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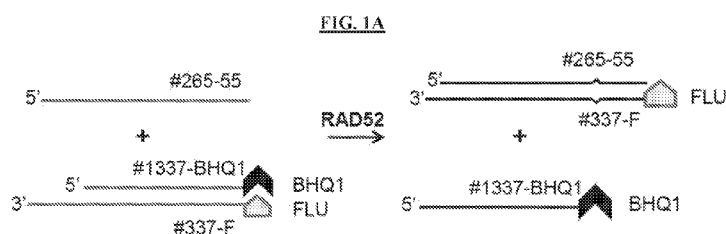
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(54) Title: Inhibitors of RAD52 Recombination Protein and Methods Using Same



(57) Abstract: The present invention includes novel RAD52 inhibitors for preventing or treating cancers in a subject in need thereof. The present invention further includes a method of preventing or treating cancers in a subject in need thereof, the method comprising administering to the subject an effective amount of a compound of the invention. In certain embodiments, the subject is further administered at least one additional therapeutic agent.

TITLE OF THE INVENTION

Inhibitors of RAD52 Recombination Protein and Methods Using Same

5 CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application No. 62/170,985, filed June 4, 2015, which application is incorporated herein by reference in its entirety.

10 STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

This invention was made with government support under grant numbers MH097512-01, CA100839 and CA188347 awarded by National Institutes of Health. The government has certain rights in the invention.

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BACKGROUND OF THE INVENTION

DNA repair is essential for maintenance of genome integrity in all organisms. Numerous DNA repair systems evolved to eliminate a broad variety of DNA lesions caused by exogenous agents or genotoxic products of metabolism. In normal cells, the specificities
20 of different DNA repair mechanisms overlap to assure efficient genome protection. However, cancer cells often lose some DNA repair pathways due to intrinsic genome instability. In this case, cancer cell viability depends on the remaining alternative DNA repair mechanisms. Poly (ADP-ribose) polymerase 1(PARP1), a protein involved in DNA damage signaling and repair of DNA single-stranded breaks (SSB), is essential for viability
25 of cancer cells that are deficient in the homologous recombination (HR) pathway. Furthermore, hereditary breast cancer and ovarian cancer cells, which often carry mutations in HR proteins BRCA1 or BRCA2, can be eliminated using PARP1 inhibitors with a minimal harm to normal cells with at least one copy of functional BRCA1/2 genes.

BRCA1/2-deficient cancer cells are not viable when RAD52 protein is
30 inactivated. In addition, RAD52 knockdown also causes lethality to human cells deficient in PALB2 (partner and localizer of BRCA2) and five RAD51 paralogs, including RAD51C. Mutations in PALB2 and RAD51C also contribute to hereditary breast and ovarian cancer. Previously, inviability of double mutations in RAD52 and RAD51C genes was reported in chicken DT-40 cells. Inactivation of PARP1 and RAD52 causes lethality of BRCA1/2-

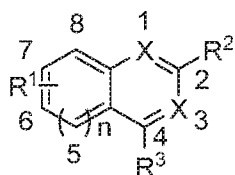
deficient and PALB2-deficient cells through different mechanisms. Inactivation of PARP1 causes disruption of repair of DNA SSBs. During DNA replication, unrepaired SSBs may cause formation of DNA double-stranded breaks (DSBs) or stalled replication forks, which are repaired by the HR pathway. BRCA1/2/PALB2 constitute the major sub-pathway of HR; mutations in these proteins incapacitates HR making hereditary breast and ovarian cancer cells vulnerable to PARP1 inhibitors. However, recent data have demonstrated that, in addition to the BRCA1/2/PALB2 sub-pathway, the secondary HR sub-pathway operates in mammalian cell that depends on RAD52 protein. In normal mammalian cells, this pathway plays a minor role, as RAD52^{-/-} mice are viable and fertile and do not display DNA damage sensitivity, abnormalities, or significant cancer predisposition. However, this sub-pathway becomes essential for viability in cells that lack the BRCA1/2/PALB2 sub-pathway.

There is a need in the art for novel compositions and methods that are useful for the treatment of cancers through inhibition of RAD52 in a mammal. The present invention addresses this unmet need.

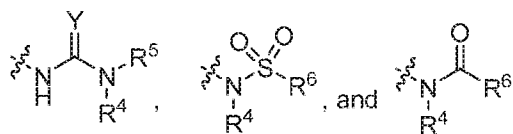
BRIEF SUMMARY OF THE INVENTION

The invention provides certain compounds that are RAD52 inhibitors. The invention further provides a pharmaceutical composition comprising at least one compound of the invention and at least one pharmaceutically acceptable carrier. The invention further provides a method of preventing or treating a RAD52 related disease or disorder in a subject in need thereof. The invention further provides a method of preventing or treating a cancer in a subject in need thereof.

In certain embodiments, the compound is a compound of formula (I):

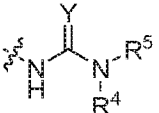
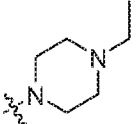


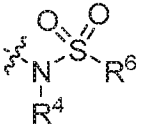
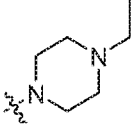
, wherein in (I): R^1 is selected from the group consisting of:



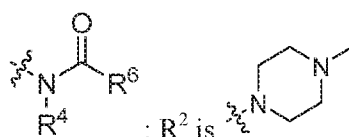
; R^2 is $-NR^4R^5$; R^3 is selected from the group consisting of hydrogen, $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ haloalkyl, $-(C_1-C_6)$ heteroalkyl, $-F$, $-Cl$, $-Br$, $-I$, $-CN$, $-NO_2$, $-OR^7$, $-SR^7$, $-S(=O)R^7$, $-S(=O)_2R^7$, $-C(=O)R^7$, $-OC(=O)R^7$, and $-CO_2R^7$; each occurrence of R^4 and R^5 is independently selected from the group consisting of hydrogen, -

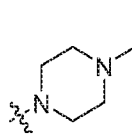
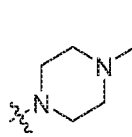
(C₁-C₆)alkyl, -(C₁-C₆)haloalkyl, -(C₁-C₆)heteroalkyl, aryl, and heteroaryl, wherein the aryl or heteroaryl group is optionally substituted; or R⁴ and R⁵, together with the nitrogen to which R⁴ and R⁵ are connected, form a -(C₃-C₁₀)heterocyclyl; each occurrence of R⁶ is independently selected from the group consisting of -(C₁-C₆)alkyl, -(C₁-C₆)heteroalkyl, -OR⁷, -(C₃-C₁₀)heterocyclyl, aryl, and heteroaryl, wherein the -(C₃-C₁₀)heterocyclyl, aryl or heteroaryl group is optionally substituted; each occurrence of R⁷ is independently selected from the group consisting of H, -(C₁-C₆)alkyl, -(C₁-C₆)heteroalkyl, -(C₃-C₆)cycloalkyl, -(C₄-C₁₀)heterocyclyl, aryl, and -(C₅-C₁₀)heteroaryl, wherein the alkyl, heteroalkyl, cycloalkyl, heterocyclyl, aryl, or heteroaryl group is optionally substituted; each occurrence of X is independently CH or N; Y is O or S; n is 0 or 1; when n is 1, R¹ is connected to the aryl ring at 5, 6, 7, or 8 position; alternatively, when n is 0, R¹ is connected to the aryl ring at that 6, 7, or 8 position; a salt, solvate, tautomer, enantiomer, diastereoisomer, or *N*-oxide thereof, and any combinations thereof; provided that the compound is not selected from the group consisting of 1-(3-(diethylamino)propyl)-3-(3-(dimethylamino)propyl)-1-((6-oxo-5,6-dihydro-[1,3]dioxolo[4,5-g]quinolin-7-yl)methyl)thiourea; 1-(2-((2-aminoethyl)(methyl)amino)-4-methylquinolin-6-yl)-3-(3-(4-ethylpiperazin-1-yl)propyl)thiourea; 1-(3-(butyl(ethyl)amino)propyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea; 1-(3-(dipropylamino)propyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea; 3-((2-((2,5-dimethoxyphenyl) amino)quinazolin-4-yl)amino)propan-1-ol; 1-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)-3-(3-(4-methylpiperazin-1-yl)propyl)thiourea; 1-(2-(diethylamino)ethyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea; 2-((2-((2,5-dimethoxyphenyl)amino) quinazolin-4-yl)amino)ethan-1-ol; and 3-((2-((2-methoxyphenyl)amino)quinazolin-4-yl)amino)propan-1-ol.

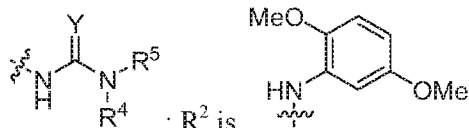
In certain embodiments, in (I) R¹ is ; R² is ; Y is O or S; and each occurrence of R⁴ and R⁵ is independently selected from the group consisting of hydrogen, -(C₁-C₆)alkyl, -(C₁-C₆)haloalkyl, -(C₁-C₆)heteroalkyl, aryl, and heteroaryl, wherein the aryl or heteroaryl group is optionally substituted; or R⁴ and R⁵, together with the nitrogen to which R⁴ and R⁵ are connected, form a -(C₃-C₁₀)heterocyclyl.

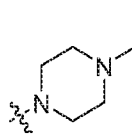
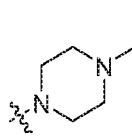
In certain embodiments, in (I) R¹ is ; R² is ; Y is O or S; each

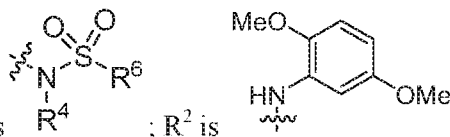
occurrence of R^4 and R^5 is independently selected from the group consisting of hydrogen, -
 (C₁-C₆)alkyl, -(C₁-C₆)haloalkyl, -(C₁-C₆)heteroalkyl, aryl, and heteroaryl, wherein the aryl or
 heteroaryl group is optionally substituted; or R^4 and R^5 , together with the nitrogen to which
 R^4 and R^5 are connected, form a -(C₃-C₁₀)heterocyclyl; and R^6 is selected from the group
 5 consisting of -(C₁-C₆)alkyl, -(C₁-C₆)heteroalkyl, -OR⁷, -(C₃-C₁₀)heterocyclyl, aryl, and
 heteroaryl, wherein the -(C₃-C₁₀)heterocyclyl, aryl or heteroaryl group is optionally
 substituted.

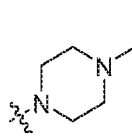
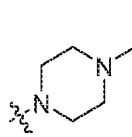


In certain embodiments, in (I) R^1 is ; R^2 is ; Y is O or S; each
 occurrence of R^4 and R^5 is independently selected from the group consisting of hydrogen, -
 10 (C₁-C₆)alkyl, -(C₁-C₆)haloalkyl, -(C₁-C₆)heteroalkyl, aryl, and heteroaryl, wherein the aryl or
 heteroaryl group is optionally substituted; or R^4 and R^5 , together with the nitrogen to which
 R^4 and R^5 are connected, form a -(C₃-C₁₀)heterocyclyl; R^6 is selected from the group
 consisting of -(C₁-C₆)alkyl, -(C₁-C₆)heteroalkyl, -OR⁷, -(C₃-C₁₀)heterocyclyl, aryl, and
 heteroaryl, wherein the -(C₃-C₁₀)heterocyclyl, aryl or heteroaryl group is optionally
 15 substituted.

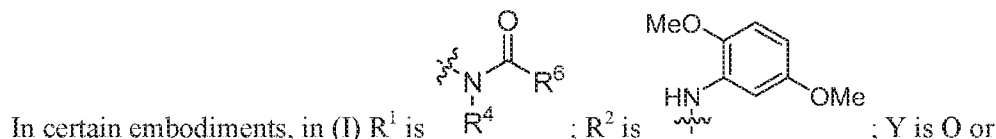


In certain embodiments, in (I) R^1 is ; R^2 is ; Y is O or
 S; and each occurrence of R^4 and R^5 is independently selected from the group consisting of
 hydrogen, -(C₁-C₆)alkyl, -(C₁-C₆)haloalkyl, -(C₁-C₆)heteroalkyl, aryl, and heteroaryl, wherein
 the aryl or heteroaryl group is optionally substituted; or R^4 and R^5 , together with the nitrogen
 20 to which R^4 and R^5 are connected, form a -(C₃-C₁₀)heterocyclyl.



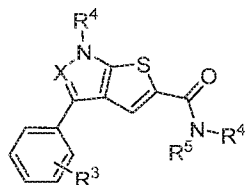
In certain embodiments, in (I) R^1 is ; R^2 is ; Y is O or
 S; each occurrence of R^4 and R^5 is independently selected from the group consisting of
 hydrogen, -(C₁-C₆)alkyl, -(C₁-C₆)haloalkyl, -(C₁-C₆)heteroalkyl, aryl, and heteroaryl, wherein
 the aryl or heteroaryl group is optionally substituted; or R^4 and R^5 , together with the nitrogen
 25 to which R^4 and R^5 are connected, form a -(C₃-C₁₀)heterocyclyl; R^6 is selected from the group
 consisting of -(C₁-C₆)alkyl, -(C₁-C₆)heteroalkyl, -OR⁷, -(C₃-C₁₀)heterocyclyl, aryl, and
 heteroaryl, wherein the -(C₃-C₁₀)heterocyclyl, aryl or heteroaryl group is optionally

substituted.



each occurrence of R^4 and R^5 is independently selected from the group consisting of hydrogen, $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ haloalkyl, $-(C_1-C_6)$ heteroalkyl, aryl, and heteroaryl, wherein the aryl or heteroaryl group is optionally substituted; or R^4 and R^5 , together with the nitrogen to which R^4 and R^5 are connected, form a $-(C_3-C_{10})$ heterocyclyl; R^6 is selected from the group consisting of $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ heteroalkyl, $-OR^7$, $-(C_3-C_{10})$ heterocyclyl, aryl, and heteroaryl, wherein the $-(C_3-C_{10})$ heterocyclyl, aryl or heteroaryl group is optionally substituted.

In certain embodiments, the compound is a compound of formula (IX):



(IX), wherein in formula (IX): R^3 is selected from the group consisting of hydrogen, $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ haloalkyl, $-(C_1-C_6)$ heteroalkyl, -F, -Cl, -Br, -I, -CN, -NO₂, $-OR^7$, $-SR^7$, $-S(=O)R^7$, $-S(=O)_2R^7$, $-C(=O)R^7$, $-OC(=O)R^7$, and $-CO_2R^7$; each occurrence of R^4 and R^5 is independently selected from the group consisting of hydrogen, $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ haloalkyl, $-(C_1-C_6)$ heteroalkyl, aryl, and heteroaryl, wherein the aryl or heteroaryl group is optionally substituted; or R^4 and R^5 , together with the nitrogen to which R^4 and R^5 are connected, form a $-(C_3-C_{10})$ heterocyclyl; X is N or CH; a salt, solvate, tautomer, enantiomer, diastereoisomer, or *N*-oxide thereof, and any combinations thereof, provided that the compound is not selected from the group consisting of 3-(4-chlorophenyl)-1-methyl-N-(3-(pyrrolidin-1-yl)propyl)-1H-thieno[2,3-c]pyrazole-5-carboxamide; N-(3-(azepan-1-yl)propyl)-3-(4-chlorophenyl)-1-methyl-1H-thieno[2,3-c]pyrazole-5-carboxamide; N-(2-(butyl(ethyl)amino)ethyl)-3-(4-chlorophenyl)-1-methyl-1H-thieno[2,3-c]pyrazole-5-carboxamide; and 3-(4-chlorophenyl)-1-methyl-N-(3-(4-methylpiperazin-1-yl)propyl)-1H-thieno[2,3-c]pyrazole-5-carboxamide.

In certain embodiments, the compound is selected from the group consisting of: 1-(3-(diethylamino)propyl)-3-(3-(dimethylamino)propyl)-1-((6-oxo-5,6-dihydro-[1,3]dioxolo[4,5-g]quinolin-7-yl)methyl)thiourea; 1-(3,4-dimethoxyphenyl)-N-(3-morpholinopropyl)-9H-pyrido[3,4-b]indole-3-carboxamide; 7-chloro-3-methyl-N-(4-(N-

methyl-N-(1-methylpiperidin-4-yl)sulfamoyl)phenyl) benzofuran-2-carboxamide; N-(5-chloro-2-(4-methylbenzoyl) benzofuran-3-yl)-2-(4-methylpiperazin-1-yl)acetamide; N-(3-morpholinopropyl)-1-(p-tolyl)-9H-pyrido[3,4-b]indole-3-carboxamide; 1-(2-((2-aminoethyl)(methyl)amino)-4-methylquinolin-6-yl)-3-(3-(4-ethylpiperazin-1-yl)propyl)thiourea; 1-(3-
 5 (butyl(ethyl)amino)propyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea; 1-(3-(3-(dipropylamino)propyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea; 3-((2-((2,5-dimethoxyphenyl)amino) quinazolin-4-yl)amino)propan-1-ol; 1-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)-3-(3-(4-methylpiperazin-1-yl)propyl)thiourea; 1-(2-(diethylamino)ethyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea; 2-((2-
 10 ((2,5-dimethoxyphenyl)amino) quinazolin-4-yl)amino)ethan-1-ol; 3-(4-chlorophenyl)-1-methyl-N-(3-(4-methylpiperazin-1-yl)propyl)-1H-thieno [2,3-c]pyrazole-5-carboxamide; N-(2-(butyl(ethyl)amino)ethyl)-3-(4-chlorophenyl)-1-methyl-1H-thieno[2,3-c]pyrazole-5-carboxamide; N-(3-(azepan-1-yl)propyl)-3-(4-chlorophenyl)-1-methyl-1H-thieno[2,3-c]pyrazole-5-carboxamide; 3-(4-chlorophenyl)-1-methyl-N-(3-(pyrrolidin-1-yl)propyl)-1H-
 15 thieno[2,3-c]pyrazole-5-carboxamide; 3-((2-((2-methoxyphenyl)amino)quinazolin-4-yl)amino)propan-1-ol; a salt, solvate, tautomer, enantiomer, diastereoisomer, or *N*-oxide thereof, and any combinations thereof.

In certain embodiments, the method comprises administering to the subject a therapeutically effective amount of at least one compound of the invention. In other
 20 embodiments, the method comprises administering to the subject a therapeutically effective amount of at least one compound of formula (I) or (IX).

In certain embodiments, the method further comprises administering to the subject at least one additional therapeutic agent that treats or prevents cancer. In other
 25 embodiments, the compound and the at least one additional therapeutic agent are co-administered to the subject. In yet other embodiments, the compound and the at least one additional therapeutic agent are coformulated.

In certain embodiments, the subject is a human.

In certain embodiments, the RAD52 related disease or disorder comprises cancer. In other embodiments, the cancer is selected from the group consisting of squamous
 30 cell cancer, lung cancer including small-cell lung cancer, non-small cell lung cancer, vulval cancer, thyroid cancer, adenocarcinoma of the lung and squamous carcinoma of the lung, cancer of the peritoneum, hepatocellular cancer, gastric or stomach cancer including gastrointestinal cancer, pancreatic cancer, glioblastoma, cervical cancer, ovarian cancer, liver cancer, bladder cancer, hepatoma, breast cancer, colon cancer, rectal cancer, colorectal

cancer, endometrial or uterine carcinoma, salivary gland carcinoma, kidney or renal cancer, prostate cancer, hepatic carcinoma, anal carcinoma, penile carcinoma, and head and neck cancer. In other embodiments, the cancer is ovarian cancer or breast cancer. In other embodiments, the human subject has mutations in BRCA1 and/or BRCA2.

5

BRIEF DESCRIPTION OF THE DRAWINGS

The following detailed description of specific embodiments of the invention will be better understood when read in conjunction with the appended drawings. For the purpose of illustrating the invention, there are shown in the drawings specific embodiments.

10 It should be understood, however, that the invention is not limited to the precise arrangements and instrumentalities of the embodiments shown in the drawings.

FIGS. 1A-1E illustrate identification and characterization of RAD52 small molecule inhibitors. FIG. 1A illustrates the experimental scheme of fluorescence-quenching assay for the RAD52 ssDNA annealing activity. FLU stands for fluorescein; BHQ 1 stands for black hole quencher 1. DNA substrates contain a mismatch to block spontaneous reaction. FIG. 1B illustrates the kinetics of ssDNA annealing measured on a FluoroMax3 fluorimeter. Shown is the representative result; the reactions were repeated at least three times. FIG. 1C illustrates RAD52 annealing activity in the presence of D-I03 over a range of concentrations, as measured on a FluoroMax3 fluorimeter. FIG. 1D illustrates the scheme of the D-loop assay. RAD52 forms a complex with ssDNA and promotes its homologous pairing with pUC19 plasmid DNA. Asterisk denotes ^{32}P label on ssDNA. FIG. 1E illustrates the test results of compounds (30 μM) on inhibition of the RAD52 DNA pairing activity. Error bars indicate standard deviation (SD) of the mean.

FIGS. 2A-2C illustrate the effect of inhibitors on DNA pairing activity of RAD52. FIG. 2A illustrates the products of DNA pairing (D-loops) analyzed by electrophoresis in 1% agarose gels. FIG. 2B is a graph illustrating the analyzed data from FIG. 2A. FIG. 2C illustrates the IC_{50} values for certain tested compounds.

FIG. 2D illustrates the effects of the RAD52 inhibitors on DNA pairing activity of RAD51. The effects of inhibitors were measured using the D-loop assay at the inhibitors concentrations that correspond to their $10 \times \text{IC}_{50}$ values for RAD52 pairing activity. Error bars indicate SD of the mean.

FIGS. 3A-3D illustrate the effects of the RAD52 inhibitors on survival of Capan-1 (BRCA2⁻) and BxPC3 (BRCA2⁺) cells. Capan-1 is denoted by the line of dots; BxPC3 is denoted by the line of squares. The experiments were repeated at least three times.

Error bars indicate SD of the mean.

FIGs. 3E-3H illustrate the effects of the RAD52 inhibitors on survival of UWB1.289 (BRCA1⁻) and [UWB1.289 (+BRCA1)] (BRCA1⁺) cells. UWB1.289 is denoted by the line of dots; UWB1.289 (+BRCA1) is denoted by the line of squares. The experiments were repeated at least three times. Error bars indicate SD of the mean.

FIG. 4A illustrates the effects of RAD52 inhibitors on survival of MDA-MB-436 (BRCA1⁻) and [MDA-MB-436 (BRCA1⁺)] (BRCA1⁺) cells. The experiments were repeated at least three times. Error bars indicate SD of the mean.

FIG. 4B illustrates the effects of RAD52 inhibitors on survival of BCR-ABL1-positive BRCA1-deficient CML cells and their BRCA1-proficient normal counterparts. The experiments were repeated at least three times. Error bars indicate SD of the mean.

FIG. 4C illustrates the structures of the RAD52 inhibitors that preferentially inhibited growth of BRCA1- or BRCA2-deficient cells.

FIG. 5A illustrates the measurement of D-I03 binding to RAD52 at concentrations of (bottom to top) 3.125, 6.25, 12.5, 25, and 50 μ M. Colored lines indicate experimental data.

FIG. 5B illustrates the measurement of D-G23 binding to RAD52 at concentrations of (bottom to top) 1.56, 3.125, 6.25, 12.5, and 25. Colored lines indicate experimental data, whereas black lines indicate fitting to the simple 1:1 binding model using the ProteOn Manager Software version 3.0 (Bio-Rad). Kinetic values are as follows: $k_a = 1.15 (\pm 0.44) \times 10^4 \text{ M}^{-1}\text{s}^{-1}$; $k_d = 3.62 (\pm 0.7) \times 10^{-1} \text{ s}^{-1}$; $K_d = 34.0 \pm 8.9 \text{ } \mu\text{M}$.

FIG. 5C is a graph illustrating the method of determining K_d of D-I03 binding to RAD52 by plotting the response at equilibrium (Req) versus concentration of D-I03.

Experiments were repeated at least three times; errors of mean indicated by SD.

FIG. 6A illustrates the effects of D-G23 and D-I03 (2.5 μ M) on GFP-RAD52 foci formation in response to cisplatin (10 μ M) treatment. GFP-RAD52 was constitutively expressed in p210BCR-ABL1-positive 32Dcl3 murine hematopoietic cells (BRCA1-deficient).

FIG. 6B is a graphical presentation of the data from FIG. 6A.

FIG. 6C illustrates the effect of D-I03 (2.5 μ M) on RAD51 foci formation with and without cisplatin (10 μ M) treatment in parental 32Dcl3 cells (BRCA1-proficient).

FIG. 6D is a graphical presentation of the data from FIG. 6C.

FIGs. 7A-7C illustrate the observation that D-I03 inhibits single-strand

annealing (SSA) , but not homology dependent recombination (HDR)(gene conversion) in U1OS cells. FIG. 7A illustrates the scheme of the SSA-GFP and HDR-GFP reporter systems. The SSA-GFP reporter contains a 5' fragment of the GFP (5'-GFP) gene, and a 3' fragment of the GFP (3'-GFP) with an I-SceI site. The HDR-GFP reporter system contains the GFP gene interrupted by a Sce-I site, and a fragment of the GFP with truncated 3'- and 5'-terminus. FIG. 7B is a graph illustrating the effect of D-I03 on the repair of the I-SceI-induced DSBs in U2OS cells carrying the chromosomally located SSA-GFP (in red) as well as the effect of D-I03 on formation GFP⁺ cells after transfection of U2OS cells with pMX-GFP plasmid expressing GFP protein (in green). FIG. 7C is a graph illustrating the effect of D-I03 on the repair of the I-SceI-induced DSBs in U2OS cells carrying the chromosomally located HDR-GFP (in red) as well as the effect of D-I03 on formation GFP⁺ cells after transfection of U2OS cells with pMX-GFP plasmid expressing GFP protein (in green).

FIGs. 8A-8D are a set of graphs illustrating the effect of E-I03 on the repair of the I-SceI-induced DSBs in U2OS cells carrying the SSA-GFP (FIGs. 8A-8B) or HDR-GFP (FIGs. 8C-8D) reporter, as measured by flow cytometry. Green fluorescence is plotted against red fluorescence for each sample of 10,000 cells. The GFP⁺ population of cells is denoted by the elliptical M1 marker.

FIG. 9 is an image illustrating analysis of RAD51 and RAD52 proteins in a SDS-polyacrylamide gel. Proteins were stained with Coomassie blue. Lane M, Migration markers; Lane 1, Rad52; Lane 2, RAD51. 1µg of each protein was loaded on a 12% SDS-polyacrylamide gel.

FIG. 10 is a graph illustrating the effect of D-I03 concentration on the initial rate of ssDNA annealing promoted by RAD52. The rates of RAD52-promoted ssDNA annealing were calculated based on the data in FIG. 1C. The data were the mean of 3 independent measurements; error bars represent the SD.

DETAILED DESCRIPTION OF THE INVENTION

The present invention relates to the unexpected discovery of novel compounds that treat or prevent a cancer through inhibition of RAD52 in a mammal. In certain embodiments, the cancer comprises ovarian and/or breast cancer. The present invention also relates to a method for treating or preventing a cancer by administering to a mammal a therapeutically effective amount of a RAD52 inhibitor.

Definitions

Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. Although any methods and materials similar or equivalent to those
5 described herein can be used in the practice or testing of the present invention, specific methods and materials are described.

As used herein, each of the following terms has the meaning associated with it in this section.

The articles “a” and “an” are used herein to refer to one or to more than one
10 (*i.e.*, to at least one) of the grammatical object of the article. By way of example, “an element” means one element or more than one element.

“About” as used herein when referring to a measurable value such as an amount, a temporal duration, and the like, is meant to encompass variations of $\pm 20\%$ or $\pm 10\%$, in certain embodiments $\pm 5\%$, in other embodiments $\pm 1\%$, and in yet other
15 embodiments $\pm 0.1\%$ from the specified value, as such variations are appropriate to perform the disclosed methods.

The term “abnormal,” when used in the context of organisms, tissues, cells or components thereof, refers to those organisms, tissues, cells or components thereof that differ in at least one observable or detectable characteristic (*e.g.*, age, treatment, time of day, etc.)
20 from those organisms, tissues, cells or components thereof that display the “normal” (expected) respective characteristic. Characteristics that are normal or expected for one cell or tissue type might be abnormal for a different cell or tissue type.

A disease or disorder is “alleviated” if the severity of a symptom of the disease or disorder, the frequency with which such a symptom is experienced by a patient, or both, is
25 reduced.

The terms “cancer” refers to the physiological condition in a subject typically characterized by unregulated cell growth. Examples of cancer include, but are not limited to, carcinoma, lymphoma, blastoma, sarcoma, and leukemia or lymphoid malignancies. More particular examples of such cancers include squamous cell cancer (*e.g.*, epithelial squamous
30 cell cancer), lung cancer including small-cell lung cancer, non-small cell lung cancer (“NSCLC”), vulval cancer, thyroid cancer, adenocarcinoma of the lung and squamous carcinoma of the lung, cancer of the peritoneum, hepatocellular cancer, gastric or stomach cancer including gastrointestinal cancer, pancreatic cancer, glioblastoma, cervical cancer, ovarian cancer, liver cancer, bladder cancer, hepatoma, breast cancer, colon cancer, rectal

cancer, colorectal cancer, endometrial or uterine carcinoma, salivary gland carcinoma, kidney or renal cancer, prostate cancer, hepatic carcinoma, anal carcinoma, penile carcinoma, as well as head and neck cancer.

As used herein, the term “composition” or “pharmaceutical composition” refers to a mixture of at least one compound useful within the invention with a pharmaceutically acceptable carrier. The pharmaceutical composition facilitates administration of the compound to a patient or subject. Multiple techniques of administering a compound exist in the art including, but not limited to, intravenous, oral, aerosol, parenteral, ophthalmic, pulmonary and topical administration.

A “disease” is a state of health of an animal wherein the animal cannot maintain homeostasis, and wherein if the disease is not ameliorated then the animal’s health continues to deteriorate.

In contrast, a “disorder” in an animal is a state of health in which the animal is able to maintain homeostasis, but in which the animal’s state of health is less favorable than it would be in the absence of the disorder. Left untreated, a disorder does not necessarily cause a further decrease in the animal’s state of health.

As used herein, the terms “effective amount,” “pharmaceutically effective amount” and “therapeutically effective amount” refer to a nontoxic but sufficient amount of an agent to provide the desired biological result. That result may be reduction and/or alleviation of the signs, symptoms, or causes of a disease, or any other desired alteration of a biological system. An appropriate therapeutic amount in any individual case may be determined by one of ordinary skill in the art using routine experimentation.

As used herein, the term “efficacy” refers to the maximal effect ($E_{\max}$) achieved within an assay.

As used herein, the term “pharmaceutically acceptable” refers to a material, such as a carrier or diluent, which does not abrogate the biological activity or properties of the compound, and is relatively non-toxic, *i.e.*, the material may be administered to an individual without causing undesirable biological effects or interacting in a deleterious manner with any of the components of the composition in which it is contained.

As used herein, the language “pharmaceutically acceptable salt” refers to a salt of the administered compounds prepared from pharmaceutically acceptable non-toxic acids, including inorganic acids, organic acids, solvates, hydrates, or clathrates thereof. Examples of such inorganic acids are hydrochloric, hydrobromic, hydroiodic, nitric, sulfuric, phosphoric, acetic, hexafluorophosphoric, citric, gluconic, benzoic, propionic, butyric,

sulfosalicylic, maleic, lauric, malic, fumaric, succinic, tartaric, amsonic, pamoic, p-toluenesulfonic, and mesylic. Appropriate organic acids may be selected, for example, from aliphatic, aromatic, carboxylic and sulfonic classes of organic acids, examples of which are formic, acetic, propionic, succinic, camphorsulfonic, citric, fumaric, gluconic, isethionic, 5 lactic, malic, mucic, tartaric, para-toluenesulfonic, glycolic, glucuronic, maleic, furoic, glutamic, benzoic, anthranilic, salicylic, phenylacetic, mandelic, embonic (pamoic), methanesulfonic, ethanesulfonic, pantothenic, benzenesulfonic (besylate), stearic, sulfanilic, alginic, galacturonic, and the like. Furthermore, pharmaceutically acceptable salts include, by way of non-limiting example, alkaline earth metal salts (*e.g.*, calcium or magnesium), 10 alkali metal salts (*e.g.*, sodium-dependent or potassium), and ammonium salts.

As used herein, the term “pharmaceutically acceptable carrier” means a pharmaceutically acceptable material, composition or carrier, such as a liquid or solid filler, stabilizer, dispersing agent, suspending agent, diluent, excipient, thickening agent, solvent or encapsulating material, involved in carrying or transporting a compound useful within the 15 invention within or to the patient such that it may perform its intended function. Typically, such constructs are carried or transported from one organ, or portion of the body, to another organ, or portion of the body. Each carrier must be “acceptable” in the sense of being compatible with the other ingredients of the formulation, including the compound useful within the invention, and not injurious to the patient. Some examples of materials that may 20 serve as pharmaceutically acceptable carriers include: sugars, such as lactose, glucose and sucrose; starches, such as corn starch and potato starch; cellulose, and its derivatives, such as sodium carboxymethyl cellulose, ethyl cellulose and cellulose acetate; powdered tragacanth; malt; gelatin; talc; excipients, such as cocoa butter and suppository waxes; oils, such as peanut oil, cottonseed oil, safflower oil, sesame oil, olive oil, corn oil and soybean oil; 25 glycols, such as propylene glycol; polyols, such as glycerin, sorbitol, mannitol and polyethylene glycol; esters, such as ethyl oleate and ethyl laurate; agar; buffering agents, such as magnesium hydroxide and aluminum hydroxide; surface active agents; alginic acid; pyrogen-free water; isotonic saline; Ringer’s solution; ethyl alcohol; phosphate buffer solutions; and other non-toxic compatible substances employed in pharmaceutical 30 formulations. As used herein, “pharmaceutically acceptable carrier” also includes any and all coatings, antibacterial and antifungal agents, and absorption delaying agents, and the like that are compatible with the activity of the compound useful within the invention, and are physiologically acceptable to the patient. Supplementary active compounds may also be incorporated into the compositions. The “pharmaceutically acceptable carrier” may further

include a pharmaceutically acceptable salt of the compound useful within the invention. Other additional ingredients that may be included in the pharmaceutical compositions used in the practice of the invention are known in the art and described, for example in Remington's Pharmaceutical Sciences (Genaro, Ed., Mack Publishing Co., 1985, Easton, PA), which is
5 incorporated herein by reference.

