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(54) Titre : COMPOSITION DE MEDICAMENT CYTOTOXIQUE POUR DES CELLULES DE CANCER PANCREATIQUE
(54) Title: DRUG COMPOSITION CYTOTOXIC FOR PANCREATIC CANCER CELLS

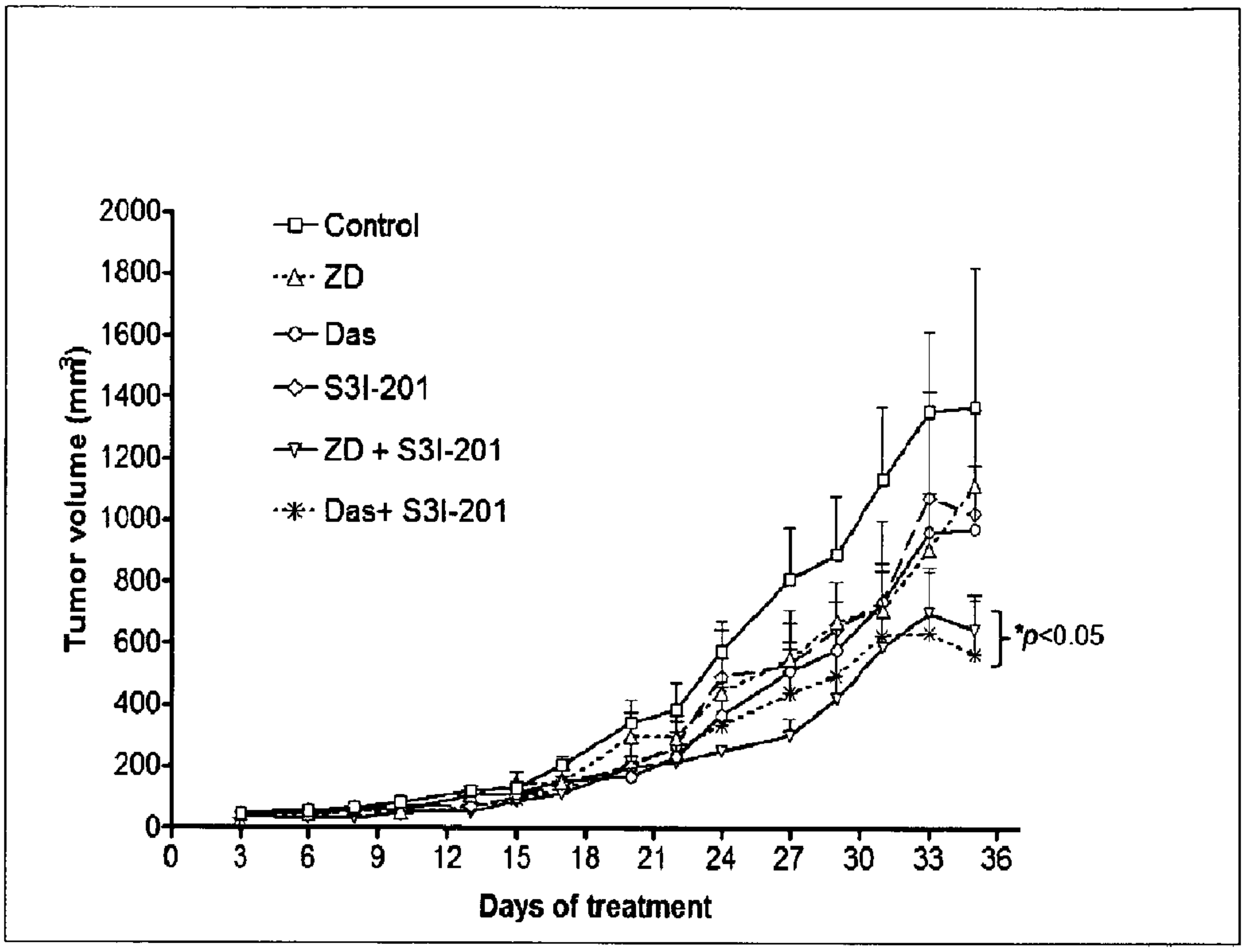

FIG. 6

(57) Abrégé/Abstract:
The invention describes a cytotoxic composition containing a drug combination targeting two or more functional elements in pancreatic cancer cells, the functional elements comprising EGFR or Src and Stat3 or Jaks. Preferred drugs in the drug

(57) Abrégé(suite)/Abstract(continued):
combination are selected from ZD and S3I-201, Das and S3I-201, ZD and AG490, Das and AG490, and combinations thereof. In a preferred embodiment of the invention, the drug combination further includes a nucleoside analog inhibitory for DNA replication, for example, Gemcitabine. Disclosed is also a method of cytotoxically affecting pancreatic cancer cells using the described drug combination. A method of making the cytotoxic composition is additionally described.

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(54) **Title**: DRUG COMPOSITION CYTOTOXIC FOR PANCREATIC CANCER CELLS

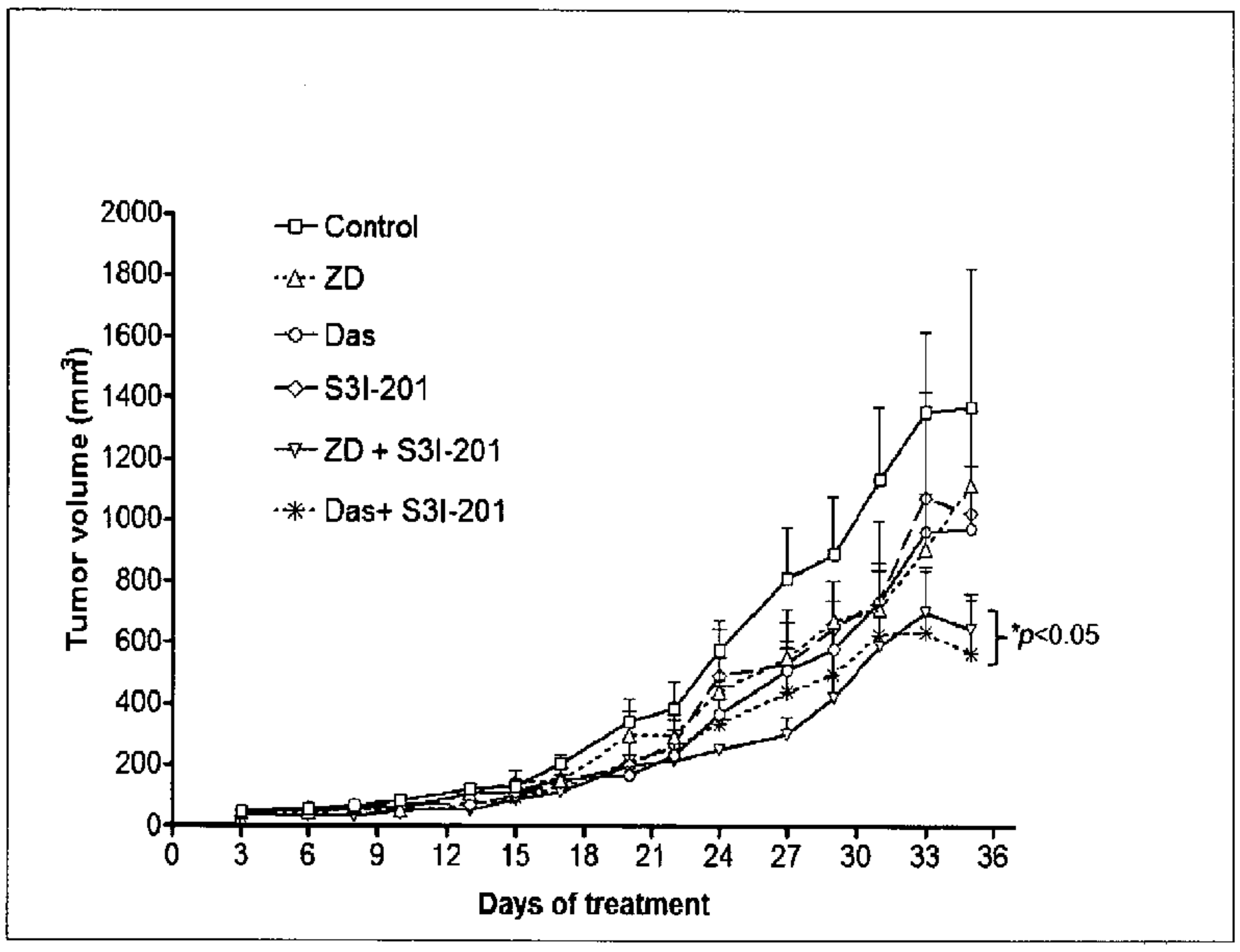

FIG. 6

(57) **Abstract**: The invention describes a cytotoxic composition containing a drug combination targeting two or more functional elements in pancreatic cancer cells, the functional elements comprising EGFR or Src and Stat3 or Jaks. Preferred drugs in the drug combination are selected from ZD and S3I-201, Das and S3I-201, ZD and AG490, Das and AG490, and combinations thereof. In a preferred embodiment of the invention, the drug combination further includes a nucleoside analog inhibitory for DNA replication, for example, Gemcitabine. Disclosed is also a method of cytotoxically affecting pancreatic cancer cells using the described drug combination. A method of making the cytotoxic composition is additionally described.

