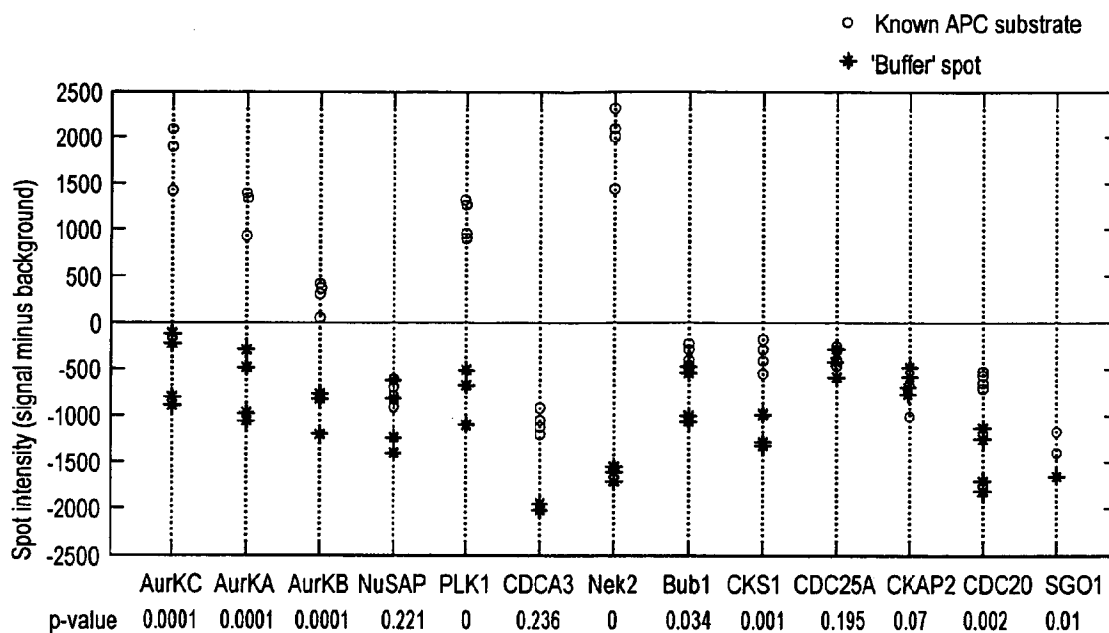
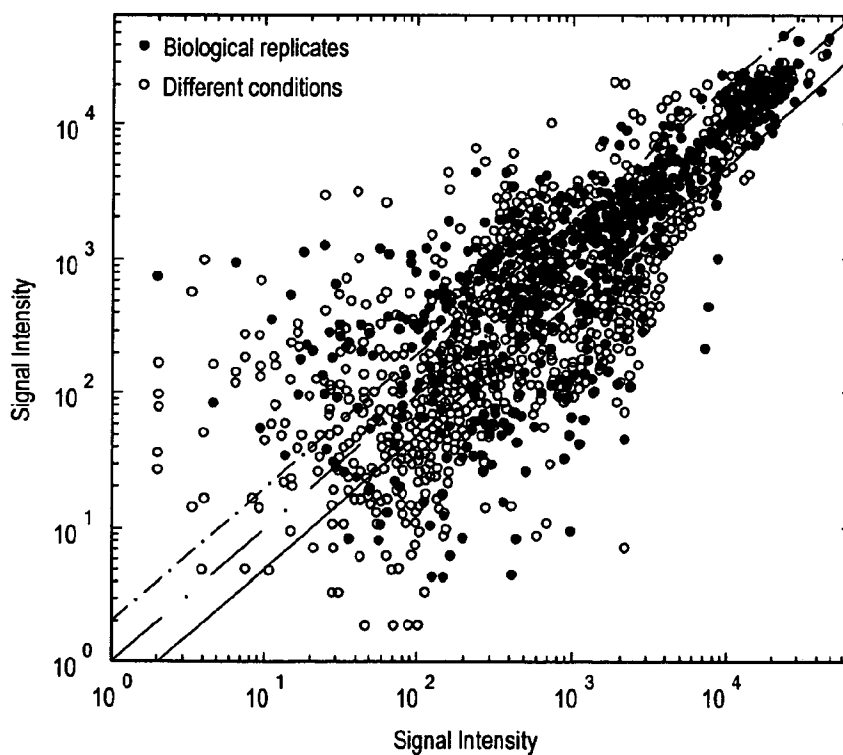


