TREATING PANCREATIC CANCER AND NON-SMALL CELL LUNG CANCER WITH ATR INHIBITORS

BACKGROUND OF THE INVENTION

[0001] Pancreatic cancer is the tenth most common site of new cancers and is responsible for 6% of all cancer related deaths. The 5-year survival rate is less than 5%.

[0002] Current therapies involve either neoadjuvant treatment with chemotherapy (e.g., with gemcitabine) and / or radiation therapy or surgical removal followed by either adjuvant chemotherapy (e.g., with gemcitabine) or radiation therapy. Although the survival rate with treatment of gemcitabine increases the 5-year survival from 10% to 20%, there still is a strong need for better therapies for treating pancreatic cancer.

[0003] Several therapeutics have been tested in phase II and phase III trials though results have not been too promising. Tipifarnib, an oral farnesyltransferase inhibitor, did not show significant improvement in overall survival when combined with gemcitabine. Similarly, cetuximab, an epidermal growth factor receptor (EGRF), also showed no clinical benefit when combined with gemcitabine. Only a small increase in overall survival (6.24 months versus 5.91 months) was observed.

[0004] Lung cancer is the second most common form of cancer and is the leading cause of cancer-related mortality. Non-small cell lung cancer (NSCLC) is the most common form of lung cancer, accounting for about 85% of all lung cancer cases. Most patients present with advanced stage III or IV NSCLC with a 5-year survival of 24% and 4% respectively. Because of the advanced nature of disease on presentation, surgical resection is often not an option. For the majority of patients therapy involves chemotherapy and / or radiation treatment. The selection of chemotherapy is highly variable based on disease stage, patient performance criteria and geographical regional preference. In most cases chemotherapy is based on a doublet that includes a platinating agent such as Cisplatin or carboplatin and a second cytotoxic drug such as

gemcitabine, etoposide or taxotere. For a small number of patients, therapy can include treatment with agents that target specific proteins that are mutated or disregulated such as ALK and EGFR (eg crizotinib, gefitinib and erlotinib). Patients are selected for these targeted treatments based on genetic or proteomic markers. A great number of agents have been assessed in late stage NSCLC clinical studies, however most have shown very little benefit over chemotherapy based treatments, with median overall survival typically less than 11 months.

[0005] Accordingly, there is a tremendous need for new strategies to improve pancreatic and non-small cell lung cancer treatments.

[0006] ATR ("ATM and Rad3 related") kinase is a protein kinase involved in cellular responses to certain forms of DNA damage (eg double strand breaks and replication stress). ATR kinase acts with ATM ("ataxia telangiectasia mutated") kinase and many other proteins to regulate a cell's response to double strand DNA breaks and replication stress, commonly referred to as the DNA Damage Response ("DDR"). The DDR stimulates DNA repair, promotes survival and stalls cell cycle progression by activating cell cycle checkpoints, which provide time for repair. Without the DDR, cells are much more sensitive to DNA damage and readily die from DNA lesions induced by endogenous cellular processes such as DNA replication or exogenous DNA damaging agents commonly used in cancer therapy.

[0007] Healthy cells can rely on a host of different proteins for DNA repair including the DDR kinases ATR and ATM. In some cases these proteins can compensate for one another by activating functionally redundant DNA repair processes. On the contrary, many cancer cells harbour defects in some of their DNA repair processes, such as ATM signaling, and therefore display a greater reliance on their remaining intact DNA repair proteins which include ATR.

[0008] In addition, many cancer cells express activated oncogenes or lack key tumour suppressors, and this can make these cancer cells prone to dysregulated phases of DNA replication which in turn cause DNA damage. ATR has been implicated as a critical component of the DDR in response to disrupted DNA replication. As a result, these cancer cells are more dependent on ATR activity for survival than healthy cells. Accordingly, ATR inhibitors may be useful for cancer treatment, either used alone or in combination with DNA damaging agents, because they shut down a DNA repair mechanism that is more important for cellular survival in many cancer cells than in healthy normal cells.

[0009] In fact, disruption of ATR function (e.g. by gene deletion) has been shown to promote cancer cell death both in the absence and presence of DNA damaging agents. This suggests that ATR inhibitors may be effective both as single agents and as potent sensitizers to radiotherapy or genotoxic chemotherapy.

[0010] Furthermore, solid tumors often contain regions that are hypoxic (low oxygen levels). This is significant because hypoxic cancer cells are known to be resistant to treatment, most notably IR treatment, and are highly aggressive. One reason for this observation is that components of the DDR can be activated under hypoxic conditions and it has also been shown that hypoxic cells are more reliant on components of the DDR for survival.

[0011] For all of these reasons, there is a need for the development of potent and selective ATR inhibitors for the treatment of pancreatic cancer, for the treatment of lung cancer, and for the development of agents that are effective against both hypoxic and normoxic cancer cells.