The terms "patient," "subject," or "individual" are used interchangeably herein, and refer to any animal, or cells thereof whether *in vitro* or *in situ*, amenable to the methods described herein. In a non-limiting embodiment, the patient, subject or individual is a human.

10 As used herein, the term "potency" refers to the dose needed to produce half the maximal response (ED_{50}).

As used herein, the term "treatment" or "treating" is defined as the application or administration of a therapeutic agent, *i.e.*, a compound of the invention (alone or in combination with another pharmaceutical agent), to a patient, or application or administration
15 of a therapeutic agent to an isolated tissue or cell line from a patient (*e.g.*, for diagnosis or *ex vivo* applications), who has a condition contemplated herein, a symptom of a condition contemplated herein or the potential to develop a condition contemplated herein, with the purpose to cure, heal, alleviate, relieve, alter, remedy, ameliorate, improve or affect a condition contemplated herein, the symptoms of a condition contemplated herein or the
20 potential to develop a condition contemplated herein. Such treatments may be specifically tailored or modified, based on knowledge obtained from the field of pharmacogenomics.

A "therapeutic" treatment is a treatment administered to a subject who exhibits signs of pathology, for the purpose of diminishing or eliminating those signs.

As used herein, the term "alkyl," by itself or as part of another substituent
25 means, unless otherwise stated, a straight or branched chain hydrocarbon having the number of carbon atoms designated (*i.e.* C_{1-6} means one to six carbon atoms) and including straight, branched chain, or cyclic substituent groups. Examples include methyl, ethyl, propyl, isopropyl, butyl, isobutyl, tert-butyl, pentyl, neopentyl, hexyl, and cyclopropylmethyl. Most preferred is (C_1-C_6) alkyl, particularly ethyl, methyl, isopropyl, isobutyl, n-pentyl, n-hexyl and
30 cyclopropylmethyl.

As used herein, the term "substituted alkyl" means alkyl as defined above, substituted by one, two or three substituents selected from the group consisting of halogen, -OH, alkoxy, $-NH_2$, $-N(CH_3)_2$, $-C(=O)OH$, trifluoromethyl, $-C\equiv N$, $-C(=O)O(C_1-C_4)alkyl$, $-C(=O)NH_2$, $-SO_2NH_2$, $-C(=NH)NH_2$, and $-NO_2$, preferably containing one or two substituents

selected from halogen, -OH, alkoxy, -NH₂, trifluoromethyl, -N(CH₃)₂, and -C(=O)OH, more preferably selected from halogen, alkoxy and -OH. Examples of substituted alkyls include, but are not limited to, 2,2-difluoropropyl, 2-carboxycyclopentyl and 3-chloropropyl.

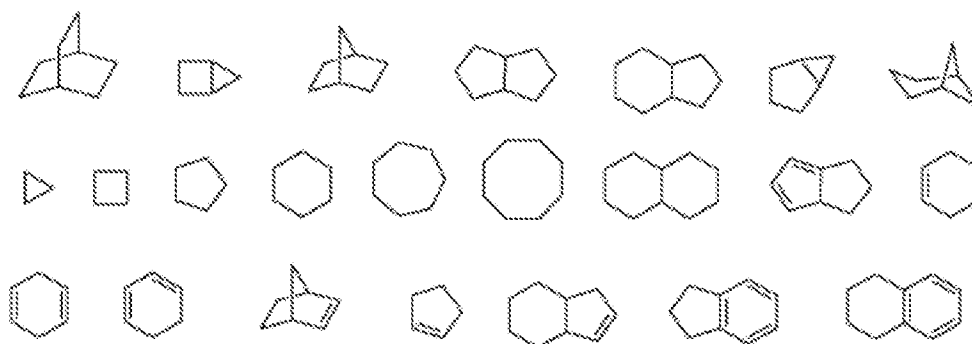
As used herein, the term "haloalkyl" means alkyl as defined above, substituted
5 by one, two or three substituents selected from the group consisting of F, Cl, Br, and I.

As used herein, the term "heteroalkyl" by itself or in combination with another term means, unless otherwise stated, a stable straight or branched chain alkyl group consisting of the stated number of carbon atoms and one or two heteroatoms selected from the group consisting of O, N, and S, and wherein the nitrogen and sulfur atoms may be
10 optionally oxidized and the nitrogen heteroatom may be optionally quaternized or substituted. The heteroatom(s) may be placed at any position of the heteroalkyl group, including between the rest of the heteroalkyl group and the fragment to which it is attached, as well as attached to the most distal carbon atom in the heteroalkyl group. Examples include: -O-CH₂-CH₂-CH₃, -CH₂-CH₂-CH₂-OH, -CH₂-CH₂-NH-CH₃, -CH₂-S-CH₂-CH₃, -
15 NH-(CH₂)_m-OH (m = 1-6), -N(CH₃)-(CH₂)_m-OH (m = 1-6), -NH-(CH₂)_m-OCH₃ (m = 1-6), and -CH₂CH₂-S(=O)-CH₃. Up to two heteroatoms may be consecutive, such as, for example, -CH₂-NH-OCH₃, or -CH₂-CH₂-S-S-CH₃.

As used herein, the term "alkoxy" employed alone or in combination with other terms means, unless otherwise stated, an alkyl group having the designated number of
20 carbon atoms, as defined above, connected to the rest of the molecule via an oxygen atom, such as, for example, methoxy, ethoxy, 1-propoxy, 2-propoxy (isopropoxy) and the higher homologs and isomers. Preferred are (C₁-C₃) alkoxy, particularly ethoxy and methoxy.

As used herein, the term "halo" or "halogen" alone or as part of another substituent means, unless otherwise stated, a fluorine, chlorine, bromine, or iodine atom,
25 preferably, fluorine, chlorine, or bromine, more preferably, fluorine or chlorine.

As used herein, the term "cycloalkyl" refers to a mono cyclic or polycyclic non-aromatic radical, wherein each of the atoms forming the ring (*i.e.* skeletal atoms) is a carbon atom. In certain embodiments, the cycloalkyl group is saturated or partially unsaturated. In other embodiments, the cycloalkyl group is fused with an aromatic ring.
30 Cycloalkyl groups include groups having from 3 to 10 ring atoms. Illustrative examples of cycloalkyl groups include, but are not limited to, the following moieties:

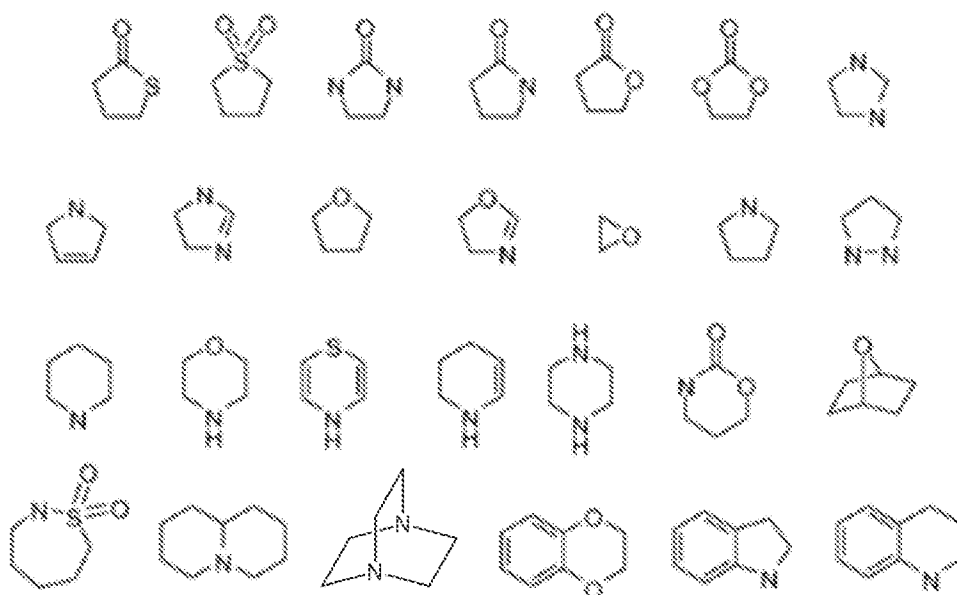


Monocyclic cycloalkyls include, but are not limited to, cyclopropyl, cyclobutyl, cyclopentyl, cyclohexyl, cycloheptyl, and cyclooctyl. Dicyclic cycloalkyls include, but are not limited to, tetrahydronaphthyl, indanyl, and tetrahydropentalene.

- 5 Polycyclic cycloalkyls include adamantane and norbornane. The term cycloalkyl includes "unsaturated nonaromatic carbocyclyl" or "nonaromatic unsaturated carbocyclyl" groups, both of which refer to a nonaromatic carbocycle as defined herein, which contains at least one carbon carbon double bond or one carbon carbon triple bond.

As used herein, the term "heterocycloalkyl" or "heterocyclyl" refers to a
 10 heteroalicyclic group containing one to four ring heteroatoms each selected from O, S and N. In certain embodiments, each heterocycloalkyl group has from 4 to 10 atoms in its ring system, with the proviso that the ring of said group does not contain two adjacent O or S atoms. In other embodiments, the heterocycloalkyl group is fused with an aromatic ring. In certain embodiments, the nitrogen and sulfur heteroatoms may be optionally oxidized, and
 15 the nitrogen atom may be optionally quaternized. The heterocyclic system may be attached, unless otherwise stated, at any heteroatom or carbon atom that affords a stable structure. A heterocycle may be aromatic or non-aromatic in nature. In certain embodiments, the heterocycle is a heteroaryl.

An example of a 3-membered heterocycloalkyl group includes, and is not
 20 limited to, aziridine. Examples of 4-membered heterocycloalkyl groups include, and are not limited to, azetidine and a beta lactam. Examples of 5-membered heterocycloalkyl groups include, and are not limited to, pyrrolidine, oxazolidine and thiazolidinedione. Examples of 6-membered heterocycloalkyl groups include, and are not limited to, piperidine, morpholine and piperazine. Other non-limiting examples of heterocycloalkyl groups are:



Examples of non-aromatic heterocycles include monocyclic groups such as aziridine, oxirane, thirane, azetidine, oxetane, thietane, pyrrolidine, pyrroline, pyrazolidine, imidazoline, dioxolane, sulfolane, 2,3-dihydrofuran, 2,5-dihydrofuran, tetrahydrofuran, thiophane, piperidine, 1,2,3,6-tetrahydropyridine, 1,4-dihydropyridine, piperazine, morpholine, thiomorpholine, pyran, 2,3-dihydropyran, tetrahydropyran, 1,4-dioxane, 1,3-dioxane, homopiperazine, homopiperidine, 1,3-dioxepane, 4,7-dihydro-1,3-dioxepin, and hexamethyleneoxide.

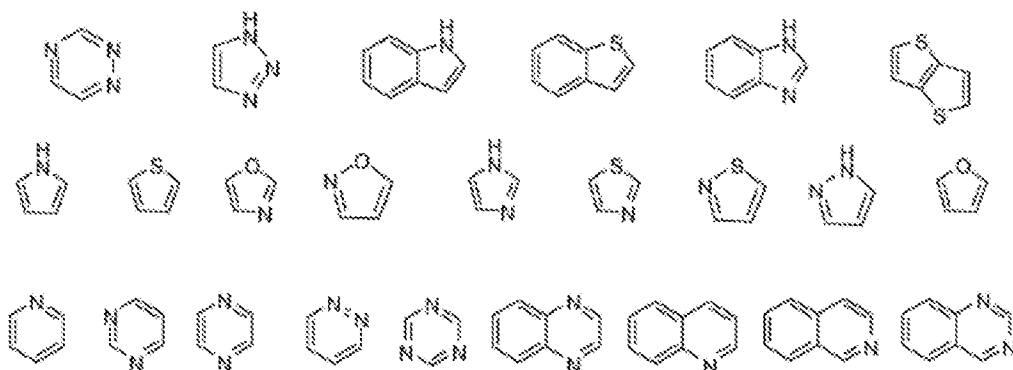
As used herein, the term “aromatic” refers to a carbocycle or heterocycle with one or more polyunsaturated rings and having aromatic character, *i.e.* having $(4n + 2)$ delocalized π (pi) electrons, where n is an integer.

As used herein, the term “aryl,” employed alone or in combination with other terms, means, unless otherwise stated, a carbocyclic aromatic system containing one or more rings (typically one, two or three rings), wherein such rings may be attached together in a pendent manner, such as a biphenyl, or may be fused, such as naphthalene. Examples of aryl groups include phenyl, anthracyl, and naphthyl. Preferred examples are phenyl and naphthyl, most preferred is phenyl.

As used herein, the term “aryl-(C₁-C₃)alkyl” means a functional group wherein a one- to three-carbon alkylene chain is attached to an aryl group, *e.g.*, -CH₂CH₂-phenyl. Preferred is aryl-CH₂- and aryl-CH(CH₃)-. The term “substituted aryl-(C₁-C₃)alkyl” means an aryl-(C₁-C₃)alkyl functional group in which the aryl group is substituted. Preferred is substituted aryl(CH₂)-. Similarly, the term “heteroaryl-

(C₁-C₃)alkyl” means a functional group wherein a one to three carbon alkylene chain is attached to a heteroaryl group, *e.g.*, -CH₂CH₂-pyridyl. Preferred is heteroaryl-(CH₂)-. The term “substituted heteroaryl-(C₁-C₃)alkyl” means a heteroaryl-(C₁-C₃)alkyl functional group in which the heteroaryl group is substituted. Preferred is substituted heteroaryl-(CH₂)-.

5 As used herein, the term “heteroaryl” or “heteroaromatic” refers to a heterocycle having aromatic character. A polycyclic heteroaryl may include one or more rings that are partially saturated. Examples include the following moieties:



Examples of heteroaryl groups also include pyridyl, pyrazinyl, pyrimidinyl
 10 (particularly 2- and 4-pyrimidinyl), pyridazinyl, thienyl, furyl, pyrrolyl (particularly 2-pyrrolyl), imidazolyl, thiazolyl, oxazolyl, pyrazolyl (particularly 3- and 5-pyrazolyl), isothiazolyl, 1,2,3-triazolyl, 1,2,4-triazolyl, 1,3,4-triazolyl, tetrazolyl, 1,2,3-thiadiazolyl, 1,2,3-oxadiazolyl, 1,3,4-thiadiazolyl and 1,3,4-oxadiazolyl.
 Examples of polycyclic heterocycles and heteroaryls include indolyl (particularly 3-, 4-, 5-,
 15 6- and 7-indolyl), indolinyl, quinolyl, tetrahydroquinolyl, isoquinolyl (particularly 1- and 5-isoquinolyl), 1,2,3,4-tetrahydroisoquinolyl, cinnolinyl, quinoxalyl (particularly 2- and 5-quinoxalyl), quinazolinyl, phthalazinyl, 1,8-naphthyridinyl, 1,4-benzodioxanyl, coumarin, dihydrocoumarin, 1,5-naphthyridinyl, benzofuryl (particularly 3-, 4-, 5-, 6- and 7-benzofuryl), 2,3-dihydrobenzofuryl, 1,2-benzisoxazolyl, benzothienyl (particularly 3-, 4-,
 20 5-, 6-, and 7-benzothienyl), benzoxazolyl, benzothiazolyl (particularly 2-benzothiazolyl and 5-benzothiazolyl), purinyl, benzimidazolyl (particularly 2-benzimidazolyl), benzotriazolyl, thioxanthinyl, carbazolyl, carbolinyl, acridinyl, pyrrolizidinyl, and quinolizidinyl.

As used herein, the term “substituted” means that an atom or group of atoms has replaced hydrogen as the substituent attached to another group. The term “substituted”
 25 further refers to any level of substitution, namely mono-, di-, tri-, tetra-, or penta-substitution, where such substitution is permitted. The substituents are independently selected, and substitution may be at any chemically accessible position. In certain embodiments, the

substituents vary in number between one and four. In other embodiments, the substituents vary in number between one and three. In yet other embodiments, the substituents vary in number between one and two.

As used herein, the term "optionally substituted" means that the referenced group may be substituted or unsubstituted. In certain embodiments, the referenced group is optionally substituted with zero substituents, *i.e.*, the referenced group is unsubstituted. In other embodiments, the referenced group is optionally substituted with one or more additional group(s) individually and independently selected from groups described herein.

In certain embodiments, the substituents are independently selected from the group consisting of oxo, halogen, -CN, -NH₂, -OH, -NH(CH₃), -N(CH₃)₂, alkyl (including straight chain, branched and/or unsaturated alkyl), substituted or unsubstituted cycloalkyl, substituted or unsubstituted heterocycloalkyl, fluoro alkyl, substituted or unsubstituted heteroalkyl, substituted or unsubstituted alkoxy, fluoroalkoxy, -S-alkyl, S(=O)₂alkyl, -C(=O)NH[substituted or unsubstituted alkyl, or substituted or unsubstituted phenyl], -C(=O)N[H or alkyl]₂, -OC(=O)N[substituted or unsubstituted alkyl]₂, -NHC(=O)NH[substituted or unsubstituted alkyl, or substituted or unsubstituted phenyl], -NHC(=O)alkyl, -N[substituted or unsubstituted alkyl]C(=O)[substituted or unsubstituted alkyl], -NHC(=O)[substituted or unsubstituted alkyl], -C(OH)[substituted or unsubstituted alkyl]₂, and -C(NH₂)[substituted or unsubstituted alkyl]₂. In other embodiments, by way of example, an optional substituent is selected from oxo, fluorine, chlorine, bromine, iodine, -CN, -NH₂, -OH, -NH(CH₃), -N(CH₃)₂, -CH₃, -CH₂CH₃, -CH(CH₃)₂, -CF₃, -CH₂CF₃, -OCH₃, -OCH₂CH₃, -OCH(CH₃)₂, -OCF₃, -OCH₂CF₃, -S(=O)₂-CH₃, -C(=O)NH₂, -C(=O)-NHCH₃, -NHC(=O)NHCH₃, -C(=O)CH₃, and -C(=O)OH. In yet one embodiment, the substituents are independently selected from the group consisting of C₁₋₆ alkyl, -OH, C₁₋₆ alkoxy, halo, amino, acetamido, oxo and nitro. In yet other embodiments, the substituents are independently selected from the group consisting of C₁₋₆ alkyl, C₁₋₆ alkoxy, halo, acetamido, and nitro. As used herein, where a substituent is an alkyl or alkoxy group, the carbon chain may be branched, straight or cyclic, with straight being preferred.

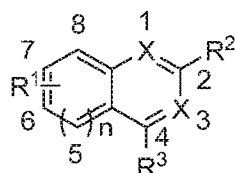
Ranges: throughout this disclosure, various aspects of the invention can be presented in a range format. It should be understood that the description in range format is merely for convenience and brevity and should not be construed as an inflexible limitation on the scope of the invention. Accordingly, the description of a range should be considered to have specifically disclosed all the possible sub-ranges as well as individual numerical values

within that range. For example, description of a range such as from 1 to 6 should be considered to have specifically disclosed sub-ranges such as from 1 to 3, from 1 to 4, from 1 to 5, from 2 to 4, from 2 to 6, from 3 to 6 etc., as well as individual numbers within that range, for example, 1, 2, 2.7, 3, 4, 5, 5.3, and 6. This applies regardless of the breadth of the range.

Compounds

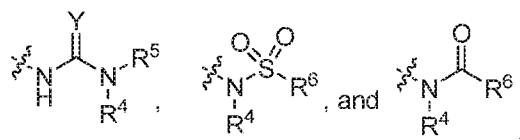
The compounds of the present invention may be synthesized using techniques well-known in the art of organic synthesis. The starting materials and intermediates required for the synthesis may be obtained from commercial sources or synthesized according to methods known to those skilled in the art.

In one aspect, the compound of the invention is a compound of formula (I), a salt, solvate, tautomer, enantiomer, diastereoisomer, or *N*-oxide thereof:



(I), wherein in (I):

R^1 is selected from the group consisting of:



R^2 is $-NR^4R^5$;

R^3 is selected from the group consisting of hydrogen, $-(C_1-C_6)alkyl$, $-(C_1-C_6)haloalkyl$, $-(C_1-C_6)heteroalkyl$, $-F$, $-Cl$, $-Br$, $-I$, $-CN$, $-NO_2$, $-OR^7$, $-SR^7$, $-S(=O)R^7$, $-S(=O)_2R^7$, $-C(=O)R^7$, $-OC(=O)R^7$, and $-CO_2R^7$;

each occurrence of R^4 and R^5 is independently selected from the group consisting of hydrogen, $-(C_1-C_6)alkyl$, $-(C_1-C_6)haloalkyl$, $-(C_1-C_6)heteroalkyl$, aryl, and heteroaryl, wherein the aryl or heteroaryl group is optionally substituted; or R^4 and R^5 , together with the nitrogen to which R^4 and R^5 are connected, form a $-(C_3-C_{10})heterocyclyl$;

each occurrence of R^6 is independently selected from the group consisting of $-(C_1-C_6)alkyl$, $-(C_1-C_6)heteroalkyl$, $-OR^7$, $-(C_3-C_{10})heterocyclyl$, aryl, and heteroaryl, wherein the $-(C_3-C_{10})heterocyclyl$, aryl or heteroaryl group is optionally substituted;

each occurrence of R^7 is independently selected from the group consisting of

H, -(C₁-C₆)alkyl, -(C₁-C₆)heteroalkyl, -(C₃-C₆)cycloalkyl, -(C₃-C₁₀)heterocyclyl, aryl, and -(C₅-C₁₀)heteroaryl, wherein the alkyl, heteroalkyl, cycloalkyl, heterocyclyl, aryl, or heteroaryl group is optionally substituted;

each occurrence of X is independently CH or N;

5 Y is O or S;

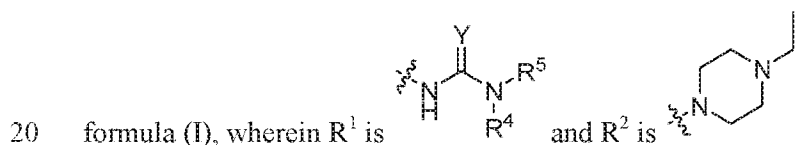
n is 0 or 1; when n is 1, R¹ is connected to the aryl ring at 5, 6, 7, or 8 position;

alternatively, when n is 0, R¹ is connected to the aryl ring at that 6, 7, or 8 position;

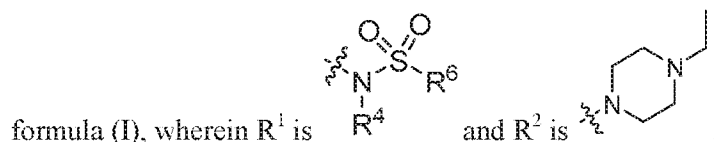
provided that the compound is not selected from the group consisting of 1-(3-

(diethylamino)propyl)-3-(3-(dimethylamino)propyl)-1-((6-oxo-5,6-dihydro-[1,3]dioxolo[4,5-
10 g]quinolin-7-yl)methyl)thiourea; 1-(2-((2-aminoethyl)(methyl)amino)-4-methylquinolin-6-yl)-3-(3-(4-ethylpiperazin-1-yl)propyl)thiourea; 1-(3-(butyl(ethyl)amino)propyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea; 1-(3-(dipropylamino)propyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea; 3-((2-((2,5-
15 dimethoxyphenyl)amino)quinazolin-4-yl)amino)propan-1-ol; 1-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)-3-(3-(4-methylpiperazin-1-yl)propyl)thiourea; 1-(2-(diethylamino)ethyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea; 2-((2-((2,5-dimethoxyphenyl)amino)quinazolin-4-yl)amino)ethan-1-ol; and 3-((2-((2-methoxyphenyl)amino)quinazolin-4-yl)amino)propan-1-ol.

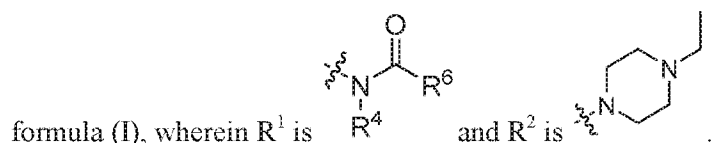
In certain embodiments, the compound of the invention is a compound of



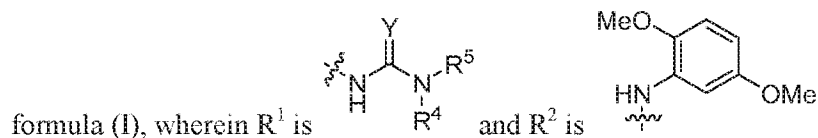
In other embodiments, the compound of the invention is a compound of



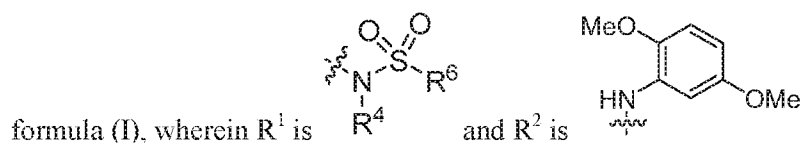
In yet other embodiments, the compound of the invention is a compound of



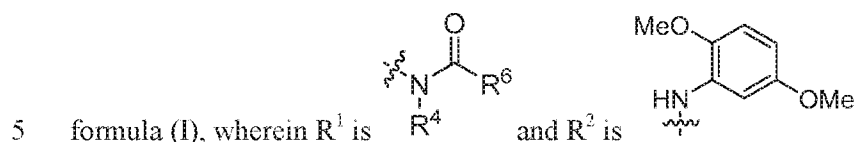
In yet other embodiments, the compound of the invention is a compound of



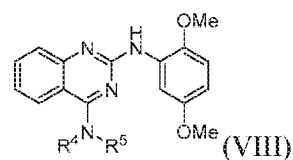
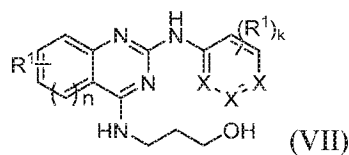
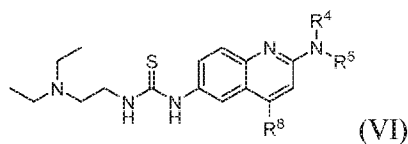
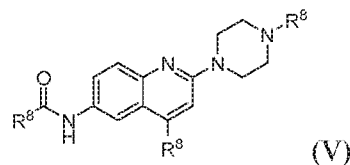
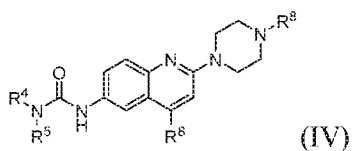
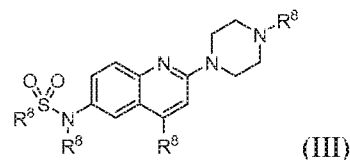
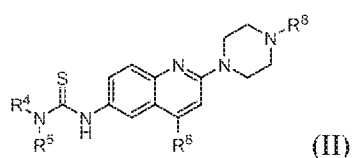
In yet other embodiments, the compound of the invention is a compound of



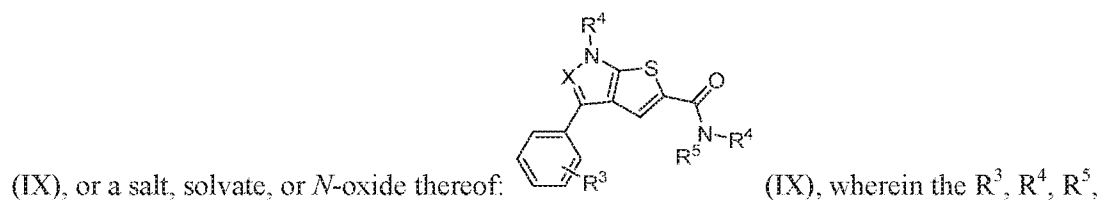
In yet other embodiments, the compound of the invention is a compound of



Exemplary embodiments of compound of the invention include formulas (II)-(VIII), wherein in formula (VII), k is 0, 1, 2, or 3.



In another aspect, the compound of the invention is a compound of formula



and X are as defined above; provided the compound is not selected from the group consisting of 3-(4-chlorophenyl)-1-methyl-N-(3-(pyrrolidin-1-yl)propyl)-1H-thieno[2,3-c]pyrazole-5-carboxamide; N-(3-(azepan-1-yl)propyl)-3-(4-chlorophenyl)-1-methyl-1H-thieno[2,3-c]pyrazole-5-carboxamide; N-(2-(butyl(ethyl)amino)ethyl)-3-(4-chlorophenyl)-1-methyl-1H-thieno[2,3-c]pyrazole-5-carboxamide; and 3-(4-chlorophenyl)-1-methyl-N-(3-(4-methylpiperazin-1-yl)propyl)-1H-thieno[2,3-c]pyrazole-5-carboxamide.

The invention further includes a pharmaceutical composition comprising at least one compound of the invention and at least one pharmaceutically acceptable carrier.

Compounds of formulas (I) to (IX) may be prepared by the general schemes described herein, using the synthetic method known by those skilled in the art. The compounds of the invention may possess one or more stereocenters, and each stereocenter may exist independently in either the (*R*) or (*S*) configuration. In certain embodiments, compounds described herein are present in optically active or racemic forms. It is to be understood that the compounds described herein encompass racemic, optically-active, regioisomeric and stereoisomeric forms, or combinations thereof that possess the therapeutically useful properties described herein. Preparation of optically active forms is achieved in any suitable manner, including by way of non-limiting example, by resolution of the racemic form with recrystallization techniques, synthesis from optically-active starting materials, chiral synthesis, or chromatographic separation using a chiral stationary phase. In certain embodiments, a mixture of one or more isomer is utilized as the therapeutic compound described herein. In other embodiments, compounds described herein contain one or more chiral centers. These compounds are prepared by any means, including stereoselective synthesis, enantioselective synthesis and/or separation of a mixture of enantiomers and/ or diastereomers. Resolution of compounds and isomers thereof is achieved by any means including, by way of non-limiting example, chemical processes, enzymatic processes, fractional crystallization, distillation, and chromatography.

The methods and formulations described herein include the use of N-oxides (if appropriate), crystalline forms (also known as polymorphs), solvates, amorphous phases, and/or pharmaceutically acceptable salts of compounds having the structure of any compound of the invention, as well as metabolites and active metabolites of these compounds having the same type of activity. Solvates include water, ether (*e.g.*, tetrahydrofuran, methyl tert-butyl ether) or alcohol (*e.g.*, ethanol) solvates, acetates and the like. In certain embodiments, the compounds described herein exist in solvated forms with pharmaceutically acceptable solvents such as water, and ethanol. In other embodiments, the compounds described herein

exist in unsolvated form.

In certain embodiments, the compounds of the invention may exist as tautomers. All tautomers are included within the scope of the compounds presented herein.

In certain embodiments, compounds described herein are prepared as
5 prodrugs. A "prodrug" refers to an agent that is converted into the parent drug *in vivo*. In certain embodiments, upon *in vivo* administration, a prodrug is chemically converted to the biologically, pharmaceutically or therapeutically active form of the compound. In other
embodiments, a prodrug is enzymatically metabolized by one or more steps or processes to the biologically, pharmaceutically or therapeutically active form of the compound.

10 In certain embodiments, sites on, for example, the aromatic ring portion of compounds of the invention are susceptible to various metabolic reactions. Incorporation of appropriate substituents on the aromatic ring structures may reduce, minimize or eliminate this metabolic pathway. In certain embodiments, the appropriate substituent to decrease or eliminate the susceptibility of the aromatic ring to metabolic reactions is, by way of example
15 only, a deuterium, a halogen, or an alkyl group.

Compounds described herein also include isotopically-labeled compounds wherein one or more atoms is replaced by an atom having the same atomic number, but an atomic mass or mass number different from the atomic mass or mass number usually found in nature. Examples of isotopes suitable for inclusion in the compounds described herein
20 include and are not limited to ^2H , ^3H , ^{11}C , ^{13}C , ^{14}C , ^{36}Cl , ^{18}F , ^{123}I , ^{125}I , ^{13}N , ^{15}N , ^{15}O , ^{17}O , ^{18}O , ^{32}P , and ^{35}S . In certain embodiments, isotopically-labeled compounds are useful in drug and/or substrate tissue distribution studies. In other embodiments, substitution with heavier isotopes such as deuterium affords greater metabolic stability (for example, increased *in vivo* half-life or reduced dosage requirements). In yet other embodiments, substitution with
25 positron emitting isotopes, such as ^{11}C , ^{18}F , ^{15}O and ^{13}N , is useful in Positron Emission Topography (PET) studies for examining substrate receptor occupancy. Isotopically-labeled compounds are prepared by any suitable method or by processes using an appropriate isotopically-labeled reagent in place of the non-labeled reagent otherwise employed.

In certain embodiments, the compounds described herein are labeled by other
30 means, including, but not limited to, the use of chromophores or fluorescent moieties, bioluminescent labels, or chemiluminescent labels.

The compounds described herein, and other related compounds having different substituents are synthesized using techniques and materials described herein and as described, for example, in Fieser & Fieser's Reagents for Organic Synthesis, Volumes 1-17

(John Wiley and Sons, 1991); Rodd's Chemistry of Carbon Compounds, Volumes 1-5 and Supplementals (Elsevier Science Publishers, 1989); Organic Reactions, Volumes 1-40 (John Wiley and Sons, 1991), Larock's Comprehensive Organic Transformations (VCH Publishers Inc., 1989), March, Advanced Organic Chemistry 4th Ed., (Wiley 1992); Carey & Sundberg, 5 Advanced Organic Chemistry 4th Ed., Vols. A and B (Plenum 2000,2001), and Green & Wuts, Protective Groups in Organic Synthesis 3rd Ed., (Wiley 1999) (all of which are incorporated by reference for such disclosure). General methods for the preparation of compound as described herein are modified by the use of appropriate reagents and conditions, for the introduction of the various moieties found in the formula as provided herein.