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DRUG COMPOSITION CYTOTOXIC FOR PANCREATIC CANCER CELLS

Related Application

This application claims priority from co-pending US provisional applications Serial No. 61/118,792, which was filed on 01 December 2008, and Serial No. 61/249,307, which was filed on 07 October 2009, both of which are incorporated herein by reference in their entirety.

Statement of Government Rights

The invention was made with support from the US Government. Accordingly, the government may have certain rights in the invention, as specified by law.

Field Of The Invention

The present invention relates to the field of drug development and, more particularly, to a drug composition cytotoxic for pancreatic cancer cells.

Background Of The Invention

Pancreatic cancer is a lethal disease with a poor prognosis and a mortality rate nearly the same as the rate of incidence. Moreover, the disease remains poorly understood. Multiple signal transduction proteins are activated during pancreatic ductal cell carcinogenesis, some may be secondary events, while many others might have critical roles and collectively contribute to the maintenance and the progression of the disease and its responsiveness to therapy. One of the major molecular abnormalities is the overexpression and/or activation of the EGFR protein, which has an incidence of 30-50% of pancreatic cancer cases (1). Evidence indicates that the hyperactive EGF/EGFR duo is important in the disease maintenance and progression (2). Similarly, the overexpression of the c-Src tyrosine kinase occurs in a large percentage of pancreatic adenocarcinoma and is observed to augment EGFR activities during tumorigenesis (3, 4). The over-activity of Src family kinases leads to deregulation of tumor cell growth and survival, disruption of cell-to-cell contacts, and the promotion of migration and invasiveness, and the induction of tumor angiogenesis (4, 5).

Another molecular abnormality is the aberrant activation of Stat3, a member of the Signal Transducer and Activator of Transcription (STAT) family of cytoplasmic transcription factors, which has also been detected in pancreatic tumors and tumor cell lines and been implicated in the disease (6-9). Stat3, as are the other STATs, requires extrinsic tyrosine phosphorylation to become activated and this is induced by growth factor receptors and cytoplasmic tyrosine kinases, such as Src and Janus kinase (Jaks) families (10). In contrast to normal STAT signaling that is transient in accordance with the requirements for normal biological processes, tumor cells harbor aberrant Stat3 activation. Studies show that aberrant Stat3 dysregulates cell growth and survival, promotes tumor angiogenesis, cell migration and invasion, and induces tumor immune tolerance (11-13).

De-regulated signal transduction provides the framework for functional cooperativity and signaling cross-talk that would not only support the malignant phenotype and the disease progression, but also influence the drug responsiveness. Within the context of the concurrent activation of EGFR, Src and Stat3 in pancreatic cancer, the potential for cooperation between EGFR and Src kinases to induce aberrant Stat3 activation and to cooperate in support of the cancer phenotype is a reasonable model to propose. Knowledge of this functional relationship and the collective roles of the proteins in supporting pancreatic cancer can facilitate the design of effective, multiple-targeted therapy for disease. We provide evidence that EGFR and Src promote constitutive Stat3 activation, with a compensatory Stat3 activation mechanism from Jaks, and together support the pancreatic cancer phenotype. Importantly, our study identifies that the concurrent inhibition of aberrant Stat3 and EGFR or Src is more effective in inducing antitumor cell response and pancreatic tumor regression in xenografts.

Summary Of The Invention

With the foregoing in mind, the present invention advantageously provides a cytotoxic composition containing a drug combination targeting two or more functional elements in pancreatic cancer cells, the functional elements comprising EGFR or Src and Stat3 or Jaks. A preferred embodiment of the cytotoxic composition is one wherein the drug combination contained therein is selected from ZD and S3I-201, Das and S3I-201, ZD and AG490, Das and AG490, and combinations thereof. Furthermore, the preferred cytotoxic composition is that wherein the drug combination inhibits said functional elements at substantially the same time. The preferred composition of the present invention may also comprise a nucleoside analog inhibitory for DNA replication, for example, Gemcitabine.

The invention herein disclosed also includes a method of cytotoxically affecting (which could result in killing) pancreatic cancer cells, the method comprising contacting the cells with a drug combination which inhibits two or more cellular functional elements, the functional elements including EGFR or Src and Stat3 or Jaks. The method of the invention also includes an embodiment wherein the drug combination is selected from ZD and S3I-201, Das and S3I-201, ZD and AG490, Das and AG490, and combinations thereof. A preferred method of the invention also includes contacting the cells with a drug combination further comprising a nucleoside analog inhibitory for DNA replication, the nucleoside analog preferably being Gemcitabine.

The invention additionally includes a method of making a therapeutic medication cytotoxic for pancreatic cancer cells, the method comprising preparing a pharmaceutically acceptable composition containing a drug combination selected from ZD and S3I-201, Das and S3I-201, ZD and AG490, Das and AG490, and combinations thereof. The method of making the medication preferably also includes an embodiment wherein the drug combination further comprises a nucleoside analog inhibitory for DNA replication, for example, Gemcitabine.

Brief Description Of The Drawings

Some of the features, advantages, and benefits of the present invention having been stated, others will become apparent as the description proceeds when taken in conjunction with the accompanying drawings in which:

FIG. 1 shows EMSA and immunoblotting analyses of Stat3, Src and EGFR activities for effects of inhibitors. (A) EMSA analysis of STAT DNA-binding activity using (i) high-affinity sis-inducible element (hSIE) probe that binds Stat3 and Stat1 or (ii) mammary gland factor element (MGFe) probe that binds Stat1 or Stat5; and (B and C) Immunoblotting analysis of whole-cell lysates from cells (B) (i) untreated or (ii) treated with ZD 1839 (ZD), or Dasatinib (Das), or transfected with or without (iii) Src siRNA, (iv) EGFR siRNA, or scrambled siRNA control (con) and probing for pY416c-Src (pY416Src), Src, pY845EGFR, and EGFR; and (C) untreated or treated with ZD or Das and probing for (i) pY1068EGFR, (ii) pY1086EGFR and (iii) pY1173EGFR, and EGFR. Positions of STAT:DNA complexes in gel are shown; *Supershifts were performed with antibodies specifically recognizing either Stat1 (a-Stat1), Stat3 (a-Stat3), or Stat5 (a-Stat5a or a-Stat5b); asterisk indicates position of supershifted complexes. Data are consistent with those obtained from 4 independent experiments.

FIG. 2 depicts EMSA and immunoblotting analyses for effects of inhibitors on Stat3. (A and B) EMSA analysis of Stat3 DNA-binding activity in (A) Panc-1 or (B) Colo-357 cells treated or untreated with the pan ErbB inhibitor, PD169540 (PD169), ZD 1839 (ZD), Dasatinib (Das), the Jak inhibitor, AG490, the ErbB2-selective inhibitor, AG879, or inhibitor combinations for the indicated times, or (C) immunoblotting analysis of whole-cell lysates from Panc-1 cells transfected with EGFR siRNA, Src siRNA, or scrambled siRNA (control) and probing for pStat3 or Stat3. *Supershift analysis. Data are consistent with those obtained from 3 independent experiments.

FIG. 3 presents data of cell viability studies for effects of inhibitors. (A and B) Trypan blue exclusion/phase-contrast microscopy for viable Panc-1 or Colo-357 cells following treatment for 0-96-h inhibitor with 1 μM ZD, 100 nM Das, 50 μM S3I-201, Jak inhibitor, AG490, or combinations; (C and D) CyQuant cell proliferation assay for viability of Panc-1 (C, left panel, and D(i)) or Colo-357 cells (C, right panel and D(ii)) for effects of 48-h treatments with the designated concentrations of ZD, Das, S3I-201, Gemcitabine (Gem) alone and in combinations. Values, mean and S.D., n=4 experiments each in triplicates. p values, * - <0.05 , ** - <0.01, and *** - <0.001.

FIG. 4 shows colony survival and apoptosis studies for effects of inhibitors. (A) Number of colonies emerging from cells in culture (500 per 6 cm dish) untreated or treated once with ZD1839 (ZD), Dasatinib (Das), S3I-201 (S3I), or combinations and allowed to culture; or (B) Annexin V binding/Flow Cytometry analysis of normal HPDEC, Panc-1 or Colo-357 cells treated or untreated with inhibitors or combinations. Values, mean and S.D., n=4 experiments each in triplicates. p values, * - <0.05 , ** - <0.01, and *** - <0.001.

FIG. 5 presents the concurrent inhibition of Stat3 and EGFR or Src inhibits migration and invasion and suppresses c-Myc expression. (A) Effects of ZD1839 (ZD), Dasatinib (Das), and/or S3I-201 (S3I) on migration and invasion; (B) Immunoblotting analysis of whole-cell lysates for c-Myc and b-Actin expression in Panc-1 cells. Values, mean and S.D., n= 3-4 experiments each in triplicates. p values, * - <0.05 , ** - <0.01, and *** - <0.001.

FIG. 6 is a line graph showing progression of tumor volume under the different therapies; concurrent inhibition of Stat3 and EGFR or Src induces human pancreatic tumor growth inhibition in xenografts.