SUMMARY OF THE INVENTION

[0012] This invention relates to uses of ATR inhibitors for treating pancreatic cancer and non-small cell lung cancer. With respect to pancreatic cancer, this invention relates to methods of treating pancreatic cancer in a patient (e.g., a human) with an ATR inhibitor in combination with gemcitabine and/or radiation therapy. Applicants have demonstrated synergistic efficacy of ATR inhibitors in combination with gemcitabine and/or radiation therapy in clonogenic and viability assays on the pancreatic cancer cell lines, (e.g. PSN-1, MiaPaCa-2 and Panc-1) as well as in a primary tumor line (e.g., Panc-M). Disruption of ATR activity was measured by assessing DNA damage induced phosphorylation of Chk1 (Ser 345) and by assessing DNA damage foci and RAD51 foci following irradiation.

[0013] With respect to non-small cell lung cancer, his invention relates to methods of treating non-small cell lung cancer with an ATR inhibitor in combination with cisplatin or carboplatin, etoposide, and ionizing radiation. Applicants have demonstrated synergy of ATR inhibitors in combination with cisplatin, etoposide, gemcitabine, oxaplatin and irinotecan in viability assays against a panel of 35 human lung cancer cell lines as well as demonstrated in vivo efficacy in a lung cancer mouse model in combination with cisplatin.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1. VE-821 radiosensitises pancreatic tumour cells.

A) Western blot analysis of Chk1 inhibition.
Cells were treated with 100 nM gemcitabine for 1 h, 1 μM VE-821 was added 1 h later and cells were irradiated (6 Gy) 1 h after that. Drugs were left for the duration of the experiment and cells were lysed at 2 h post-irradiation and subjected to Western blot analysis.

B) VE-821 radiosensitizes pancreatic tumour cells but not normal fibroblasts.
PSN-1, Panc-1, MiaPaCa-2 pancreatic cancer cell lines and MRC5 fibroblasts were treated with increasing concentrations of VE-821 for 96 h combined with or without 4 Gy radiation at 1 h after VE-821 addition. Cell viability was measured after 8 days and shown as normalized to DMSO-treated cells.

C) Scheduling of VE-821 affects radiosensitivity.
PSN-1 cells were plated as single cells, treated with 1 μM VE-821 at different time points in relation to 4 Gy irradiation and assessed for colony formation after 10 days. The survival fraction at 4 Gy for each of the treatment schedules was determined by taking into account the relevant plating efficiency of unirradiated cells.

D) Clonogenic survival of cells pancreatic cancer cells in response to ATR inhibition.
Cells were treated with 1 μM VE-821 4 h after plating and 1 h prior to irradiation. Drug was removed after 72 h and colony-forming ability was assessed after 10 to 21 days. *(n=3).* *, $P < 0.05$; **, $P < 0.01$ over DMSO-treated control.

Figure 2. VE-821 radiosensitises pancreatic tumour cells under hypoxic conditions.
A) clonogenic survival curves of cells treated with 1 μM VE-821 and irradiation under hypoxic conditions. Plated cells were transferred to hypoxia (0.5% O_2) and acclimatised for 6 h. VE-821 (1 μM) was then added at 1h prior to irradiation and left for 72 h upon which the medium was replaced. Cells were transferred to normoxia at 1 h post-irradiation.

B) clonogenic survival of cells after irradiation with 6 Gy and treatment with 1 μM VE-821 in oxic and hypoxic (0.5% O_2) conditions, as described above and in Fig. 1 *(n=3).* *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$ over DMSO-treated control.

Figure 3. VE-821 sensitises pancreatic cancer cells to gemcitabine treatment.
A) clonogenic survival of cells treated with gemcitabine and 1 μM VE-821. Cells were treated with increasing concentrations of gemcitabine for 24 h followed by 72 h treatment of 1 μM VE-821. Colony forming ability was assessed after 10 to 21 days.

B) clonogenic survival of cells treated with gemcitabine in hypoxia. Plated cells were transferred to hypoxia (0.5% O_2) and acclimatised for 6 h. Cells were then treated with increasing concentrations of gemcitabine for 24 h followed by 72 h treatment of 1 μM VE-821. Hypoxic cells were transferred to normoxia 1 h after VE-821 addition.

C) clonogenic survival after treatment with 20 nM gemcitabine and VE-821 in oxic and hypoxic (0.5% O_2) conditions, as described above.

D) clonogenic survival of cells treated with gemcitabine and irradiation. PSN-1 and MiaPaCa-2 cells were treated with 5 nM or 10 nM gemcitabine, respectively, for 24 h, medium was then replaced and 1 μM VE-821 was added from 1 h prior to 72 h post 4 Gy irradiation. Colony forming ability was assessed after 10 to 21 days *(n=3)*. *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$ over DMSO-treated control.