10 Compounds described herein are synthesized using any suitable procedures starting from compounds that are available from commercial sources, or are prepared using procedures described herein.

 In certain embodiments, reactive functional groups, such as hydroxyl, amino, imino, thio or carboxy groups, are protected in order to avoid their unwanted participation in 15 reactions. Protecting groups are used to block some or all of the reactive moieties and prevent such groups from participating in chemical reactions until the protective group is removed. In other embodiments, each protective group is removable by a different means. Protective groups that are cleaved under totally disparate reaction conditions fulfill the requirement of differential removal.

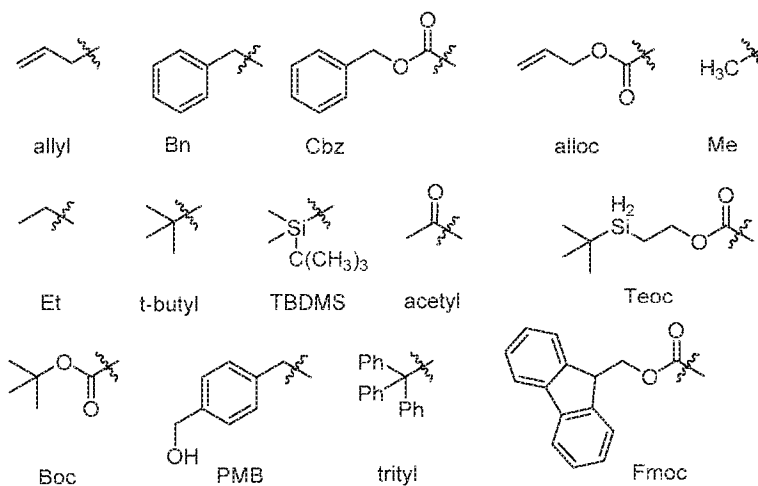
20 In certain embodiments, protective groups are removed by acid, base, reducing conditions (such as, for example, hydrogenolysis), and/or oxidative conditions. Groups such as trityl, dimethoxytrityl, acetal and t-butyldimethylsilyl are acid labile and are used to protect carboxy and hydroxy reactive moieties in the presence of amino groups protected with Cbz groups, which are removable by hydrogenolysis, and Fmoc groups, which are base 25 labile. Carboxylic acid and hydroxy reactive moieties are blocked with base labile groups such as, but not limited to, methyl, ethyl, and acetyl, in the presence of amines that are blocked with acid labile groups, such as t-butyl carbamate, or with carbamates that are both acid and base stable but hydrolytically removable.

 In certain embodiments, carboxylic acid and hydroxy reactive moieties are 30 blocked with hydrolytically removable protective groups such as the benzyl group, while amine groups capable of hydrogen bonding with acids are blocked with base labile groups such as Fmoc. Carboxylic acid reactive moieties are protected by conversion to simple ester compounds as exemplified herein, which include conversion to alkyl esters, or are blocked with oxidatively-removable protective groups such as 2,4-dimethoxybenzyl, while co-

existing amino groups are blocked with fluoride labile silyl carbamates.

Allyl blocking groups are useful in the presence of acid- and base- protecting groups since the former are stable and are subsequently removed by metal or pi-acid catalysts. For example, an allyl-blocked carboxylic acid is deprotected with a palladium-catalyzed reaction in the presence of acid labile t-butyl carbamate or base-labile acetate amine protecting groups. Yet another form of protecting group is a resin to which a compound or intermediate is attached. As long as the residue is attached to the resin, that functional group is blocked and does not react. Once released from the resin, the functional group is available to react.

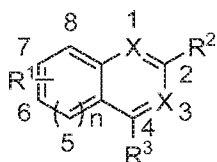
Typically blocking/protecting groups may be selected from:



Other protecting groups, plus a detailed description of techniques applicable to the creation of protecting groups and their removal are described in Greene & Wuts, *Protective Groups in Organic Synthesis*, 3rd Ed., John Wiley & Sons, New York, NY, 1999, and Kocienski, *Protective Groups*, Thieme Verlag, New York, NY, 1994, which are incorporated herein by reference for such disclosure.

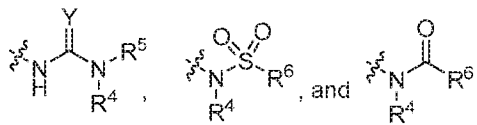
Compositions

The invention includes a pharmaceutical composition comprising at least one compound selected from the group consisting of a compound of formula (I):



(I), wherein in formula (I):

R^1 is selected from the group consisting of:



R^2 is $-NR^4R^5$;

R^3 is selected from the group consisting of hydrogen, $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ haloalkyl, $-(C_1-C_6)$ heteroalkyl, $-F$, $-Cl$, $-Br$, $-I$, $-CN$, $-NO_2$, $-OR^7$, $-SR^7$, $-S(=O)R^7$, $-S(=O)_2R^7$, $-C(=O)R^7$, $-OC(=O)R^7$, and $-CO_2R^7$;

each occurrence of R^4 and R^5 is independently selected from the group consisting of hydrogen, $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ haloalkyl, $-(C_1-C_6)$ heteroalkyl, aryl, and heteroaryl, wherein the aryl or heteroaryl group is optionally substituted; or R^4 and R^5 , together with the nitrogen to which R^4 and R^5 are connected, form a $-(C_3-C_{10})$ heterocyclyl;

each occurrence of R^6 is independently selected from the group consisting of $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ heteroalkyl, $-OR^7$, $-(C_3-C_{10})$ heterocyclyl, aryl, and heteroaryl, wherein the $-(C_3-C_{10})$ heterocyclyl, aryl or heteroaryl group is optionally substituted;

each occurrence of R^7 is independently selected from the group consisting of H, $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ heteroalkyl, $-(C_3-C_6)$ cycloalkyl, $-(C_3-C_{10})$ heterocyclyl, aryl, and $-(C_3-C_{10})$ heteroaryl, wherein the alkyl, heteroalkyl, cycloalkyl, heterocyclyl, aryl, or heteroaryl group is optionally substituted;

each occurrence of X is independently CH or N;

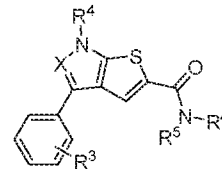
Y is O or S;

n is 0 or 1; when n is 1, R^1 is connected to the aryl ring at 5, 6, 7, or 8 position;

alternatively, when n is 0, R^1 is connected to the aryl ring at that 6, 7, or 8 position;

a salt, solvate, or N-oxide thereof, and any combinations thereof.

The invention also includes a pharmaceutical composition comprising at least

one compound of formula (IX):  (IX), wherein in formula (IX):

R^3 is selected from the group consisting of hydrogen, $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ haloalkyl, $-(C_1-C_6)$ heteroalkyl, $-F$, $-Cl$, $-Br$, $-I$, $-CN$, $-NO_2$, $-OR^7$, $-SR^7$, $-S(=O)R^7$, $-S(=O)_2R^7$, $-C(=O)R^7$, $-OC(=O)R^7$, and $-CO_2R^7$;

each occurrence of R^4 and R^5 is independently selected from the group consisting of hydrogen, $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ haloalkyl, $-(C_1-C_6)$ heteroalkyl, aryl, and heteroaryl, wherein the aryl or heteroaryl group is optionally substituted; or R^4 and R^5 , together with the nitrogen

to which R⁴ and R⁵ are connected, form a -(C₃-C₁₀)heterocyclyl;

X is N or CH; a salt, solvate, or *N*-oxide thereof, and any combinations thereof.

Methods

5 The invention includes a method of treating or preventing a cancer by inhibiting RAD52 in a subject in need thereof. Examples of cancers that can be treated or prevented by the present invention include but are not limited to: squamous cell cancer, lung cancer including small-cell lung cancer, non-small cell lung cancer, vulval cancer, thyroid cancer, adenocarcinoma of the lung and squamous carcinoma of the lung, cancer of the
10 peritoneum, hepatocellular cancer, gastric or stomach cancer including gastrointestinal cancer, pancreatic cancer, glioblastoma, cervical cancer, ovarian cancer, liver cancer, bladder cancer, hepatoma, breast cancer, colon cancer, rectal cancer, colorectal cancer, endometrial or uterine carcinoma, salivary gland carcinoma, kidney or renal cancer, prostate cancer, hepatic carcinoma, anal carcinoma, penile carcinoma, and head and neck cancer. In certain
15 embodiments, the cancer comprises ovarian or breast cancer.

 The method comprises administering to the subject a therapeutically effective amount of a compound of the invention, which is optionally in a pharmaceutical composition. In certain embodiments, the method further comprises administering to the subject an additional therapeutic agent that treats or prevents cancer.

20 In certain embodiments, administering the compound of the invention to the subject allows for treatment of a subject having mutations in BRCA1 and/or BRCA2. The Examples described herein demonstrate that inhibition of RAD52 caused the death of BRCA-1 and/or BRCA-2 deficient cells.

 In certain embodiments, administering the compound of the invention to the
25 subject allows for administering a lower dose of the additional therapeutic agent compared to the dose of the additional therapeutic agent alone that is required to achieve similar results in treating or preventing a cancer in the subject. For example, in certain embodiments, the compound of the invention enhances the anti-cancer activity of the additional therapeutic compound, thereby allowing for a lower dose of the additional therapeutic compound to
30 provide the same effect.

 In certain embodiments, the compound of the invention and the therapeutic agent are co-administered to the subject. In other embodiments, the compound of the invention and the therapeutic agent are coformulated and co-administered to the subject.

 In certain embodiments, the subject is a mammal. In other embodiments, the

mammal is a human.

Combination Therapies

The compounds useful within the methods of the invention may be used in combination with one or more additional therapeutic agents useful for treating a cancer. These additional therapeutic agents may comprise compounds that are commercially available or synthetically accessible to those skilled in the art. These additional therapeutic agents are known to treat, prevent, or reduce the symptoms of a cancer.

In non-limiting examples, the compounds useful within the invention may be used in combination with one or more of the following therapeutic agents: Erlotinib (TARCEVA®, Genentech/OSI Pharm.), docetaxel (TAXOTERE®, Sanofi-Aventis), 5-FU (fluorouracil, 5-fluorouracil, CAS No. 51-21-8), gemcitabine (GEMZAR®, Lilly), PD-0325901 (CAS No. 391210-10-9, Pfizer), cisplatin (cis-diamine,dichloroplatinum(II), CAS No. 15663-27-1), carboplatin (CAS No. 41575-94-4), paclitaxel (TAXOL®, Bristol-Myers Squibb Oncology, Princeton, N.J.), pemetrexed (ALIMTA®, Eli Lilly), trastuzumab (HERCEPTIN®, Genentech), temozolomide (4-methyl-5-oxo-2,3,4,6,8-pentazabicyclo[4.3.0]nona-2,7,9-triene-9-carboxamide, CAS No. 85622-93-1, TEMODAR®, TEMODAL®, Schering Plough), tamoxifen ((Z)-2-[4-(1,2-diphenylbut-1-enyl)phenoxy]-N,N-dimethylethanamine, NOLVADEX®, ISTUBAL®, VALODEX®), and doxorubicin (ADRIAMYCIN®), Akti-1/2, HPPD, rapamycin, oxaliplatin (ELOXATIN®, Sanofi), bortezomib (VELCADE®, Millennium Pharm.), sunitinib (SUNITINIB®, SU11248, Pfizer), letrozole (FEMARA®, Novartis), imatinib mesylate (GLEEVEC®, Novartis), XL-518 (Mek inhibitor, Exelixis, WO 2007/044515), ARRY-886 (Mek inhibitor, AZD6244, Array BioPharma, Astra Zeneca), SF-1126 (PI3K inhibitor, Semaphore Pharmaceuticals), BEZ-235 (PI3K inhibitor, Novartis), XL-147 (PI3K inhibitor, Exelixis), PTK787/ZK 222584 (Novartis), fulvestrant (FASLODEX®, AstraZeneca), leucovorin (folinic acid), rapamycin (sirolimus, RAPAMUNE®, Wyeth), lapatinib (TYKERB®, GSK572016, Glaxo Smith Kline), lonafamib (SARASAR™, SCH 66336, Schering Plough), sorafenib (NEXAVAR®, BAY43-9006, Bayer Labs), gefitinib (IRESSA®, AstraZeneca), irinotecan (CAMPTOSAR®, CPT-11, Pfizer), tipifarnib (ZARNESTRA™, Johnson & Johnson), ABRAXANE™ (Cremophor-free), albumin-engineered nanoparticle formulations of paclitaxel (American Pharmaceutical Partners, Schaumburg, Ill.), vandetanib (rINN, ZD6474, ZACTIMA®, AstraZeneca), chlorambucil, AG1478, AG1571 (SU 5271; Sugen), temsirolimus (TORISEL®, Wyeth), pazopanib (GlaxoSmithKline), canfosfamide

(TELCYTA®, Telik), thiotepa and cyclophosphamide (CYTOXAN®, NEOSAR®).

A synergistic effect may be calculated, for example, using suitable methods such as, for example, the Sigmoid- $E_{\max}$ equation (Holford & Scheiner, 1981, Clin. Pharmacokinet. 6:429-453), the equation of Loewe additivity (Loewe & Muischnek, 1926, Arch. Exp. Pathol Pharmacol. 114:313-326) and the median-effect equation (Chou & Talalay, 1984, Adv. Enzyme Regul. 22:27-55). Each equation referred to above may be applied to experimental data to generate a corresponding graph to aid in assessing the effects of the drug combination. The corresponding graphs associated with the equations referred to above are the concentration-effect curve, isobologram curve and combination index curve, respectively.

Administration/Dosage/Formulations

The regimen of administration may affect what constitutes an effective amount. The therapeutic formulations may be administered to the subject either prior to or after the onset of a cancer. Further, several divided dosages, as well as staggered dosages may be administered daily or sequentially, or the dose may be continuously infused, or may be a bolus injection. Further, the dosages of the therapeutic formulations may be proportionally increased or decreased as indicated by the exigencies of the therapeutic or prophylactic situation.

Administration of the compositions of the present invention to a patient, preferably a mammal, more preferably a human, may be carried out using known procedures, at dosages and for periods of time effective to treat a cancer in the patient. An effective amount of the therapeutic compound necessary to achieve a therapeutic effect may vary according to factors such as the state of the disease or disorder in the patient; the age, sex, and weight of the patient; and the ability of the therapeutic compound to treat a cancer in the patient. Dosage regimens may be adjusted to provide the optimum therapeutic response. For example, several divided doses may be administered daily or the dose may be proportionally reduced as indicated by the exigencies of the therapeutic situation. A non-limiting example of an effective dose range for a therapeutic compound of the invention is from about 1 and 5,000 mg/kg of body weight/per day. One of ordinary skill in the art would be able to study the relevant factors and make the determination regarding the effective amount of the therapeutic compound without undue experimentation.

Actual dosage levels of the active ingredients in the pharmaceutical compositions of this invention may be varied so as to obtain an amount of the active ingredient that is effective to achieve the desired therapeutic response for a particular patient,

composition, and mode of administration, without being toxic to the patient.

In particular, the selected dosage level depends upon a variety of factors including the activity of the particular compound employed, the time of administration, the rate of excretion of the compound, the duration of the treatment, other drugs, compounds or materials used in combination with the compound, the age, sex, weight, condition, general health and prior medical history of the patient being treated, and like factors well known in the medical arts.

A medical doctor, *e.g.*, physician or veterinarian, having ordinary skill in the art may readily determine and prescribe the effective amount of the pharmaceutical composition required. For example, the physician or veterinarian could start doses of the compounds of the invention employed in the pharmaceutical composition at levels lower than that required in order to achieve the desired therapeutic effect and gradually increase the dosage until the desired effect is achieved.

In particular embodiments, it is especially advantageous to formulate the compound in dosage unit form for ease of administration and uniformity of dosage. Dosage unit form as used herein refers to physically discrete units suited as unitary dosages for the patients to be treated; each unit containing a predetermined quantity of therapeutic compound calculated to produce the desired therapeutic effect in association with the required pharmaceutical vehicle. The dosage unit forms of the invention are dictated by and directly dependent on (a) the unique characteristics of the therapeutic compound and the particular therapeutic effect to be achieved, and (b) the limitations inherent in the art of compounding/formulating such a therapeutic compound for the treatment of a cancer in a patient.

In certain embodiments, the compositions of the invention are formulated using one or more pharmaceutically acceptable excipients or carriers. In certain embodiments, the pharmaceutical compositions of the invention comprise a therapeutically effective amount of a compound of the invention and a pharmaceutically acceptable carrier.

The carrier may be a solvent or dispersion medium containing, for example, water, ethanol, polyol (for example, glycerol, propylene glycol, and liquid polyethylene glycol, and the like), suitable mixtures thereof, and vegetable oils. The proper fluidity may be maintained, for example, by the use of a coating such as lecithin, by the maintenance of the required particle size in the case of dispersion and by the use of surfactants. Prevention of the action of microorganisms may be achieved by various antibacterial and antifungal agents, for example, parabens, chlorobutanol, phenol, ascorbic acid, thimerosal, and the like. In

many cases, it is preferable to include isotonic agents, for example, sugars, sodium chloride, or polyalcohols such as mannitol and sorbitol, in the composition. Prolonged absorption of the injectable compositions may be brought about by including in the composition an agent which delays absorption, for example, aluminum monostearate or gelatin.

5 In certain embodiments, the compositions of the invention are administered to the patient in dosages that range from one to five times per day or more. In other embodiments, the compositions of the invention are administered to the patient in range of dosages that include, but are not limited to, once every day, every two, days, every three days to once a week, and once every two weeks. It is readily apparent to one skilled in the art that
10 the frequency of administration of the various combination compositions of the invention varies from individual to individual depending on many factors including, but not limited to, age, disease or disorder to be treated, gender, overall health, and other factors. Thus, the invention should not be construed to be limited to any particular dosage regime and the precise dosage and composition to be administered to any patient is determined by the
15 attending physical taking all other factors about the patient into account.

Compounds of the invention for administration may be in the range of from about 1 µg to about 10,000 mg, about 20 µg to about 9,500 mg, about 40 µg to about 9,000 mg, about 75 µg to about 8,500 mg, about 150 µg to about 7,500 mg, about 200 µg to about 7,000 mg, about 3050 µg to about 6,000 mg, about 500 µg to about 5,000 mg, about 750 µg
20 to about 4,000 mg, about 1 mg to about 3,000 mg, about 10 mg to about 2,500 mg, about 20 mg to about 2,000 mg, about 25 mg to about 1,500 mg, about 30 mg to about 1,000 mg, about 40 mg to about 900 mg, about 50 mg to about 800 mg, about 60 mg to about 750 mg, about 70 mg to about 600 mg, about 80 mg to about 500 mg, and any and all whole or partial increments therebetween.

25 In some embodiments, the dose of a compound of the invention is from about 1 mg and about 2,500 mg. In some embodiments, a dose of a compound of the invention used in compositions described herein is less than about 10,000 mg, or less than about 8,000 mg, or less than about 6,000 mg, or less than about 5,000 mg, or less than about 3,000 mg, or less than about 2,000 mg, or less than about 1,000 mg, or less than about 500 mg, or less than
30 about 200 mg, or less than about 50 mg. Similarly, in some embodiments, a dose of a second compound as described herein is less than about 1,000 mg, or less than about 800 mg, or less than about 600 mg, or less than about 500 mg, or less than about 400 mg, or less than about 300 mg, or less than about 200 mg, or less than about 100 mg, or less than about 50 mg, or

less than about 40 mg, or less than about 30 mg, or less than about 25 mg, or less than about 20 mg, or less than about 15 mg, or less than about 10 mg, or less than about 5 mg, or less than about 2 mg, or less than about 1 mg, or less than about 0.5 mg, and any and all whole or partial increments thereof.

5 In certain embodiments, the present invention is directed to a packaged pharmaceutical composition comprising a container holding a therapeutically effective amount of a compound of the invention, alone or in combination with a second pharmaceutical agent; and instructions for using the compound to treat, prevent, or reduce one or more symptoms of a cancer in a patient.

10 Formulations may be employed in admixtures with conventional excipients, *i.e.*, pharmaceutically acceptable organic or inorganic carrier substances suitable for oral, parenteral, nasal, intravenous, subcutaneous, enteral, or any other suitable mode of administration, known to the art. The pharmaceutical preparations may be sterilized and if desired mixed with auxiliary agents, *e.g.*, lubricants, preservatives, stabilizers, wetting agents, 15 emulsifiers, salts for influencing osmotic pressure buffers, coloring, flavoring and/or aromatic substances and the like. They may also be combined where desired with other active agents, *e.g.*, other analgesic agents.

 Routes of administration of any of the compositions of the invention include oral, nasal, rectal, intravaginal, parenteral, buccal, sublingual or topical. The compounds for 20 use in the invention may be formulated for administration by any suitable route, such as for oral or parenteral, for example, transdermal, transmucosal (*e.g.*, sublingual, lingual, (trans)buccal, (trans)urethral, vaginal (*e.g.*, trans- and perivaginally), (intra)nasal and (trans)rectal), intravesical, intrapulmonary, intraduodenal, intragastrical, intrathecal, subcutaneous, intramuscular, intradermal, intra-arterial, intravenous, intrabronchial, 25 inhalation, and topical administration.

 Suitable compositions and dosage forms include, for example, tablets, capsules, caplets, pills, gel caps, troches, dispersions, suspensions, solutions, syrups, granules, beads, transdermal patches, gels, powders, pellets, magmas, lozenges, creams, pastes, plasters, lotions, discs, suppositories, liquid sprays for nasal or oral administration, dry 30 powder or aerosolized formulations for inhalation, compositions and formulations for intravesical administration and the like. It should be understood that the formulations and compositions that would be useful in the present invention are not limited to the particular formulations and compositions that are described herein.

Oral Administration

For oral application, particularly suitable are tablets, dragees, liquids, drops, suppositories, or capsules, caplets and gelcaps. The compositions intended for oral use may be prepared according to any method known in the art and such compositions may contain one or more agents selected from the group consisting of inert, non-toxic pharmaceutically excipients that are suitable for the manufacture of tablets. Such excipients include, for example an inert diluent such as lactose; granulating and disintegrating agents such as cornstarch; binding agents such as starch; and lubricating agents such as magnesium stearate. The tablets may be uncoated or they may be coated by known techniques for elegance or to delay the release of the active ingredients. Formulations for oral use may also be presented as hard gelatin capsules wherein the active ingredient is mixed with an inert diluent.

For oral administration, the compounds of the invention may be in the form of tablets or capsules prepared by conventional means with pharmaceutically acceptable excipients such as binding agents (*e.g.*, polyvinylpyrrolidone, hydroxypropylcellulose or hydroxypropylmethylcellulose); fillers (*e.g.*, cornstarch, lactose, microcrystalline cellulose or calcium phosphate); lubricants (*e.g.*, magnesium stearate, talc, or silica); disintegrates (*e.g.*, sodium starch glycollate); or wetting agents (*e.g.*, sodium lauryl sulphate). If desired, the tablets may be coated using suitable methods and coating materials such as OPADRY™ film coating systems available from Colorcon, West Point, Pa. (*e.g.*, OPADRY™ OY Type, OYC Type, Organic Enteric OY-P Type, Aqueous Enteric OY-A Type, OY-PM Type and OPADRY™ White, 32K18400). Liquid preparation for oral administration may be in the form of solutions, syrups or suspensions. The liquid preparations may be prepared by conventional means with pharmaceutically acceptable additives such as suspending agents (*e.g.*, sorbitol syrup, methyl cellulose or hydrogenated edible fats); emulsifying agent (*e.g.*, lecithin or acacia); non-aqueous vehicles (*e.g.*, almond oil, oily esters or ethyl alcohol); and preservatives (*e.g.*, methyl or propyl p-hydroxy benzoates or sorbic acid).

Granulating techniques are well known in the pharmaceutical art for modifying starting powders or other particulate materials of an active ingredient. The powders are typically mixed with a binder material into larger permanent free-flowing agglomerates or granules referred to as a “granulation.” For example, solvent-using “wet” granulation processes are generally characterized in that the powders are combined with a binder material and moistened with water or an organic solvent under conditions resulting in the formation of a wet granulated mass from which the solvent must then be evaporated.

Melt granulation generally consists in the use of materials that are solid or

semi-solid at room temperature (*i.e.* having a relatively low softening or melting point range) to promote granulation of powdered or other materials, essentially in the absence of added water or other liquid solvents. The low melting solids, when heated to a temperature in the melting point range, liquefy to act as a binder or granulating medium. The liquefied solid spreads itself over the surface of powdered materials with which it is contacted, and on cooling, forms a solid granulated mass in which the initial materials are bound together. The resulting melt granulation may then be provided to a tablet press or be encapsulated for preparing the oral dosage form. Melt granulation improves the dissolution rate and bioavailability of an active (*i.e.* drug) by forming a solid dispersion or solid solution.

U.S. Patent No. 5,169,645 discloses directly compressible wax-containing granules having improved flow properties. The granules are obtained when waxes are admixed in the melt with certain flow improving additives, followed by cooling and granulation of the admixture. In certain embodiments, only the wax itself melts in the melt combination of the wax(es) and additives(s), and in other cases both the wax(es) and the additives(s) melt.

The present invention also includes a multi-layer tablet comprising a layer providing for the delayed release of one or more compounds of the invention, and a further layer providing for the immediate release of a medication for treatment of G-protein receptor-related diseases or disorders. Using a wax/pH-sensitive polymer mix, a gastric insoluble composition may be obtained in which the active ingredient is entrapped, ensuring its delayed release.

Parenteral Administration

For parenteral administration, the compounds of the invention may be formulated for injection or infusion, for example, intravenous, intramuscular or subcutaneous injection or infusion, or for administration in a bolus dose and/or continuous infusion. Suspensions, solutions or emulsions in an oily or aqueous vehicle, optionally containing other formulatory agents such as suspending, stabilizing and/or dispersing agents may be used.

Additional Administration Forms

Additional dosage forms of this invention include dosage forms as described in U.S. Patents Nos. 6,340,475; 6,488,962; 6,451,808; 5,972,389; 5,582,837; and 5,007,790. Additional dosage forms of this invention also include dosage forms as described in U.S. Patent Applications Nos. 20030147952; 20030104062; 20030104053; 20030044466; 20030039688; and 20020051820. Additional dosage forms of this invention also include dosage forms as described in PCT Applications Nos. WO 03/35041; WO 03/35040; WO

03/35029; WO 03/35177; WO 03/35039; WO 02/96404; WO 02/32416; WO 01/97783; WO 01/56544; WO 01/32217; WO 98/55107; WO 98/11879; WO 97/47285; WO 93/18755; and WO 90/11757.

Controlled Release Formulations and Drug Delivery Systems

5 In certain embodiments, the formulations of the present invention may be, but are not limited to, short-term, rapid-offset, as well as controlled, for example, sustained release, delayed release and pulsatile release formulations.

 The term sustained release is used in its conventional sense to refer to a drug formulation that provides for gradual release of a drug over an extended period of time, and
10 that may, although not necessarily, result in substantially constant blood levels of a drug over an extended time period. The period of time may be as long as a month or more and should be a release which is longer than the same amount of agent administered in bolus form.

 For sustained release, the compounds may be formulated with a suitable polymer or hydrophobic material which provides sustained release properties to the
15 compounds. As such, the compounds for use the method of the invention may be administered in the form of microparticles, for example, by injection or in the form of wafers or discs by implantation.

 In one embodiment of the invention, the compounds of the invention are administered to a patient, alone or in combination with another pharmaceutical agent, using a
20 sustained release formulation.

 The term delayed release is used herein in its conventional sense to refer to a drug formulation that provides for an initial release of the drug after some delay following drug administration and that may, although not necessarily, includes a delay of from about 10 minutes up to about 12 hours.

25 The term pulsatile release is used herein in its conventional sense to refer to a drug formulation that provides release of the drug in such a way as to produce pulsed plasma profiles of the drug after drug administration.

 The term immediate release is used in its conventional sense to refer to a drug formulation that provides for release of the drug immediately after drug administration.

30 As used herein, short-term refers to any period of time up to and including about 8 hours, about 7 hours, about 6 hours, about 5 hours, about 4 hours, about 3 hours, about 2 hours, about 1 hour, about 40 minutes, about 20 minutes, or about 10 minutes and any or all whole or partial increments thereof after drug administration after drug administration.

As used herein, rapid-offset refers to any period of time up to and including about 8 hours, about 7 hours, about 6 hours, about 5 hours, about 4 hours, about 3 hours, about 2 hours, about 1 hour, about 40 minutes, about 20 minutes, or about 10 minutes, and any and all whole or partial increments thereof after drug administration.

5 *Dosing*

The therapeutically effective amount or dose of a compound of the present invention depends on the age, sex and weight of the patient, the current medical condition of the patient and the progression of a cancer in the patient being treated. The skilled artisan is able to determine appropriate dosages depending on these and other factors.

10 A suitable dose of a compound of the present invention may be in the range of from about 0.01 mg to about 5,000 mg per day, such as from about 0.1 mg to about 1,000 mg, for example, from about 1 mg to about 500 mg, such as about 5 mg to about 250 mg per day. The dose may be administered in a single dosage or in multiple dosages, for example from 1 to 4 or more times per day. When multiple dosages are used, the amount of each dosage may
15 be the same or different. For example, a dose of 1 mg per day may be administered as two 0.5 mg doses, with about a 12-hour interval between doses.

It is understood that the amount of compound dosed per day may be administered, in non-limiting examples, every day, every other day, every 2 days, every 3 days, every 4 days, or every 5 days. For example, with every other day administration, a 5
20 mg per day dose may be initiated on Monday with a first subsequent 5 mg per day dose administered on Wednesday, a second subsequent 5 mg per day dose administered on Friday, and so on.

In the case wherein the patient's status does improve, upon the doctor's discretion the administration of the inhibitor of the invention is optionally given
25 continuously; alternatively, the dose of drug being administered is temporarily reduced or temporarily suspended for a certain length of time (*i.e.*, a "drug holiday"). The length of the drug holiday optionally varies between 2 days and 1 year, including by way of example only, 2 days, 3 days, 4 days, 5 days, 6 days, 7 days, 10 days, 12 days, 15 days, 20 days, 28 days, 35 days, 50 days, 70 days, 100 days, 120 days, 150 days, 180 days, 200 days, 250 days, 280
30 days, 300 days, 320 days, 350 days, or 365 days. The dose reduction during a drug holiday includes from 10%-100%, including, by way of example only, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, or 100%.

Once improvement of the patient's conditions has occurred, a maintenance dose is administered if necessary. Subsequently, the dosage or the frequency of

administration, or both, is reduced, as a function of the viral load, to a level at which the improved disease is retained. In certain embodiments, patients require intermittent treatment on a long-term basis upon any recurrence of symptoms and/or infection.

The compounds for use in the method of the invention may be formulated in unit dosage form. The term "unit dosage form" refers to physically discrete units suitable as unitary dosage for patients undergoing treatment, with each unit containing a predetermined quantity of active material calculated to produce the desired therapeutic effect, optionally in association with a suitable pharmaceutical carrier. The unit dosage form may be for a single daily dose or one of multiple daily doses (*e.g.*, about 1 to 4 or more times per day). When multiple daily doses are used, the unit dosage form may be the same or different for each dose.

Toxicity and therapeutic efficacy of such therapeutic regimens are optionally determined in cell cultures or experimental animals, including, but not limited to, the determination of the LD₅₀ (the dose lethal to 50% of the population) and the ED₅₀ (the dose therapeutically effective in 50% of the population). The dose ratio between the toxic and therapeutic effects is the therapeutic index, which is expressed as the ratio between LD₅₀ and ED₅₀. The data obtained from cell culture assays and animal studies are optionally used in formulating a range of dosage for use in human. The dosage of such compounds lies preferably within a range of circulating concentrations that include the ED₅₀ with minimal toxicity. The dosage optionally varies within this range depending upon the dosage form employed and the route of administration utilized.

Those skilled in the art will recognize, or be able to ascertain using no more than routine experimentation, numerous equivalents to the specific procedures, embodiments, claims, and examples described herein. Such equivalents were considered to be within the scope of this invention and covered by the claims appended hereto. For example, it should be understood, that modifications in reaction conditions, including but not limited to reaction times, reaction size/volume, and experimental reagents, such as solvents, catalysts, pressures, atmospheric conditions, *e.g.*, nitrogen atmosphere, and reducing/oxidizing agents, with art-recognized alternatives and using no more than routine experimentation, are within the scope of the present application.

It is to be understood that wherever values and ranges are provided herein, all values and ranges encompassed by these values and ranges, are meant to be encompassed within the scope of the present invention. Moreover, all values that fall within these ranges, as well as the upper or lower limits of a range of values, are also contemplated by the present

application.

The following examples further illustrate aspects of the present invention. However, they are in no way a limitation of the teachings or disclosure of the present invention as set forth herein.

5

EXAMPLES

The invention is now described with reference to the following Examples. These Examples are provided for the purpose of illustration only and the invention should in no way be construed as being limited to these Examples, but rather should be construed to encompass any and all variations which become evident as a result of the teaching provided herein.

Methods and Materials

Biochemical assays

15 The effect of inhibitors was tested during HTS using DNA fluorescent substrates. The compounds were re-tested using radioactively labeled substrates, and the IC50s are shown in Table 1.

The selectivity test was run against RAD51 that is structurally unrelated to RAD52, but displaying similar activities. The test was run at compound concentrations = 10
20 x of IC50. The selectivity data was shown in Table 1. Compounds that showed more than 50% inhibition were discarded.