Detailed Description of Preferred Embodiments

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. Unless otherwise defined, 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 pertains. Although methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present invention, suitable methods and materials are described below. Any publications, patent applications, patents, and other references mentioned herein are incorporated by reference in their entirety. In case of conflict, the present specification, including any definitions, will control. In addition, the materials, methods and examples given are illustrative in nature only and not intended to be limiting. Accordingly, this invention may be embodied in many different forms and should not be construed as limited to the illustrated embodiments set forth herein. Rather, these illustrated embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Other features and advantages of the invention will be apparent from the following detailed description, and from the claims.

Materials and Methods

Cells and Reagents.

v-Src-transformed mouse fibroblasts (NIH3T3/v-Src), human pancreatic cancer (Panc-1) and leukemic (K562) lines have been described (14-16). The human pancreatic cancer lines, Colo-357 and Mia-PaCa-2 were kind gifts from Drs. Lancaster and Mokenge (Moffitt Cancer Center). The immortalized human pancreatic duct epithelial cell (HPDEC) line was obtained from Dr. Tsao, OCI, UHN-PMH, Toronto) (17). Except for HPDEC grown in Keratinocyte-SFM media supplemented with 0.2 ng EGF, 30 µg/mL bovine pituitary extract and containing antimycol, and K562 line in RPMI 1640 containing 10% heat-inactivated FBS and 100 units/ml penicillin-streptomycin, all other cell lines were grown in Dulbecco's modified Eagle's medium (DMEM) containing 5% iron-supplemented bovine calf serum and 100 units/ml penicillin-streptomycin. Recombinant human EGF (hEGF) is from Creative Biolabs, Port Jefferson Station, NY); Gemcitabine is from Ely Lilly (Indianapolis, IN).

Nuclear Extract Preparation and Gel Shift Assays.

Nuclear extract preparation and DNA-binding with electrophoretic mobility shift assay (EMSA) were carried out, as previously reported (14, 15). The ^{32}P-labeled oligonucleotide probes used were hSIE (high affinity *sis*-inducible element from the *c-fos* gene, m67 variant), 5'-AGCTTCATTTCCCGTAAATCCCTA; (SEQ ID NO:1) that binds Stat1 and Stat3 (Wagner et al., 1990) and the MGFe (mammary gland factor element from the bovine β-casein gene promoter, 5'-AGATTTCTAGGAATTCAA; (SEQ ID NO:2) that binds Stat1 and Stat5 (Gouilleux et al., 1995; Seidel et al., 1995).

SDS-PAGE/Western Blot Analysis.

Western blotting analysis was performed as previously described (15, 18). Primary antibodies used were anti-Stat3 (C20) (Santa Cruz, Santa Cruz, CA), anti-pY845EGFR (Upstate Biotech, Millipore, Billerica, MA), and antibodies against pY705Stat3, Stat3, pY1068EGFR, pY1086EGFR, pY1173EGFR, EGFR, pY416Src, Src, c-Myc, and ß-Actin from Cell Signaling (Danvers, MA).

Small-interfering RNA (siRNA) Transfection.

siRNA sequences for EGFR and Src were ordered from Dharmacon RNAi Technologies, Thermo Scientific (Lafayette, CO). Sequences used are: EGFR sense strand, 5'-GAAGGAAACUGAAUUCAAAUU-3', SEQ ID NO:3; EGFR antisense strand, 5'-UUUGAAUUCAGUUUCCUUCUU-3, SEQ ID NO:4'; control siRNA sense strand, 5'-AGUAAUACAACGGUAAAGAUU-3', SEQ ID NO:5; and control siRNA antisense strand, 5'-UCUUUACCGUUGUAUUACUUU-3', SEQ ID NO:6. The c-Src SMARTpool siRNA reagent (NM-005417, Catalog # M-003175-01-05) was used for Src. Transfection into cells was performed using 20 nM of EGFR siRNA or 25 nM of Src siRNA and 8 µl Lipofectamine RNAiMAX (Invitrogen Corporation, Carlsbad, CA) in OPTI-MEM culture medium (GIBCO, Invitrogen).

Cell Proliferation/Viability Assay and Annexin V Binding and Flow Cytometry.

Proliferating cells in 6-well or 96-well plates were treated once with 0.1-1 mM ZD1839 (Iressa), 100 nM Dasatinib, 50-100 µM S3I-201, 1 µM Gemcitabine, or combinations of inhibitors for up to 96 h. Viable cells were counted by trypan blue exclusion/phase contrast microscopy or assessed by CyQuant cell viability assay, according to manufacturer's (Invitrogen) instructions, or cells were processed for Annexin V binding (BD Biosciences) with flow cytometry for apoptosis. S3I-201 is fully described in reference 30 (see below).

Colony Survival Assay.

Single-cell suspension of Panc-1 and Colo-357 cells were seeded in 6-cm dishes (500 cells per well) and assayed as previously reported (19), treated the next day with inhibitors for 48 h, and allowed to grow until large colonies were visible. Colonies were stained with crystal violet for 4 h and counted under phase-contrast microscope.

Cell Migration and Matrigel Invasion Assays.

Cell migration and invasion experiments were carried out and quantified as previously described (20), using Bio-Coat migration chambers (Becton Dickinson, Franklin, NJ) of 24-well companion plates with cell culture inserts containing 8 µm pore size filters, according to the manufacturer's protocol.

Statistical analysis.

Statistical analysis was performed on mean values using Prism GraphPad Software, Inc. (La Jolla, CA). The significance of differences between groups was determined by paired t-test at $p < 0.05$*, < 0.01**, and < 0.001***.

Results

Aberrant EGFR, Src and Stat3 in pancreatic cancer lines.

Consistent with published reports (6, 7), Stat3 activity, per DNA-binding with EMSA analysis in nuclear extract preparations is constitutive in Panc-1 and Colo-357, low in Mia-Paca-2, and undetectable in the normal human pancreatic duct epithelial cells (HPDEC), compared to aberrant levels in NIH3T3/v-Src (15) (FIG. 1A(i)). Per supershift analysis, the DNA-protein complex contains Stat3 (FIG. 1A(i), lane 3). By contrasts, Stat5 activity is undetectable in pancreatic cancer cells (FIG. 1A(ii)), compared to aberrant levels in the K562 leukemic cells (16).

EGFR and c-Src are aberrant in many human cancers (2, 4). Immunoblotting analysis showed a moderate pY416c-Src level in Mia-Paca-2, but enhanced levels in Panc-1 and Colo-357 cells similar to levels in NIH3T3/v-Src, compared to low levels in HPDEC (FIG. 1B(i), upper panel). The elevated pY416Src levels parallel enhanced levels of the Src-sensitive pY845EGFR motif (21) in Panc-1 and Colo-357 cells, compared to low levels of same in HPDEC (FIG. 1B(i), lower panel). Total Src or EGFR protein remained unchanged. Immunoblotting analysis further showed elevated levels of the EGFR autophosphorylation motifs (22), pY1068EGFR (FIG. 1C(i), lanes 2 and 7), pY1086EGFR (FIG. 1C(ii), lanes 2 and 7) and pY1173EGFR (FIG. 1C(iii), lanes 2 and 7) in Panc-1 and Colo-357, compared to basal levels of same in HPDEC (FIG. 1C(i)-(iii), lane 1).

Functional integration of EGFR and Src in pancreatic cancer cells.

We next examined the functional relationship between the activated EGFR and Src. Immunoblotting analysis showed treatment of cells with Dasatinib (Das) inhibited Src activity (pY416Src) (23) and induced an early (1 h) and a sustained (24 h) decrease in pY845EGFR levels (FIG. 1B(ii)). By contrast, no detectable changes in pY416Src and pY845EGFR levels were induced by treatment with the pan-ErbB inhibitor, PD169540 (PD169) (24) (data not shown) or the selective EGFR inhibitor, ZD 1839 (ZD, Iressa) (25) (FIG. 1B(ii)). In confirmation, siRNA knockdown of c-Src abrogated pY845EGFR levels (FIG. 1B(iii), Src siRNA), while EGFR knockdown by siRNA had minimal effect on pY416Src level (FIG. 1B(iv), EGFR siRNA). Scrambled siRNA has no effect (FIG. 1B(iii) and (iv), con siRNA). Thus, elevated pY845EGFR levels in pancreatic cancer cells are sensitive to Src activity.

Immunoblotting analysis further showed that treatment of Panc-1 and Colo-357 cells with ZD diminished pY1173EGFR levels (FIG. 1C(iii), lanes 3, 4, 8 and 9) by as early as 1 h and up to 24 h, with no effect on pY1068EGFR (/FIG. 1C(i), lanes 3, 4, 8 and 9) or pY1086EGFR level (FIG. 1C(ii), lanes 3, 4, 8 and 9), suggesting that EGFR kinase is essential for the induction of pY1173EGFR levels, but not pY1068EGFR or pY1086EGFR. By contrast, Das treatment decreased pY1068EGFR and pY1086EGFR levels (FIG. 1C(i) and (ii), lanes 5, 6, 10 and 11), with minimal effect on pYEGFR1173 (FIG. 1C(iii), lanes 5, 6, 10 and 11).