FIG. 3A

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**FIG. 3B****FIG. 3C**

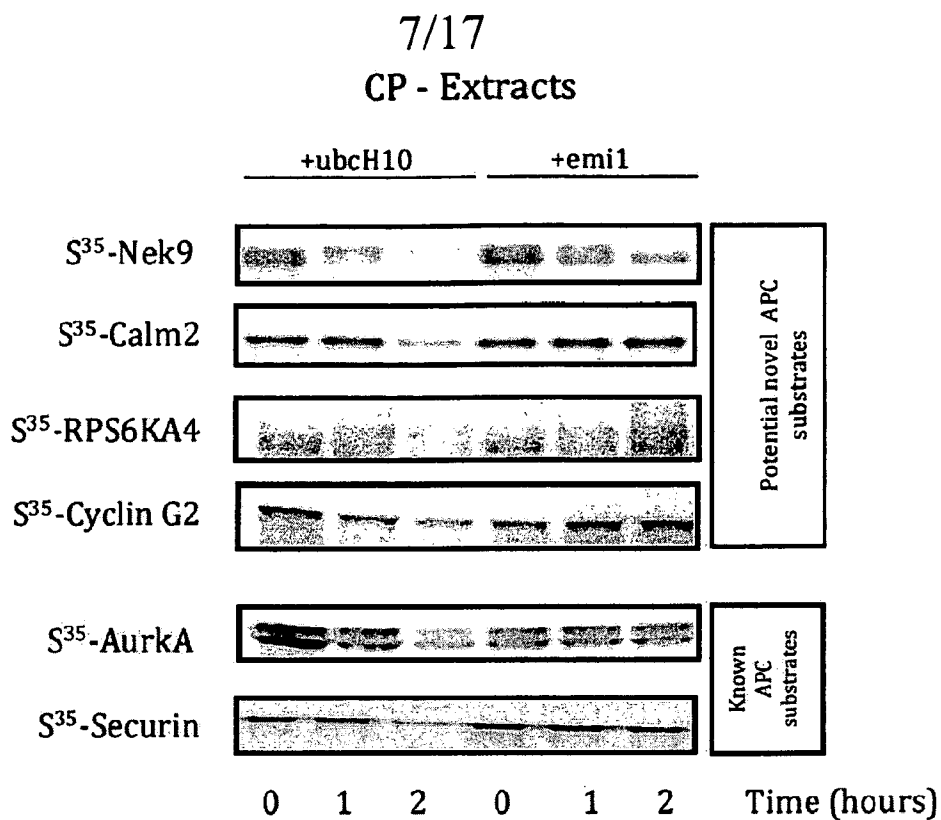


FIG. 4A