Cellular assays

Cell lines:

- 25
1. BRCA1deficient/proficient cell line: UWB1.298/UWB1.298 (BRCA1+).
 2. BRCA2deficient/proficient cell line:

Protocol:

BxPC3 cells were kept in RPMI 1640 (ATCC) media supplemented with 10% FBS (Gibco). Capan-1/BxPC3 Capan-1cells were kept in IMDM (ATCC) media containing
30 20% FBS (GIBCO). UWB1.298 and UWB1.298 (BRCA1+) cells were kept in 48.5% RPMI1640 (ATCC), 48.5% MEGM (Clonetics/Lonza, MEGM kit, CC-3150) and 3% FBS (GIBCO) respectively. Cells in log-phase were harvested and 100 µl cell suspensions were replated in a 96-well plate with a final density of 4000 cells/well. After overnight growth,

cells were treated with indicated concentrations of compounds. Media containing the invariant concentration of compounds were refreshed every 3 days until cells were finally lysed by 30 µl/well of Promega CellTiter-Glo reagents and read on a Promega GloMax 96 reader on day 10 (9 days exposure).

5 Promega CellTiter-Glo protocol is available on the web: www.dot.promega.com/resources/protocols/technical-bulletins/0/celltiter-glo-luminescent-cell-viability-assay-protocol/.

Chemicals, proteins, and DNA

10 Cisplatin was purchased from Sigma-Aldrich. Human RAD52 and RAD51 were purified as described (Bugreev *et al.*, 2005, Mol. Cell. Biol. 33, 387-395). The oligonucleotides (Table 2) were purchased from IDT, Inc and further purified by electrophoresis (Rossi *et al.*, 2010, Methods 51, 336-346). Supercoiled pUC19 plasmid DNA was purified using Qiagen kits. All DNA concentrations are expressed as moles of
15 nucleotide.

Compound libraries, and compounds

A Broad's diversity-oriented synthesis (DOS) library having 93,672 compounds and a Molecular Libraries Probe Center Network (MPLCN) library having
20 279,231 compounds were used. All the compounds were dissolved in DMSO (Sigma, Cat # D8418). In the working solutions the DMSO concentration added with the stock of compounds was 2% (v/v), unless indicated otherwise. The compounds for confirmation analysis were purchased from Asinex Ltd., ChemBridge Co., ChemDiv Inc, Enamine, FCH Group, Frontier Scientific Services Inc., InterBioScreen Ltd., Life Chemicals Inc., Scientific
25 Exchange Inc., Sigma-Aldrich Co., and Vitas-M Laboratory Ltd.

Fluorescence-quenching assay for RAD52 DNA annealing

Tailed dsDNA substrate was prepared by thermal annealing of ssDNA oligonucleotides 337-F and 1337-BHQ1 (SEQ ID NO: 2) containing Fluorescein and Black
30 Hole Quencher 1 residues at the 5' and 3' end, respectively. DNA annealing was initiated by adding RAD52 (20 nM) to the mixture of ssDNA oligonucleotide 265-55 (SEQ ID NO: 3) (5 nM, molecules) and tailed dsDNA 337-F/1337-BHQ1 (SEQ ID NO: 2) (5 nM, molecules) in buffer containing 25 mM Tris-acetate pH 7.5, 100 µg.ml⁻¹ BSA and 1 mM DTT. The

fluorescence intensity was measured in a 3-mm quartz cuvette (Starna Cells) using a FluoroMax-3 (HORIBA) fluorimeter with 492 nm excitation wavelength and 520 nm emission wavelength at 30 °C for at least 2000 s.

5 *HTS for RAD52 inhibitors*

The fluorescence-quenching assay for RAD52-promoted DNA annealing was optimized to a 4 µl 1536 well protocol using 25 nM RAD52 and 8 nM (molecules) DNA in buffer containing 25 mM Tris-acetate pH 7.5, 100 µg.ml⁻¹ BSA, 1 mM DTT, and 0.01% Pluronic F-68. Wells containing no RAD52 were used as a positive control to estimate the activity of fully inhibited protein; wells in which the compounds were replaced with only the vehicle (DMSO) were used as neutral control. The HTS was performed using the 8 channel BioRAPTR 1536 (Beckman) for reagent dispensing. The reactions were carried out for 30 minutes followed by measurement of an endpoint fluorescence (485 nm excitation, 535 nm emission) using an EnVision multimode plate reader (Perkin Elmer). Wells containing no RAD52 enzyme were used to as positive control, and data were analyzed using Genedata. The compounds with an inhibitory effect of 30% or greater were tested further by measuring the concentration dependence (in a range from 1 nM to 100 µM) of their inhibition of RAD51. The most potent inhibitory compounds were analyzed further using non-fluorescent assays. Detailed methods for RAD52 screening are in PubMed: *pubchem dot ncbi dot nlm dot nih dot gov/assay/assay dot cgi?aid=651660*.

D-loop formation by RAD52 or RAD51

To form RAD52 nucleoprotein complexes, RAD52 (0.45 µM) was incubated with a ³²P-labeled ssDNA (oligo 90 / SEQ ID NO: 4) (3 µM, nt) in buffer containing 25 mM Tris-Acetate, pH 7.5, 100 µg.ml⁻¹ BSA, 0.3 mM magnesium acetate, and 2 mM DTT at 37 °C for 15 min. To form RAD51 nucleoprotein filament, RAD51 (1 µM) was incubated with ³²P-labeled ssDNA (3 µM, nt) in buffer containing 25 mM Tris-Acetate, pH 7.5, 100 µg.ml⁻¹ BSA, 1 mM calcium chloride, 1 mM ATP and 2 mM DTT for 15 min at 37 °C. Then inhibitors were added to both reactions and incubation continued for 15 min at 37 °C. D-Loop formation was initiated by addition of supercoiled pUC19 DNA (50 µM, nucleotides) and was carried out 15 min at 37 °C. The reactions were stopped and deproteinized by the addition of 1.5% SDS and proteinase K (0.8 mg/ml) for 15 min at 37 °C, mixed with a 0.10 volume of loading buffer (70% glycerol, 0.1% bromphenol blue), and analyzed by electrophoresis in 1% agarose gels in TAE buffer (40 mM Tris acetate, pH 8.3, and 1 mM

EDTA) at 5 V/cm for 3 h. The gels were dried on DEAE-81 paper (Whatman) and the yield of D-loops quantified using a Storm 840 PhosphorImager and ImageQuant 5.2 (GE Healthcare). The D-loop yield was expressed as a percentage of plasmid DNA carrying D-loops relative to the total plasmid DNA.

5

Calculation of the IC₅₀ value for RAD52 inhibitors

IC₅₀ values were calculated using GraphPad Prism V5.0 software. The data were obtained from three independent repeats of experiments.

10 *Acridine orange displacement assay for DNA binding*

The selected compounds were tested their abilities to bind DNA to rule out DNA binding as an undesired mechanism of action. The compounds in varied concentrations were added into 30 µl reaction mixtures containing 50 nM acridine orange and 6 µg/ml salmon sperm DNA, 10 mM HEPES, pH 7.5; 1 mM EDTA pH 7.5; 100 mM NaCl in 384-well plates, and the reactions were incubated at room temperature for 20 min followed by fluorescence polarization measurement using an EnVision (Perkin Elmer) equipped with a 480 nm excitation filter and 535 nm S and P emission filters with a D505 FP/D535 dichroic mirror. Mitoxantrone (10 µM) was used as a positive control. The S and P values are processed with the standard fluorescence polarization calculation formula ($mP = 1000 * (S - G * P) / (S + G * P)$ where G is the G-factor and is approximately 1.

20

Luminescent cell viability assay

BxPC3 cells were kept in RPMI 1640 (ATCC) media supplemented with 10% FBS (Gibco); Capan-1 cells were kept in IMDM (ATCC) media containing 20% FBS (GIBCO); UWB1.298 and UWB1.298 (BRCA1+) cells were kept in 48.5% RPMI1640 (ATCC), 48.5% MEGM (Clonetics/Lonza, MEGM kit, CC-3150) and 3% FBS (GIBCO) respectively. Cells in log-phase were harvested and 100 µl cell suspensions were replated in a 96-well plate with a final density of 4000 cells/well. After overnight growth, cells were treated with indicated concentrations of compounds. Media containing the invariant concentration of compounds were refreshed every 3 days until cells were finally lysed by 30 µl/well of Promega CellTiter-Glo reagents and read on a Promega GloMax 96 reader on day 10 (9 days exposure). Promega CellTiter-Glo protocol is available on the web: www.dot.promega.com/resources/protocols/technical-bulletins/0/celltiter-glo-luminescent-cell-viability-assay-protocol/

30

Clonogenic survival assay

MDA-MB-436 cells were cultured in RPMI + 10%FBS. BRCA-proficient and BRCA-deficient cells were plated on day 0 in triplicate at 5,000 cells/well. On days 1 and 3, the cells were treated with 0, 2.5 uM, 5 uM, or 10 uM of D-I03 or I09. Cells were counted on day 4 on a hemocytometer, using Trypan Blue exclusion, and immediately were plated in a clonogenic assay at a density of 500 cells/well in a 6 well plate, in RPMI + 10% FBS. After two weeks, the colonies were fixed/stained with 0.05% of 10 mg/ml ethidium bromide in 50% ethanol and visualized with Alphaimager gel imager (Alpha Innotech).

CML viability assay

Lin-CD34+ primary CML and normal cells were obtained by magnetic sorting using the EasySep negative selection human progenitor cell enrichment cocktail followed by treatment with human CD34 positive selection cocktail (StemCell Technologies), and were subsequently cultured in StemSpan H3000 media (StemCell Technologies) supplemented with a cocktail of growth factors (100 ng/ml stem cell factor, 20 ng/ml interleukin3 [IL-3], 100 ng/ml fms-related tyrosine kinase 3 ligand, 20 ng/ml granulocyte colony-stimulating factor, 20 ng/ml IL-6). For the viability assay, CD34+ CML (n = 3) and normal (n = 5) cells were plated at 1×10^4 cells/well in 96 well plates on day 0, and treated with 0 μ M, 2 μ M, 5 μ M, or 10 μ M D-I03 on days 0 and 2. Viable cells were counted on day 4 using Trypan Blue staining.

Measurement of compound binding to RAD52 by SPR

Experiments were performed using the ProteOn XPR36 SPR array system (Bio-Rad). ProteOn GLH sensor chips were preconditioned with two short pulses each (10 s) of 50 mM NaOH, 100 mM HCl, and 0.5% SDS. Then the system was equilibrated with PBS-T buffer (20 mM Na-phosphate, 150 mM NaCl, and 0.1% polysorbate 20, pH 7.4). Individual ligand flow channels were activated for 5 min at 25 °C with a mixture of 1-ethyl-3-[3-dimethylamino propyl carbodiimide hydrochloride) (0.2 M) and sulfo-N-hydroxy succinimide (0.05 M). Immediately after chip activation, either RAD52 (100 μ g.ml⁻¹ in 25 mM Tris-Acetate, 20mM KCl, 0.3 mM magnesium acetate, pH 7.5) or the anti-HIV mAb 2F5 (100 μ g.ml⁻¹ in 10 mM sodium acetate, pH 5.0) was injected across ligand flow channels for 5 min at a flow rate of 30 μ l.min⁻¹.

Excess active ester groups on the sensor surface were capped by a 5-min

injection of 1 M ethanolamine HCl (pH 8.5). This resulted in the coupling of RAD52 and 2F5 at a density of 9,000 RUs (response unit, which is an arbitrary unit that corresponds to 1 pg/mm²). The standard deviation in the immobilization level from the six spots within each channel was less than 4%. Compounds in indicated concentrations in 25 mM Tris-Acetate, 20 mM KCl, 0.3 mM magnesium acetate, pH 7.5, supplemented with 0.005% polysorbate 20 and 2% DMSO were injected over the control and RAD52 surfaces at a flow rate of 200 µl min⁻¹, for either a 30s (D-I09) or 1-min association phase (D-I03, D-G23), followed by a variable dissociation phase at 25 °C using the “one-shot” functionality of the ProteOn (Bravman *et al.*, 2006, Anal Biochem 358, 281-288).

Specific regeneration of the surfaces between injections was not needed owing to the nature of the interaction. Data were analyzed using the ProteOn Manager Software version 3.0 (Bio-Rad). The responses of a buffer injection and responses from the reference flow cell were subtracted to account for nonspecific binding. Experimental data were fitted globally to a simple 1:1 binding model. The average kinetic parameters (association [ka] and dissociation [kd] rates) generated from three data sets were used to define the equilibrium dissociation constant (KD). Data that could not be adequately fit to a binding model were analyzed using equilibrium analysis, plotting the response at equilibrium versus concentration and fitting to a steady state model.

Measuring the effect of inhibitors on GFP-RAD52 and RAD51 foci formation

GFP-RAD52 foci formation was measured in BCR-ABL1-positive BRCA1-deficient 32Dcl3 murine hematopoietic cell line that expresses GFP-RAD52 (Cramer-Morales *et al.*, 2013, Blood 122, 1293-1304). RAD51 foci formation was measured in parental 32Dcl3.

Both cell lines were cultured in IMDM plus 10% FBS. The cells were plated at 500,000 cells/ml and pretreated for 4 h with either D-G23 or D-I03 (2.5 µM) for GFP-RAD52 foci or with D-I03 (2.5 µM) for RAD51 foci (or no pretreatment for the control and cisplatin-treated cells). After 4 h of incubation, the cells were treated with 3 µg/mL cisplatin for 16 h. Following cisplatin treatment, cytopins were prepared using polylysine coated slides (Thermo Scientific). DNA was counterstained with DAPI. To detect RAD51 foci, cells were stained with an anti-RAD51 antibody (Thermo Scientific), followed by a secondary antibody conjugated with AlexaFluor 594. RAD51 and GFP-RAD52 foci were visualized with an inverted Olympus IX70 fluorescence microscope equipped with a Cooke Sensicam QE camera (The Cooke Co., Auburn Hills, MI, USA). Images from 25-60

cells/group were processed using SlideBook 3.0 (Intelligent Imaging Innovation).

Measuring the effect of D-103 on single-strand annealing (SSA) and gene conversion (HDR) in U2OS cells

5 U2OS cells with chromosomally integrated SSA(U2OSSSA) or gene conversion HDR(U2OS-HDR)-reporter were cultured in DMEM (Sigma D-6429) containing 10% FBS (Gibco) supplemented with antibiotics (penicillin 100 U/ml, streptomycin 100 μ g/ml, and plasmodin (2.5 μ g/ml). At 80% confluence, cells were trypsinized and plated in triplicate at a density of 2×10^5 cells/well in 6 well plates. After 22 h cells were washed with
10 1X PBS and further incubated for 2 h in antibiotic-free DMEM-10% FBS. Cells were transfected with pCBASee (0.8 μ g) expressing I-SceI endonuclease or, in controls, with pUC19 (0.8 μ g) or pMXGFP (0.8 μ g) plasmids using Lipofectamine 2000. After 3 h of transfection, cells were washed with antibiotic-free DMEM-10% FBS. Then, cells were incubated in DMEM-10% FBS supplemented with antibiotics and containing D-103 at
15 indicated concentrations followed by additional incubation for 48 h. In each well, cells were washed with 1X PBS, trypsinized and fixed with 3.3% formaldehyde. Fixed cells were kept on ice. The yield of GFP+ positive cells was measured by flow cytometry using Guava EasyCyte PRO (EMD Millipore).

20 **Example 1: High Throughput Screening (HTS) for RAD52 Inhibitors**

Small molecule inhibitors of RAD52 were discovered using high throughput screening (HTS) of compound libraries. In vitro, RAD52 carries out annealing of complementary ssDNA molecules and an invasion of ssDNA into homologous duplex DNA. A fluorescence-quenching assay was used to screen for inhibitors of RAD52 ssDNA
25 annealing activity (FIGs. 1A-1E). In this assay, RAD52 promotes DNA annealing between homologous synthetic ssDNA (Oligo 265-55; 55 nt / SEQ ID NO: 3) and tailed dsDNA (tdsDNA) substrates. The tdsDNA was generated by thermal annealing of an ssDNA 60-mer (Oligo 337-FLU, SEQ ID NO: 1) carrying fluorescein (FLU), a fluorescence donor group, and an ssDNA 39-mer (1337-BHQ1/SEQ ID NO: 2) carrying black hole quencher 1 (BHQ1),
30 a non-fluorescent acceptor group (FIG. 1A). Annealing promoted by RAD52 between ssDNA and tdsDNA led to displacement of the FLU-carrying DNA strand from the tdsDNA and in an increase in fluorescence due to secession of fluorescence quenching by the BHQ1 group (FIG. 1B).

The fluorescence-quenching assay was optimized for 1,536 well plates (Z'

Avg = 0.64). The primary HTS of the 372,903-compound library yielded 1,687 positive hits that caused more than 30% inhibition of the RAD52-dependent fluorescence increase (0.5 % activities), including 628 hits in a 93,672-compound Broad's diversity-oriented synthesis (DOS) library (0.7% activities) and 1,115 hits in a 279,231-compound Molecular Libraries
5 Probe Center Network (MPLCN) library (0.4% Activities). The hits were further analyzed for a concentration dependence in inhibiting of RAD52 and by testing their DNA binding affinity using the acridine orange assay. As a result, 187 compounds were identified that inhibited RAD52 with the IC₅₀ lower than 10 µM and displayed no DNA binding. These remaining compounds were assessed for their potential chemical tractability by removing
10 compounds with highly reactive or unstable functional groups and focusing on chemotypes that were synthetically accessible and attractive. The selected compounds as well as some closely related new analogs of certain hits were next purchased as dry powders from commercial sources. After executing this selection process, 70 compounds were obtained for further analyses.

15 The inhibitory effect of the 70 selected compounds were tested using the D-loop assay, in which RAD52 promotes pairing between 32P-labeled ssDNA and homologous supercoiled plasmid pUC19 DNA (FIG. 1D); the product of the reaction, D-loops, were analyzed by electrophoresis in 1% agarose gels. First, by testing the effect of the selected compounds at fixed (30 µM) concentration, 17 compounds were identified to inhibit D-loop
20 formation by more than 90% (FIG. 1E). Then, the effects of each of the 17 compounds on RAD52-dependent D-loop formation were measured in a concentration dependent manner. The IC₅₀ of these compounds varied in a range between 2.7 µM and 17.5 µM (FIG. 2A-2C; Tables 1 and 4). In the D-loop assay the IC₅₀ values were generally higher than in the fluorescence-quenching assay likely due to the higher RAD52 concentration employed by the
25 former assay, 450 nM vs 25 nM.

Then, the selectivity of the RAD52 inhibitors were examined using RAD51 as a non-specific target. RAD51 is structurally unrelated to RAD52, but shares DNA pairing activity with RAD52. Using the D-loop assay, at concentrations 10-fold higher than the IC₅₀ for RAD52 DNA pairing, only three out of 17 tested compounds showed non-specific
30 inhibition of RAD51 greater than 2-fold relative to the DMSO control (FIG. 2D). Overall, as a result of the HTS and several confirmatory and selectivity assays, 14 specific inhibitors of ssDNA annealing and ssDNA pairing activity of RAD52 in vitro were identified.

Example 2: Analysis of RAD52 inhibitors in human BRCA1- and BRCA2-deficient

cells.

The effects of 14 RAD52 inhibitors identified in the biochemical assays were tested on the growth of BRCA2-deficient Capan-1 cells and BRCA2-proficient BxPC3 cells. Five of the tested inhibitors preferentially suppressed the growth of Capan-1 cells (FIGs. 3A-3D).

Likewise, the effects of RAD52 inhibitors on the growth of BRCA1-deficient (UWB1.289 BRCA1⁻) and BRCA1-proficient (UWB1.289 BRCA1⁺) cells were tested. 7 out of 14 tested RAD52 inhibitors preferentially suppress the growth of BRCA1-deficient cells. Importantly, these 7 compounds included the 5 compounds that inhibited the growth of BRCA2-deficient cells (FIGs. 3E-3H). The effects of the 14 RAD52 inhibitors were tested on the survival of another BRCA1-deficient cells, and MDA-MB-436 cells. Three out of 14 compounds, which also inhibited growth of UWB1.289 cells, showed an inhibitory effect on these cells compared with the isogenic MDA-MB-436 (BRCA1⁺) cells (FIG. 4A). Finally, the effects of D-I03, the strongest inhibitor on BRCA1- and BRCA2-deficient cells, was tested on BCR-ABL1-positive BRCA1-deficient chronic myeloid leukemia (CML) patient cells (Podsiwylow-Bartnicka *et al.*, 2014, Cell Cycle 13, 3727-3741). BRCA1-deficiency in these cells is due to constitutive downregulation of this protein. D-I03 selectively diminished the growth potential of BRCA1-deficient CML patient cells in comparison to BRCA1-proficient normal counterparts (FIG. 4B).

Overall, two compounds, D-G09 and D-I03, showed an inhibitory effect on all three tested BRCA1- and BRCA2-deficient cell lines. Importantly, these compounds showed significant structural similarity sharing the quinoline core (FIG. 4C). Another member of this structural group, D-G11, showed activity on two of the tested cell lines (UWB1.289 and Capan-1). Remarkably, three other compounds, D-G23, D-I05, and D-K17, that preferentially inhibited at least two BRCA1/2-deficient cell lines also share similarity, but belonging to another structural type with the quinazoline core. From all tested compounds, D-I03 showed the strongest and most consistent inhibitory effect on all tested BRCA1^{-/-} and BRCA2^{-/-} cell lines; moreover, it selectively inhibited growth of BRCA1-deficient CML cells from patients. Further, D-I03 and D-G23 have calculated properties within ranges generally considered “drug-like” by the research community and favorable for important parameters such as oral bioavailability (Table 3).

Example 3: Measurement of inhibitors binding to RAD52 by SPR

RAD52 inhibitors were tested to show activity in the biochemical and cell-

based assays physically interact with RAD52. D-I03 (3.12-50 μ M) and D-G23 (3.12 -25 μ M) have been demonstrated to bind directly to RAD52 (FIG. 5) using the surface plasmon resonance (SPR) method. The anti-HIV mAb 2F5 structurally unrelated to RAD52 was used in control and non-specific binding signal was subtracted from the RAD52 binding signal.

5 The K_d values for D-I03 and D-G23 are $26.1 \pm 4.5 \mu$ M and $34.0 \pm 8.9 \mu$ M, respectively. These values are somewhat higher than one might expect from the IC_{50} values in the biochemical and cell-based assays with these inhibitors. Without wishing to be limited by any theory, because the active form of RAD52 is a hexamer, the apparent differences in the activities of inhibitors may suggest that inhibition of RAD52 requires only partial
10 saturation of the RAD52 hexamer with inhibitors. D-I03 and D-G23 did not bind DNA using the acridine orange displacement assay. Thus, these compounds inhibit DNA annealing and pairing activities of RAD52 through direct binding, not through interaction with DNA substrates.

15 **Example 4: Inhibitors disrupt the RAD52, but not RAD51, foci formation in BRCA1-deficient cells**

 D-I03 and D-G23 were tested to determine whether they inhibit RAD52 activities in the cell. In response to DNA damage, RAD52 accumulates in the nucleus forming distinct structures known as foci (Essers *et al.*, 2002, EMBO J. 21, 2030-2037; Liu *et al.*, 2000, EMBO Rep 1, 85-90). The foci represent RAD52 complexes with DNA repair
20 intermediates. Inhibitors of RAD52 may decrease RAD52 foci formation by disrupting its interaction with DNA substrates. Indeed, both D-I03 and D-G23 inhibited RAD52 foci formation induced by cisplatin in BCR-ABL1-positive BRCA1-deficient 32Dcl3 murine hematopoietic cell line that expresses GFP-RAD52 (Cramer-Morales *et al.*, 2013, Blood 122, 1293-1304) (FIG. 6A). In the presence of D-I03 (2.5 μ M) and D-G23 (2.5 μ M), the fraction
25 of cells with RAD52 foci (≥ 5 foci) was decreased approximately 2.0 - 2.5-fold, from $38.7 \pm 10\%$ to $17 \pm 1\%$ and $19 \pm 0.4\%$, respectively; at the same time, the fraction of cisplatin-treated cells without foci was increased from $48.4 \pm 6.2\%$ to $71.9 \pm 4.1 \%$ and $57.6 \pm 0.5 \%$ (FIG. 6B). Thus, compounds of two chemotypes, represented by D-I03 and G-23, inhibited
30 the biochemical activities of RAD52 *in vitro*, showed preference in suppressing survival of BRCA1- and BRCA2-deficient cells and inhibited formation of damage-induced RAD52 foci formation.

 The non-specific effect of D-I03, the strongest of the RAD52 inhibitors, on RAD51 foci formation was also tested. Using parental 32Dcl3 (BRCA1-proficient) cells, D-

I03 was found not to have a significant effect on RAD51 foci induced by cisplatin (FIG. 6C). This result supports the specificity of this compound towards the target RAD52, because it inhibits RAD52-dependent foci formation induced by cisplatin (as described elsewhere herein).

5 In addition, D-I03 alone induced neither RAD51 foci nor RAD52 foci (in BRCA1-deficient cells; FIG. 6A) indicating low genotoxicity of this compound.

Example 5: D-I03 inhibition of single-strand DNA annealing and lack of inhibition of gene conversion in U2OS cells

10 In both yeast and mammalian cells, RAD52 promotes single-strand DNA annealing (SSA). SSA is a type of HR that is initiated at DSBs and mediated by annealing of fortuitous direct repeats flanking DSB ends after exonucleolytic resection. This mechanism leads to end rejoining with concomitant deletion of sequences between direct repeats.

 Using SA-GFP construct integrated chromosomal DNA, the effect of RAD52 inhibitor D-I03 on SSA in U2OS cells was examined. The SA-GFP reporter system contains a 5'-fragment of the GFP (5'-GFP) gene, and a 3'-fragment of the GFP (3'-GFP) that contains an 18-bp I-SceI site (FIG. 7A). The GFP fragments are separated by 2.7 kb region and share a 266 bp region of homology. Transfection of cells with I-SceI expressing vector pCBASce induces DSB in the 3'-GFP. Repair of the DSB by SSA leads to formation of GFP⁺ cells. Thus, each SSA event can be scored by the appearance of a green fluorescent cell.

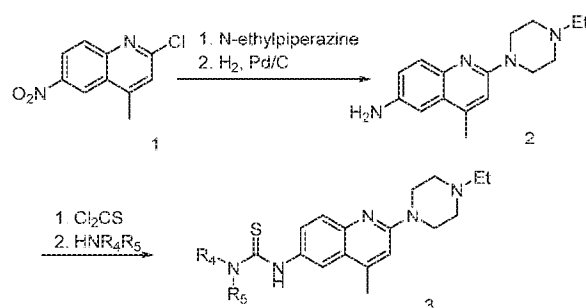
20 D-I03 reduces formation of GFP⁺ cells in a concentration dependent manner; at 30 μM D-I03 the yield of GFP⁺ cells was reduced about 3.4-fold (FIG. 7B, red line; FIGs. 8A-8B). In control, the effect of D-I03 on formation of GFP⁺ cells when U2OS cells were transfected was measured with pMX-GFP plasmid encoding GFP (FIG. 7B, green line). Up to 30 μM, D-I03 had no significant effect on the recovery of GFP⁺ cells.

 The effect of D-I03 on DSB repair was tested via the canonical homology dependent recombination (HDR; also known as gene conversion) mechanism using the chromosomally integrated DR-GFP construct in U2OS cells. RAD52 has no significant effect on the HDR in mammalian cells (Stark, *et al.*, 2004, Mol. Cell. Biol. 24:9305-9316). The DR-GFP construct consists of two inactive copies of the GFP gene, one that is disabled by insertion of I-SceI recognition site and another (iGFP) is truncated at both ends (FIG. 7A). A unique DSB is generated in this construct after the cells are transfected with pCBASce plasmid. The repair of this DSB gene by gene conversion using iGFP as a template gives rise to the functional GFP gene. D-I03 does not have a significant effect on formation of GFP-

positive cells (FIG. 7C, red line; FIG. 8C-8D). D-I03 also has no effect on GFP expression or on recovery of GFP-positive cells when U2OS cells were transfected with pMX-GFP plasmid encoding GFP (FIG. 7C, green line). Taken together, these results indicate that, consistent with inhibition of RAD52 in human cells, D-I03 reduces the level of DSB-induced SSA, but not HDR (which does not depend on RAD52).

Taken together, the results presented herein demonstrate that D-I03 inhibits RAD52 specifically in human cells.

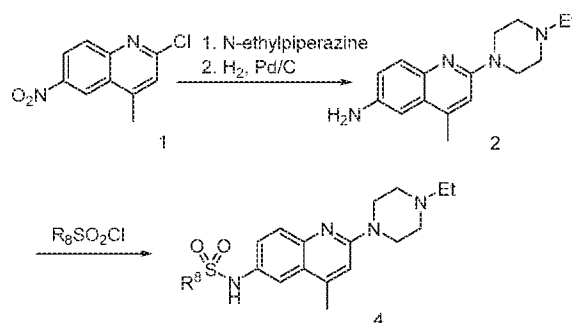
Example 6: Synthesis of exemplary compounds of Formula (II)



Scheme 1: Synthesis of exemplary compounds of Formula (II)

Briefly, as illustrated in Scheme 1, commercially available 2-chloro-4-methyl-6-nitroquinoline (1) is reacted in a S_NAr reaction with N-ethylpiperazine, and the resultant intermediate is reduced to afford amine intermediate (2). Amine (2) can be reacted with thiophosgene to afford the corresponding isothiocyanate, which can be reacted with various amines to generate thiourea (3).

Example 7: Synthesis of exemplary compounds of Formula (III)

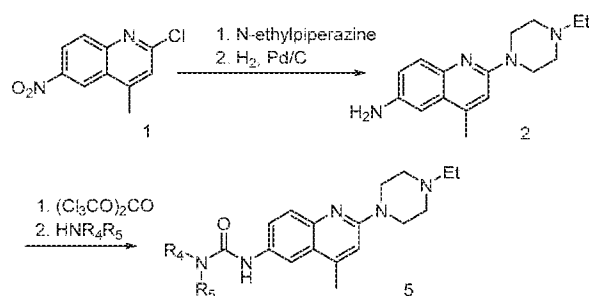


Scheme 2: Synthesis of exemplary compounds of Formula (III)

Briefly, as illustrated in Scheme 2, commercially available 2-chloro-4-methyl-6-nitroquinoline (1) is reacted in a S_NAr reaction with N-ethylpiperazine, and the resultant

intermediate is reduced to afford amine intermediate (2). Amine (2) can be reacted with sulfonyl chloride to afford the corresponding sulfonamide (4).

Example 8: Synthesis of exemplary compounds of Formula (IV)



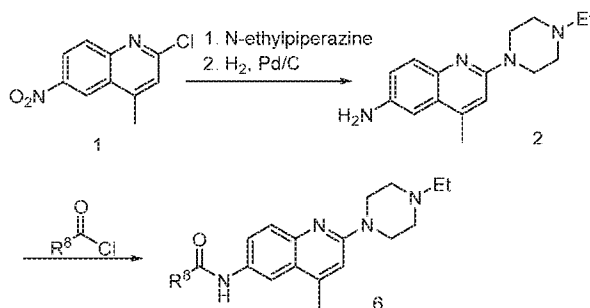
5

Scheme 3: Synthesis of exemplary compounds of Formula (IV).

Briefly, as illustrated in Scheme 3, commercially available 2-chloro-4-methyl-6-nitroquinoline (1) is reacted in a S_NAr reaction with N-ethylpiperazine, and the resultant intermediate is reduced to afford amine intermediate (2). Amine (2) can be reacted with triphosgene, followed by various amine to afford the corresponding urea (5).

10

Example 9: Synthesis of exemplary compounds of Formula (V)



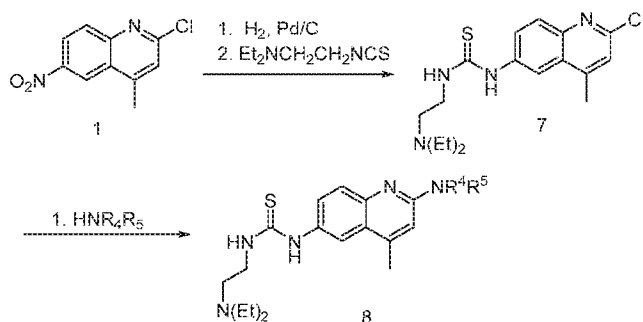
Scheme 4: Synthesis of exemplary compounds of Formula (V)

Briefly, as illustrated in Scheme 4, commercially available 2-chloro-4-methyl-6-nitroquinoline (1) is reacted in a S_NAr reaction with N-ethylpiperazine, and the resultant intermediate is reduced to afford amine intermediate (2). Amine (2) can be reacted with acid chloride to afford the corresponding amide (6).

15

Example 10: Synthesis of exemplary compounds of Formula (VI)

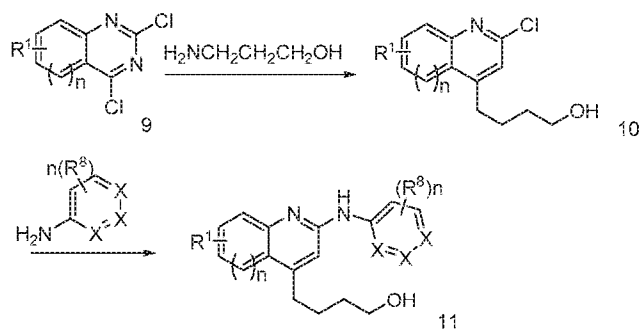
20



Scheme 5: Synthesis of exemplary compounds of Formula (VI)

Briefly, as illustrated in Scheme 5, commercially available 2-chloro-4-methyl-6-nitroquinoline (1) is reduced to afford the corresponding amine, using hydrogenation or any alternative reduction method. The amine intermediate can be reacted with commercially available N,N-diethyl-2-isothiocyanatoethan-1-amine to afford the key thiourea intermediate (7). Intermediate 7 is reacted with various amines to afford the compound (8).