Both EGFR and Src promote aberrant Stat3 activation.

Both the pY1068EGFR and pY1086EGFR levels are binding sites for Stat3 (27, 28). Given the concurrent EGFR and Src activation in Panc-1 and Colo-357 cells, we sought to define the regulation of aberrant Stat3 activation. By *in vitro* DNA-binding assay with EMSA analysis of nuclear extract preparations, we observe an early repression (in the first 30 min to 1 h of treatment) of constitutively-active Stat3 by the pan-ErbB inhibitor, PD169540 (PD169), the ErbB2-selective inhibitor, AG879 (7), ZD, or Das (FIG. 2A(i), lanes 4, 5, 7, and 8, and (ii), lanes 2, 4, 6, and 11, and FIG. 2B, 1 h), or by a combined PD169 and Das (FIG. 2A(i), lanes 10 and 11, and (ii), lane 8). However, the Stat3 activity in Panc-1 cells consistently rebounded following 24 h treatments with Das, ZD, or PD169 (FIG. 2A(i) and (ii), 24 h), even though EGFR or Src activity remained inhibited (Fig 1B and 1C, 24 h). Twenty-four hour treatment with the AG879 moderately inhibited Stat3 activity (FIG. 2A(ii), lane 12), which we speculate may be due to its widespread activity as a pan-ErbB inhibitor. By contrast, treatment with the Jak inhibitor, AG490 for 1 h had no effect on constitutive Stat3 activity, but surprisingly abolished Stat3 activity at 24 h treatment (FIG. 2A(ii), lanes 9 and 10). Moreover, combined treatment with AG490 and ZD, Das or PD169 for 24 h similarly abolished constitutively-active Stat3 (FIG. 2A(ii), lanes 14, 15, and 16). In Colo-357, Stat3 activity was inhibited by both ZD and Das, with the effects more striking for Dasatinib (FIG.2B). These findings together reveal a pattern of constitutive Stat3 activation in pancreatic cancer cells that is mediated by both EGFR and Src, and a compensatory, Jak-dependent secondary Stat3 activity. A similar pattern of Stat3 activation has been observed in head and neck squamous carcinoma, mesothelioma, squamous cell skin carcinoma, and non-small cell lung cancer cell lines following the inhibition of Src (29). In further support, the siRNA knockdown of EGFR (EGFR siRNA) or Src (Src siRNA) led to pStat3 suppression, as assayed by immunoblotting analysis (FIG. 2C). Scrambled siRNA (con) has no effect. Immunoblotting analysis also shows that EGF stimulation induces pY705Stat3, pY1086EGFR, pY1173EGFR, pY845EGFR and pY416c-Src (Supplemental FIG. S1(i)-(iii), lane 4) over and above constitutive levels in Panc-1 cells, in a manner that is similar to the induction of same in response to the stimulation of normal HPDEC (Supplemental FIG. S1, lane 2), except for pY1068EGFR levels in Panc-1 (FIG. S1(ii), upper right panel). In control studies, immunoblotting analysis showed elevated pErk1/pErk2MAPK and pAkt in Panc-1 and Colo-357 cells compared to normal HPDEC, neither of which was significantly affected by treatment with ZD or Das (data not shown).

Inhibition of Stat3 sensitizes pancreatic cancer cells *in vitro* to EGFR and Src inhibitors.

Given the preceding data on the inter-relation between EGFR, Src and Stat3 activation, we investigated the biological implications and the therapeutic potential of a combinatorial approach. Dasatinib and ZD were used at 100 nM and 0.1-1 μM, respectively, as in literature reports (23, 24), while the Stat3 inhibitor, S3I-201 was used at the sub-optimum, 50 μM, or at the 100 μM required to inhibit Stat3 activation (30). Viable cell count by trypan blue exclusion/phase-contrast microscopy showed that treatment with 1 μM ZD, 100 nM Das, or 50 μM S3I-201 alone minimally affected cell viability by 24 h (FIG. 3A Day 1). By contrast, treatment for 48 to 96 h with or Das or S3I-201 alone progressively decreased cell viability, while treatment for the same period with ZD showed minimal effect (FIG. 3A), except at 96 h when the number of viable Panc-1 cells decreased (FIG. 3A(i), ZD, Day 4). Comparatively, the combined inhibition of Stat3 (by S3I-201) and EGFR (by ZD) or Src (by Das) or the combined treatment with AG490 (Jaks inhibitor) and ZD or Das induced greater losses of viability at 48-96 h (FIG. 3A and B). The effects on cell viability as captured by trypan blue exclusion were confirmed by the CyQuant cell proliferation/viability assay. Unlike 24 h treatment duration that showed minimal effect on viability (FIG. 3A), CyQuant assay showed that 48-h treatment with each inhibitor alone decreased viable cell numbers (quantified as fluorescent unit, FU) in a dose-dependent manner (FIG. 3C, ZD, Das and S3I-201). We infer from the graphs that treatment with 1 μM ZD for 48 h has minimal effect on cell viability (FIG. 3C(i) and (iv)), as observed by the trypan blue exclusion assay (FIG. 3A). However, the observed effects of single agents were significantly weaker compared to the concurrent treatment with a Stat3 inhibitor and an inhibitor of EGFR or Src. Results show that the treatment with S3I-201 increased the sensitivity of Panc-1 and Colo-357 cells to ZD and Das, shifting the dose-response curves to the left (FIG. 3C, ZD + S3I-201, and Das + S3I-201). Concurrent treatment with S3I-201 significantly decreased the IC50 values as follows: 17 to 0.4 μM, and 100 to 6 nM, respectively, for ZD and Das against Panc-1 viability (FIG. 3C(i) and (ii)); and 6.5 to 2.4 μM, and 90 to 8 nM, respectively for ZD and Das against Colo-357 viability (FIG. 3C(iv) and (v)). For the impact of ZD and Das on the sensitivity to S3I-201, CyQuant cell viability assay showed that Das, but not ZD increased the sensitivity of both cell lines to S3I-201, decreasing its IC50 from 40 to 15 μM, and from 45 to 20 μM, respectively, for effects on Panc-1 and Colo-357 cells (FIG. 3C(iii) and (iv)). Thus, treatment with S3I-201 sensitized cells to ZD and Das, while treatment with Das, but not ZD similarly sensitized cells to S3I-201.

Given the clinical implications of these findings, we extended these studies to examine the effect of EGFR Src and Stat3 pathway on the response to Gemcitabine, the anti-metabolite agent used in the treatment of pancreatic cancer. CyQuant cell proliferation/viability studies showed that inhibition of EGFR, Src or Stat3 sensitized Panc-1 and Colo-357 cells to Gemcitabine (FIG. 3D). More importantly, the combined inhibition of Stat3 and EGFR or Src induced a higher sensitization of cells to Gemcitabine than that induced by the inhibition of any one alone (FIG. 3D).

As known to the skilled, Gemcitabine is a nucleoside analog of cytidine which interferes with DNA replication, arresting tumor growth and resulting in apoptosis of the cell. Gemcitabine is also known to bind to the active site of the enzyme ribonucleotide reductase (RNR) to irreversibly inactive the enzyme, thus interfering with the cell's ability to produce deoxyribonucleotides necessary for DNA replication and repair. This also leads to apoptosis. As noted above, the combined inhibition of Stat3 and EGFR or Src induces a higher sensitization of cells to Gemcitabine, creating another possibility for combination therapy of tumors.

To further explore the sensitization potential of inhibition of aberrant Stat3, we performed colony survival assay (19). Results show that inhibition of Src (by Das) or

Stat3 (by S3I-201 (S3I)), but not EGFR inhibition (by ZD) resulted in reduced colony numbers (FIG. 4A). More importantly, the concurrent inhibition of Stat3 and EGFR or Src resulted in much lower colony numbers (FIG. 4A), consistent with the much greater loss of viable cells due to the combined inhibition of Stat3 and EGFR or Src (FIG. 3). To extend these studies, we performed Annexin V binding/Flow Cytometric analysis for apoptosis. Higher percentages of Panc-1 and Colo-357 cells undergoing apoptosis were observed for concurrent inhibition of Stat3 and EGFR or Src than for the inhibition any one signaling molecule alone (FIG. 4B(ii) and (iii)). Similar results were obtained for the concurrent treatments with AG490 and ZD or Das (FIG. 4B(ii) and (iii)). By contrast, similar treatments of normal HPDECs showed no significant apoptosis (FIG. 4B(i)) with the combination treatments. Thus, we establish that pancreatic cancer cells have higher sensitivity to concurrent inhibition of Stat3 and EGFR or Src than to the inhibition of a single entity.

EGFR, Src and Stat3 together promote pancreatic cancer cell migration and invasion.

Aberrantly-active Src and Stat3 have both been implicated in tumor cell motility, migration, invasion and metastasis (4, 23). *in vitro* matrigel assay confirmed that inhibition of Src or Stat3 alone suppresses migration and invasion (FIG. 5A). However, concurrent inhibition of Stat3 and EGFR or Src for 24-h has a stronger effect on Colo-357 migration and Panc-1 invasion, except for Src inhibition, which showed a similar effect on Panc-1 migration (FIG. 5A). At the 24-h treatment when these studies were done, there is no significant effect on cell viability (FIG. 3). These findings are further evidence that pancreatic cancer lines are more sensitive to concurrent inhibition of Stat3 and Src or EGFR.