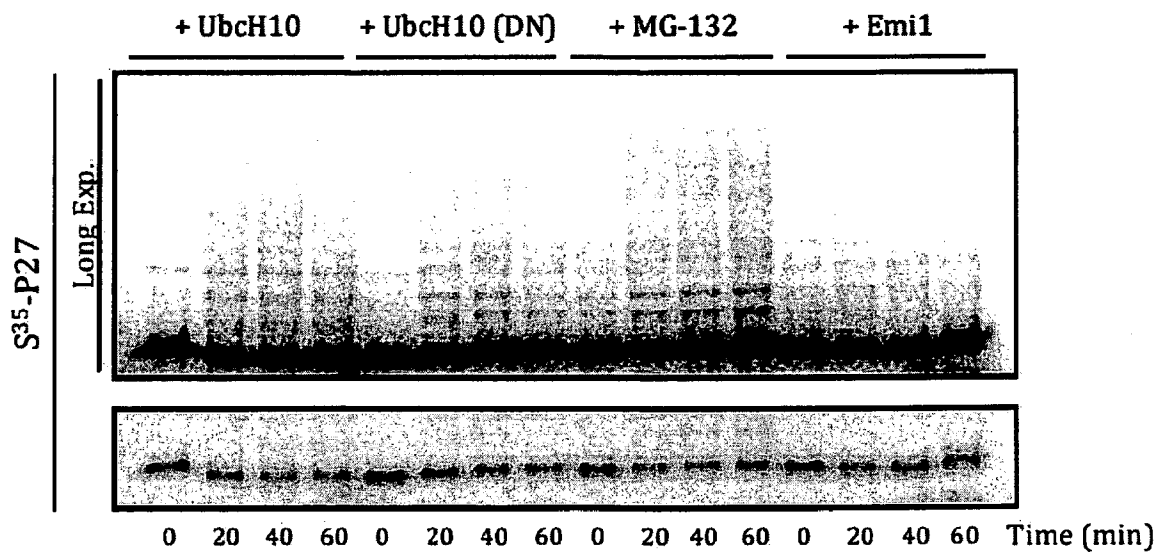
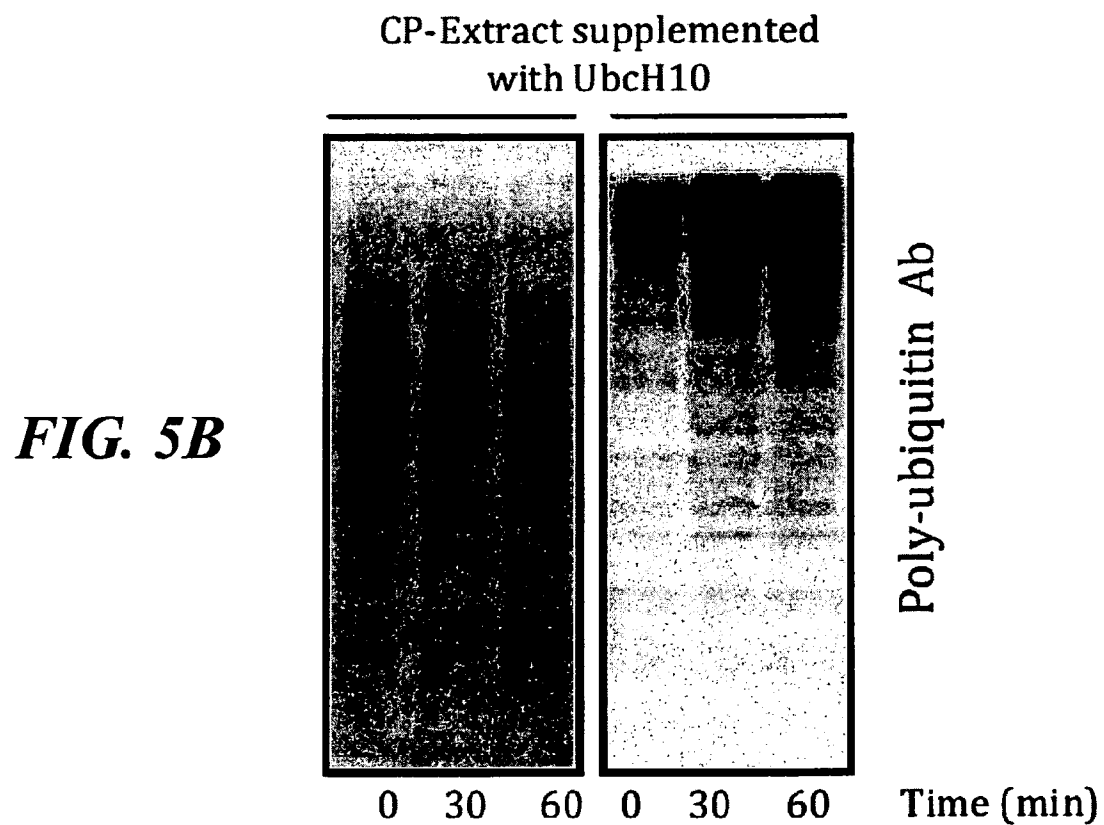
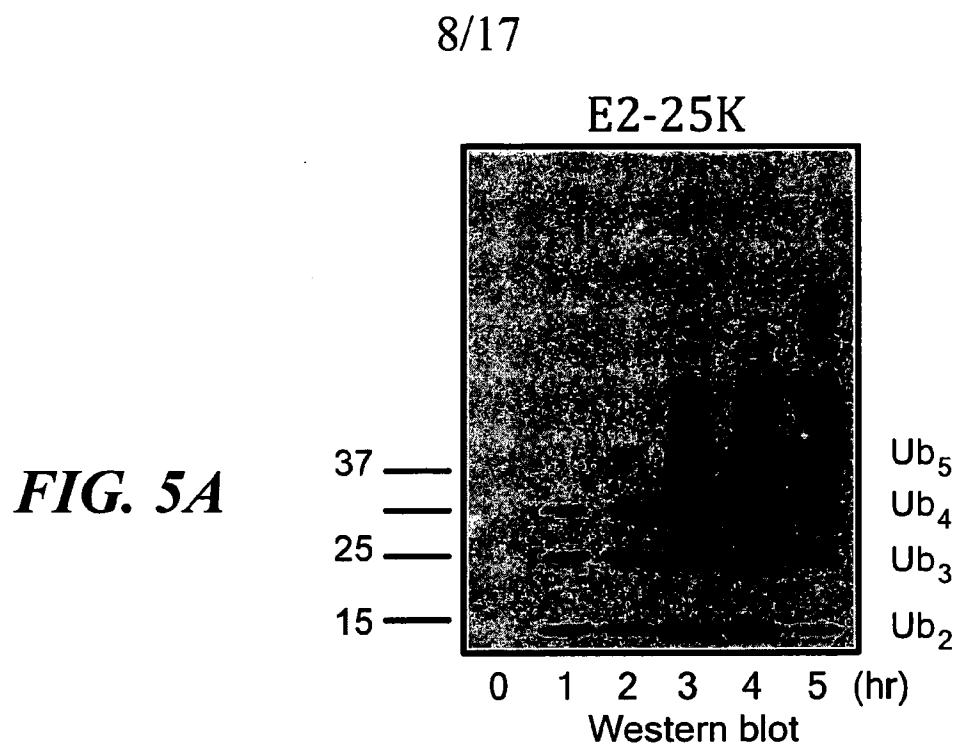
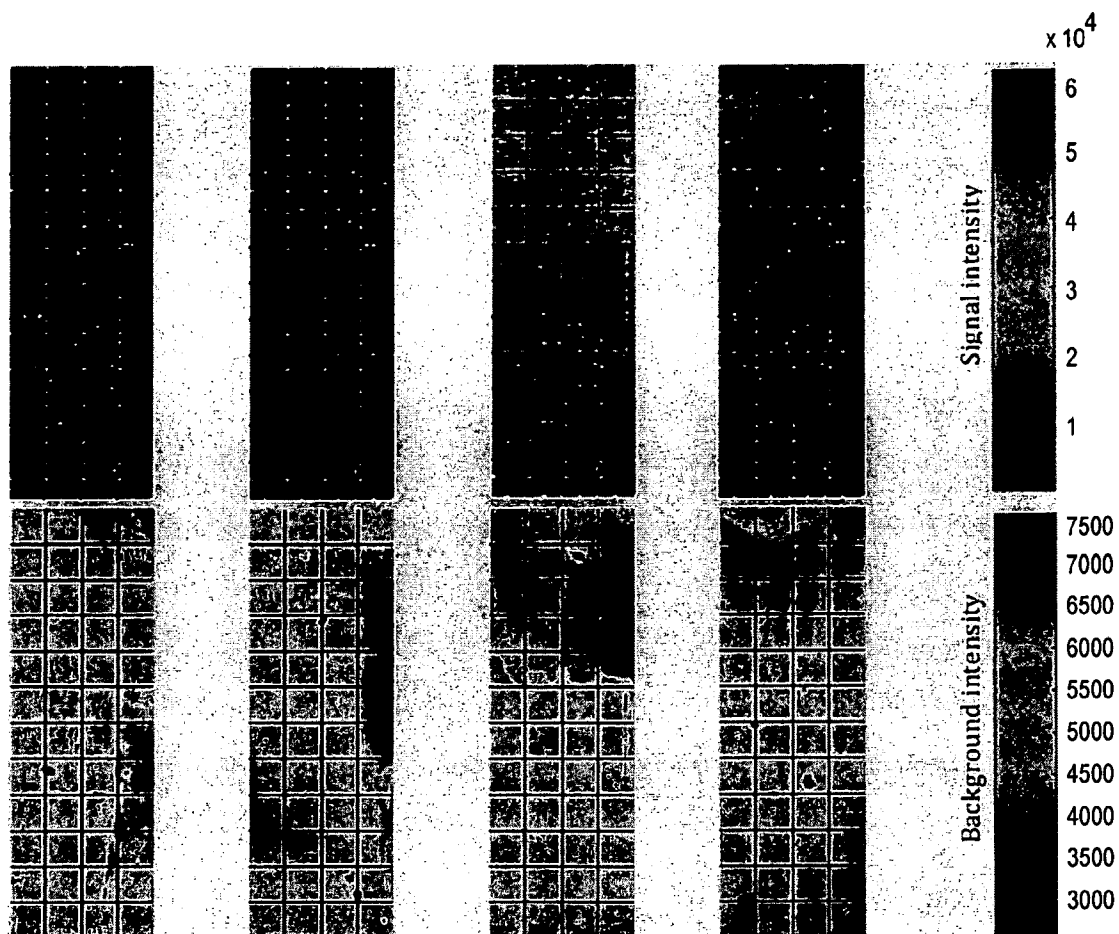