Figure 4. VE-821 perturbs the irradiation-induced cell cycle checkpoint in pancreatic cancer cells.
[0014] VE-821 (1 μM) was added 1 h prior to 6 Gy irradiation and left for the duration of the experiment. Cells were lifted and fixed at 12 h or 24 h after irradiation, stained with propidium iodide and analysed for cell cycle distribution by flow cytometry *(n=3)*

Figure 5. VE-821 increases 53BP1 and γH2AX foci number and reduces RAD51 foci formation.
[0015] Cells were treated with 1 μM VE-821 at various time points in relation to 6 Gy irradiation, as indicated, and fixed at 24 h post-irradiation. Subsequently, cells were stained for (A) γH2AX and (B) 53BP1 foci and the percentage of cells with more than 7 and 5 foci per cell was quantitated, respectively. C, for analysing Rad51 foci formation, cells were fixed at 6 h post-irradiation and the percentage of cells with

more than 9 foci per cell was quantitated. Representative images are shown on the right (n=3). *, $P < 0.05$

Supplementary figures.

Suppl Fig 1. Effect of VE-821 incubation time on plating efficiency.

[0016] PSN-1 cells were plated as single cells, treated with 1uM VE-821 for various time periods and assessed for colony formation after 10 days.

Suppl Fig. 2.

[0017] VE-821 perturbs the irradiation-induced G2/M checkpoint in pancreatic cancer cells in hypoxic conditions.

[0018] Cells were pre-incubated under hypoxic (0.5% O_2) conditions for 6 h and 1 μM VE-821 was added 1 h prior to irradiation (6 Gy). Cells were transferred to normoxia 1 h after irradiation and were lifted and fixed at 12 h or 24 h after irradiation, stained with propidium iodide and analysed for cell cycle distribution by flow cytometry (n=3).

Fig 1X. Dose response relationship for radiosensitivity induced by Compounds 821, 822, 823, and 824.

[0019] Small scale clonogenic survival assays were performed on HeLa cells treated with the different ATR inhibitors at increasing concentrations followed by irradiation at 6Gy. Data is plotted as decrease in clonogenic survival in relation to the DMSO-treated cells for both irradiated (SF 6Gy, pink line) and unirradiated cells (plating efficiency, PE; blue line). A high degree of increased radiosensitivity can be seen as a large decrease in survival after irradiation accompanied by a small decrease in unirradiated survival at a specific drug concentration.

Fig 2X. Assessment of radiosensitivity in tumour cells and normal cells.

A) Clonogenic survival after drug treatment in the absence of irradiation. PSN1 and MiaPaca cells were plated at low densities, treated with the drugs indicated and assessed for clonogenic survival.

B) Clonogenic survival of PSN1, MiaPaca, and MRC5 cells pretreated with Compounds 821, 822, 823 and 824 drugs followed by irradiation. Cells were plated at low densities, treated with drugs indicated 1h prior to irradiation and assessed for clonogenic survival.

Fig 3X. Assessment of dependency of drug addition and removal timing on radiosensitivity.

[0020] MiaPaca cells were plated at low densities and drug was added at various time points in relation to the 4Gy radiation treatment: 1h prior to IR, 5min after IR, 2h or 4h after IR; and removed at various time points: 5min after, 1h after, or 19h after IR. Clonogenic survival was assessed after 14 days. Results are shown as the surviving fraction at 4Gy (top panel) or the percentage radiosensitisation (middle panel) compared to the DMSO-treated cells. The different treatment schedules did not cause differences in plating efficiency (bottom panel).

Fig 4X. DNA damage foci analysis after Compound 822 treatment and irradiation.

A) Assessment of gH2AX, 53BP1 foci at 24h after IR at 6Gy and of RAD51 foci at 6h after IR. MiaPaca cells were treated with 80nM Compound 822 1h prior or 1h post irradiation and drug was washed away at 5min after or 1h after IR. Cells were fixed after 6h (for RAD51 foci) or 24h (for gH2AX and 53BP1 foci). The percentage of cells containing more than a certain number of foci was quantitated.

B) Time course of DNA damage foci. Cells were treated as in A and fixed at the time points shown followed by staining for gH2AX, 53BP1 and RAD51 foci. Data is shown as the mean number of foci at a particular time point (upper panels) or the percentage of cells containing more than a certain number of foci (lower panels).

Fig 5X. Cell cycle analysis of Compound 822-treated cells after 6Gy irradiation.

[0021] PSN1 cells were treated with 40nM Compound 822 1h prior to 6Gy irradiation in triplicate wells. Cells were lifted and fixed at several time points after IR, stained with propidium iodide and analysed by flow cytometry.

A) Cell cycle histogram plots. Fitted peaks are coloured red for G1 phase, shaded for S-phase, and green for G2/M phase. One out of three wells is shown for each time point and treatment.

B) Average cell cycle percentages over time. Cell cycle percentage values were obtained from fitted histogram plots (n=3) and plotted for control-treated and Compound 822-treated cells.

Figure 6X. MiaPaCa Tumor Volume over Time for Compound 822.

Figure 7X and 8X. PSN-1 Tumor Volume over Time for Compound 822.