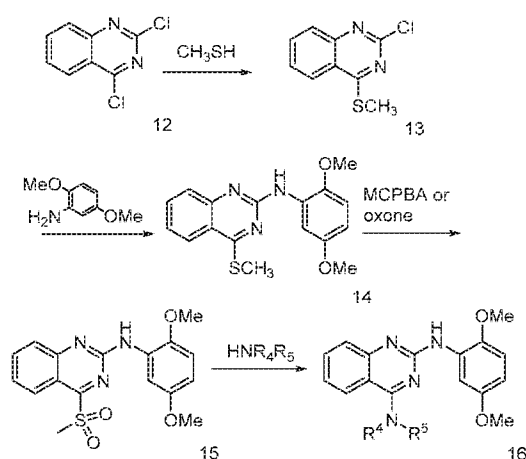
Example 11: Synthesis of exemplary compounds of Formula (VII)



Scheme 6: Synthesis of exemplary compounds of Formula (VII)

Briefly, as illustrated in Scheme 6, substituted dichloroquinazolines or isosteres (9) (e.g., substituted pyrimidines, thienopyrimidines, pyridopyrimidines, etc) are reacted with 3-aminopropan-1-ol to afford intermediate (10). Intermediate (10) undergoes catalytic coupling reaction to afford the compound (11).

Example 12: Synthesis of exemplary compounds of Formula (VIII)

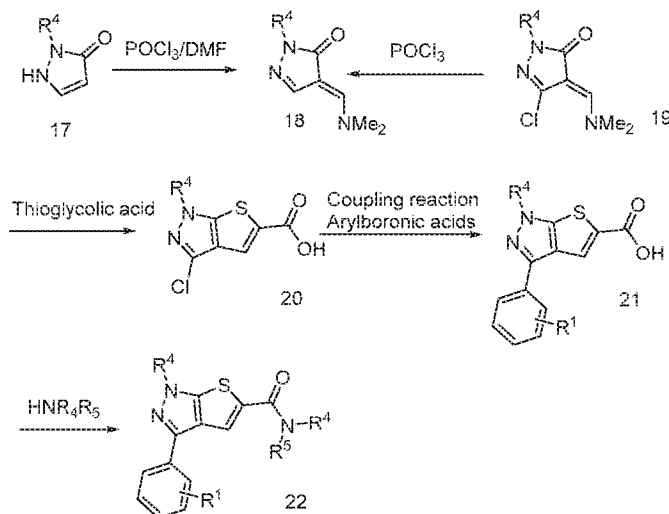


Scheme 7: Synthesis of exemplary compounds of Formula (VIII)

Briefly, as illustrated in Scheme 7, commercially available 2,4-dichloroquinazoline (12) is reacted with methanethiol to yield intermediate (13).

- 5 Intermediate 13 is reacted with 2,5-dimethoxyaniline to generate intermediate (14). Oxidation of the intermediate (14) affords sulfone (15). Sulfone (15) is reacted with various amines to generate the compound (16).

Example 13: Synthesis of exemplary compounds of Formula (VIII)



10

Scheme 8: Synthesis of exemplary compounds of Formula (IX)

- Briefly, as illustrated in Scheme 8, pyrazolinone (17) is reacted with POCl₃/DMF, followed by POCl₃ to afford intermediate (19) (Koshelev, *et al.*, 1972, *Organicheskoi Khimii*, 8:1750-1754). Intermediate (19) is reacted with thioglycolic acid to yield pyrazolothienophene (20). Catalytic coupling reaction of pyrazolothienophene (20) affords intermediate (21), which is converted to compound (22) through amide formation.
- 15

Table 1. Effect of inhibitors on the ssDNA annealing and DNA pairing activities of RAD52 and on the DNA pairing activity of RAD51

Inhibitors	ssDNA annealing (Fluorescence quenching), IC ₅₀ , μ M	Inhibition of DNA pairing (D-loop formation), IC ₅₀ , μ M	Inhibition of RAD51 pairing (D- loop formation), %*
D-A13	5.2	13.6 $\pm$ 0.64	102.5 $\pm$ 1.1
D-A19	4.8	7.2 $\pm$ 0.28	93.7 $\pm$ 2.1
D-A21	9.8	16.2 $\pm$ 0.42	97.5 $\pm$ 2.5
D-C17	6.0	17.6 $\pm$ 0.78	92.5 $\pm$ 5.0
D-C19	2.0	4.3 $\pm$ 0.35	73.6 $\pm$ 2.2
D-E05	1.7	11.3 $\pm$ 0.35	110.9 $\pm$ 4.3
D-G09	2.0	14.8 $\pm$ 2.47	108.2 $\pm$ 3.1
D-G11	6.0	8.9 $\pm$ 1.6	110.7 $\pm$ 0.2
D-G23	5.6	7.2 $\pm$ 0.96	75.6 $\pm$ 7.1
D-I01	3.6	15.4 $\pm$ 0.57	112.5 $\pm$ 4.2
D-I03	5.0	8.0 $\pm$ 1.7	95.5 $\pm$ 4.3
D-I05	4.3	8.8 $\pm$ 0.42	75.1 $\pm$ 4.8
D-I07	2.0	2.7 $\pm$ 0.35	38.4 $\pm$ 6.4
D-I09	6.8	10.6 $\pm$ 1.4	58.6 $\pm$ 2.9
D-I11	4.1	6.7 $\pm$ 0.78	48.6 $\pm$ 2.0
D-I19	3.5	4.1 $\pm$ 0.14	35.3 $\pm$ 5.8
D-K17	2.9	4.8 $\pm$ 0.85	89.7 $\pm$ 0.4

Note: * The effect of the inhibitors on RAD51 DNA pairing activity was measured at the concentrations that correspond their 10 x IC₅₀ for RAD52 pairing activity. 100% of the D-loop yield correspond to the extent of reaction in the presence of 4% DMSO; the actual extent of D-loops was 44.7 $\pm$ 0.2 % under these conditions.

Table 2. Sequences of the oligonucleotides

N	Length, nt	Sequence (5'→3')
337-FLU SEQ ID NO: 1	60	FLU-CACTGTGATGCACGATGATCGACGACAGTAGTCAGT GCTGGGTCAACATCTGTATGCAGG

1337-BHQ1 SEQ ID NO: 2	39	AGCACTGACTACTGTCGTCGATCATCGTGCATCACAGTG-BHQ1
265-55 SEQ ID NO: 3	55	ATACAGATGTTGACCCAGCACTGACTACTGTCGTCATCATCGT GCATCACAGTG
90 SEQ ID NO: 4	90	CGGGTGTCTGGGGCTGGCTTAATATGCGGCATCAGAGCAGATTG TACT GAG AGT GCA CCA TAT GCG GTG TGA AAT ACC GCA CAG ATG CGT

Note: "FLU" and "BHQ1" denote Fluorescein and Black Hole Quencher 1, respectively

Table 3. Calculated properties of D-I03 and D-G23 compounds*

	D-I03	D-G23
molecular weight	429	354
cLogP	3.65	3.29
TPSA	47	89
HBD	2	3
HBA	5	7
rotatable bonds	7	7

* calculated using ADRIANA code

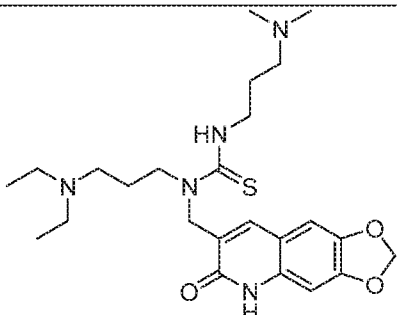
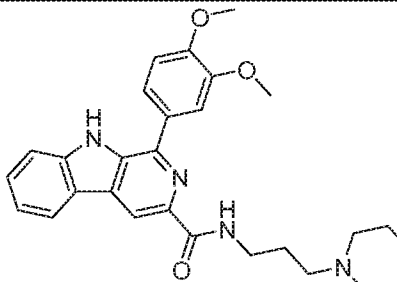
TPSA = topological polar surface area

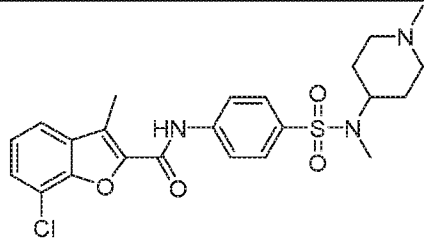
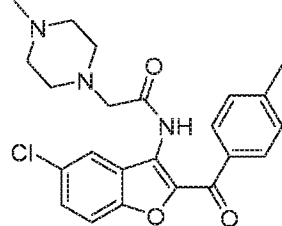
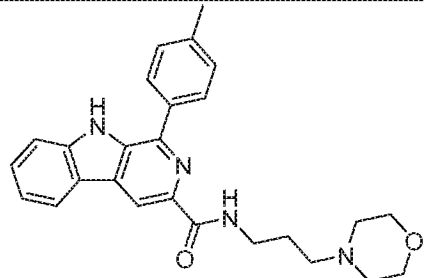
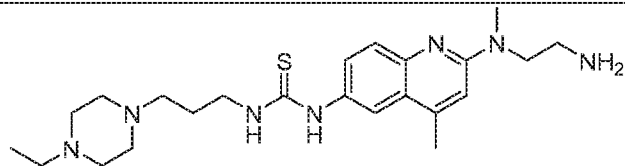
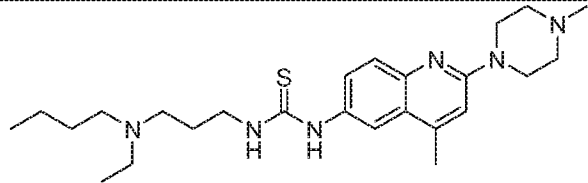
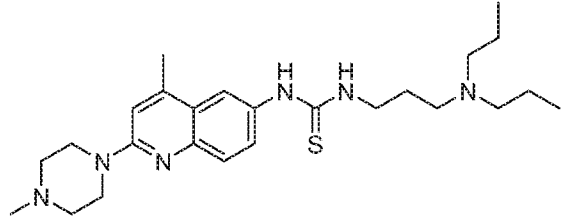
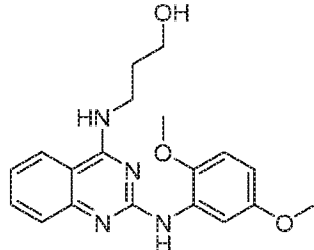
5 HBD = hydrogen bond donors

HBA = hydrogen bond acceptors

(www.dot-molecular-networks.com/files/docs/adrianacode/adrianacode_flyer_dot.pdf)

Table 4: Chemical Structures and IUPAC Names of the Compounds in Table 1.

Inhibitor	Structure	IUPAC name
D-A13		1-(3-(diethylamino)propyl)-3-(3-(dimethylamino)propyl)-1-((6-oxo-5,6-dihydro-[1,3]dioxolo[4,5-g]quinolin-7-yl)methyl)thiourea
D-A19		1-(3,4-dimethoxyphenyl)-N-(3-morpholinopropyl)-9H-pyrido[3,4-b]indole-3-carboxamide

D-A21		7-chloro-3-methyl-N-(4-(N-methyl-N-(1-methylpiperidin-4-yl)sulfamoyl)phenyl)benzofuran-2-carboxamide
D-C17		N-(5-chloro-2-(4-methylbenzoyl)benzofuran-3-yl)-2-(4-methylpiperazin-1-yl)acetamide
D-C19		N-(3-morpholinopropyl)-1-(p-tolyl)-9H-pyrido[3,4-b]indole-3-carboxamide
D-E05		1-(2-((2-aminoethyl)(methyl)amino)-4-methylquinolin-6-yl)-3-(3-(4-ethylpiperazin-1-yl)propyl)thiourea
D-G09		1-(3-(butyl(ethyl)amino)propyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea
D-G11		1-(3-(dipropylamino)propyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea
D-G23		3-((2-((2,5-dimethoxyphenyl)amino)quinazolin-4-yl)amino)propan-1-ol

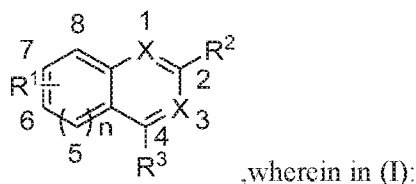
D-I01		1-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)-3-(3-(4-methylpiperazin-1-yl)propyl)thiourea
D-I03		1-(2-(diethylamino)ethyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea
D-I05		2-((2-((2,5-dimethoxyphenyl)amino)quinazolin-4-yl)amino)ethan-1-ol
D-I07		3-(4-chlorophenyl)-1-methyl-N-(3-(4-methylpiperazin-1-yl)propyl)-1H-thieno[2,3-c]pyrazole-5-carboxamide
D-I09		N-(2-(butyl(ethyl)amino)ethyl)-3-(4-chlorophenyl)-1-methyl-1H-thieno[2,3-c]pyrazole-5-carboxamide
D-I11		N-(3-(azepan-1-yl)propyl)-3-(4-chlorophenyl)-1-methyl-1H-thieno[2,3-c]pyrazole-5-carboxamide
D-I19		3-(4-chlorophenyl)-1-methyl-N-(3-(pyrrolidin-1-yl)propyl)-1H-thieno[2,3-c]pyrazole-5-carboxamide
D-K17		3-((2-((2-methoxyphenyl)amino)quinazolin-4-yl)amino)propan-1-ol

The disclosures of each and every patent, patent application, and publication cited herein are hereby incorporated herein by reference in their entirety. While this invention has been disclosed with reference to specific embodiments, it is apparent that other embodiments and variations of this invention may be devised by others skilled in the art
5 without departing from the true spirit and scope of the invention. The appended claims are intended to be construed to include all such embodiments and equivalent variations.

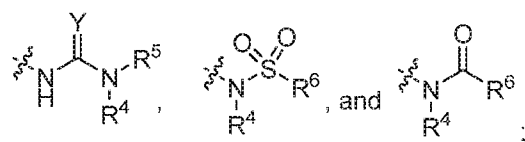
CLAIMS

What is claimed is:

1. A compound of formula (I):



R^1 is selected from the group consisting of:



R^2 is $-NR^4R^5$;

R^3 is selected from the group consisting of hydrogen, $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ haloalkyl, $-(C_1-C_6)$ heteroalkyl, $-F$, $-Cl$, $-Br$, $-I$, $-CN$, $-NO_2$, $-OR^7$, $-SR^7$, $-S(=O)R^7$, $-S(=O)_2R^7$, $-C(=O)R^7$, $-OC(=O)R^7$, and $-CO_2R^7$;

each occurrence of R^4 and R^5 is independently selected from the group consisting of hydrogen, $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ haloalkyl, $-(C_1-C_6)$ heteroalkyl, aryl, and heteroaryl, wherein the aryl or heteroaryl group is optionally substituted; or R^4 and R^5 , together with the nitrogen to which R^4 and R^5 are connected, form a $-(C_3-C_{10})$ heterocyclyl;

each occurrence of R^6 is independently selected from the group consisting of $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ heteroalkyl, $-OR^7$, $-(C_3-C_{10})$ heterocyclyl, aryl, and heteroaryl, wherein the $-(C_3-C_{10})$ heterocyclyl, aryl or heteroaryl group is optionally substituted;

each occurrence of R^7 is independently selected from the group consisting of H, $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ heteroalkyl, $-(C_3-C_6)$ cycloalkyl, $-(C_4-C_{10})$ heterocyclyl, aryl, and $-(C_5-C_{10})$ heteroaryl, wherein the alkyl, heteroalkyl, cycloalkyl, heterocyclyl, aryl, or heteroaryl group is optionally substituted;

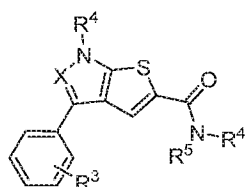
each occurrence of X is independently CH or N;

Y is O or S;

n is 0 or 1; when n is 1, R^1 is connected to the aryl ring at 5, 6, 7, or 8 position; alternatively, when n is 0, R^1 is connected to the aryl ring at that 6, 7, or 8 position; a salt, solvate, tautomer, enantiomer, diastereoisomer, or *N*-oxide thereof, and any combinations thereof;

provided that the compound is not selected from the group consisting of 1-(3-(diethylamino)propyl)-3-(3-(dimethylamino)propyl)-1-((6-oxo-5,6-dihydro-[1,3]dioxolo[4,5-g]quinolin-7-yl)methyl)thiourea; 1-(2-((2-aminoethyl)(methyl)amino)-4-methylquinolin-6-yl)-3-(3-(4-ethylpiperazin-1-yl)propyl)thiourea; 1-(3-(butyl(ethyl)amino)propyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea; 1-(3-(dipropylamino)propyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea; 3-((2-((2,5-dimethoxyphenyl)amino)quinazolin-4-yl)amino)propan-1-ol; 1-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)-3-(3-(4-methylpiperazin-1-yl)propyl)thiourea; 1-(2-(diethylamino)ethyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea; 2-((2-((2,5-dimethoxyphenyl)amino)quinazolin-4-yl)amino)ethan-1-ol; and 3-((2-((2-methoxyphenyl)amino)quinazolin-4-yl)amino)propan-1-ol.

2. A compound of formula (IX):



(IX), wherein in formula (IX):

R^3 is selected from the group consisting of hydrogen, $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ haloalkyl, $-(C_1-C_6)$ heteroalkyl, $-F$, $-Cl$, $-Br$, $-I$, $-CN$, $-NO_2$, $-OR^7$, $-SR^7$, $-S(=O)R^7$, $-S(=O)_2R^7$, $-C(=O)R^7$, $-OC(=O)R^7$, and $-CO_2R^7$;

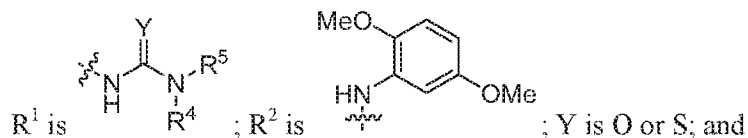
each occurrence of R^4 and R^5 is independently selected from the group consisting of hydrogen, $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ haloalkyl, $-(C_1-C_6)$ heteroalkyl, aryl, and heteroaryl, wherein the aryl or heteroaryl group is optionally substituted; or R^4 and R^5 , together with the nitrogen to which R^4 and R^5 are connected, form a $-(C_3-C_{10})$ heterocyclyl;

X is N or CH;

a salt, solvate, tautomer, enantiomer, diastereoisomer, or *N*-oxide thereof, and any combinations thereof,

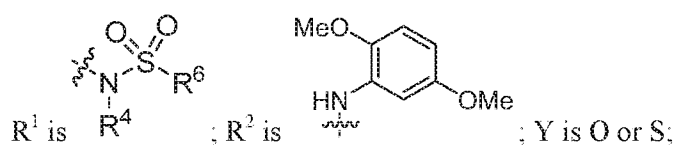
provided that the compound is not selected from the group consisting of 3-(4-chlorophenyl)-1-methyl-N-(3-(pyrrolidin-1-yl)propyl)-1H-thieno[2,3-c]pyrazole-5-carboxamide; N-(3-(azepan-1-yl)propyl)-3-(4-chlorophenyl)-1-methyl-1H-thieno[2,3-c]pyrazole-5-carboxamide; N-(2-(butyl(ethyl)amino)ethyl)-3-(4-chlorophenyl)-1-methyl-1H-thieno[2,3-c]pyrazole-5-carboxamide; and 3-(4-chlorophenyl)-1-methyl-N-(3-(4-methylpiperazin-1-yl)propyl)-1H-thieno[2,3-c]pyrazole-5-carboxamide.

6. The compound of claim 1, wherein:



each occurrence of R^4 and R^5 is independently selected from the group consisting of hydrogen, $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ haloalkyl, $-(C_1-C_6)$ heteroalkyl, aryl, and heteroaryl, wherein the aryl or heteroaryl group is optionally substituted; or R^4 and R^5 , together with the nitrogen to which R^4 and R^5 are connected, form a $-(C_3-C_{10})$ heterocyclyl.

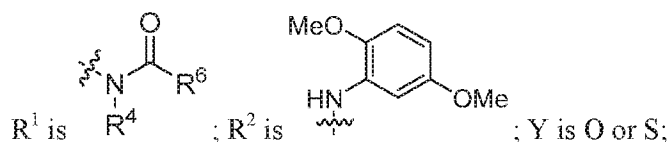
7. The compound of claim 1, wherein:



each occurrence of R^4 and R^5 is independently selected from the group consisting of hydrogen, $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ haloalkyl, $-(C_1-C_6)$ heteroalkyl, aryl, and heteroaryl, wherein the aryl or heteroaryl group is optionally substituted; or R^4 and R^5 , together with the nitrogen to which R^4 and R^5 are connected, form a $-(C_3-C_{10})$ heterocyclyl;

R^6 is selected from the group consisting of $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ heteroalkyl, $-OR^7$, $-(C_3-C_{10})$ heterocyclyl, aryl, and heteroaryl, wherein the $-(C_3-C_{10})$ heterocyclyl, aryl or heteroaryl group is optionally substituted.

8. The compound of claim 1, wherein:



each occurrence of R^4 and R^5 is independently selected from the group consisting of hydrogen, $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ haloalkyl, $-(C_1-C_6)$ heteroalkyl, aryl, and heteroaryl, wherein the aryl or heteroaryl group is optionally substituted; or R^4 and R^5 , together with the nitrogen to which R^4 and R^5 are connected, form a $-(C_3-C_{10})$ heterocyclyl;

R^6 is selected from the group consisting of $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ heteroalkyl, $-OR^7$, $-(C_3-C_{10})$ heterocyclyl, aryl, and heteroaryl, wherein the $-(C_3-C_{10})$ heterocyclyl, aryl or heteroaryl group is optionally substituted.

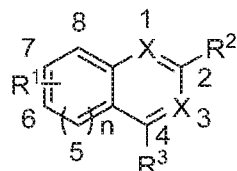
9. A pharmaceutical composition comprising at least one compound of any of claims 1-8 and at least one pharmaceutically acceptable carrier.

10. A pharmaceutical composition comprising at least one pharmaceutically acceptable carrier and at least one compound selected from the group consisting of: 1-(3-(diethylamino)propyl)-3-(3-(dimethylamino)propyl)-1-((6-oxo-5,6-dihydro-[1,3]dioxolo[4,5-g]quinolin-7-yl)methyl)thiourea; 1-(3,4-dimethoxyphenyl)-N-(3-morpholinopropyl)-9H-pyrido[3,4-b]indole-3-carboxamide; 7-chloro-3-methyl-N-(4-(N-methyl-N-(1-methylpiperidin-4-yl)sulfamoyl)phenyl) benzofuran-2-carboxamide; N-(5-chloro-2-(4-methylbenzoyl) benzofuran-3-yl)-2-(4-methylpiperazin-1-yl)acetamide; N-(3-morpholinopropyl)-1-(p-tolyl)-9H-pyrido[3,4-b]indole-3-carboxamide; 1-(2-((2-aminoethyl)(methyl)amino)-4-methylquinolin-6-yl)-3-(3-(4-ethylpiperazin-1-yl)propyl)thiourea; 1-(3-(butyl(ethyl)amino)propyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea; 1-(3-(dipropylamino)propyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea; 3-((2-((2,5-dimethoxyphenyl)amino) quinazolin-4-yl)amino)propan-1-ol; 1-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)-3-(3-(4-methylpiperazin-1-yl)propyl)thiourea; 1-(2-(diethylamino)ethyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea; 2-((2-((2,5-dimethoxyphenyl)amino) quinazolin-4-yl)amino)ethan-1-ol; 3-(4-chlorophenyl)-1-methyl-N-(3-(4-methylpiperazin-1-yl)propyl)-1H-thieno [2,3-c]pyrazole-5-carboxamide; N-(2-(butyl(ethyl)amino)ethyl)-3-(4-chlorophenyl)-1-methyl-1H-thieno[2,3-c]pyrazole-5-carboxamide; N-(3-(azepan-1-yl)propyl)-3-(4-chlorophenyl)-1-methyl-1H-thieno[2,3-c]pyrazole-5-carboxamide; 3-(4-chlorophenyl)-1-methyl-N-(3-(pyrrolidin-1-yl)propyl)-1H-thieno[2,3-c]pyrazole-5-carboxamide; 3-((2-((2-methoxyphenyl)amino)quinazolin-4-yl)amino)propan-1-ol; a salt, solvate, tautomer, enantiomer, diastereoisomer, or *N*-oxide thereof, and any combinations thereof.

11. The composition of claim 9 or 10, further comprising at least one additional therapeutic agent that treats or prevents cancer.

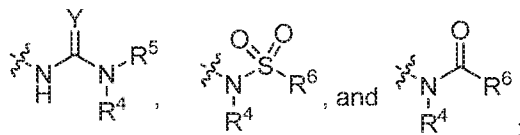
12. A method of preventing or treating a cancer in a subject in need thereof, the method comprising administering to the subject a therapeutically effective amount of at least one selected from the group consisting of:

a compound of formula (I):



(I), wherein in (I):

R^1 is selected from the group consisting of:



R^2 is $-NR^4R^5$;

R^3 is selected from the group consisting of hydrogen, $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ haloalkyl, $-(C_1-C_6)$ heteroalkyl, $-F$, $-Cl$, $-Br$, $-I$, $-CN$, $-NO_2$, $-OR^7$, $-SR^7$, $-S(=O)R^7$, $-S(=O)_2R^7$, $-C(=O)R^7$, $-OC(=O)R^7$, and $-CO_2R^7$;

each occurrence of R^4 and R^5 is independently selected from the group consisting of hydrogen, $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ haloalkyl, $-(C_1-C_6)$ heteroalkyl, aryl, and heteroaryl, wherein the aryl or heteroaryl group is optionally substituted; or R^4 and R^5 , together with the nitrogen to which R^4 and R^5 are connected, form a $-(C_3-C_{10})$ heterocyclyl;

each occurrence of R^6 is independently selected from the group consisting of $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ heteroalkyl, $-OR^7$, $-(C_3-C_{10})$ heterocyclyl, aryl, and heteroaryl, wherein the $-(C_3-C_{10})$ heterocyclyl, aryl or heteroaryl group is optionally substituted;

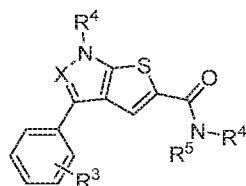
each occurrence of R^7 is independently selected from the group consisting of H, $-(C_1-C_6)$ alkyl, $-(C_1-C_6)$ heteroalkyl, $-(C_3-C_6)$ cycloalkyl, $-(C_4-C_{10})$ heterocyclyl, aryl, and $-(C_3-C_{10})$ heteroaryl, wherein the alkyl, heteroalkyl, cycloalkyl, heterocyclyl, aryl, or heteroaryl group is optionally substituted;

each occurrence of X is independently CH or N;

Y is O or S;

n is 0 or 1; when n is 1, R^1 is connected to the aryl ring at 5, 6, 7, or 8 position; alternatively, when n is 0, R^1 is connected to the aryl ring at that 6, 7, or 8 position;

a compound of formula (IX):



(IX), wherein in formula (IX):

X is CH or N;

R³ is selected from the group consisting of hydrogen, -(C₁-C₆)alkyl, -(C₁-C₆)haloalkyl, -(C₁-C₆)heteroalkyl, -F, -Cl, -Br, -I, -CN, -NO₂, -OR⁷, -SR⁷, -S(=O)R⁷, -S(=O)₂R⁷, -C(=O)R⁷, -OC(=O)R⁷, and -CO₂R⁷;

each occurrence of R⁴ and R⁵ is independently selected from the group consisting of hydrogen, -(C₁-C₆)alkyl, -(C₁-C₆)haloalkyl, -(C₁-C₆)heteroalkyl, aryl, and heteroaryl, wherein the aryl or heteroaryl group is optionally substituted; or R⁴ and R⁵, together with the nitrogen to which R⁴ and R⁵ are connected, form a -(C₃-C₁₀)heterocyclyl;

a salt, solvate, tautomer, enantiomer, diastereoisomer, or *N*-oxide thereof, and any combinations thereof.

13. The method of claim 12, wherein the method further comprises administering to the subject at least one additional therapeutic agent that treats or prevents cancer.

14. The method of claim 13, wherein the pharmaceutical composition and the at least one additional therapeutic agent are co-administered to the subject.

15. The method of claim 13, wherein the pharmaceutical composition and the at least one additional therapeutic agent are coformulated.

16. The method of claim 12, wherein the compound is selected from the group consisting of: 1-(3-(diethylamino)propyl)-3-(3-(dimethylamino)propyl)-1-((6-oxo-5,6-dihydro-[1,3]dioxolo[4,5-g]quinolin-7-yl)methyl)thiourea; 1-(3,4-dimethoxyphenyl)-N-(3-morpholinopropyl)-9H-pyrido[3,4-b]indole-3-carboxamide; 7-chloro-3-methyl-N-(4-(N-methyl-N-(1-methylpiperidin-4-yl)sulfamoyl)phenyl) benzofuran-2-carboxamide; N-(5-chloro-2-(4-methylbenzoyl) benzofuran-3-yl)-2-(4-methylpiperazin-1-yl)acetamide; N-(3-morpholinopropyl)-1-(p-tolyl)-9H-pyrido[3,4-b]indole-3-carboxamide; 1-(2-((2-aminoethyl)(methyl)amino)-4-methylquinolin-6-yl)-3-(3-(4-ethylpiperazin-1-yl)propyl)thiourea; 1-(3-(butyl(ethyl)amino)propyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea; 1-(3-(dipropylamino)propyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea; 3-((2-((2,5-dimethoxyphenyl)amino) quinazolin-4-yl)amino)propan-1-ol; 1-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)-3-(3-(4-methylpiperazin-1-yl)propyl)thiourea; 1-(2-(diethylamino)ethyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea; 2-((2-((2,5-dimethoxyphenyl)amino)

quinazolin-4-yl)amino)ethan-1-ol; 3-(4-chlorophenyl)-1-methyl-N-(3-(4-methylpiperazin-1-yl)propyl)-1H-thieno [2,3-c]pyrazole-5-carboxamide; N-(2-(butyl(ethyl)amino)ethyl)-3-(4-chlorophenyl)-1-methyl-1H-thieno[2,3-c]pyrazole-5-carboxamide; N-(3-(azepan-1-yl)propyl)-3-(4-chlorophenyl)-1-methyl-1H-thieno[2,3-c]pyrazole-5-carboxamide; 3-(4-chlorophenyl)-1-methyl-N-(3-(pyrrolidin-1-yl)propyl)-1H-thieno[2,3-c]pyrazole-5-carboxamide; 3-((2-((2-methoxyphenyl)amino)quinazolin-4-yl)amino)propan-1-ol; a salt, solvate, tautomer, enantiomer, diastereoisomer, or *N*-oxide thereof, and any combinations thereof.

17. The method of claim 12, wherein the subject is human.

18. The method of claim 12, wherein the cancer is selected from the group consisting of squamous cell cancer, lung cancer including small-cell lung cancer, non-small cell lung cancer, vulval cancer, thyroid cancer, adenocarcinoma of the lung and squamous carcinoma of the lung, cancer of the peritoneum, hepatocellular cancer, gastric or stomach cancer including gastrointestinal cancer, pancreatic cancer, glioblastoma, cervical cancer, ovarian cancer, liver cancer, bladder cancer, hepatoma, breast cancer, colon cancer, rectal cancer, colorectal cancer, endometrial or uterine carcinoma, salivary gland carcinoma, kidney or renal cancer, prostate cancer, hepatic carcinoma, anal carcinoma, penile carcinoma, and head and neck cancer.

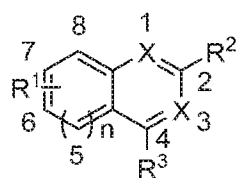
19. The method of claim 12, wherein the cancer is ovarian cancer or breast cancer.