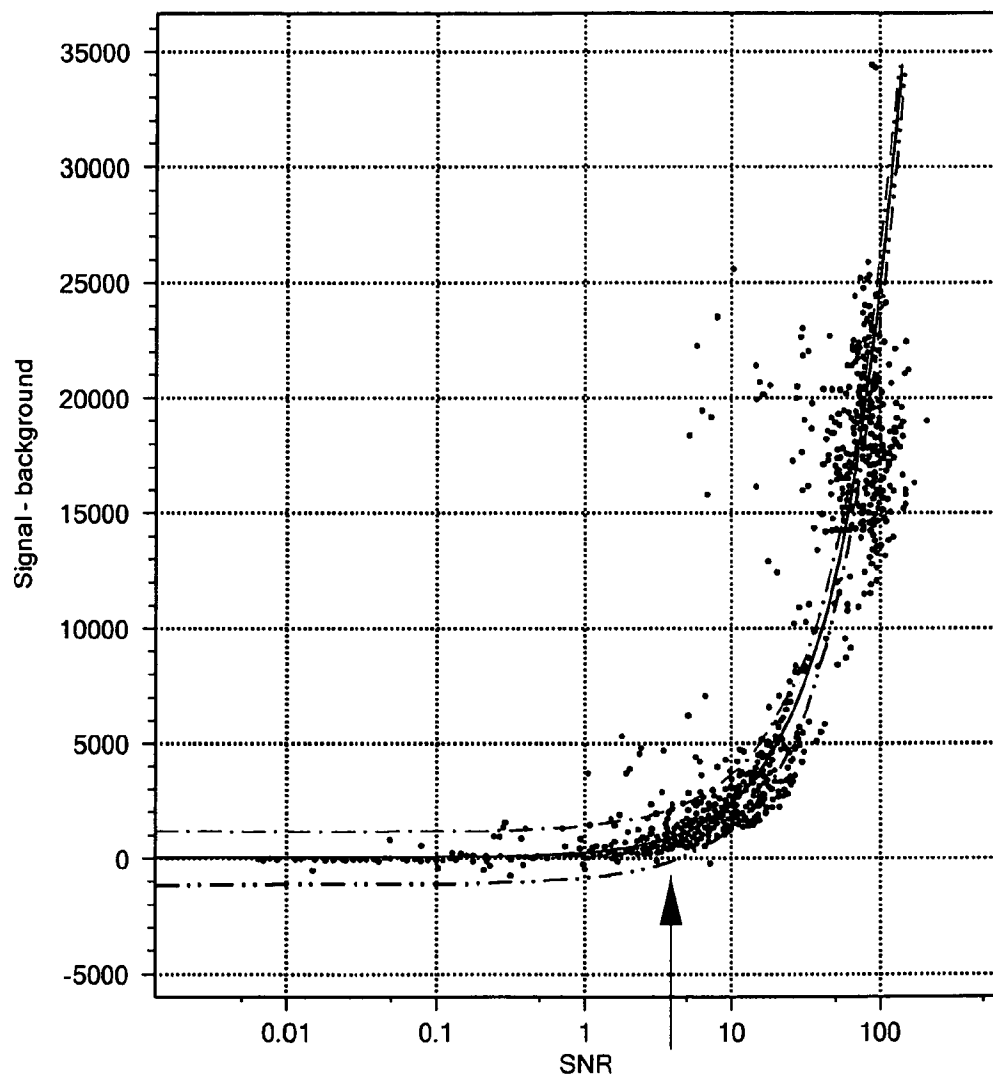
FIG. 4B



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**FIG. 6**

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**FIG. 7**