Figure 1Y. Lung Cancer Cell Screen: VE-822 Synergizes with Chemotoxics Across a Panel of Lung Cancer Cell Lines in Lung Cell Viability Assay

Figure 2Y. Lung Cancer Cell Screen: VE-822 Exhibits Greater than 3-fold Synergy with Chemotoxics in Lung Cancer Cell Lines in a Cell Viability Assay

Figure 3Y. Pancreatic Cancer Cell Screen: VE-822 Synergizes with Cisplatin and Gemcitabine in Pancreatic Cancer Cell Lines in a Cell Viability Assay

Figure 4Y. Pancreatic Cancer Cell Screen: VE-822 Exhibits Greater than 3-fold Synergy with Chemotoxics in Pancreatic Cancer Cell Lines a Cell Viability Assay

Figure 5Y. Effect of VE-822 and cisplatin on tumor volume and body weight in a primary adenocarcinoma NSCLC xenograft in SCID mice.

Figure 6Y: Effect of VE-822 administered PO q2d at 10, 30 or 60 mg/kg in combination with gemcitabine (15 mg/kg IP q3d) on the tumor volume of mice bearing PSN1 pancreatic cancer xenografts.

DETAILED DESCRIPTION OF THE INVENTION

[0022] One aspect of this invention provides methods for treating pancreatic cancer in a patient by administering to the patient an ATR inhibitor in combination with another known pancreatic cancer treatment. One aspect of the invention includes administering the ATR inhibitor in combination with gemcitabine. In some embodiments, the pancreatic cancer comprises one of the following cell lines: PSN-1, MiaPaCa-2 or Panc-1. According to another aspect, the cancer comprises the primary tumor line Panc-M.

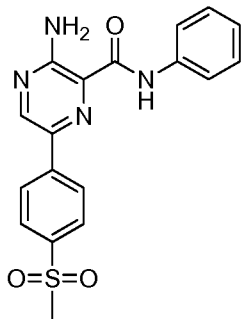
[0023] Another aspect of the invention provides methods for treating cancer (e.g., pancreatic or non-small cell lung) in a patient by administering to the patient an ATR inhibitor in combination with radiation therapy.

[0024] Another aspect of the invention provides methods for treating non-small cell lung cancer in a patient by administering to the patient an ATR inhibitor in combination with cisplatin or carboplatin, etoposide, and/or ionizing radiation. Applicants have demonstrated synergy of ATR inhibitors in combination with cisplatin, etoposide, gemcitabine, oxaliplatin and irinotecan in viability assays against

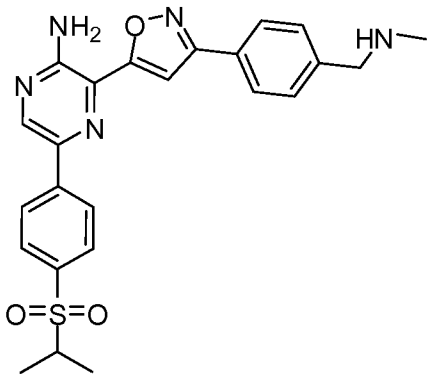
a panel of 35 human lung cancer cell lines as well as demonstrated in vivo efficacy in a lung cancer mouse model in combination with cisplatin. This invention also relates to the use of ATR inhibitors in combination with cisplatin or carboplatin, etoposide, and/or ionizing radiation for treating non-small cell lung cancer.

[0025] Examples of ATR inhibitors are shown in Table 1 below:

Table 1



821



822

[0026] The terms referring to compounds 821 and 822 are interchangeable with VE-821 and VE-822, respectively.

[0027] Another aspect provides a method of treating pancreatic cancer by administering to pancreatic cancer cells an ATR inhibitor selected from a compound in Table 1 in combination with one or more cancer therapies. In some embodiments, the ATR inhibitor is combined with chemoradiation, chemotherapy, and/or radiation therapy. As would be understood by one of skill in the art, chemoradiation refers to a treatment regime that includes both chemotherapy (such as gemcitabine) and radiation. In some embodiments, the chemotherapy is gemcitabine.

[0028] Yet another aspect provides a method of increasing the sensitivity of pancreatic cancer cells to a cancer therapy selected from gemcitabine or radiation therapy by administering an ATR inhibitor selected from a compound in Table 1 in combination with the cancer therapy.

[0029] In some embodiments, the cancer therapy is gemcitabine. In other embodiments, the cancer therapy is radiation therapy. In yet another embodiment the cancer therapy is chemoradiation.

[0030] Another aspect provides a method of inhibiting phosphorylation of Chk1 (Ser 345) in a pancreatic cancer cell comprising administering an ATR inhibitor

selected from a compound in Table 1 after treatment with gemcitabine (e.g., 100 nM) and/or radiation (e.g., 6 Gy) to a pancreatic cancer cell.

[0031] Another aspect provides method of radiosensitizing hypoxic PSN-1, MiaPaCa-2 or PancM tumor cells by administering an ATR inhibitor selected from a compound in Table 1 to the tumor cell in combination with radiation therapy.

[0032] Yet another aspect provides a method of sensitizing hypoxic PSN-1, MiaPaCa-2 or PancM tumor cells by administering an ATR inhibitor selected from a compound in Table 1 to the tumor cell in combination with gemcitabine.

[0033] Another aspect provides a method of sensitizing PSN-1 and MiaPaCa-2 tumor cells to chemoradiation by administering an ATR inhibitor selected from a compound in Table 1 to the tumor cells in combination with chemoradiation.