20. The method of claim 12, wherein the human has mutations in BRCA1 and/or BRCA2.

21. The method of claim 12, wherein treating or preventing the cancer comprises inhibiting RAD52.

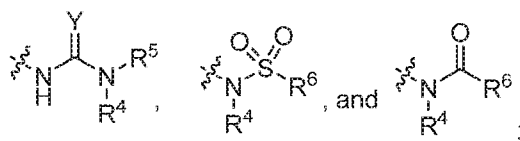
22. A method of preventing or treating a RAD52 related disease or disorder in a subject in need thereof, the method comprising administering to the subject a therapeutically effective amount of at least one selected from the group consisting of:

a compound of formula (I):



(I), wherein in (I):

R^1 is selected from the group consisting of:



R^2 is $-NR^4R^5$;

R^3 is selected from the group consisting of hydrogen, $-(C_1-C_6)alkyl$, $-(C_1-C_6)haloalkyl$, $-(C_1-C_6)heteroalkyl$, $-F$, $-Cl$, $-Br$, $-I$, $-CN$, $-NO_2$, $-OR^7$, $-SR^7$, $-S(=O)R^7$, $-S(=O)_2R^7$, $-C(=O)R^7$, $-OC(=O)R^7$, and $-CO_2R^7$;

each occurrence of R^4 and R^5 is independently selected from the group consisting of hydrogen, $-(C_1-C_6)alkyl$, $-(C_1-C_6)haloalkyl$, $-(C_1-C_6)heteroalkyl$, aryl, and heteroaryl, wherein the aryl or heteroaryl group is optionally substituted; or R^4 and R^5 , together with the nitrogen to which R^4 and R^5 are connected, form a $-(C_3-C_{10})heterocyclyl$;

each occurrence of R^6 is independently selected from the group consisting of $-(C_1-C_6)alkyl$, $-(C_1-C_6)heteroalkyl$, $-OR^7$, $-(C_3-C_{10})heterocyclyl$, aryl, and heteroaryl, wherein the $-(C_3-C_{10})heterocyclyl$, aryl or heteroaryl group is optionally substituted;

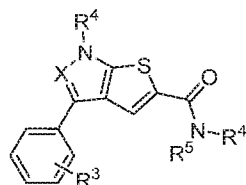
each occurrence of R^7 is independently selected from the group consisting of H, $-(C_1-C_6)alkyl$, $-(C_1-C_6)heteroalkyl$, $-(C_3-C_6)cycloalkyl$, $-(C_4-C_{10})heterocyclyl$, aryl, and $-(C_5-C_{10})heteroaryl$, wherein the alkyl, heteroalkyl, cycloalkyl, heterocyclyl, aryl, or heteroaryl group is optionally substituted;

each occurrence of X is independently CH or N;

Y is O or S;

n is 0 or 1; when n is 1, R^1 is connected to the aryl ring at 5, 6, 7, or 8 position; alternatively, when n is 0, R^1 is connected to the aryl ring at that 6, 7, or 8 position;

a compound of formula (IX):



(IX), wherein in formula (IX):

X is CH or N;

R^3 is selected from the group consisting of hydrogen, $-(C_1-C_6)alkyl$, $-(C_1-C_6)haloalkyl$, $-(C_1-C_6)heteroalkyl$, $-F$, $-Cl$, $-Br$, $-I$, $-CN$, $-NO_2$, $-OR^7$, $-SR^7$, $-S(=O)R^7$, $-S(=O)_2R^7$, $-C(=O)R^7$, $-OC(=O)R^7$, and $-CO_2R^7$;

each occurrence of R^4 and R^5 is independently selected from the group consisting of hydrogen, $-(C_1-C_6)alkyl$, $-(C_1-C_6)haloalkyl$, $-(C_1-C_6)heteroalkyl$, aryl, and heteroaryl, wherein the aryl or heteroaryl group is optionally substituted; or R^4 and R^5 , together with the nitrogen to which R^4 and R^5 are connected, form a $-(C_3-C_{10})heterocycl$ yl;

a salt, solvate, tautomer, enantiomer, diastereoisomer, or *N*-oxide thereof, and any combinations thereof.

23. The method of claim 22, wherein the RAD52 related disease or disorder comprises cancer.

24. The method of claim 23, the method further comprising administering to the subject at least one additional therapeutic agent that treats or prevents cancer.

25. The method of claim 24, wherein the pharmaceutical composition and the at least one additional therapeutic agent are co-administered to the subject.

26. The method of claim 24, wherein the pharmaceutical composition and the at least one additional therapeutic agent are coformulated.

27. The method of claim 22, wherein the compound is selected from the group consisting of: 1-(3-(diethylamino)propyl)-3-(3-(dimethylamino)propyl)-1-((6-oxo-5,6-dihydro-[1,3]dioxolo[4,5-g]quinolin-7-yl)methyl)thiourea; 1-(3,4-dimethoxyphenyl)-N-(3-morpholinopropyl)-9H-pyrido[3,4-b]indole-3-carboxamide; 7-chloro-3-methyl-N-(4-(N-methyl-N-(1-methylpiperidin-4-yl)sulfamoyl)phenyl) benzofuran-2-carboxamide; N-(5-chloro-2-(4-methylbenzoyl) benzofuran-3-yl)-2-(4-methylpiperazin-1-yl)acetamide; N-(3-morpholinopropyl)-1-(p-tolyl)-9H-pyrido[3,4-b]indole-3-carboxamide; 1-(2-((2-aminoethyl)(methyl)amino)-4-methylquinolin-6-yl)-3-(3-(4-ethylpiperazin-1-yl)propyl)thiourea; 1-(3-(butyl(ethyl)amino)propyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea; 1-(3-(dipropylamino)propyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea; 3-((2-((2,5-dimethoxyphenyl)amino) quinazolin-4-yl)amino)propan-1-ol; 1-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)-3-(3-(4-

methylpiperazin-1-yl)propyl)thiourea; 1-(2-(diethylamino)ethyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea; 2-((2-((2,5-dimethoxyphenyl)amino)quinazolin-4-yl)amino)ethan-1-ol; 3-(4-chlorophenyl)-1-methyl-N-(3-(4-methylpiperazin-1-yl)propyl)-1H-thieno [2,3-c]pyrazole-5-carboxamide; N-(2-(butyl(ethyl)amino)ethyl)-3-(4-chlorophenyl)-1-methyl-1H-thieno[2,3-c]pyrazole-5-carboxamide; N-(3-(azepan-1-yl)propyl)-3-(4-chlorophenyl)-1-methyl-1H-thieno[2,3-c]pyrazole-5-carboxamide; 3-(4-chlorophenyl)-1-methyl-N-(3-(pyrrolidin-1-yl)propyl)-1H-thieno[2,3-c]pyrazole-5-carboxamide; 3-((2-((2-methoxyphenyl)amino)quinazolin-4-yl)amino)propan-1-ol; a salt, solvate, tautomer, enantiomer, diastereoisomer, or *N*-oxide thereof, and any combinations thereof.

28. The method of claim 22, wherein the subject is human.

29. The method of claim 23, wherein the cancer is selected from the group consisting of squamous cell cancer, lung cancer including small-cell lung cancer, non-small cell lung cancer, vulval cancer, thyroid cancer, adenocarcinoma of the lung and squamous carcinoma of the lung, cancer of the peritoneum, hepatocellular cancer, gastric or stomach cancer including gastrointestinal cancer, pancreatic cancer, glioblastoma, cervical cancer, ovarian cancer, liver cancer, bladder cancer, hepatoma, breast cancer, colon cancer, rectal cancer, colorectal cancer, endometrial or uterine carcinoma, salivary gland carcinoma, kidney or renal cancer, prostate cancer, hepatic carcinoma, anal carcinoma, penile carcinoma, and head and neck cancer.

30. The method of claim 23, wherein the cancer is ovarian cancer or breast cancer.

31. The method of claim 23, wherein the human has mutations in BRCA1 and/or BRCA2.

FIG. 1A

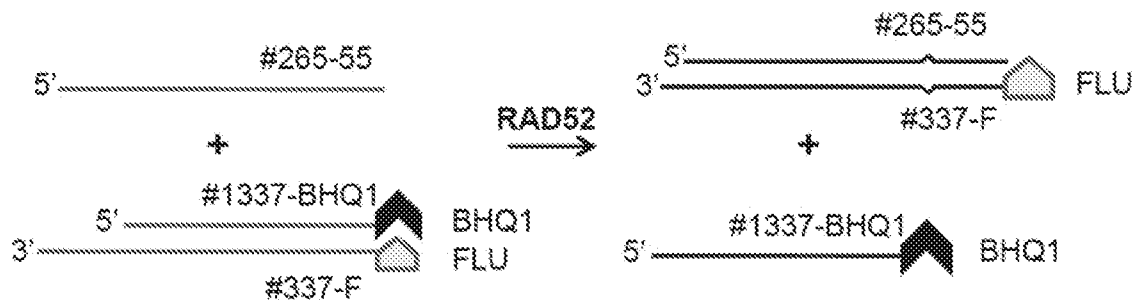


FIG. 1B

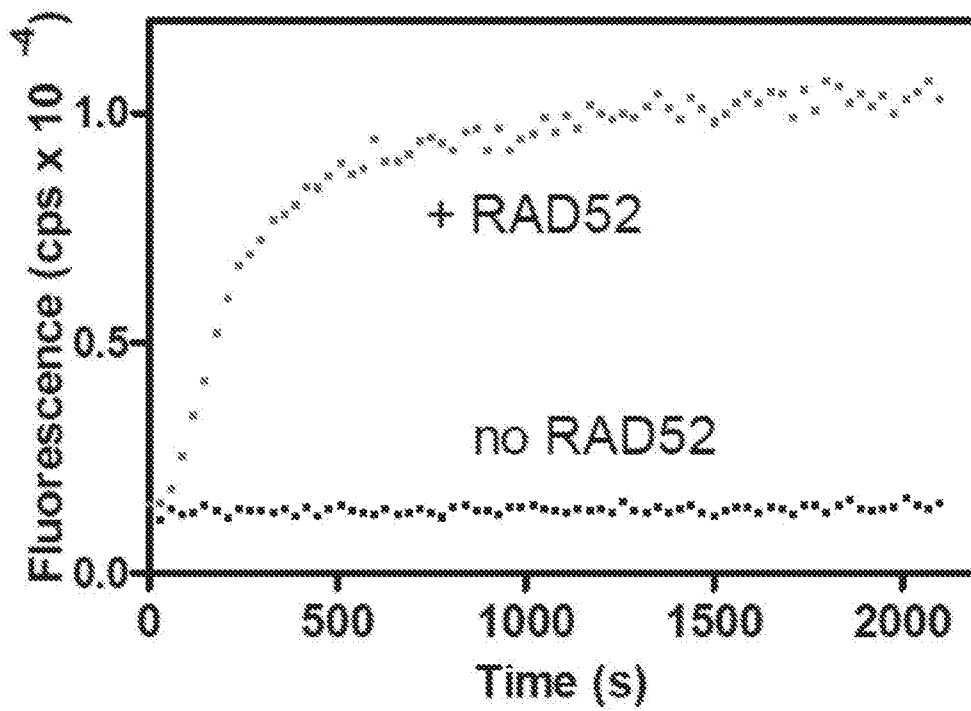


FIG. 1C

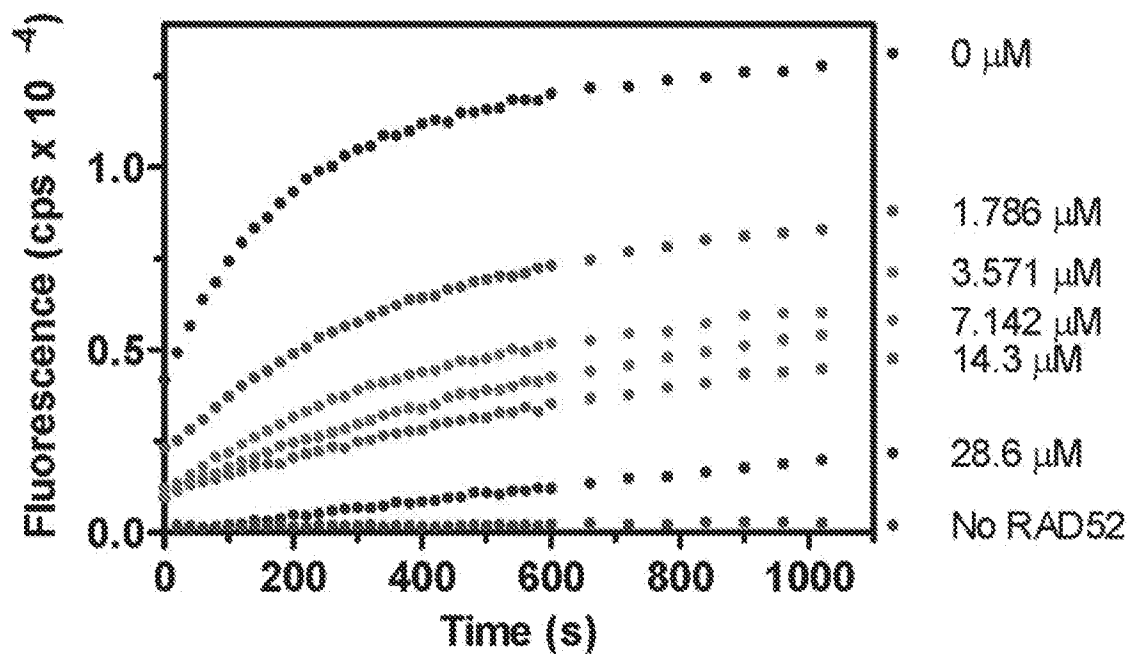


FIG. 1D

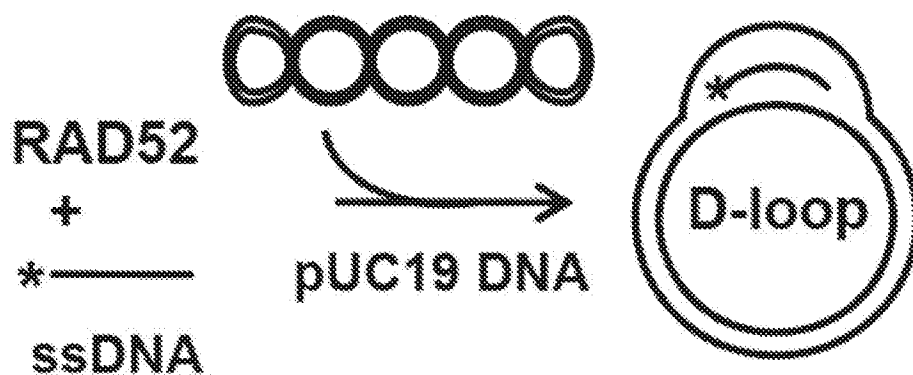


FIG. 1E

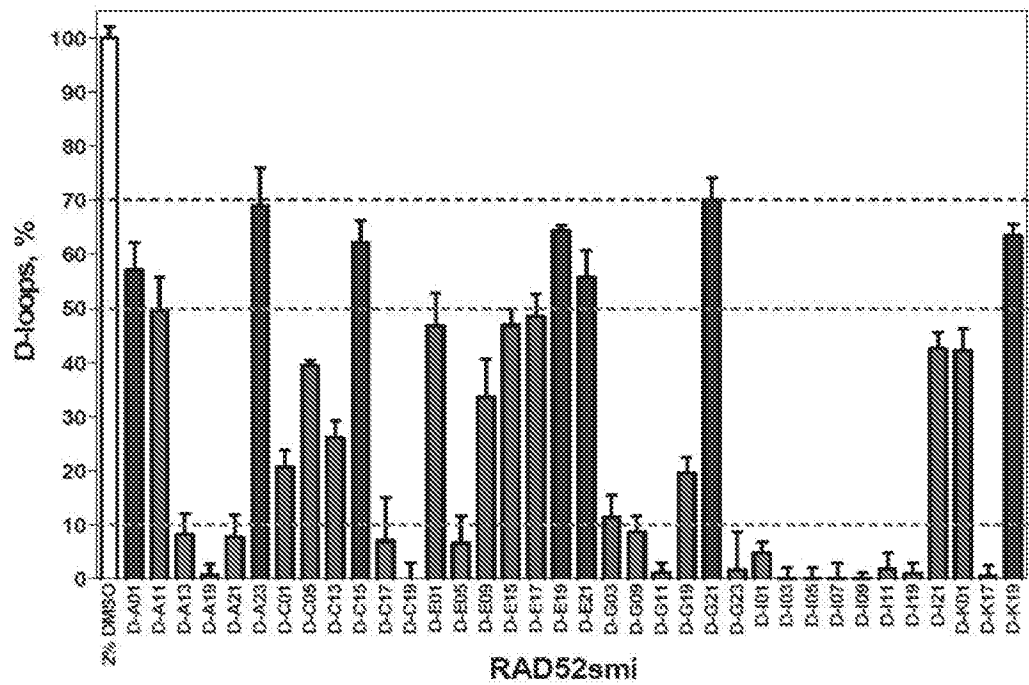


FIG. 2A

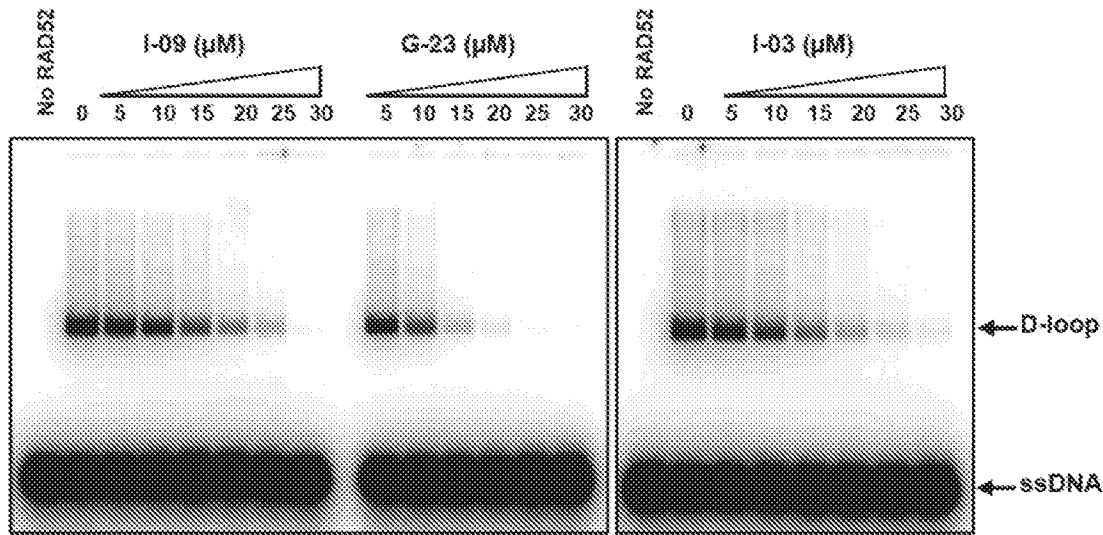


FIG. 2B

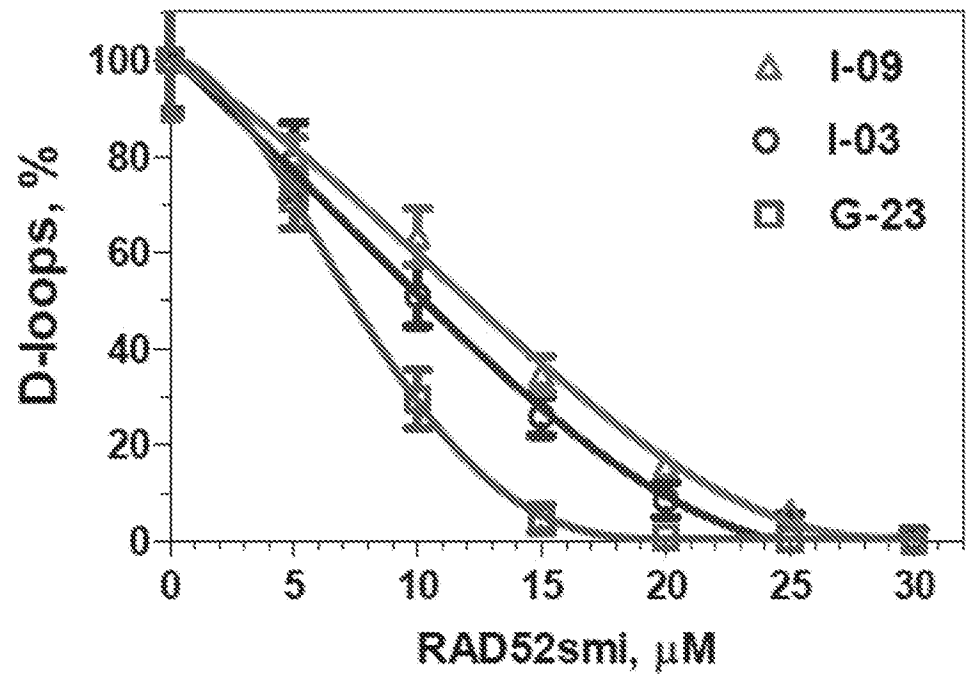


FIG. 2C

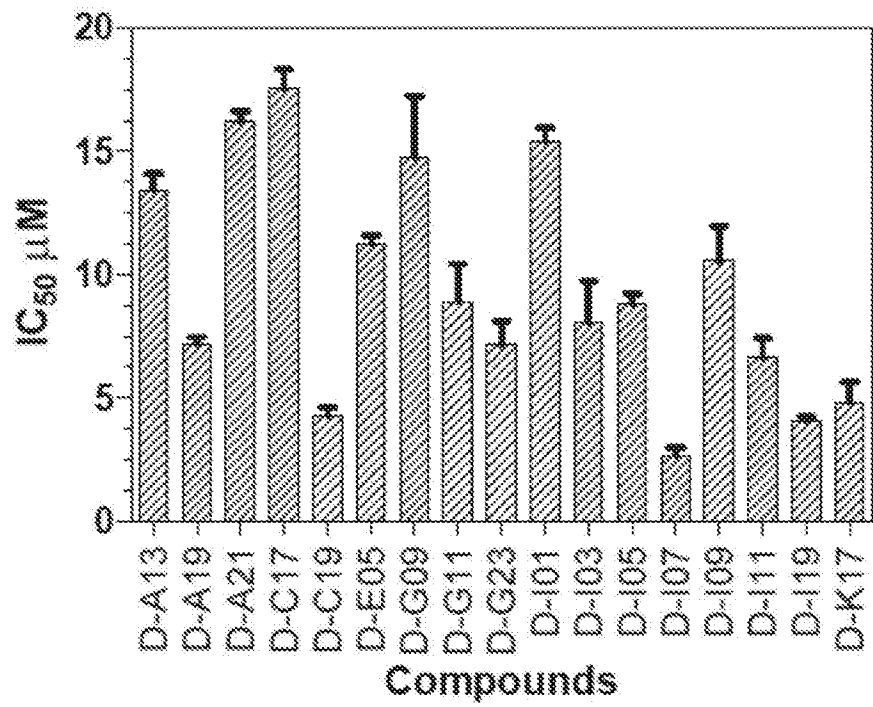


FIG. 2D

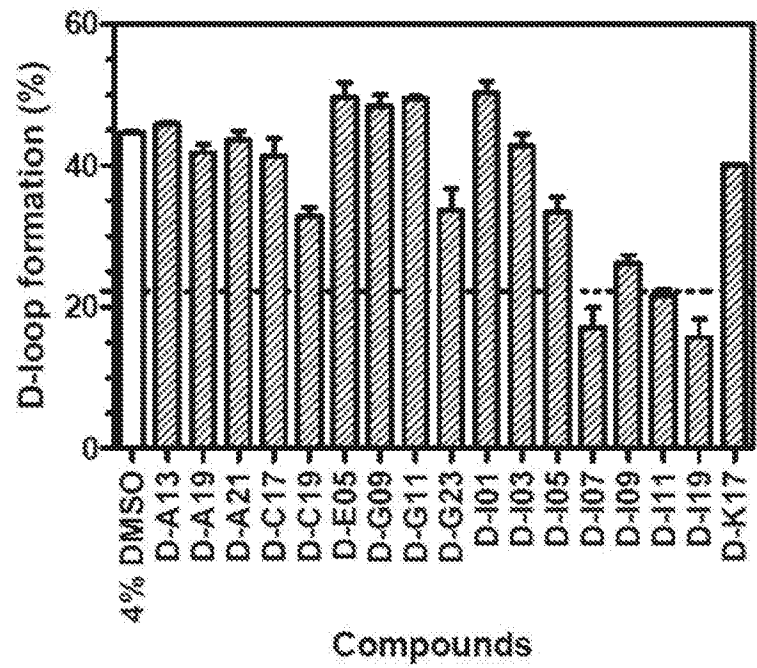


FIG. 3A

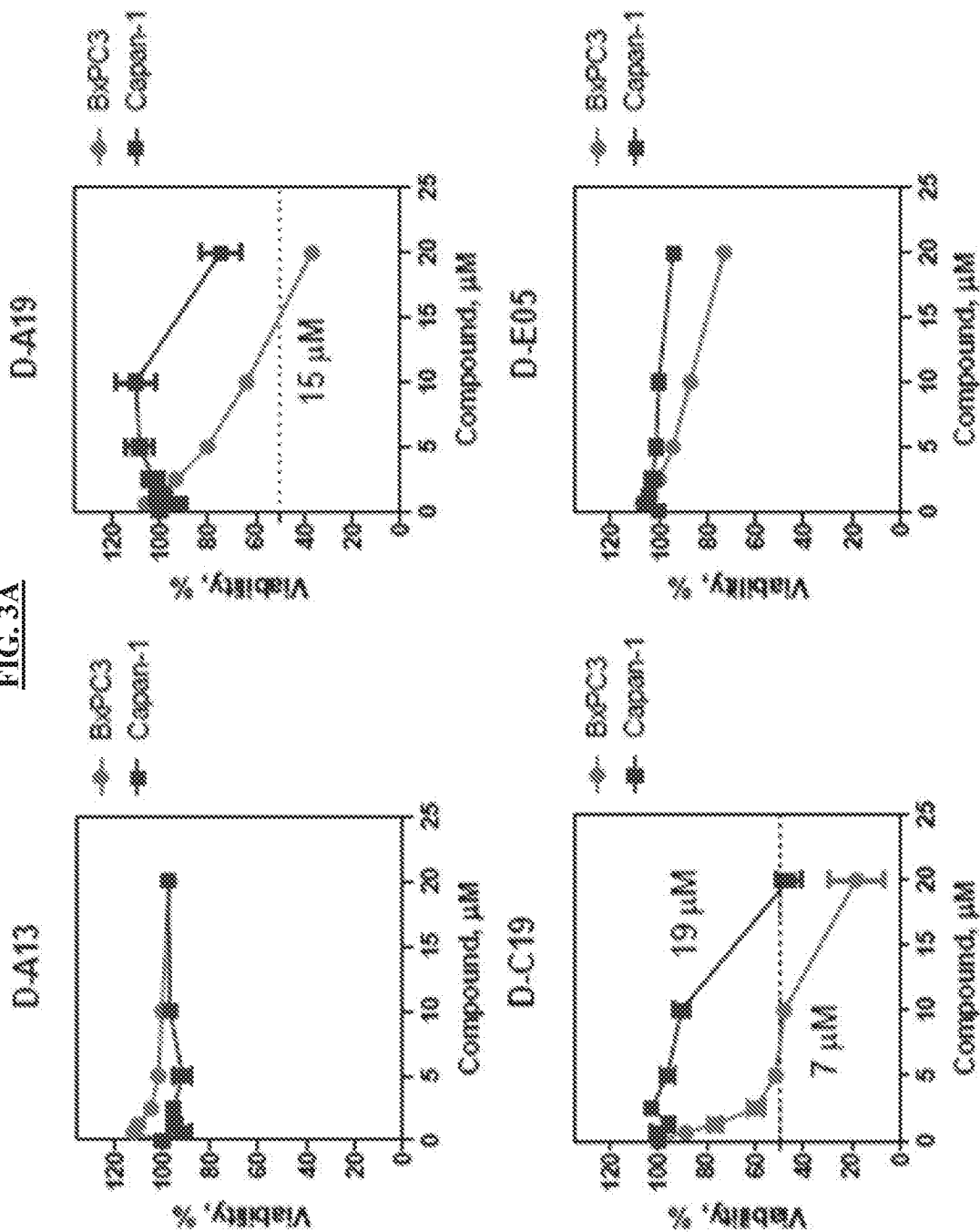


FIG. 3B

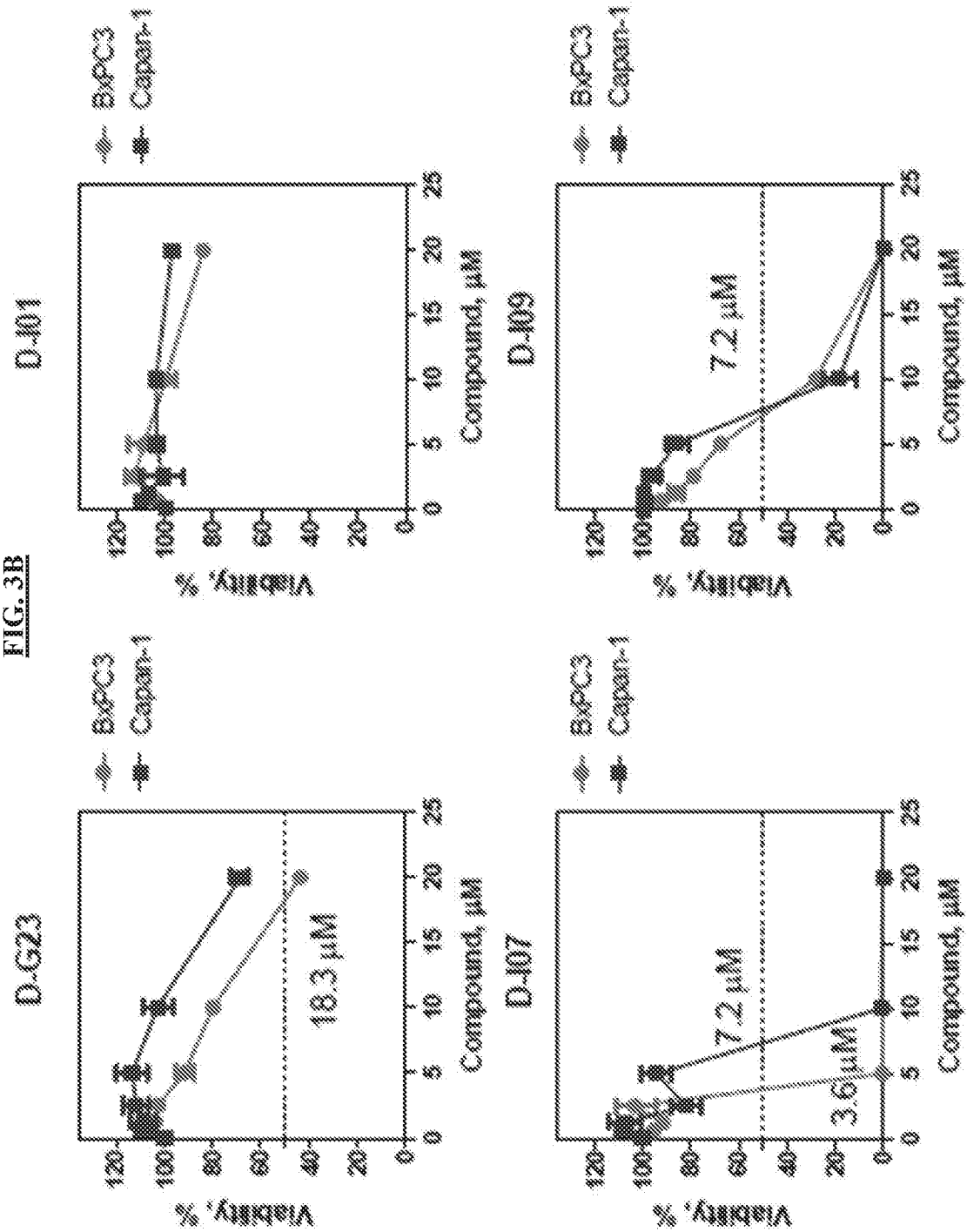
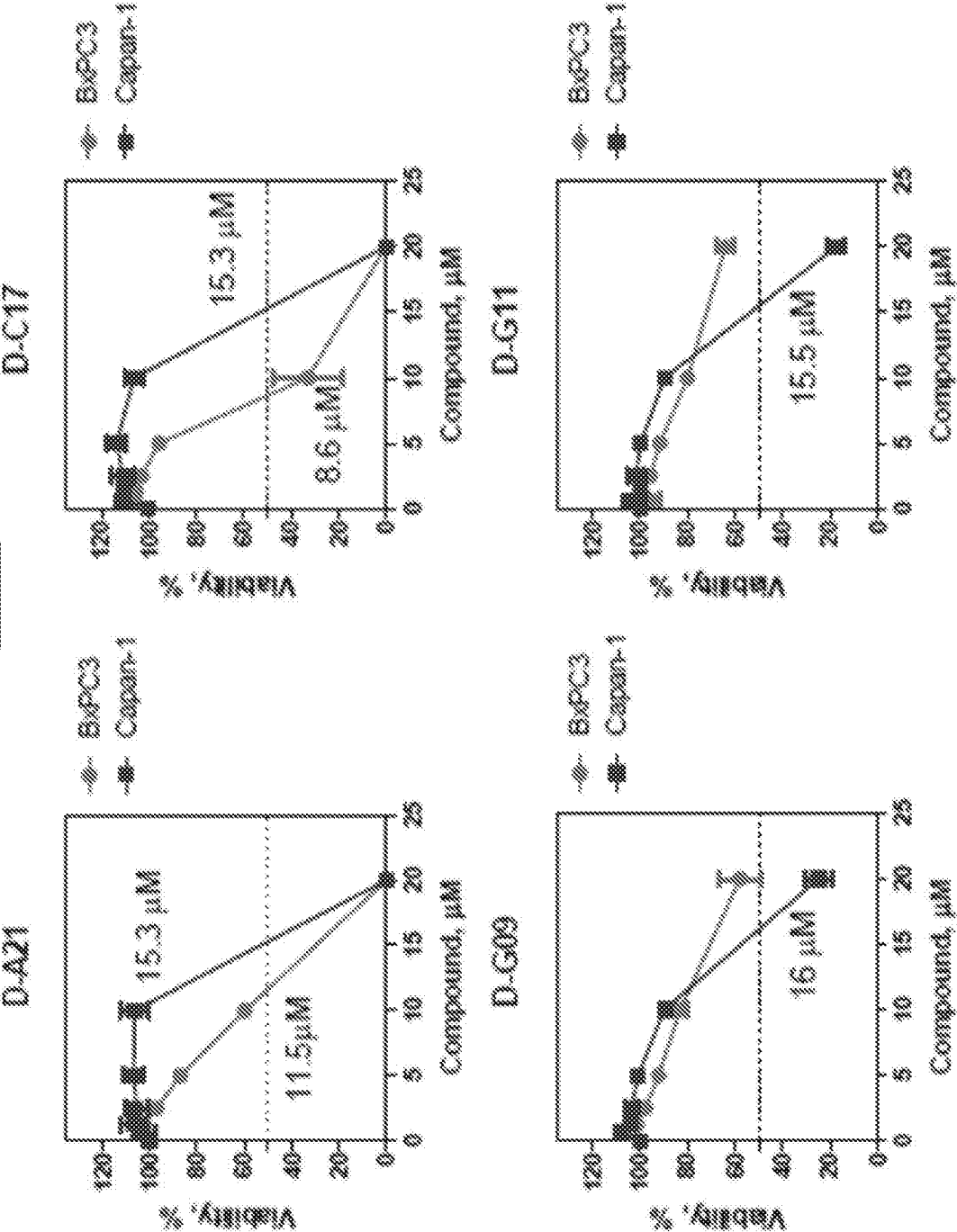
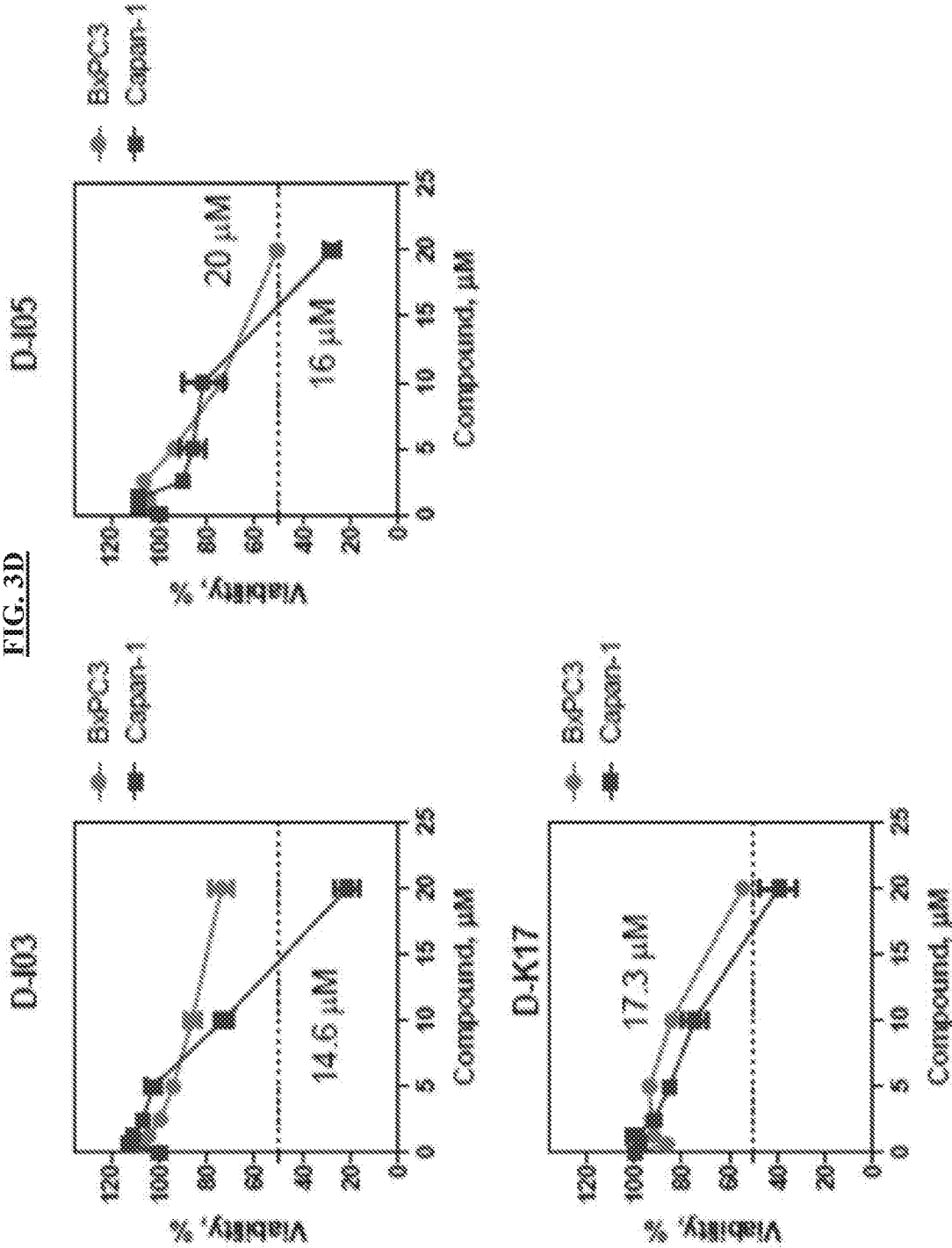