EGFR, Src and Stat3 module regulates c-Myc over-expression in pancreatic cancer cells.

For insight into the underlying molecular mechanisms by which the EGFR, Src and Stat3 pathway may support the cancer phenotype, we studied the regulation of key cancer-relevant genes. We show that c-Myc is over-expressed in pancreatic cancer lines compared to normal HPDEC (FIG. 5B). Furthermore, the concurrent inhibition of Stat3 and EGFR or Src consistently repressed c-Myc expression. These findings suggest a functional synergy between EGFR, Src and Stat3 in inducing c-Myc expression in the context of pancreatic cancer phenotype and that the stronger repression of c-Myc expression contributes to the antitumor cell effects of and the increased sensitivity of pancreatic cancer lines to concurrent Stat3 and EGFR or Src inhibition.

Inhibition of Tumor Growth by Combination Treatment

Concurrent inhibition of Stat3 and EGFR or Src induces human pancreatic tumor growth inhibition in xenografts. Subcutaneous xenografts of Colo-357, a metastatic pancreatic adenocarcinoma line were used to study the therapeutic implication of the Stat3, EGFR and Src inter-relationships and to evaluate the *in vivo* antitumor effects of concurrent inhibition of Stat3 and EGFR or Src. Data showed that in general, xenografts of Colo-357 cells showed low responsiveness to treatment with inhibitor of EGFR, Src or Stat3 alone, although, as the therapy progressed, those tumors treated with only one inhibitor alone appeared to show reduced growth, which was statistically not significant from the control, non-treated tumors (FIG. 6). By contrast, tumors from mice treated with combined S3I-201 and Das or S3I-201 and ZD consistently showed reduced growth and smaller tumor sizes throughout the entire study (FIG. 6). Thus, the residual tumor volumes (sizes) for tumors in mice treated with combination inhibitors were significantly different ($p<0.05$) from tumor volumes for tumors in control mice at days 20 and upwards post treatment. These *in vivo* antitumor effects of combination treatment with inhibitors of S3I-201 and Das or S3I-201 and ZD are consistent with the *in vitro* antitumor cell data and together indicate that aberrant Stat3 cooperates with hyperactive EGFR or Src to sustain human pancreatic cancer.

Discussion

Within the context of aberrations in the EGFR, Src and Stat3 pathway in pancreatic cancer, present study reveals a strong role for Src in supporting aberrant EGFR activation by not only inducing the phosphorylation of Y845EGFR motif (31), but also promoting the induction of pY1068EGFR and pY1086EGFR motifs. These Src-promoted events will greatly influence the status of EGFR in pancreatic cancer cells. A role for EGFR in aberrant Stat3 activation in cancer cells has previously been reported in other tumor cells, including head and neck squamous cell carcinoma and breast cancer (26, 32). Present study extends those findings to pancreatic cancer and show that EGFR is key in facilitating aberrant Stat3 activation. Moreover, the pY1068EGFR and pY1086EGFR induction by Src is likely to have significant impact on the activation of Stat3, given that these two motifs are essential sites for the binding of Stat3 to EGFR in order to promote its phosphorylation and activation (27, 28). Furthermore, Src may not only facilitate Stat3 activation via the induction of those two Tyr motifs of EGFR, but it can also directly phosphorylate Stat3, as has been previously reported in other systems (18). It is therefore consistent that both hyperactive EGFR and Src promote baseline constitutive Stat3 activation in pancreatic cancer, as revealed by our study.

The present study is also in agreement with an earlier report of ErbB-2-dependent constitutive Stat3 activation in Mia-Paca-2 and UK Pan-1 cells (7) and another study that showed that the full induction of Stat3 activation by ErbB2 required both Src and Jaks (33). Our findings indicate that Jaks contribute to the maintenance of constitutive activation in revealing a Jak-dependent compensatory mechanism of Stat3 activation upon inhibition of EGFR and Src. Given that Jaks inhibition did not abolish aberrant Stat3 at the earliest time point, we deduce that this family of cytoplasmic tyrosine kinases may not be the predominant mediators of the baseline aberrant Stat3. Thus, in pancreatic cancer cells, a two-phase model of activation of Stat3 signaling emerges composed of an EGFR- and Src- dependent baseline, constitutive Stat3 induction, and an induced Stat3 activation that is dependent on Jaks. The observed secondary induction of Stat3 activation via Jaks has similarly been reported in head and neck squamous cell carcinoma line (29) and could be due to growth-stimulatory factors released from tumor cells (34), which in turn would induce the activation of Jaks and thereby promote Stat3 activation.

EGFR, Src and Stat3 has each independently been established to have critical roles in malignant transformation (6, 14, 23, 26, 35), while their collective roles in promoting tumorigenesis have not been explored. While the inhibition of the activity of each of the three proteins induced antitumor cell response to some degree, data presented here strongly indicate that the multiple targeting of Stat3 and EGFR or Src together has a higher potential to inhibit growth, viability, survival, malignant transformation, and migration and invasion *in vitro*.

Significantly, hyperactivation of the EGFR signaling has been deemed a prognostic indicator of low survival among pancreatic cancer patients (36-38). Also, there is evidence to indicate that the concurrence with aberrant Src signaling potentiates the effects of aberrant EGFR and induces biological synergy (3, 21, 39). Given the potential collective roles of Stat3, EGFR and Src in promoting and supporting pancreatic cancer, the inhibition of any single entity alone is unlikely to be insufficient to impact the disease. Present data that simultaneous inhibition of Stat3 and EGFR or Src induced greater antitumor cell effects and a higher sensitization to Gemcitabine provides a strong support for the opinion that Stat3 may cooperate with EGFR and Src to support the malignant phenotype. Indeed, the inhibition of Stat3 seemed to sensitize pancreatic cancer cells to the antitumor cell effects of ZD and Das. Multiple targeting of Stat3 and EGFR or Src therefore has the potential to induce a greater antitumor efficacy. This is supported by our present data that concurrent treatment with theStat3 inhibitor, S3I-201 and ZD or Das induced greater regression of xenografts of Colo-357 than treatment with either inhibitor alone. Such a multiple-targeted therapy has received a strong interest in recent times, particularly given the dismal results in certain cases of molecular targeted monotherapy, such as anti-EGFR monotherapy (40, 41). Thus, a combined Gemcitabine and Erlotinib (EGFR TK inhibitor) therapy has recently been approved for patients with locally advanced/metastatic pancreatic cancer (42, 43), although we note by our data that the inhibition of Stat3 and EGFR or Src together induces a higher Gemcitabine sensitivity than inhibition of EGFR alone. The enhanced antitumor effects due combined Stat3 and EGFR or Src inhibitors may in part be due stronger repression of the expression of c-Myc oncogene. Altogether, present study provides support for a multiple-modality therapeutic approach and lays the foundation for concurrent targeting of aberrant Stat3 and EGFR or Src as a more effective approach for achieving an enhanced antitumor therapeutic efficacy in pancreatic cancer.

Accordingly, in the drawings and specification there have been disclosed typical preferred embodiments of the invention and although specific terms may have been employed, the terms are used in a descriptive sense only and not for purposes of limitation. The invention has been described in considerable detail with specific reference to these illustrated embodiments. It will be apparent, however, that various modifications and changes can be made within the spirit and scope of the invention as described in the foregoing specification and as defined in the appended claims.

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THAT WHICH IS CLAIMED:

1. A cytotoxic composition containing a drug combination targeting two or more functional elements in pancreatic cancer cells, the functional elements comprising EGFR or Src and Stat3 or Jaks.

2. The cytotoxic composition of claim 1 wherein the drug combination contained therein is selected from ZD and S3I-201, Das and S3I-201, ZD and AG490, Das and AG490, and combinations thereof.

3. The cytotoxic composition of claim 1, wherein the drug combination inhibits said functional elements at substantially the same time.

4. The cytotoxic composition of claim 1, further comprising a nucleoside analog inhibitory for DNA replication.

5. The cytotoxic composition of claim 1, further comprising Gemcitabine.

6. A method of cytotoxically affecting pancreatic cancer cells, the method comprising contacting the cells with a drug combination which inhibits two or more cellular functional elements, the functional elements including EGFR or Src and Stat3 or Jaks.

7. The method of claim 6, wherein the drug combination is selected from ZD and S3I-201, Das and S3I-201, ZD and AG490, Das and AG490, and combinations thereof.

8. The method of claim 6, wherein the drug combination further comprises a nucleoside analog inhibitory for DNA replication.

9. The method of claim 6, wherein the drug combination further comprises Gemcitabine.

10. A method of making a composition cytotoxic for pancreatic cancer cells, the method comprising preparing a pharmaceutically acceptable composition containing a drug combination selected from ZD and S3I-201, Das and S3I-201, ZD and AG490, Das and AG490, and combinations thereof.