[0034] Another aspect provides a method of disrupting damage-induced cell cycle checkpoints by administering an ATR inhibitor selected from a compound in Table 1 in combination with radiation therapy to a pancreatic cancer cell.

[0035] Another aspect provides a method of inhibiting repair of DNA damage by homologous recombination in a pancreatic cancer cell by administering an ATR inhibitor selected from a compound in Table 1 in combination with one or more of the following treatments: chemoradiation, chemotherapy, and radiation therapy.

[0036] In some embodiments, the chemotherapy is gemcitabine.

[0037] Another aspect provides a method of inhibiting repair of DNA damage by homologous recombination in a pancreatic cancer cell by administering an ATR inhibitor selected from a compound in Table 1 in combination with gemcitabine and radiation therapy.

[0038] In some embodiments, the pancreatic cancer cells are derived from a pancreatic cell line selected from PSN-1, MiaPaCa-2 or Panc-1.

[0039] In other embodiments, the pancreatic cancer cells are in a cancer patient. In other embodiments, the cancer cells are part of a tumor.

[0040] Another embodiment provides methods for treating non-small cell lung cancer in a patient by administering to the patient an ATR inhibitor in combination with other known non-small cell lung cancer treatments. One aspect of the invention includes administering to a patient an ATR inhibitor in combination with cisplatin or carboplatin, etoposide, and / or ionizing radiation.

[0041] Another aspect provides a method of treating non-small cell lung cancer by administering to a patient an ATR inhibitor selected from a compound in Table 1

in combination with one or more cancer therapies. In some embodiments, the ATR inhibitor is combined with chemoradiation, chemotherapy, and/or radiation therapy. As would be understood by one of skill in the art, chemoradiation refers to a treatment regime that includes both chemotherapy (such as cisplatin, carboplatin, or etoposide) and radiation. In some embodiments, the chemotherapy comprises Cisplatin or carboplatin, and etoposide.

[0042] Yet another aspect provides a method of increasing the sensitivity of non-small cell lung cancer cells to a cancer therapy selected from cisplatin or carboplatin, etoposide, and ionizing radiation by administering to a patient an ATR inhibitor selected from a compound in Table 1 in combination with one or more cancer therapy.

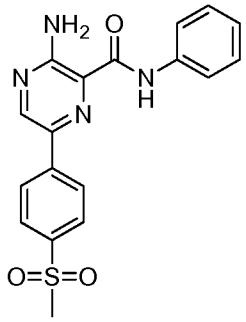
[0043] In some embodiments, the cancer therapy is cisplatin or carboplatin. In other embodiments, the cancer therapy is radiation therapy. In yet another embodiment the cancer therapy is etoposide.

[0044] In some embodiments, the cancer therapy is a combination of cisplatin or carboplatin, etoposide, and ionizing radiation. In some embodiments the cancer therapy is cisplatin or carboplatin and etoposide. In other embodiments the cancer therapy is cisplatin or carboplatin and etoposide and ionizing radiation. In yet other embodiments the cancer therapy is cisplatin or carboplatin and ionizing radiation.

[0045] Another aspect provides a method of inhibiting phosphorylation of Chk1 (Ser 345) in a non-small cell lung cancer cell comprising administering to a patient an ATR inhibitor selected from a compound in Table 1. In some embodiments, the ATR inhibitor is administered in combination with gemcitabine (e.g., 100 nM), cisplatin or carboplatin, etoposide, ionizing radiation or radiation (e.g., 6 Gy) to a non-small cell lung cancer cell.

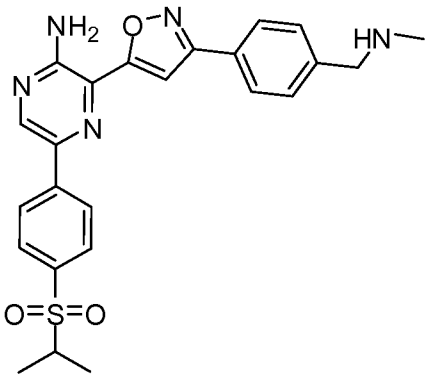
[0046] In other embodiments, the non-small cell lung cancer cells are in a cancer patient.

[0047] In some embodiments, the ATR inhibitor is



821

[0048] In other embodiments, the ATR inhibitor is



822.

Uses

[0049] Another aspect provides use of an ATR inhibitor selected from a compound in Table 1 in combination with gemcitabine and radiation therapy for treating pancreatic cancer.

[0050] Another aspect provides use of an ATR inhibitor selected from a compound in Table 1 in combination with cisplatin or carboplatin, etoposide, and ionizing radiation for treating non-small cell lung cancer.

[0051] In some embodiments, the ATR inhibitor is Compound VE-821. In other embodiments, the ATR inhibitor is Compound VE-822.

Manufacture of Medicaments

[0052] Another aspect provides use of an ATR inhibitor selected from a compound in Table 1 in combination with gemcitabine and radiation therapy for the manufacture of a medicament for treating pancreatic cancer.