FIG. 3C





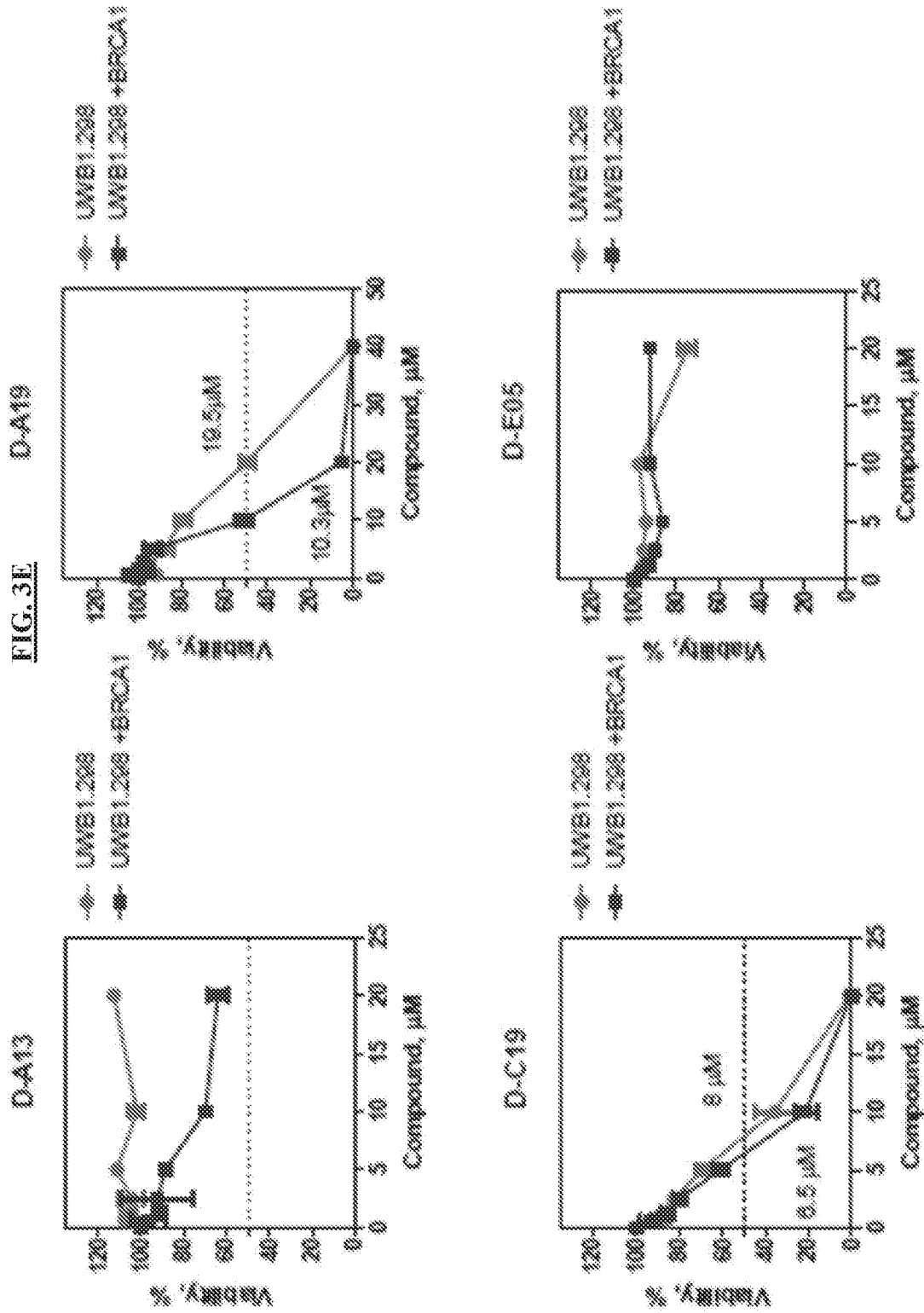


FIG. 3F

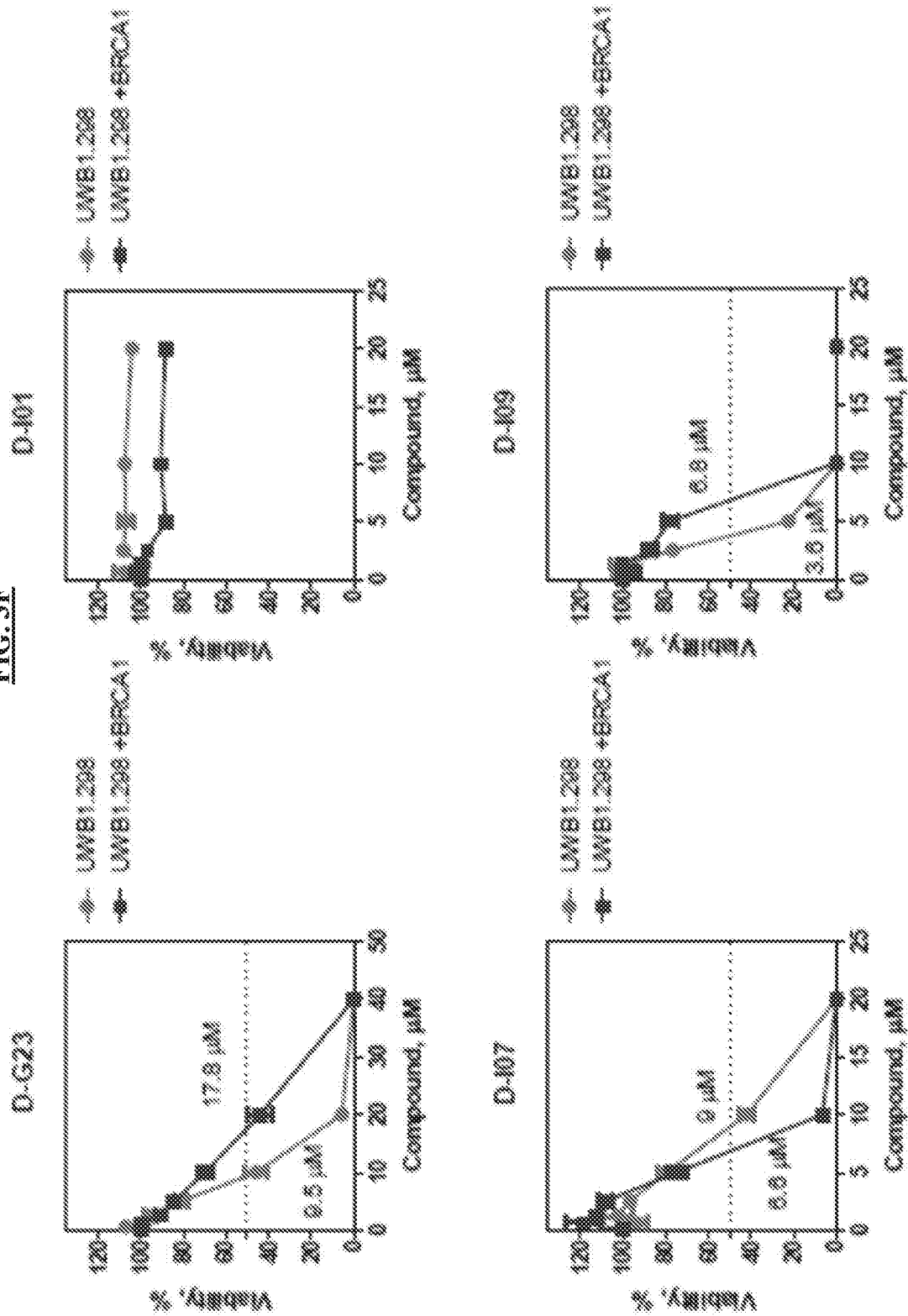


FIG. 3G

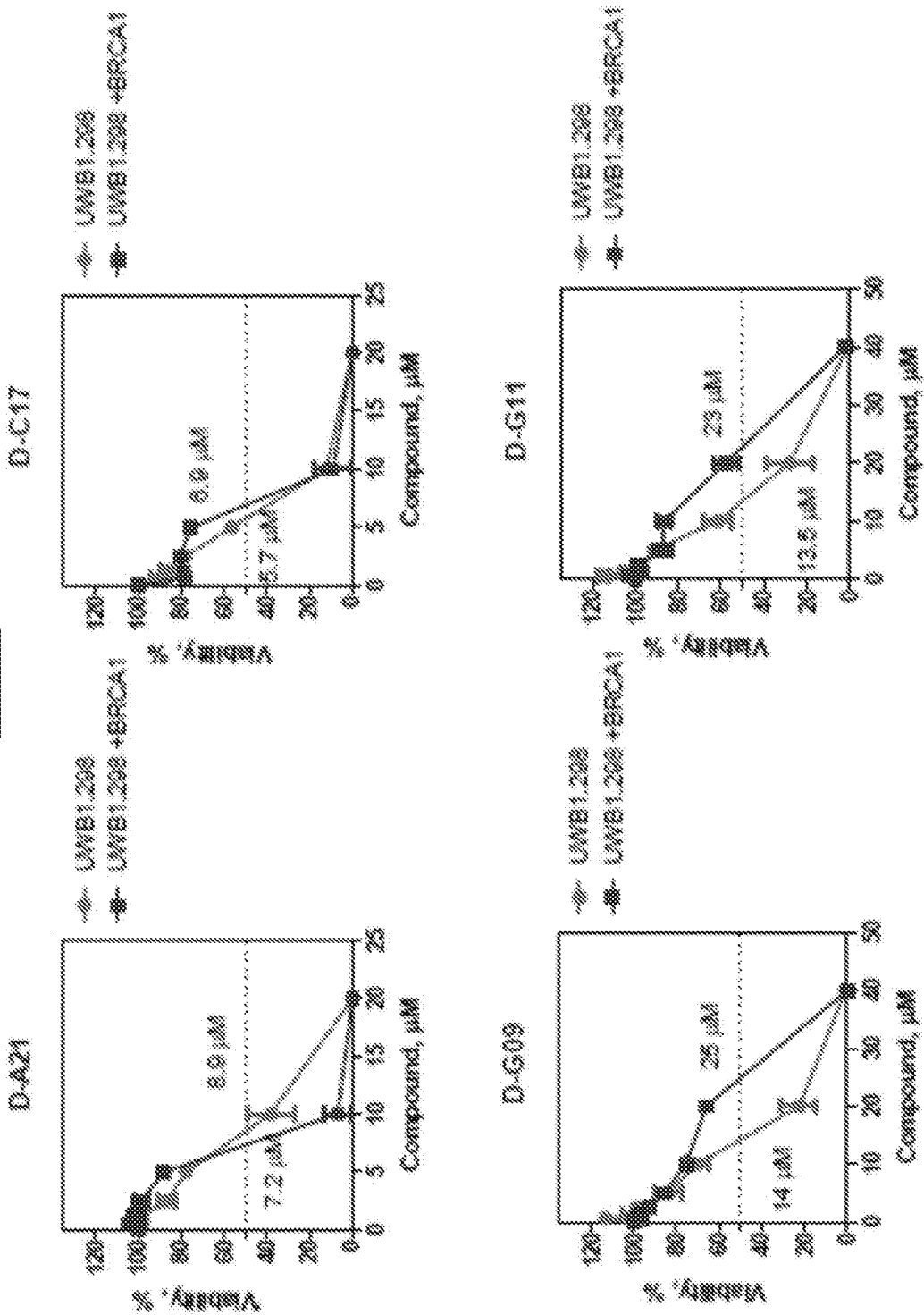


FIG. 3H

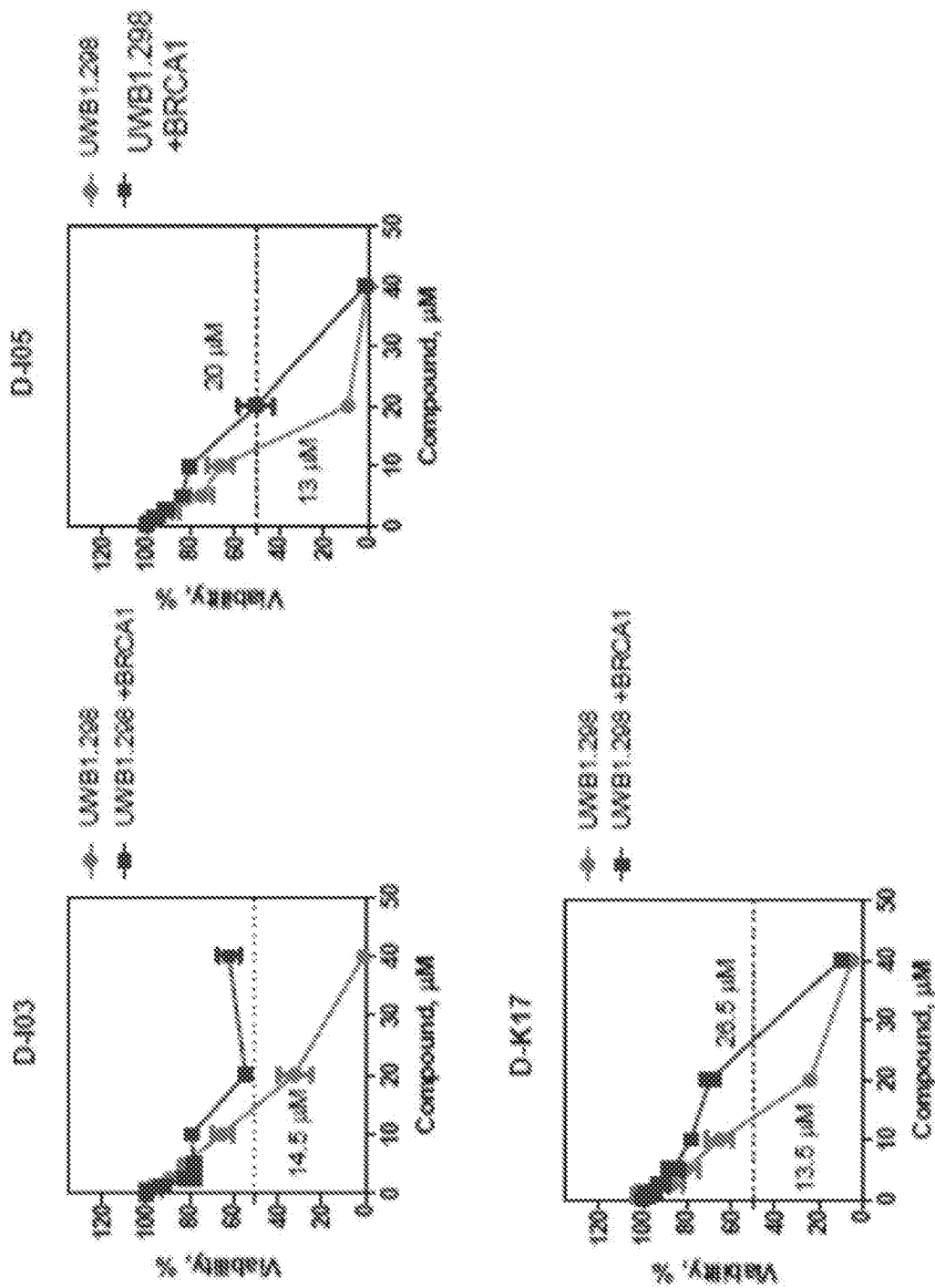


FIG. 4A

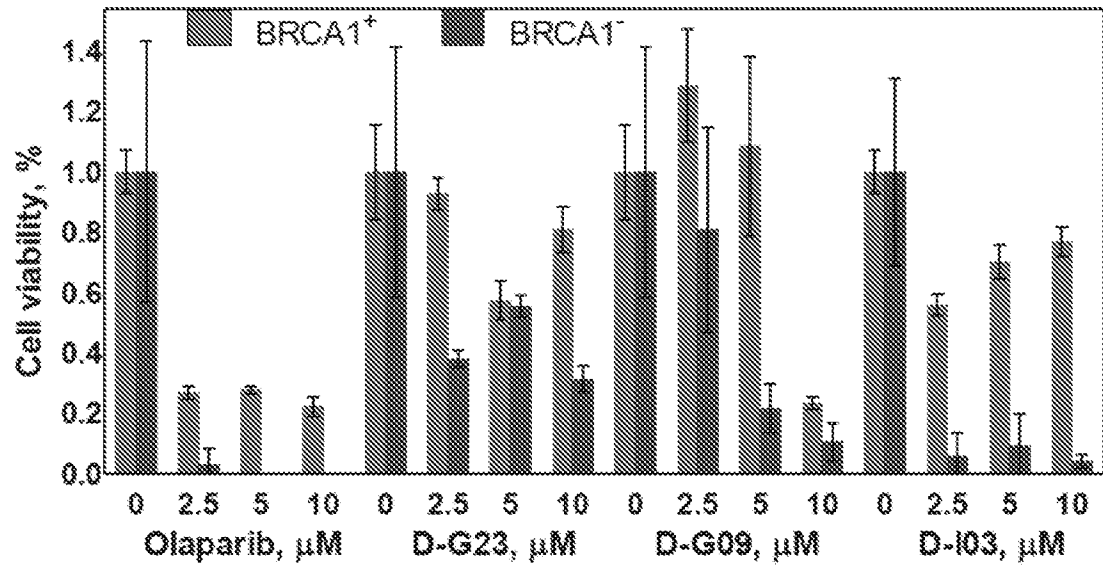


FIG. 4B

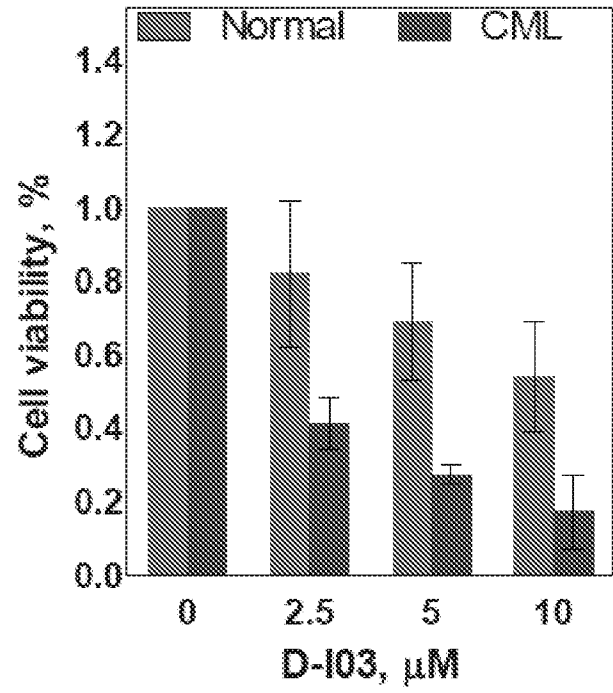


FIG. 4C

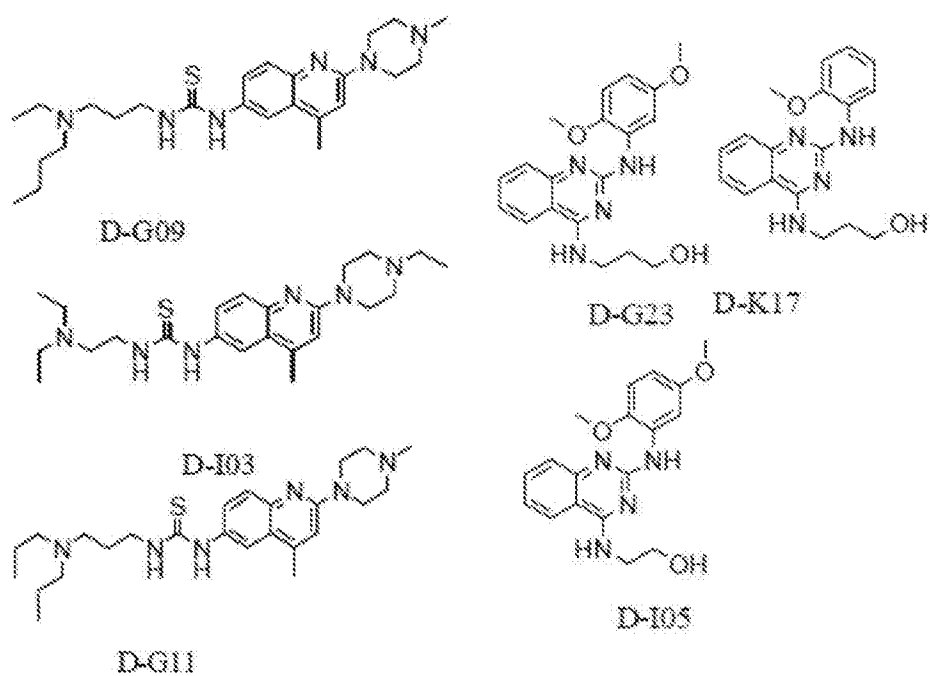


FIG. 5A

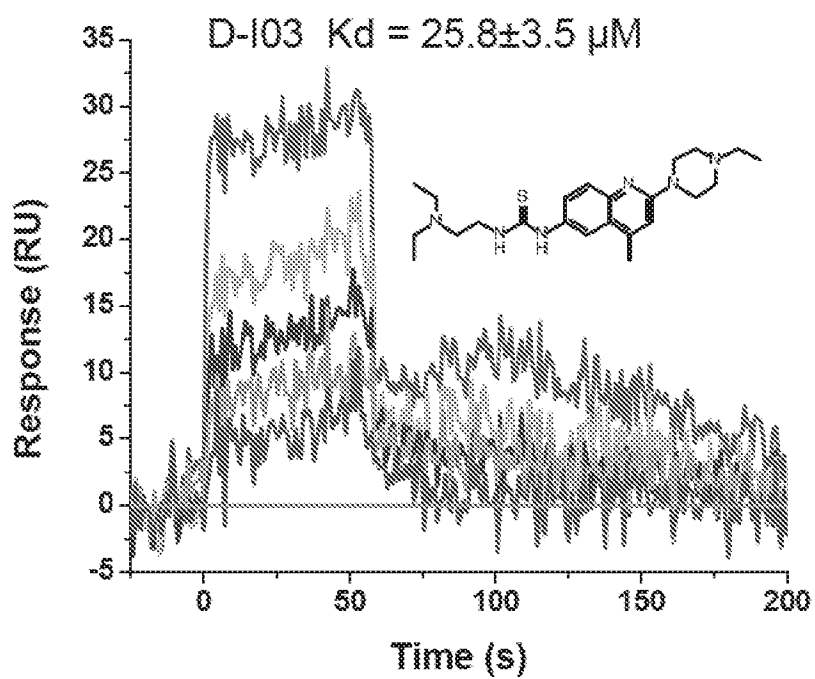


FIG. 5B

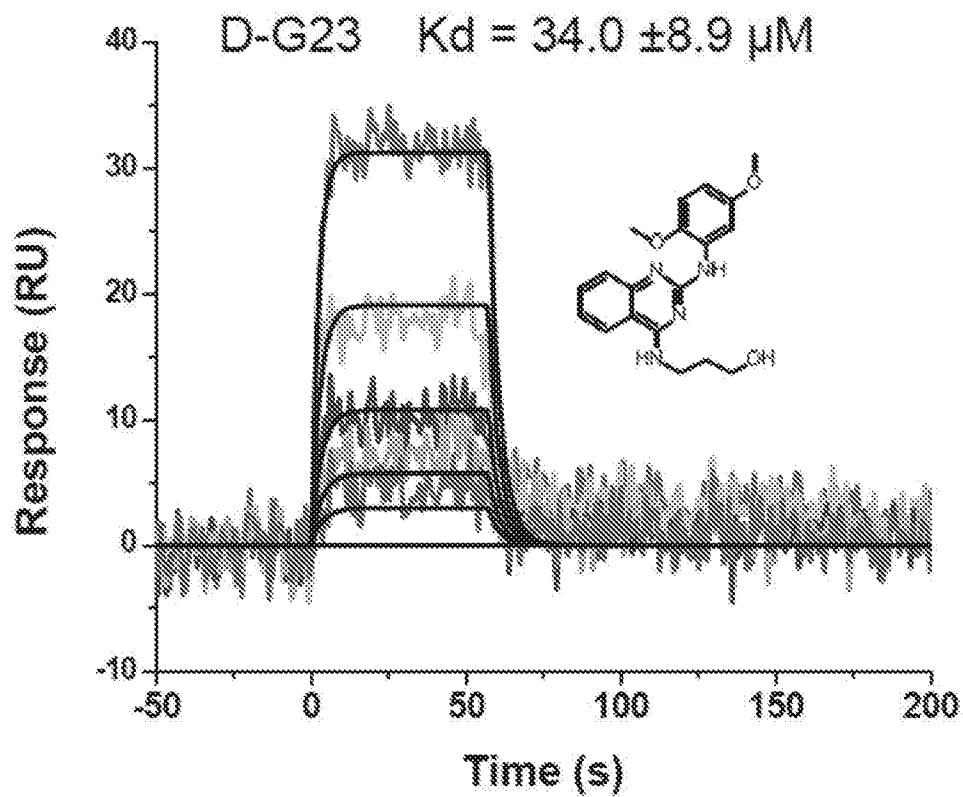


FIG. 5C

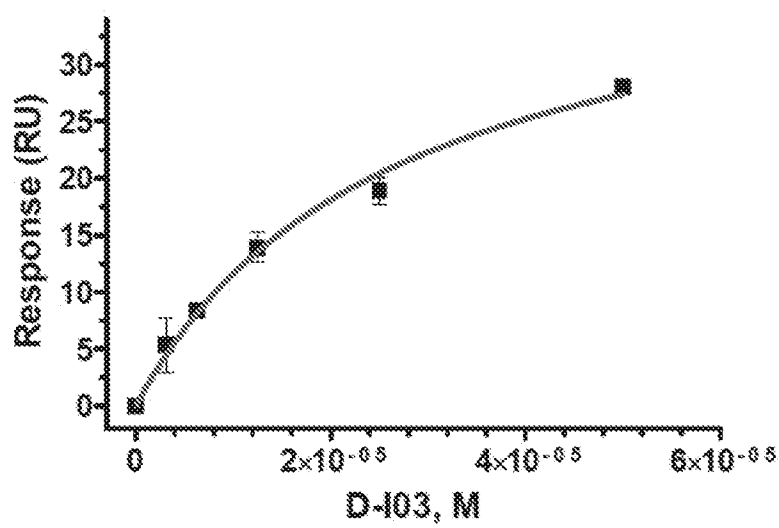


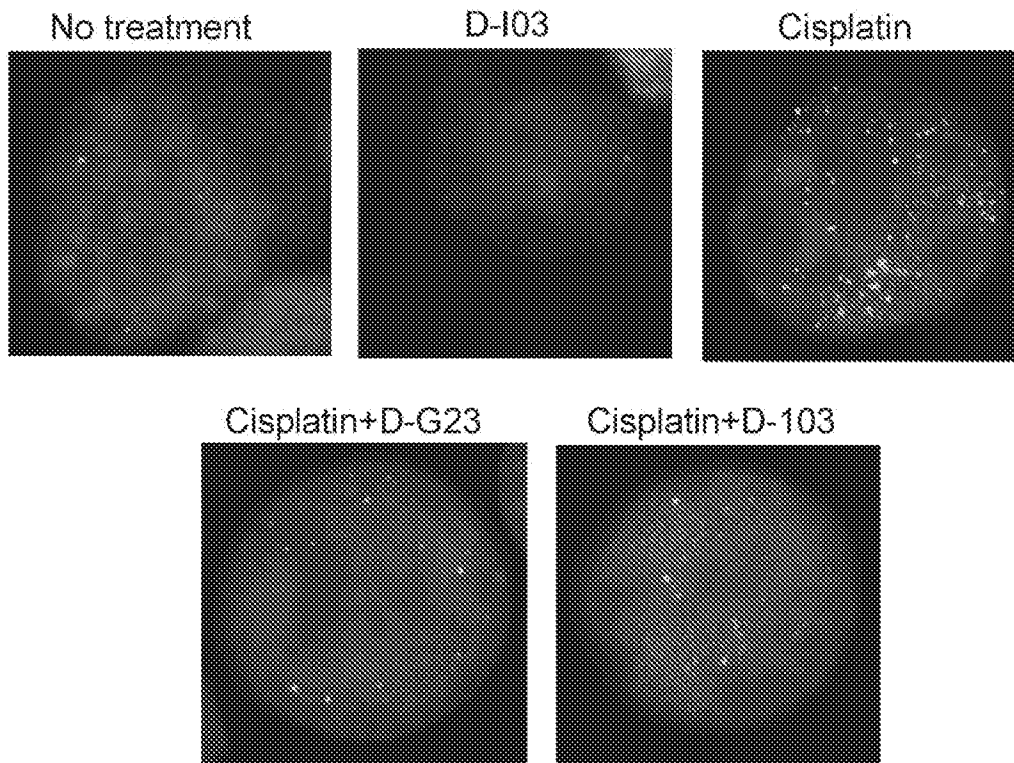
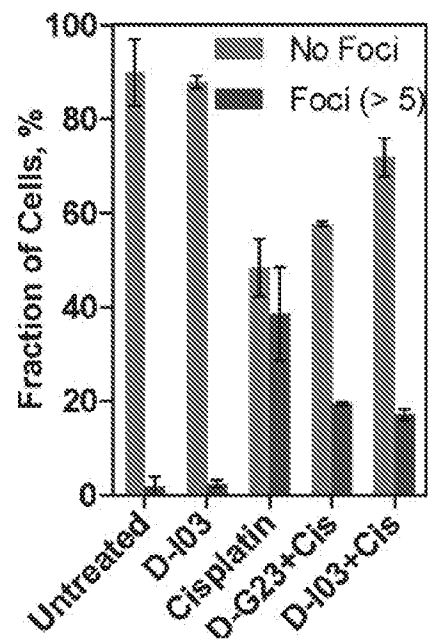
FIG. 6AFIG. 6B