11. The method of claim 10, wherein the drug combination further comprises a nucleoside analog inhibitory for DNA replication.

12. The method of claim 10, wherein the drug combination further comprises Gemcitabine.

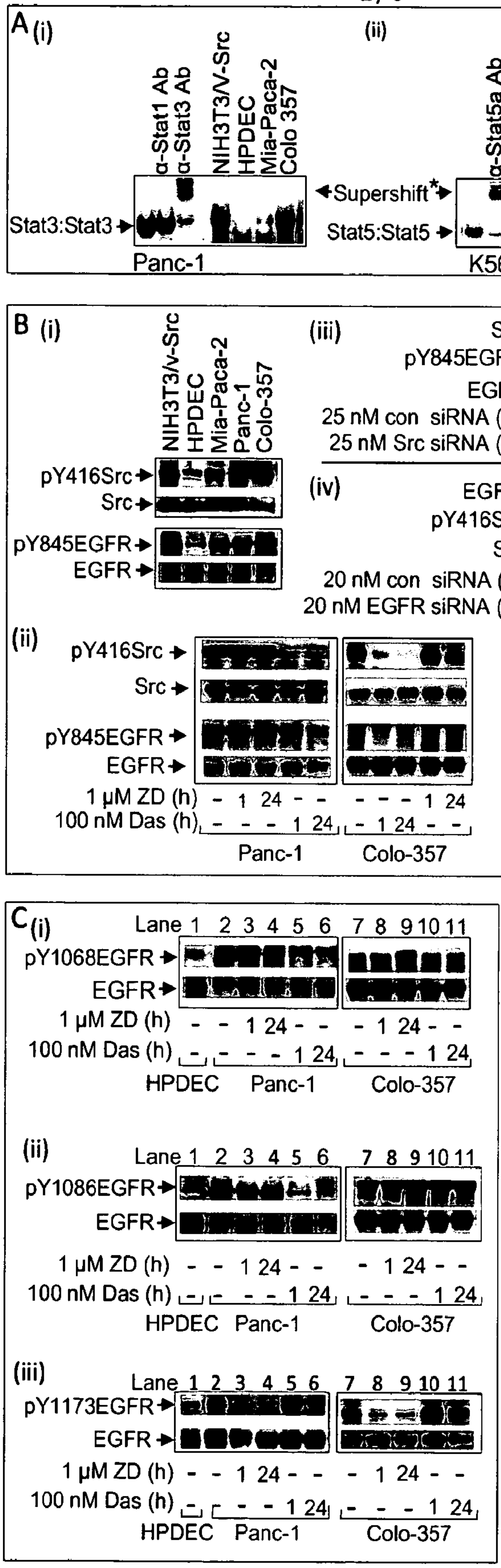
A (i)
α-Stat1 Ab
α-Stat3 Ab
NIH3T3/V-Src
HPDEC
Mia-Paca-2
Colo 357
Stat3:Stat3
Panc-1
(ii)
Supershift*
α-Stat5a Ab
α-Stat5b Ab
NIH3T3/v-Src
HPDEC
Colo-357
Miapaca-2
Panc-1
Stat5:Stat5
K562
B (i)
NIH3T3/v-Src
HPDEC
Mia-Paca-2
Panc-1
Colo-357
pY416Src
Src
pY845EGFR
EGFR
(iii)
Src
pY845EGFR
EGFR
25 nM con siRNA (48 h) - + -
25 nM Src siRNA (48 h) - - +
(iv)
EGFR
pY416Src
Src
20 nM con siRNA (48 h) - + -
20 nM EGFR siRNA (48 h) - - +
(ii)
pY416Src
Src
pY845EGFR
EGFR
1 μM ZD (h) - 1 24 - - - - - 1 24
100 nM Das (h) - - - 1 24 - 1 24 - -
Panc-1
Colo-357
C (i)
Lane 1 2 3 4 5 6 7 8 9 10 11
pY1068EGFR
EGFR
1 μM ZD (h) - - 1 24 - - - 1 24 - -
100 nM Das (h) - - - - 1 24 - - - 1 24
HPDEC
Panc-1
Colo-357
(ii)
Lane 1 2 3 4 5 6 7 8 9 10 11
pY1086EGFR
EGFR
1 μM ZD (h) - - 1 24 - - - 1 24 - -
100 nM Das (h) - - - - 1 24 - - - 1 24
HPDEC
Panc-1
Colo-357
(iii)
Lane 1 2 3 4 5 6 7 8 9 10 11
pY1173EGFR
EGFR
1 μM ZD (h) - - 1 24 - - - 1 24 - -
100 nM Das (h) - - - - 1 24 - - - 1 24
HPDEC
Panc-1
Colo-357

FIG. 1

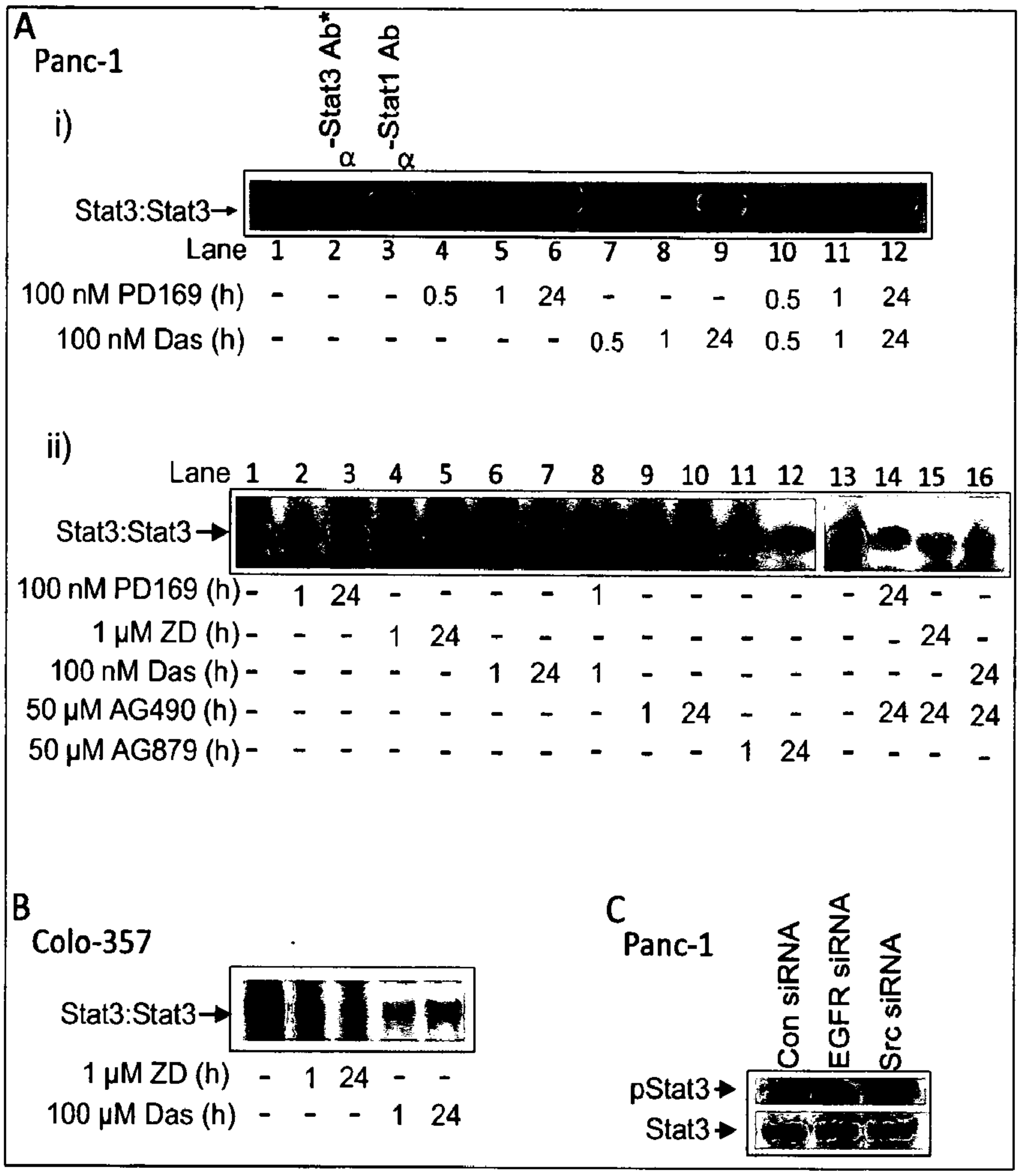
A
Panc-1
i)
α-Stat3 Ab*
α-Stat1 Ab
Stat3:Stat3
Lane 1 2 3 4 5 6 7 8 9 10 11 12
100 nM PD169 (h) - - - 0.5 1 24 - - - 0.5 1 24
100 nM Das (h) - - - - - - 0.5 1 24 0.5 1 24
ii)
Lane 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Stat3:Stat3
100 nM PD169 (h) - 1 24 - - - - 1 - - - - - 24 - -
1 μM ZD (h) - - - 1 24 - - - - - - - - - 24 -
100 nM Das (h) - - - - - 1 24 1 - - - - - - - 24
50 μM AG490 (h) - - - - - - - - 1 24 - - - 24 24 24
50 μM AG879 (h) - - - - - - - - - - 1 24 - - - -
B
Colo-357
Stat3:Stat3
1 μM ZD (h) - 1 24 - -
100 μM Das (h) - - - 1 24
C
Panc-1
Con siRNA
EGFR siRNA
Src siRNA
pStat3
Stat3