[0053] Another aspect provides use of an ATR inhibitor selected from a compound in Table 1 in combination with cisplatin or carboplatin, etoposide, and ionizing radiation for the manufacture of a medicament for treating non-small cell lung cancer.

[0054] In some embodiments, the ATR inhibitor is Compound VE-821. In other embodiments, the ATR inhibitor is Compound VE-822.

EXAMPLES

[0055] The examples are for the purpose of illustration only and are not to be construed as limiting the scope of the invention in any way.

Cell viability assays

[0056] MiaPaCa-2, PSN-1, Panc1 and MRC5 cells (5 x 104) were plated in 96-well plates and after 4 h treated with increasing concentrations of VE-821 at 1 h before irradiation with a single dose of 6 Gy. Medium was replaced 96 h post-irradiation at which point viability was measured using the using the Alamar Blue assay (Resazurin substrate, SIGMA). Cells were allowed to proliferate and cell viability was again analyzed at day 8 for the different treatment conditions. Cell viability and surviving fraction were normalized to the untreated (control) group.

Clonogenic survival assay

[0057] Logarithmically growing cells were plated in triplicate in 6-well tissue culture dishes under oxic (21% O_2) or hypoxic conditions (0.5% O_2) using an InVivo2 300 chamber (Ruskinn Technology, UK). Cells were incubated for 6 hours before irradiation under oxia or hypoxia using tightly sealed chambers. The target O_2 level was achieved within 6 h of gassing and maintained during irradiation, as confirmed by an OxyLite oxygen probe (Oxford Optronix). Cells irradiated under hypoxia were exposed to normoxia at 1 h post-irradiation. As standard, VE-821 (1 μM) was added 1 h prior to irradiation (6 Gy) and was washed away 72 h after irradiation. For the chemotherapy experiments, cells were initially exposed to increasing concentrations

of gemcitabine (5, 10 and 20 nM) for 24 h before addition of the VE-821 (1 μM) for another 72 h. The effect of triple combination of irradiation with VE-821 and gemcitabine was examined as well. Cells were incubated for 10-21 days until colonies were stained with 0.5% crystal violet and counted in a CellCount automated colony counter (Oxford Optronix). Clonogenic survival was calculated and data were fitted in the GraphPad Prism 4.0 (GraphPad Software, CA).

Western blot

[0058] MiaPaCa-2 and PSN-1 cells were exposed to gemcitabine and/or 1 μM VE-821 drug 1 h prior to irradiation with a single dose of 6 Gy. Cells were lysed in RIPA buffer 2 h post-irradiation and subjected to SDS-PAGE electrophoresis and immunoblotting. Chemoluminescence (SuperSignal, Millipore) and film exposure was used to detect antibody binding. Exposed film was digitized and figures were assembled using Microsoft PowerPoint.

Nuclear foci analysis

[0059] Cells growing in 96-well plates were treated with 1 μM VE-821 drug 1 h prior to 6 Gy irradiation and fixed in 3% formaldehyde at multiple time points. Cells were subsequently pearmeabalised and blocked in PBS with 0.1% Triton 1% BSA (w/v). Cells were incubated with primary antibody overnight at 4°C and after a PBS wash incubated with fluorescently labeled secondary antibody followed gy a PBS wash and nuclear staining with DAPI. Images were acquired and foci quantitated using an IN Cell Analyzer 1000 automated epifluorescence microscope and analysis software (GE Healthcare, Cahlfont St. Giles, UK)

Cell Cycle Analysis

[0060] Cells growing in 6-well dishes were treated with 1 μM VE-821 drug 1 h prior to 6 Gy irradiation. Cells were incubated for 6 h before irradiation under oxia (21% O2) or hypoxia (0.5% O2) using tightly sealed chambers. At multiple time points, cells were lifted in trypsin and fixed in 70% ethanol and stored at 4°C. Cells were incubated with propidium iodide (50 μg/ml in PBS containing 200 μg/ml RNAse) for 1 h at room temperature and analysed by flow cytometry (FACSort, Becton Dickinson). Cell cycle phase was quantitated using ModFit Cell Cycle Analysis software.

Cell Seeding and Compound Addition for Lung Cancer Cell Screen

[0061] All cell lines were seeded in 30 µl of tissue culture medium containing 10% FBS into 384-well opaque-bottom assay plates. The seeding density was based on the logarithmic growth rate of each cell line. After 24 hours, compound stock solutions were added to each well to afford a matrix consisting of 5 concentrations for VE-822 and 6 concentrations for chemotoxics. Each well contains either, agent alone or a combination of both agents. The final concentration range for VE-822 was 25 nM-2 µM. The concentration ranges for the chemotoxics were as follows: Etoposide, 10 nM-10 µM; Gemcitabine, 0.16 nM-160 nM; Cisplatin, 20 nM-20 µM; Oxaliplatin, 40 nM-40 µM; Irinotecan (SN-38), 0.12 nM-120 nM. The cells were then incubated for 96 hours at 37°C in an atmosphere of 5% CO_2 and 95% humidity.