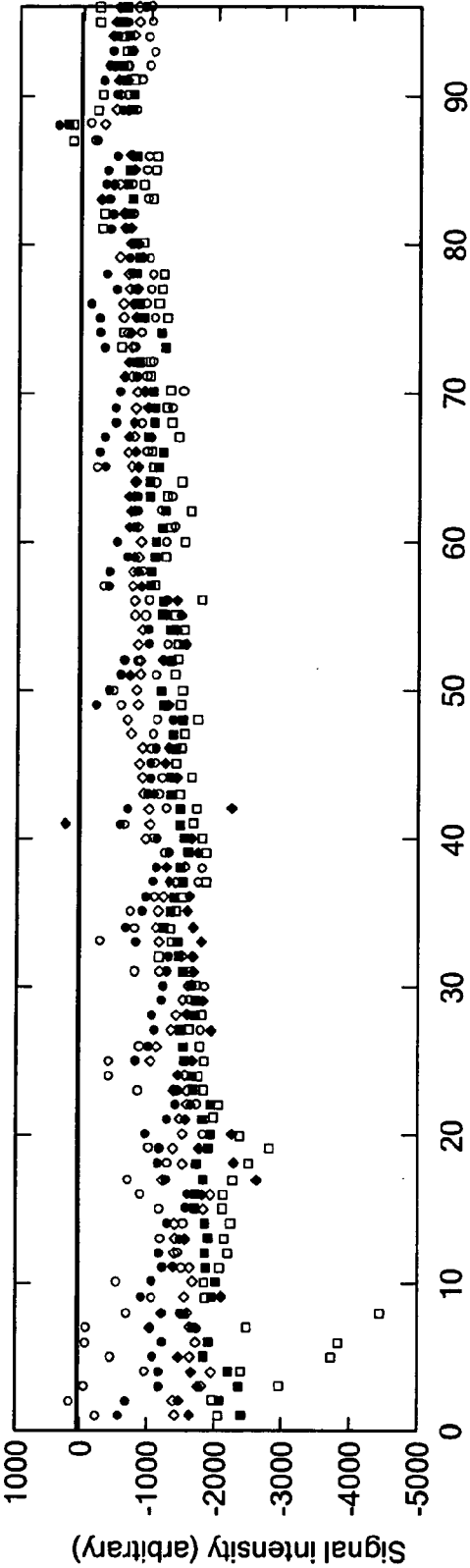


FIG. 8

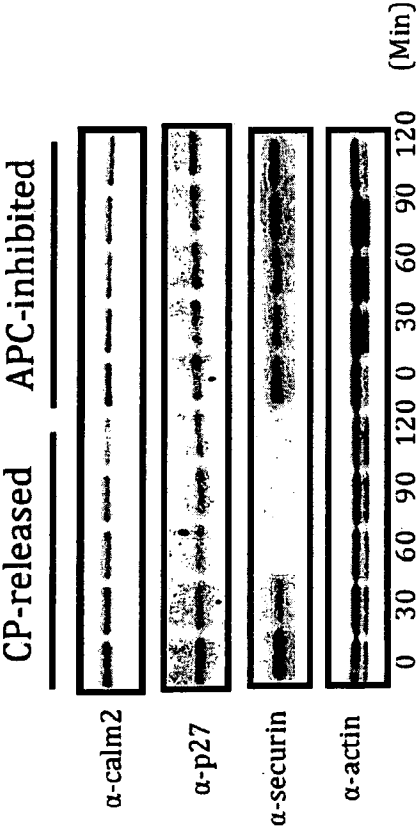
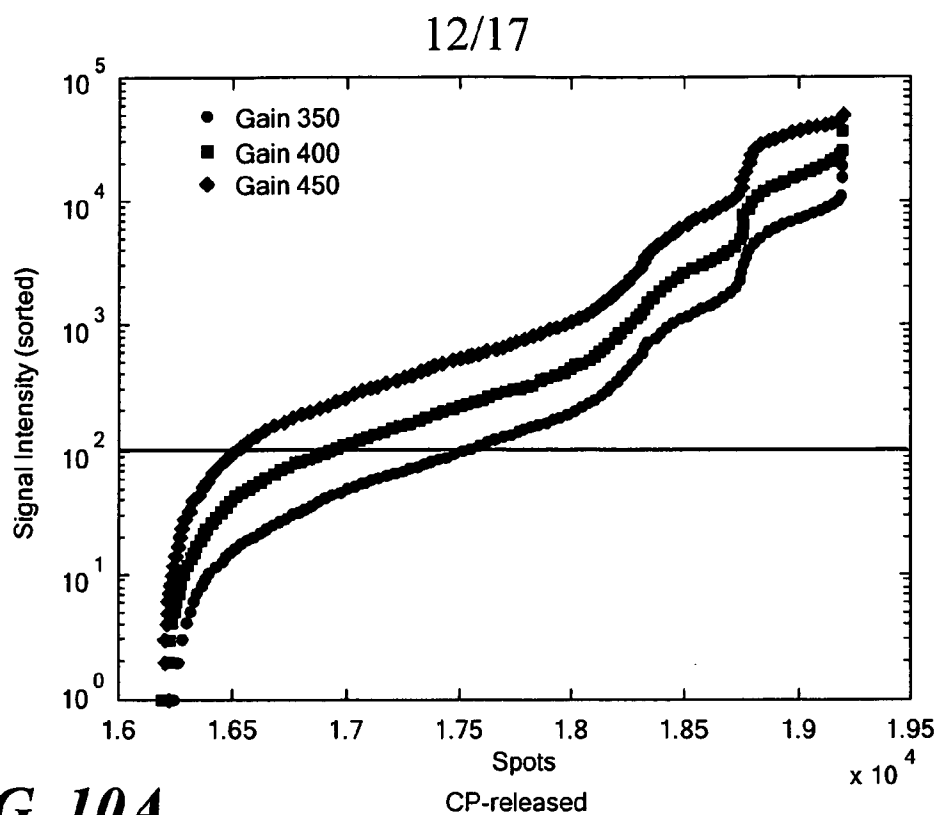
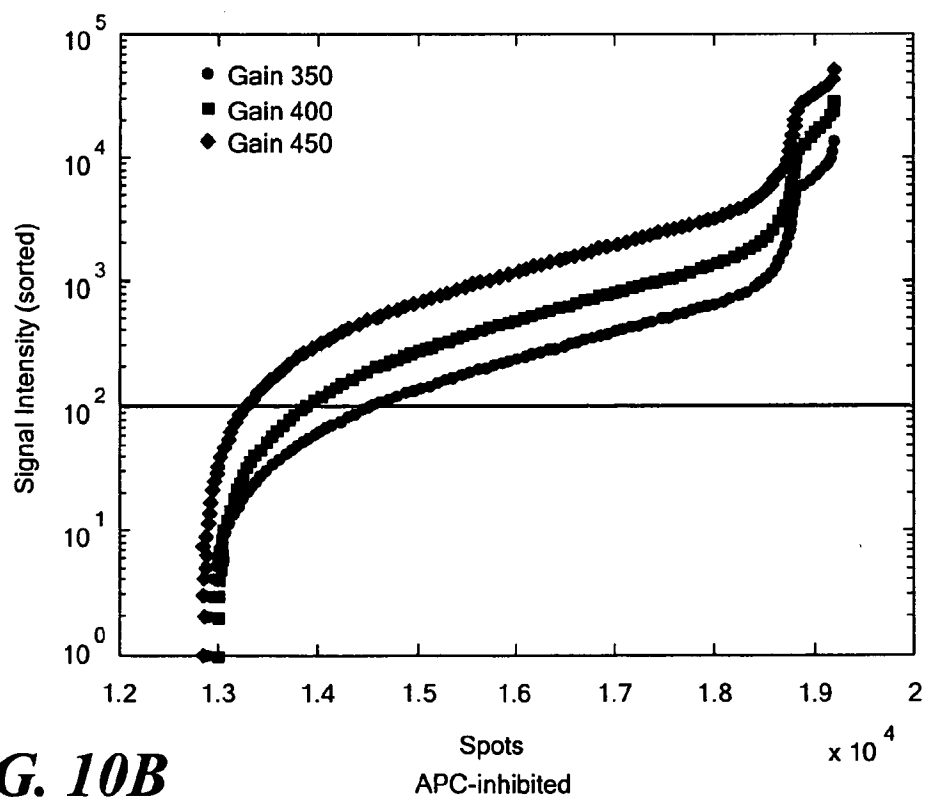