FIG. 2

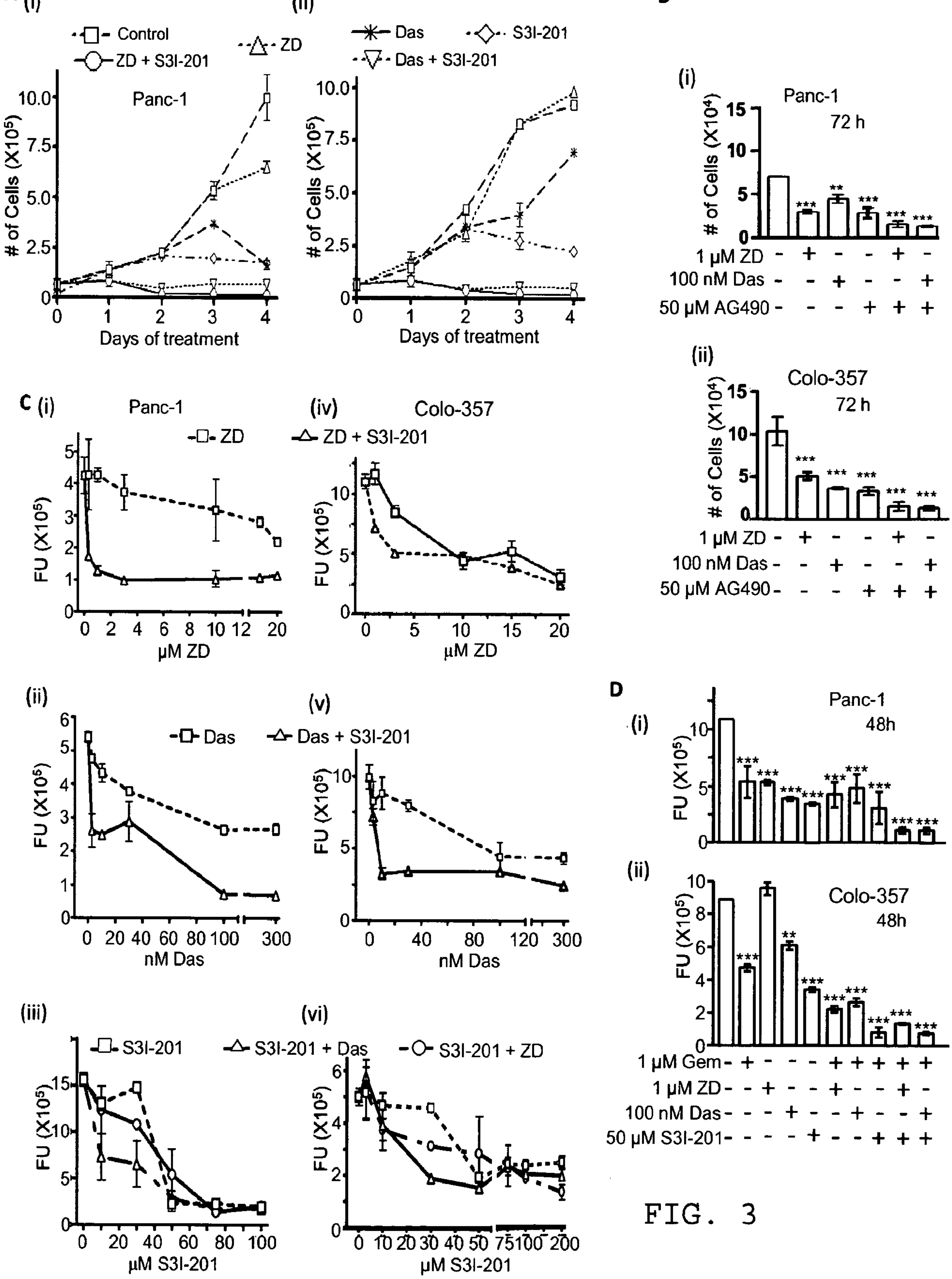
A (i)
Control
ZD
ZD + S3I-201
Panc-1
# of Cells (X10⁵)
Days of treatment
(ii)
Das
S3I-201
Das + S3I-201
# of Cells (X10⁵)
Days of treatment
B
(i)
Panc-1
72 h
# of Cells (X10⁴)
1 μM ZD
100 nM Das
50 μM AG490
(ii)
Colo-357
72 h
# of Cells (X10⁴)
1 μM ZD
100 nM Das
50 μM AG490
C (i)
Panc-1
ZD
ZD + S3I-201
FU (X10⁵)
μM ZD
(iv)
Colo-357
FU (X10⁵)
μM ZD
(ii)
Das
Das + S3I-201
FU (X10⁵)
nM Das
(v)
FU (X10⁵)
nM Das
(iii)
S3I-201
S3I-201 + Das
S3I-201 + ZD
FU (X10⁵)
μM S3I-201
(vi)
FU (X10⁵)
μM S3I-201
D
(i)
Panc-1
48h
FU (X10⁵)
(ii)
Colo-357
48h
FU (X10⁵)
1 μM Gem
1 μM ZD
100 nM Das
50 μM S3I-201

FIG. 3

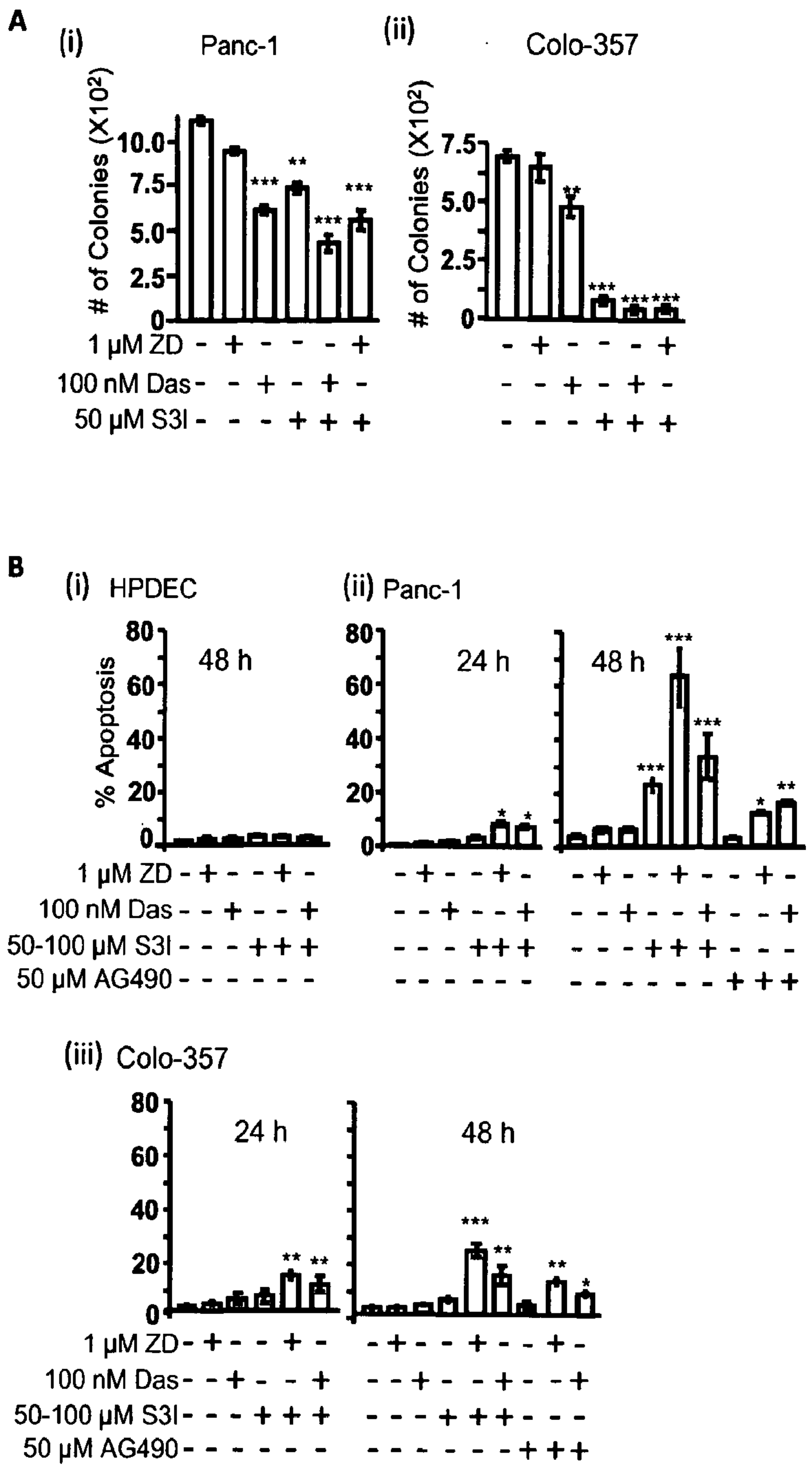
A
(i) Panc-1
# of Colonies (X10²)
1 μM ZD
100 nM Das
50 μM S3I
(ii) Colo-357
# of Colonies (X10²)
B
(i) HPDEC
48 h
% Apoptosis
1 μM ZD
100 nM Das
50-100 μM S3I
50 μM AG490
(ii) Panc-1
24 h
48 h
(iii) Colo-357
24 h
48 h
1 μM ZD
100 nM Das
50-100 μM S3I
50 μM AG490