Cell Seeding and Compound Addition for the Pancreatic Cancer Cell Screen

[0062] All cell lines were seeded in 30 µl of tissue culture medium containing 10% FBS into 384-well opaque-bottom plates. The seeding density was based on the logarithmic growth rate of each cell line. After 24 hours, compound stock solutions were added to each well to afford a matrix consisting of 9 concentrations for VE-822 and 7 concentrations for Gemcitabine and Cisplatin. Each well contains either, agent alone or a combination of both agents.The final concentration ranges were as follows: VE-822, 0.3 nM-2 µM; Gemcitabine, 0.3 nM-0.22 µM; Cisplatin, 30 nM-20 µM. The cells were then incubated for 96 hours at 37°C in an atmosphere of 5% CO_2 and 95% humidity.

Cell Viability Assay

[0063] This assay measures the number of viable cells in a culture based on the quantitation of ATP, which is present in metabolically active cells.

[0064] CellTiter-Glo Reagent (Promega, Madison, WI, USA) was prepared according to the manufacturer's instructions and added 96 hours after compound addition (25 µl/well) to measure cell viability. Luminescence signal was measured with the PHERAStarFS (BMG Labtech, Cary, NC, USA) automated plate reader. All cell lines were screened in duplicate.

[0065] Raw luminescence CellTiter-Glo (CTG) values were normalized to the mean CTG value for the negative control DMSO-treated samples on each assay plate. IC_{50} values for chemotoxic alone were calculated using DMSO-normalized cell survival

values for the samples treated with chemotoxic compound alone. To determine fraction of cell survival in the presence of VE-822, raw CTG values were normalized to the mean CTG value for the samples exposed to the same concentration of VE-822 in the absence of the chemotoxic compound. VE-822 -treated chemotoxic IC_{50} values were calculated using VE-822 -normalized cell survival values for all samples treated with the chemotoxic at a given concentration of VE-822. A 3x or greater reduction in IC_{50} was used to identify strongly synergistic effects between VE-822 and chemotoxics.

Primary Adenocarcinoma NSCLC Xenograft Model

[0066] Tumor tissue was excised from a patient with a poorly differentiated adenocarcinoma. This tumor tissue was implanted subcutaneously in the flank of a SCID mouse and passaged twice before compound testing. For compound testing passage-two tumor tissue was implanted subcutaneously in the flank of SCID mice and tumors grown to a volume of about $200mm^3$. Cisplatin was dosed alone at either 1 or 3 mg/kg ip, once per week (ip, q7d, on day 2 of each week) for two weeks. VE-822 was dosed as a solution alone at 60 mg/kg *po* on 4 consecutive days per weekly cycle (qd4, dosed on days 1, 2, 3 and 4 each week). Two combination groups received cisplatin at 1 or 3 mg/kg plus VE-822 at 60 mg/kg *po* on the same schedule as the single agent group. A control group received vehicle alone (10% Vitamin E TPGS in water, po qd4). All drug treatment was stopped on Day 28. Vehicle, cisplatin (1 mg/kg) and VE-822 (60 mg/kg) groups were sacrificed and the remainder monitored for a further 40 days to assess tumor re-growth.

PSN1 Pancreatic Cancer Xenograft Model

[0067] PSN1 cells (1×10^6 cells per mouse) were implanted as a mixture in Matrigel (100µl per mouse) into the flank of female nude MF1 mice and grown to a volume of about $200mm^3$ prior to compound administration. Gemcitabine was dosed alone at 15 mg/kg ip, once every three days (ip, q3d) in 0.5% methylcellulose in water for a maximum of 10 cycles. VE-822 was dosed, as a suspension in 0.5% methylcellulose in water, alone at either 10, 30 or 60 mg/kg *po* every other day for 28 days (po q2d). Three combination groups received gemcitabine at 15 mg/kg plus VE-822 either at 10, 30 or at 60 mg/kg *po* on the same schedule as the single agent groups. A control group received vehicle alone (0.5% methylcellulose ip q3d). All

drug treatment was stopped on Day 30. Vehicle and VE-822 groups were sacrificed on day 13 due to excessive tumor volumes.

RESULTS

Compounds VE-821 and VE-822 sensitize pancreatic cancer cells to radiation therapy

Compound VE-821 inhibits phosphorylation of Chk1 (Ser 345) after treatment with gemcitabine (100 nM), radiation (6 Gy) or both (see Fig. 1A). Compound VE-821 radiosensitises pancreatic tumour cells but not normal cells. When cells were irradiated in the presence of Compound VE-821, a decrease in surviving fraction was observed and this radiosensitising effect increased as the drug incubation time after irradiation was extended (see figure 1C).

[0068] Compound VE-821 radiosensitises tumour PSN-1, MiaPaCa-2 and PancM cells under hypoxic conditions (see figure 2A-B). Compound VE-821 also sensitises normoxic and hypoxic cancer cells to gemcitabine (see figure 3B-C). Compound VE-821 potentiates the effect of chemoradiation in both PSN-1 and MiaPaCa-2 cancer cells (see figure 3D). Compound VE-821 disrupts damage-induced cell cycle checkpoints (see supplementary figure 2). Compound VE-821 inhibits repair of DNA damage by homologous recombination (see figures 5A, 5B, and 5C).