FIG. 9

**FIG. 10A****FIG. 10B**

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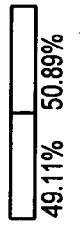
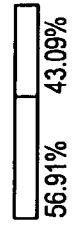
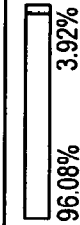
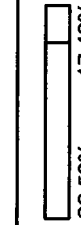
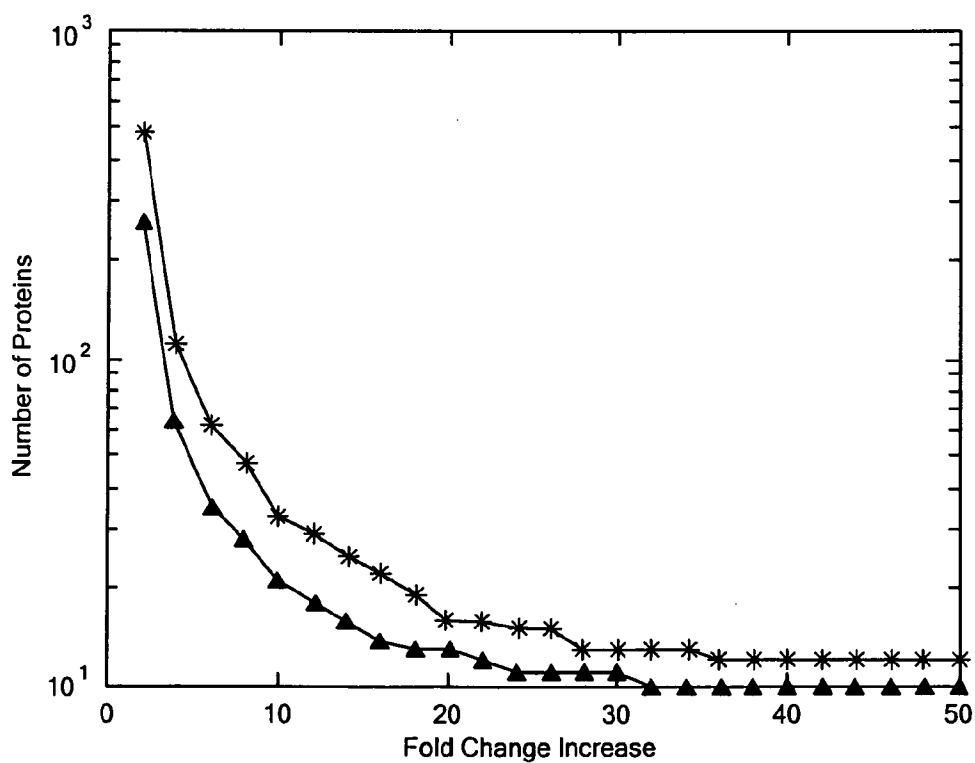
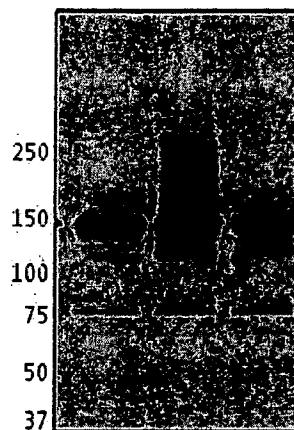
Gene Ontology term	#1: predicted list #2: background list	percentage in#1 percentage in#2	relative %	pval
muscle contraction (GO:0006936)	#1: NM_000723 #2: BC037311 NM_...	 4.17% 0.89%	 82.44% 17.56%	1.96e-1
response to stress (GO:0006950)	#1: NM_003146 NM... #2: BC056409 NM_...	 8.33% 8.64%	 49.11% 50.89%	1
cell morphogenesis (GO:0000902)	#1: NM_002291 #2: BC032449 NM_...	 4.17% 3.15%	 56.91% 43.09%	5.383-1
regulation of action potential (GO:0001508)	#1: BC014649 NM... #2: BC014649 NM_...	 8.7% 0.35%	 96.08% 3.92%	3.66e-3
ensheathment of neurons (GO:0007272)	#1: BC014649 NM... #2: NM_000533 BC	 11.76% 0.31%	 97.42% 2.58%	1.67e-3
microtubule cytoskeleton organization and biogenesis (GO:0000226)	#1: NM_031845 #2: NM_153477 BC..	 5.88% 1.25%	 82.52% 17.48%	1.96e-1