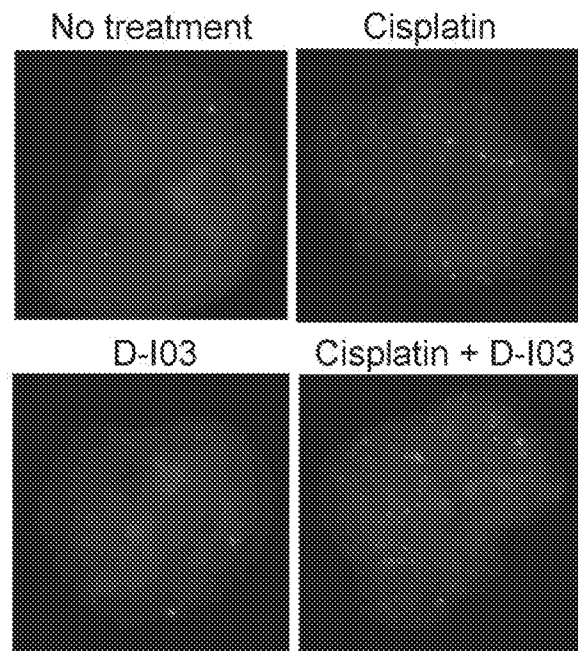
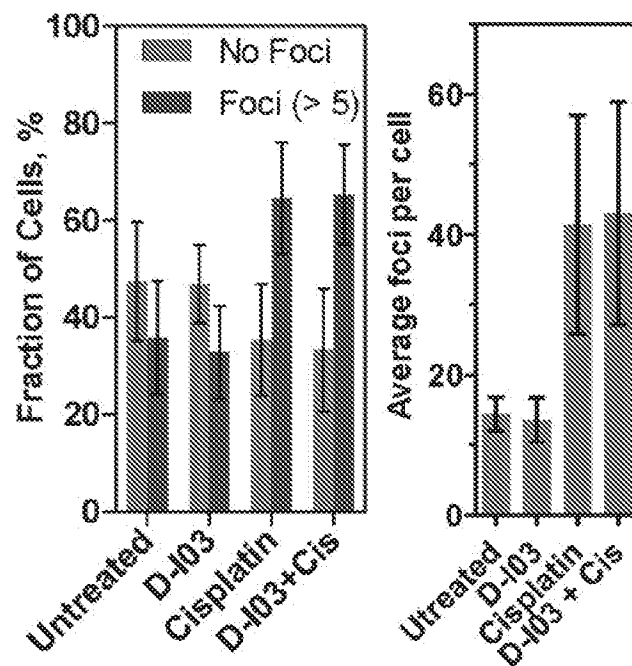
FIG. 6CFIG. 6D

FIG. 7A

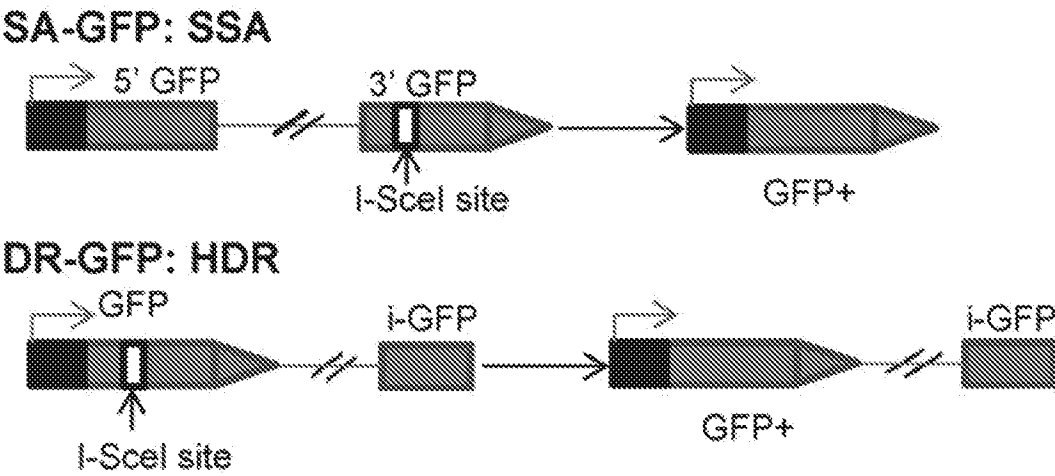


FIG. 7B

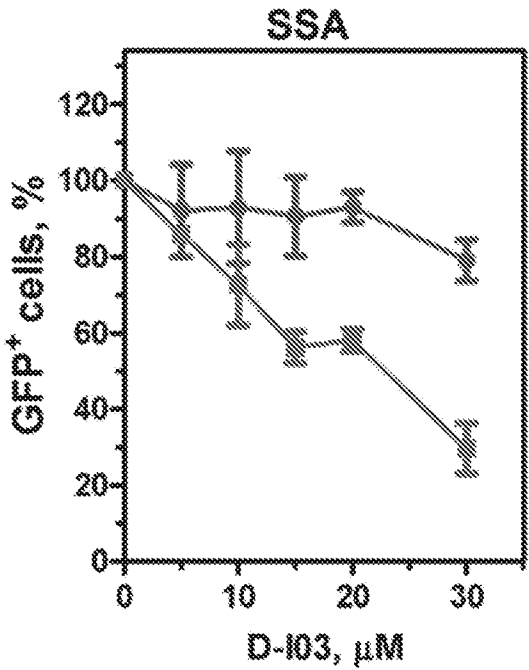


FIG. 7C

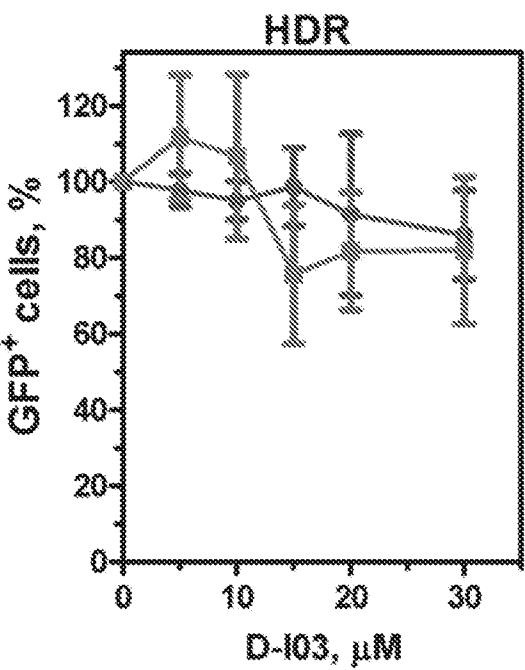


FIG. 8A

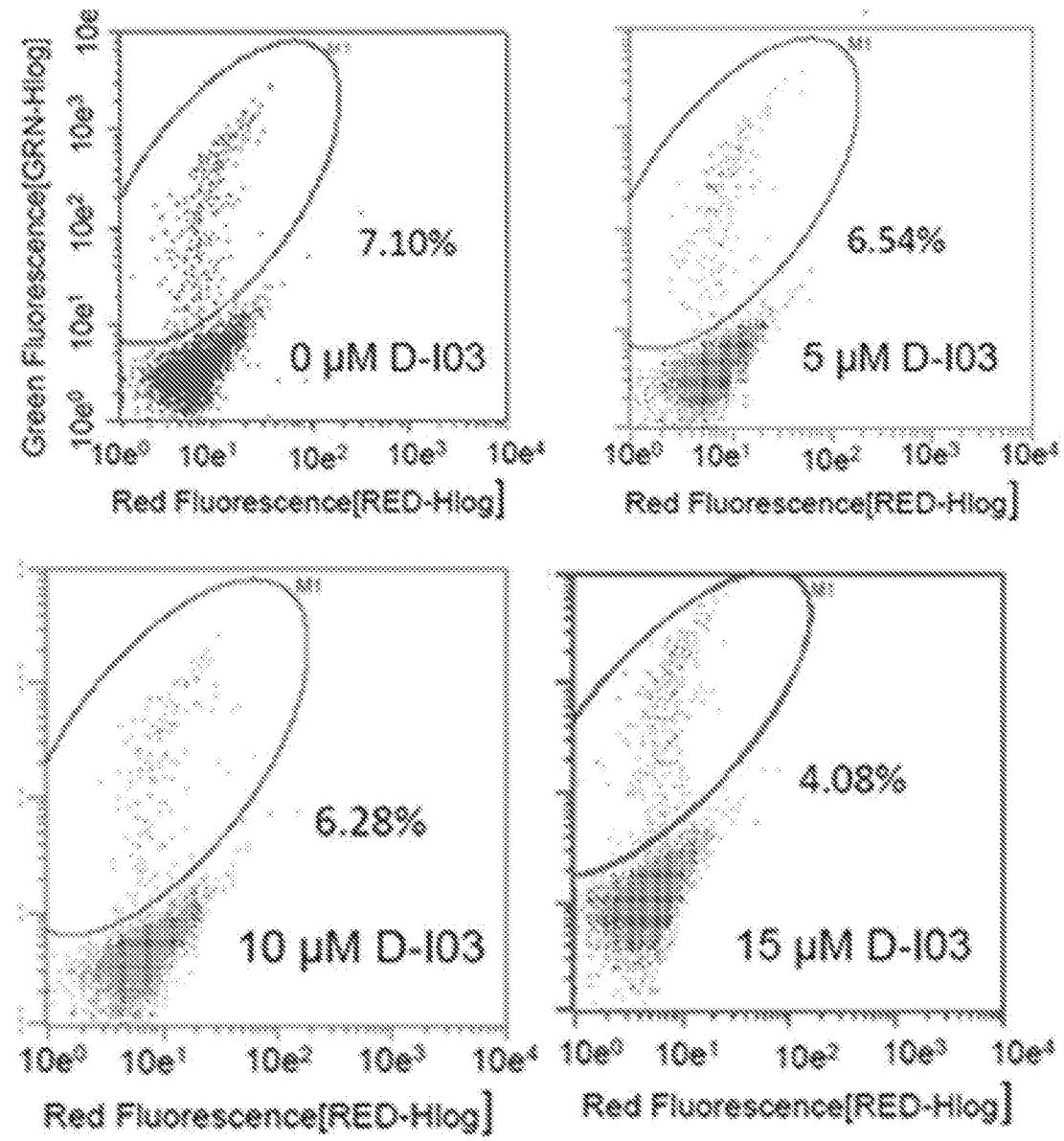


FIG. 8B

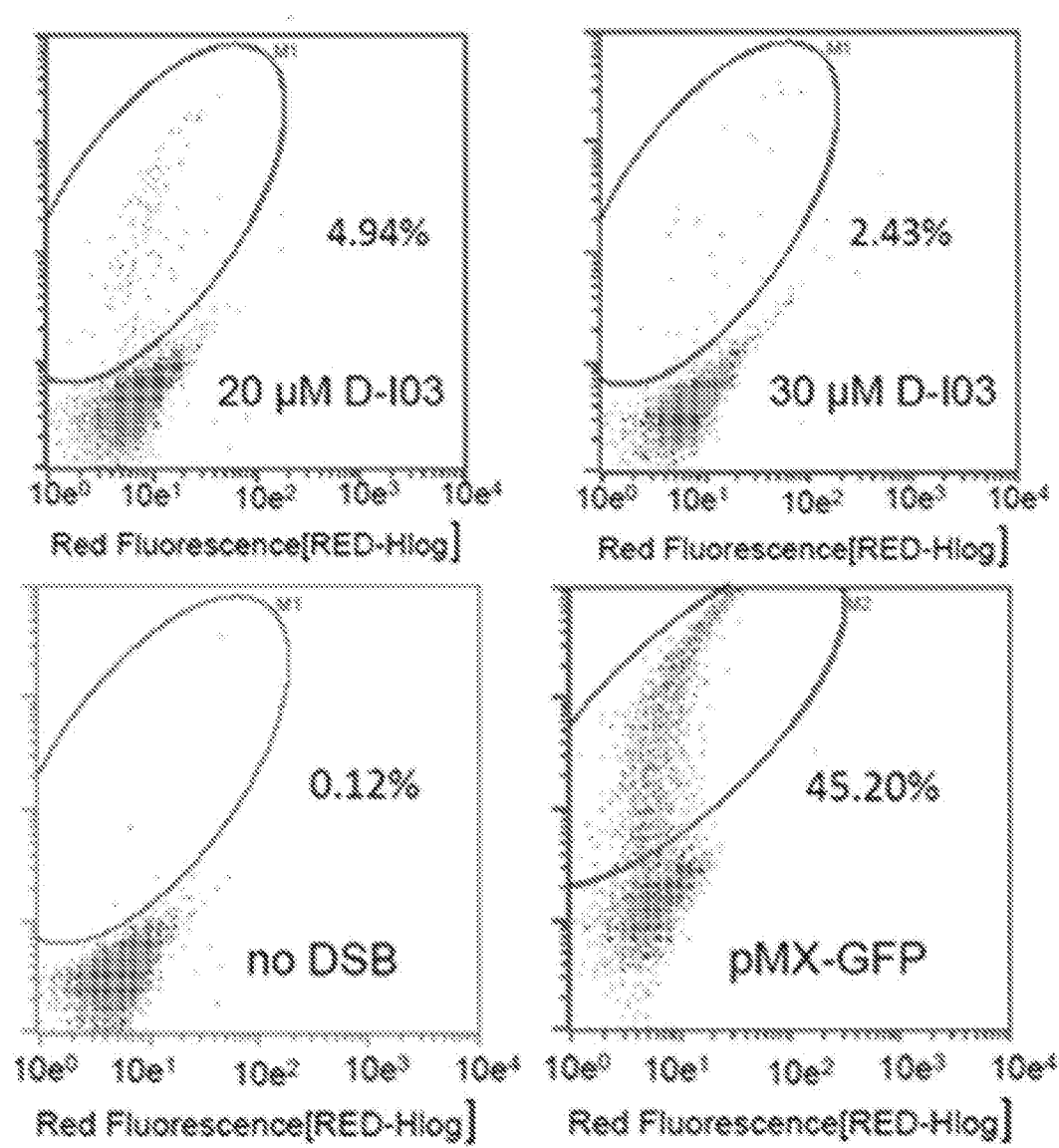


FIG. 8C

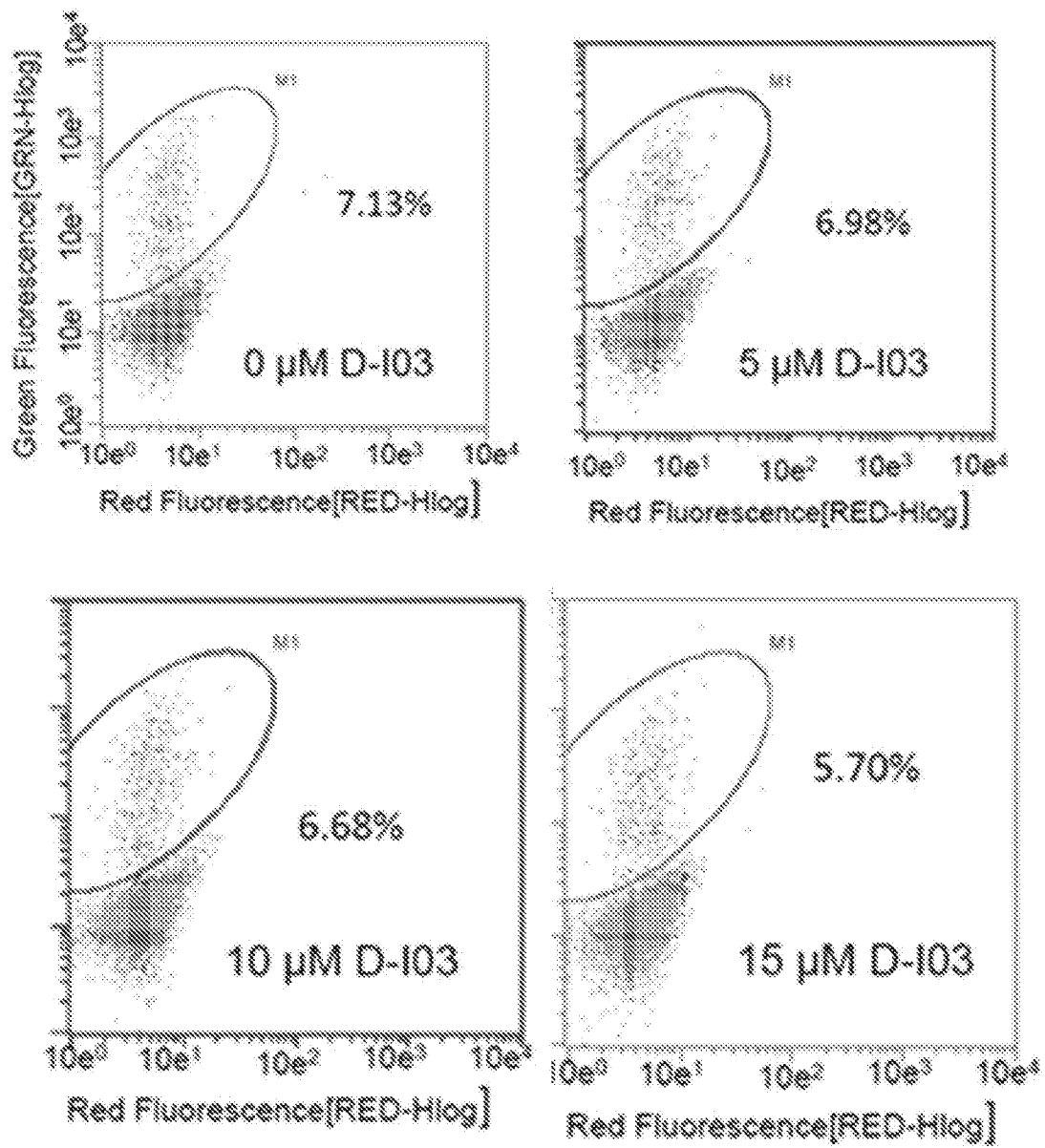


FIG. 8D

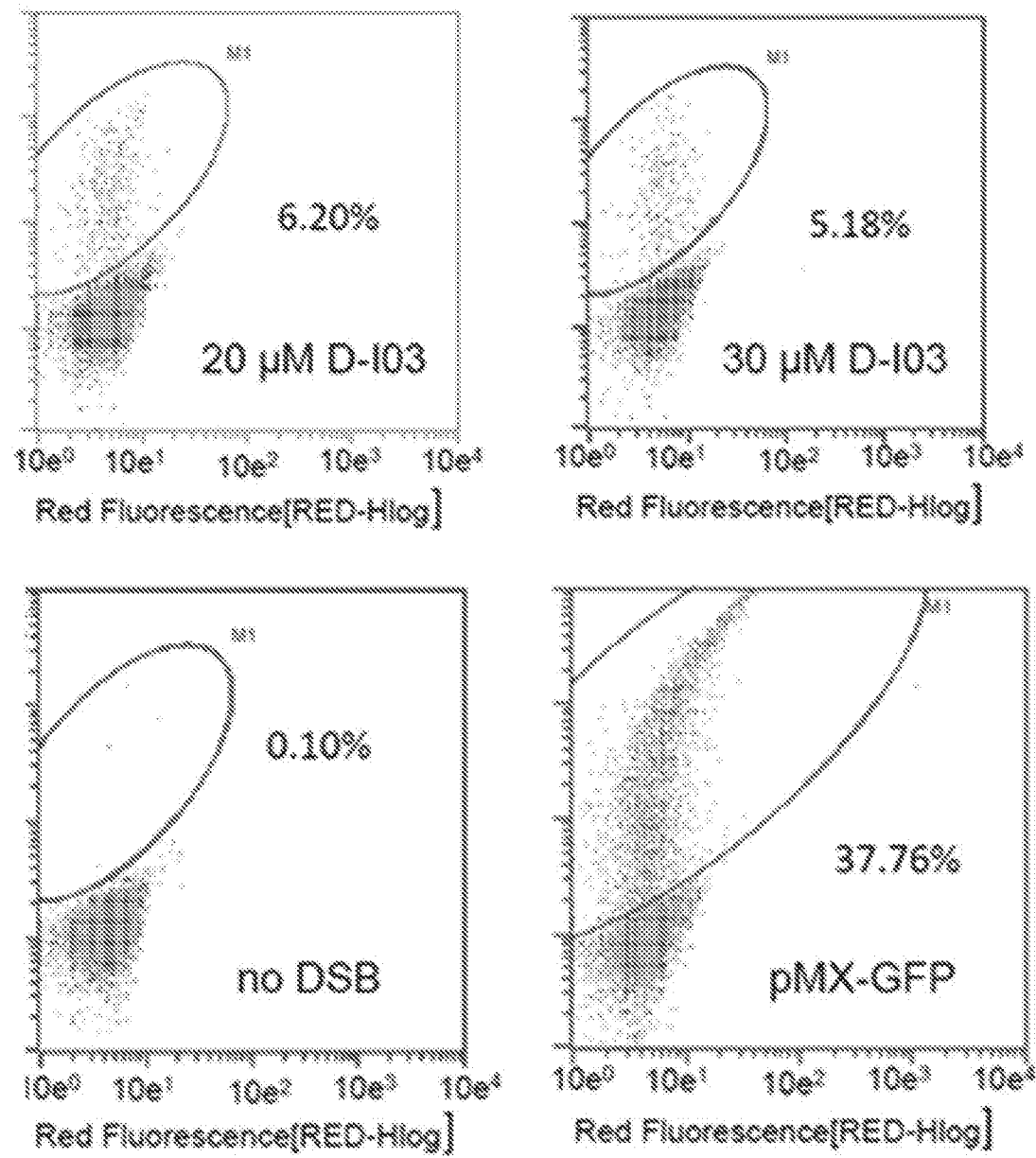


FIG. 9

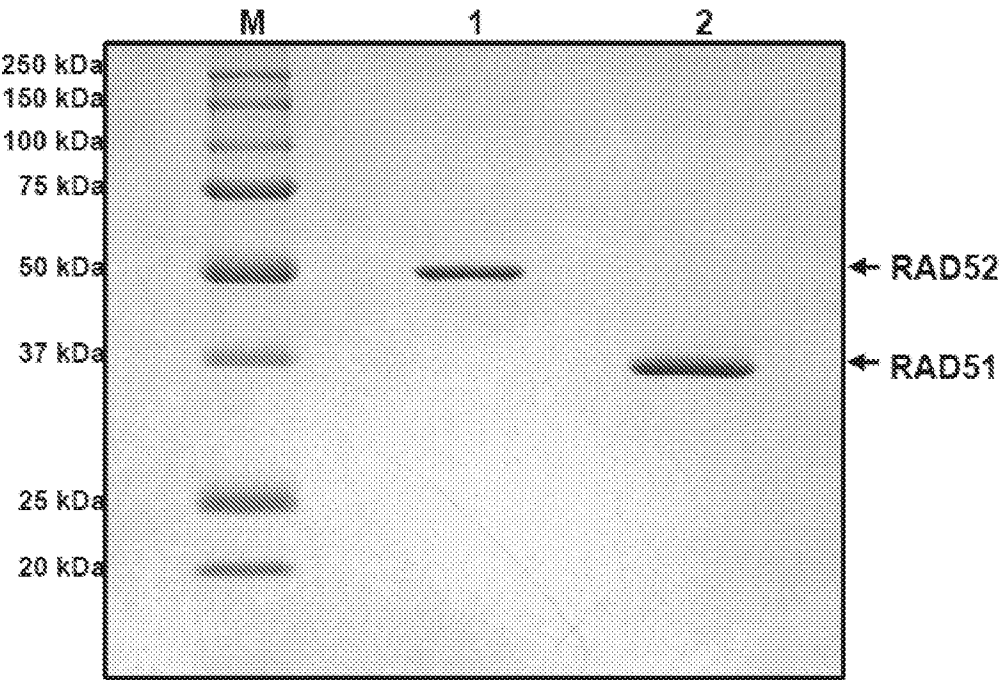
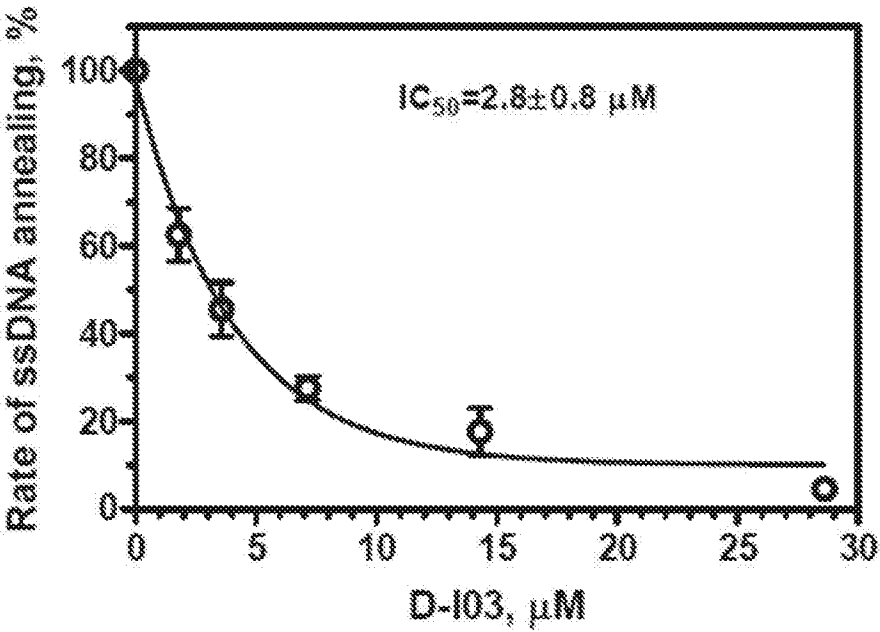


FIG. 10



INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2016/035750

A. CLASSIFICATION OF SUBJECT MATTER IPC(8) - A61K 31/17; A61K 31/135; A61K 31/136; C07C 211/41; C07C 211/42; C07C 211/43 (2016.01) CPC - A61K 31/17; A61K 31/135; A61K 31/136; C07C 211/41; C07C 211/42; C07C 211/43 (2016.08) 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 - A61K 31/17; A61K 31/135; A61K 31/136; C07C 211/41; C07C 211/42; C07C 211/43 CPC - A61K 31/17; A61K 31/135; A61K 31/136; C07C 211/41; C07C 211/42; C07C 211/43 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched USPC - 514/588; 514/595; 514/649; IPC(8) - A61K 31/17; A61K 31/135; A61K 31/136; C07C 211/41; C07C 211/42; C07C 211/43 (2016.01); CPC - A61K 31/17; A61K 31/135; A61K 31/136; C07C 211/41; C07C 211/42; C07C 211/43 (2016.08) (keyword delimited) Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) PatBase, PubChem, STN, Google Patents, Google Scholar Search terms used: 5-amino inden-1-yl urea RAD52		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2005/0026984 A1 (BIGOT et al) 03 February 2005 (03.02.2005) entire document	1, 9, 12-15, 17-26, 28-31
A	US 2014/0235634 A1 (KALA PHARMACEUTICALS INC) 21 August 2014 (21.08.2014) entire document	1, 9, 12-15, 17-26, 28-31
A	US 6,737,547 B1 (SKLARZ et al) 18 May 2004 (18.05.2004) entire document	1, 9, 12-15, 17-26, 28-31
☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "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 "X" 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 26 September 2016		Date of mailing of the international search report 14 OCT 2016
Name and mailing address of the ISA/ Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, VA 22313-1450 Facsimile No. 571-273-8300		Authorized officer Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2016/035750

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☒ Claims Nos.: 11
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See Extra Sheet

Claims 1, 9, 12-15, 17-26, and 28-31 have been analyzed subject to the restriction that the claims read on the compound of formula (I) as described in the Lack of Unity of Invention (See Box IV). The claims are restricted to a compound of formula (I): wherein in (I): R1 is the first shown structure, which is attached at 6 position; R2 is -NR4R5; R3 is hydrogen; each occurrence of R4 and R5 are independently hydrogen; each occurrence of X is CH; Y is O; n is 0; or a salt, solvate, tautomer, enantiomer, diastereoisomer, or N-oxide thereof, and any combination thereof.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1, 9, 12-15, 17-26, 28-31

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

Continued from Box No. III Observations where unity of invention is lacking

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees need to be paid.

Group I+: claims 1-10 and 12-31 are drawn to compounds of formula (I), formula (IX): a salt, solvate, tautomer, enantiomer, diastereoisomer, or N-oxide thereof, and any combinations thereof, compositions thereof, and methods thereof.

The first invention of Group I+ is restricted based on the proviso when n is 1, R1 is connected to the aryl ring at 5, 6, 7, or 8 position; alternatively, when n is 0, R1 is connected to the aryl ring at that 6, 7, or 8 position; and provided that the compound is not selected from the group consisting of 1-(3-(diethylamino)propyl)-3-(3-(dimethylamino)propyl)-1-((6-oxo-5,6-dihydro-[1,3]dioxolo[4,5-g]quinolin-7-yl)methyl)thiourea; 1-(2-((2-aminoethyl)(methyl)amino)-4-methylquinolin-6-yl)-3-(3-(4-ethylpiperazin-1-yl)propyl)thiourea; 1-(3-(butyl(ethyl)amino)propyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea; 1-(3-(dipropylaminopropyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea; 3-((2-((2,5-dimethoxyphenyl)amino)quinazolin-4-yl)amino)propan-1-ol; 1-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)-3-(3-(4-methylpiperazin-1-yl)propyl)thiourea; 1-(2-(diethylamino)ethyl)-3-(4-methyl-2-(4-methylpiperazin-1-yl)quinolin-6-yl)thiourea; 2-((2-((2,5-dimethoxyphenyl)amino)quinazolin-4-yl)amino)ethan-1-ol; and 3-((2-((2-methoxyphenyl)amino)quinazolin-4-yl)amino)propan-1-ol; and is restricted to a compound of formula (I); wherein in (I): R1 is the first shown structure, which is attached at 6 position; R2 is -NR4R5; R3 is hydrogen; each occurrence of R4 and R5 are independently hydrogen; each occurrence of X is CH; Y is O; n is 0; or a salt, solvate, tautomer, enantiomer, diastereoisomer, or N-oxide thereof, and any combination thereof; compositions thereof, and methods thereof. It is believed that claims 1, 9, 12-15, 17-26, and 28-31 read on this first named invention and thus these claims will be searched without fee to the extent that they read on the above embodiment.

Applicant is invited to elect additional formula(e) for each additional compound to be searched in a specific combination by paying an additional fee for each set of election. Each additional elected formula(e) requires the selection of a single definition for each compound variable. An exemplary election would a compound of formula (I): wherein in (I): R1 is the first shown structure, which is attached at 6 position; R2 is -NR4R5; R3 is C6 alkyl; each occurrence of R4 and R5 are independently C6 alkyl; each occurrence of X is N; Y is S; n is 1; or a salt, solvate, tautomer, enantiomer, diastereoisomer, or N-oxide thereof, and any combination thereof; compositions thereof, and methods thereof. Additional formula(e) will be searched upon the payment of additional fees. Applicants must specify the claims that read on any additional elected inventions. Applicants must further indicate, if applicable, the claims which read on the first named invention if different than what was indicated above for this group. Failure to clearly identify how any paid additional invention fees are to be applied to the "+" group(s) will result in only the first claimed invention to be searched/examined.

The inventions listed in Groups I+ do not relate to a single general inventive concept under PCT Rule 13.1, because under PCT Rule 13.2 they lack the same or corresponding special technical features for the following reasons:

The Groups I+ formulae do not share a significant structural element requiring the selection of alternatives for the compound variables X, R1, R2, R3, n, R4, and R5.

The Groups I+ share the technical features of a compound of formula (I): or a salt, solvate, tautomer, enantiomer, diastereoisomer, or N-oxide thereof, and any combination thereof; a compound of formula (IX): or a salt, solvate, tautomer, enantiomer, diastereoisomer, or N-oxide thereof, and any combination thereof; a pharmaceutical composition comprising at least one compound and at least one pharmaceutically acceptable carrier; a method of preventing or treating a cancer in a subject in need thereof, the method comprising administering to the subject a therapeutically effective amount of at least one compound selected from a compound of formula (I) or a compound of formula (IX); and a method of preventing or treating a RAD52 related disease or disorder in a subject in need thereof, the method comprising administering to the subject a therapeutically effective amount of at least one compound selected from a compound of formula (I) or a compound of formula (IX). However, these shared technical features do not represent a contribution over the prior art.

Specifically, US 2014/0235634 A1 to Kala Pharmaceuticals Inc. teaches a compound of formula (I): wherein in (I): R1 is the first shown structure; R2 is -NR4R5; R3 is hydrogen; R4 is hydrogen and R5 is aryl, wherein the aryl is substituted; each occurrence of X is independently CH and N; Y is O; n is 1 (Para. [0188];...see shown structure...); a pharmaceutical composition (Abstract; Claim 49) comprising at least one compound and at least one pharmaceutically acceptable carrier (Paras. [0012] and [0198]); a method of preventing or treating a cancer in a subject in need thereof (Paras. [0106] and [0345]), the method comprising administering to the subject a therapeutically effective amount of a compound of formula (I) (Paras. [0019] and [0020]); and a method of preventing or treating a RAD52 related disease or disorder in a subject in need thereof (Paras. [0106] and [0345]). The present invention further provides methods of using the compounds of Formulae (I)-(VI) as therapeutics, e.g., in the treatment and/or prevention of diseases associated with growth factor activities or angiogenesis. In certain embodiments, the disease being treated is a proliferative disease. Exemplary proliferative diseases include, but are not limited to, cancers...; See Pg. 6, Lns. 28-30, of the applicants specification that states cancer is a RAS52 disease), the method comprising administering to the subject a therapeutically effective amount of a compound of formula (I) (Paras. [0019] and [0020]).

Additionally, US 2005/0026984 A1 to Bigot et al. teach a compound of formula (IX): wherein in formula (IX): R3 is hydrogen; R4 attached to acyclic nitrogen is C1 alkyl, R4 attached to cyclic nitrogen is hydrogen, and R5 is aryl; X is N (Para. [0078], Method for Preparing 3-phenyl-1H-thieno[2,3-c]pyrazole-5-carboxylic acid N-methylphenylamide;...see shown structure...).

The inventions listed in Groups I+ therefore lack unity under Rule 13 because they do not share a same or corresponding special technical feature.