[0069] Results for Compounds 821 and 822 are shown in Figures 1X to 8X and 1Y to 6Y. VE-821 and VE-822 sensitize cancer cells to radiation therapy (see Figures 1X-5X).

VE-822 enhances the antitumor effects of cancer therapies in xenograft models

[0070] VE-822 enhances the antitumor effects of ionizing radiation in a MiaPaCa pancreatic cancer xenograft model (see Figure 6X) and in a PSN-1 pancreatic cancer xenograft model (see Figures 7X and 8X).

[0071] VE-822 enhances the antitumor effects of cisplatin in a primary adenocarcinoma NSCLC xenograft model. Figure 5Y shows the effect of VE-822 and cisplatin on tumor volume and body weight in a primary adenocarcinoma NSCLC xenograft in SCID mice. Data are mean ± sem, n = 9-10. Black filled circles are vehicle treatment; Red filled diamonds are Cisplatin treatment (1mg/kg q7d); Blue filled diamonds are Cisplatin treatment (3mg/kg q7d); Green filled squares are VE-822 treatment (60mg/kg qd4); Green empty triangles are Cisplatin (1mg/kg) and VE-

822 (60mg/kg qd4); Blue empty triangles are Cisplatin (3mg/kg) and VE-822 (60mg/kg qd4) (see Figure 5Y).

[0072] VE-822 also enhances the antitumor effects of gemcitamine in a PSN1 pancreatic cancer xenograft model. Figure 6Y shows the effect of VE-822 administered PO q2d at 10, 30 or 60 mg/kg in combination with gemcitabine (15 mg/kg IP q3d) on the tumor volume of mice bearing PSN1 pancreatic cancer xenografts. Data shown are mean tumor volume ± SEM (n = 8 per group). Red filled circles are VE-822 treatment; Black filled squares are vehicle treatment; Green filled circles are gemcitabine treatment; Blue filled circles are gemcitabine and VE-822 (10mg/kg) treatment; Red filled circles are gemcitabine and VE-822 (30mg/kg) treatment; Pink filled circles are gemcitabine and VE-822 (60mg/kg) treatment;

VE-822 synergizes with chemotoxics across a panel of lung cancer cell lines

[0073] The heat map represents the maximum shift in IC_{50} of each chemotoxic achieved when combined with VE-822 for 96 hours. Colors represent an IC_{50} shift range from -10 (antagonism, blue) to 10 (synergy, red) (see Figure 1Y). VE-822 exhibits greater than 3-fold synergy with cisplatin, etoposide, gemcitabine, oxaplatin and irinotecan in lung cancer cell lines (see Figure 2Y).

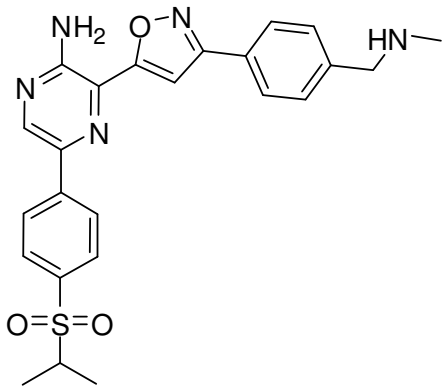
VE-822 Synergizes with Cisplatin and Gemcitabine in pancreatic cancer cell lines.

[0074] The heat map represents the maximum shift in IC_{50} of each chemotoxic achieved when combined with VE-822 for 96 hours. Colors represent an IC_{50} shift range from -10 (antagonism, blue) to 10 (synergy, red) (see Figure 3Y).

[0075] While we have described a number of embodiments of this invention, it is apparent that our basic examples may be altered to provide other embodiments that utilize the compounds, methods, and processes of this invention. Therefore, it will be appreciated that the scope of this invention is to be defined by the appended claims rather than by the specific embodiments that have been represented by way of example herein.

CLAIMS

1. Use of an ATR inhibitor of the formula



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in the manufacture of a medicament for treating pancreatic cancer in combination with another cancer therapy selected from:

- gemcitabine;
- radiation therapy; and
- both gemcitabine and radiation therapy.

2. The use according to claim 1, comprising sensitising pancreatic cancer cells to the cancer therapy, wherein the cancer therapy is gemcitabine and radiation therapy.

3. The use according to claim 2, wherein the pancreatic cancer cells are hypoxic pancreatic cancer cells.

4. The use according to any one of claims 1-3, wherein the cancer therapy is radiation therapy.

5. The use according to any one of claims 1-3, wherein the cancer therapy is gemcitabine.

6. The use according to claim 1, in combination with both gemcitabine and radiation therapy, comprising sensitizing pancreatic cancer cells to chemoradiation.

7. The use according to claim 1, in combination with radiation therapy, comprising disrupting damage-induced cell cycle checkpoints in pancreatic cancer cells.

8. The use according to claim 1, in combination with radiation therapy, comprising inhibiting repair of DNA damage by homologous recombination in pancreatic cancer cells.