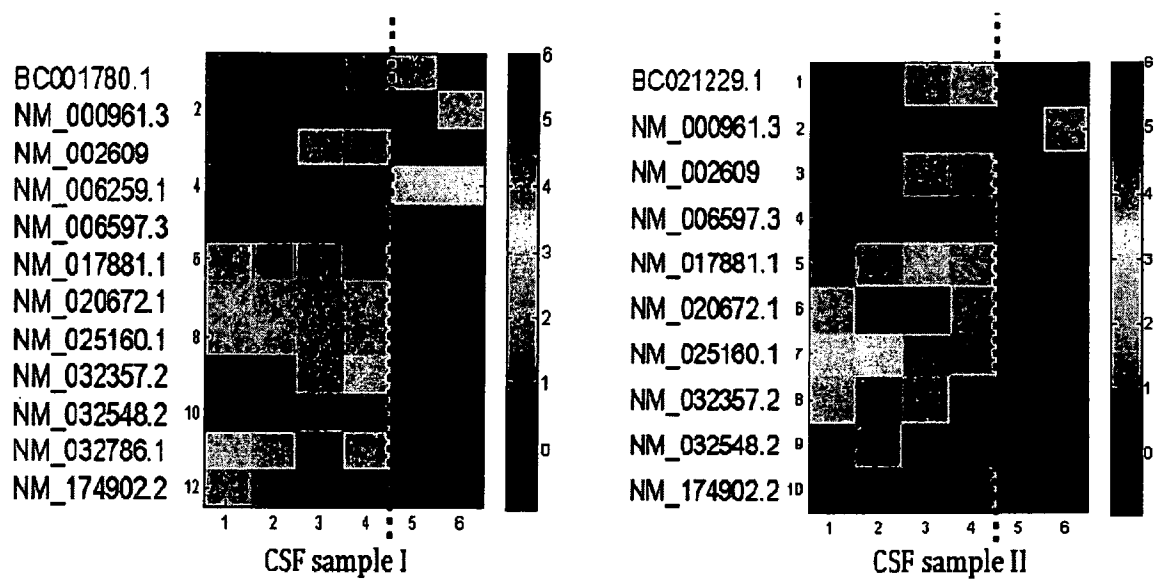
FIG. 11

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Boiled:	+	-	-
ATP	+	+	+
Ubi.	+	+	-

FIG. 12**FIG. 13**

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**FIG. 14**

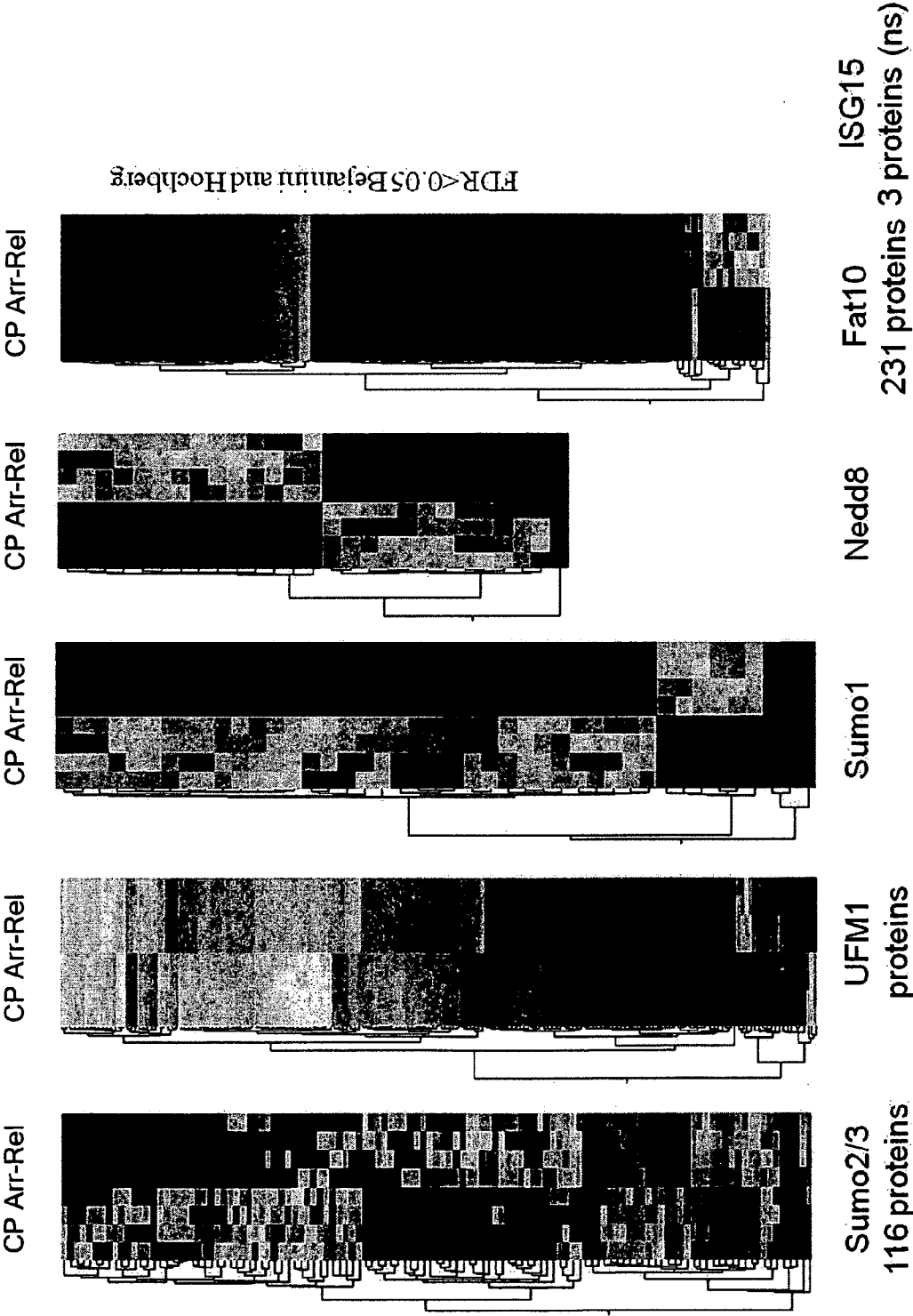
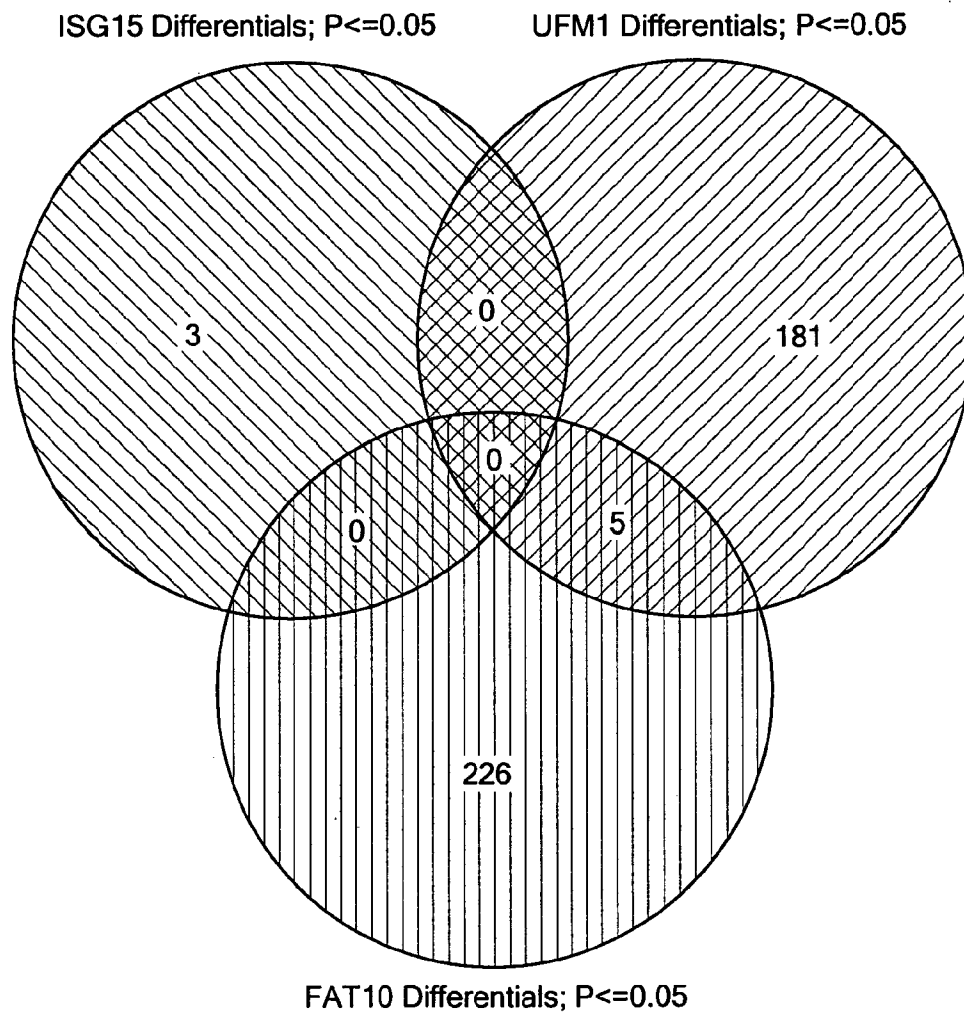


FIG. 15

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**FIG. 16**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 09/05670

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - C12Q 1/68 (2009.01)

USPC - 435/6

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8): C12Q 1/68 (2009.01)

USPC: 435/6

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC: 435/6, 7,1.4 (text search)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Electronic data base: USPTO PubWEST (EPAB, JPAB, USPT, PGPB); Google Scholar

search terms: microarray, phosphorylation, ubiquitination, sumoylation, neddylation, disease (cancer, infectious, metabolic, neurodegenerative, ubiquitin-like modifying protein (SUMO-1,2,3, NEDD8, ISG15, UCRP, Apg8, Apg12, Urm1, UBL5, Urm1)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ----- Y	US 2008/0138836 A1 (MICHAUD, et al.) 12 June 2008 (12.06.2008), especially, para [0010], [0072], [0109], [0111], [0120], [0237], [0238],[0249], [0293], [0301], [0302], [0337]-[0345], sheets 32, 33	1-5, 7-28, 30-50, 52-61, 63, 64 6, 21, 29, 43, 51, 57
Y	US 2007/0003951 A1 (KODADEK) 04 January 2007 (04.01.2007), especially, para [0014], [0124]	6, 29, 51
Y	YAO, et al. Cyclization of Polyubiquitin by the E2-25K Ubiquitin Conjugating Enzyme. J. Biol Chem. 24 November 2000, Vol. 275, No. 47, pp 36862-36868; especially, pg 36863, left col, para 2	21, 43, 57
A	GUPTA, et al. Ubiquitination Screen Using Protein Microarrays For Comprehensive Identification of Rsp5 Substrates In Yeast. Mol Syst Biol Epub. 05 June 2007, Vol. 3, Article No. 116, pp 1-12; [online] (Retrieved on 07 December 2009). Available on the internet: <URL: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1911201/?tool=pubmed >; Abstract.	1-61, 63-64

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Further documents are listed in the continuation of Box C.

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* Special categories of cited documents:

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"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T"

later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y"

document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&"

document member of the same patent family

Date of the actual completion of the international search

07 December 2009 (07.12.2009)

Date of mailing of the international search report

23 DEC 2009

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