FIG. 4

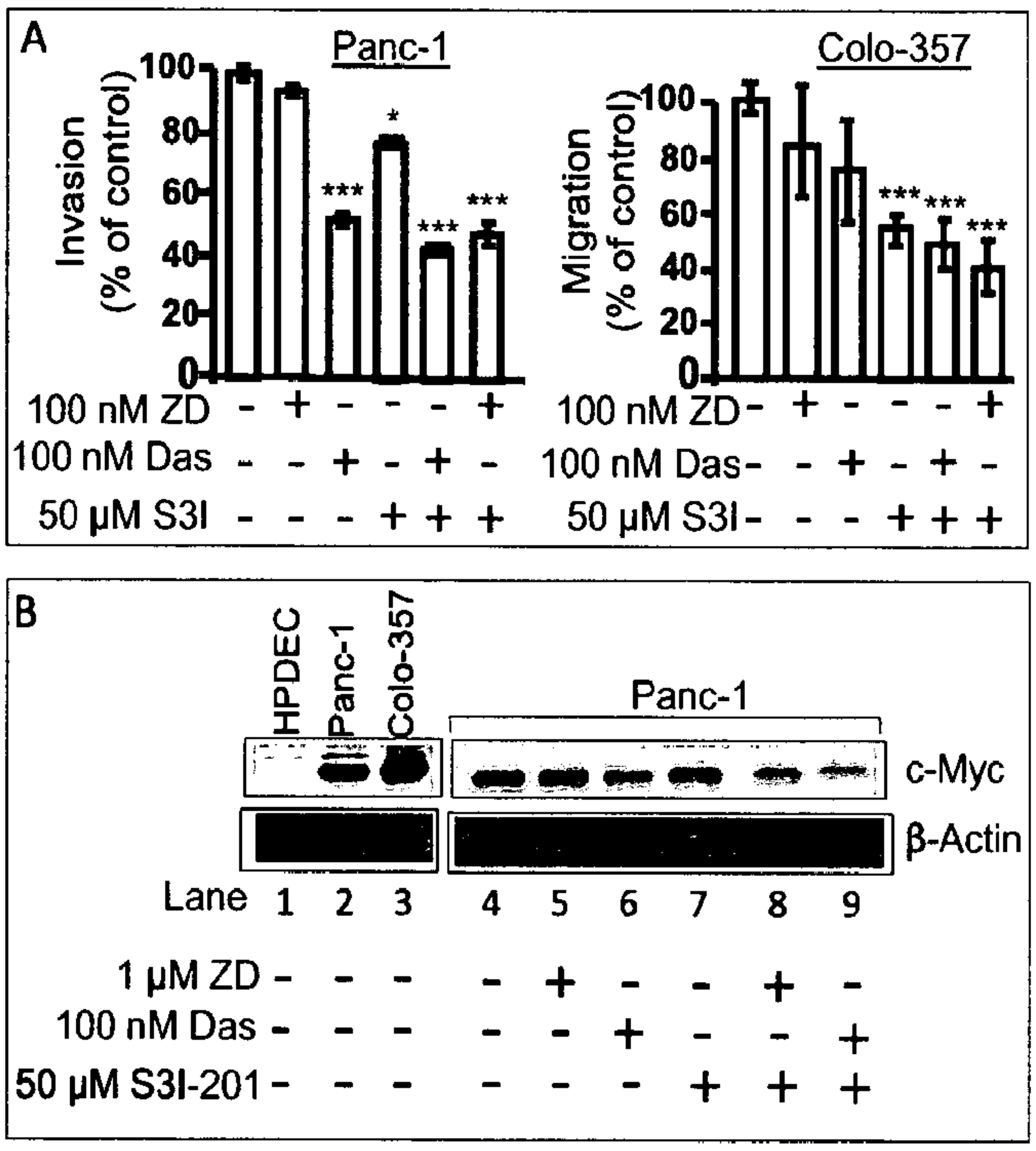
A
Panc-1
Invasion (% of control)
100
80
60
40
20
0
*
***
100 nM ZD - + - - - +
100 nM Das - - + - + -
50 μM S3I - - - + + +
Colo-357
Migration (% of control)
100
80
60
40
20
0
100 nM ZD - + - - - +
100 nM Das - - + - + -
50 μM S3I - - - + + +
B
HPDEC
Panc-1
Colo-357
Panc-1
c-Myc
β-Actin
Lane 1 2 3 4 5 6 7 8 9
1 μM ZD - - - - + - - + -
100 nM Das - - - - - + - - +
50 μM S3I-201 - - - - - - + + +

FIG. 5

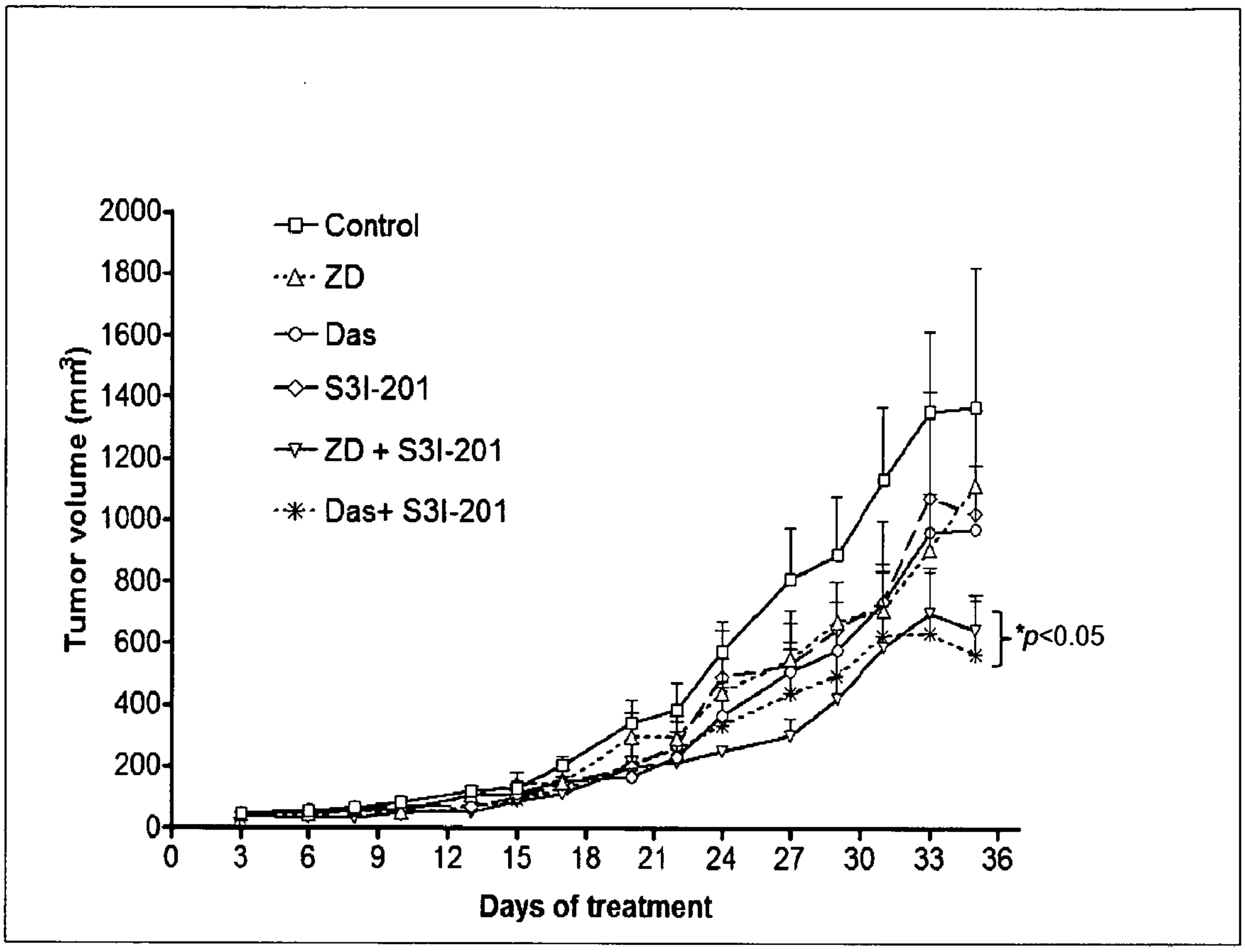
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Tumor volume (mm³)
Control
ZD
Das
S3I-201
ZD + S3I-201
Das+ S3I-201
*p<0.05
0 3 6 9 12 15 18 21 24 27 30 33 36
Days of treatment

FIG. 6

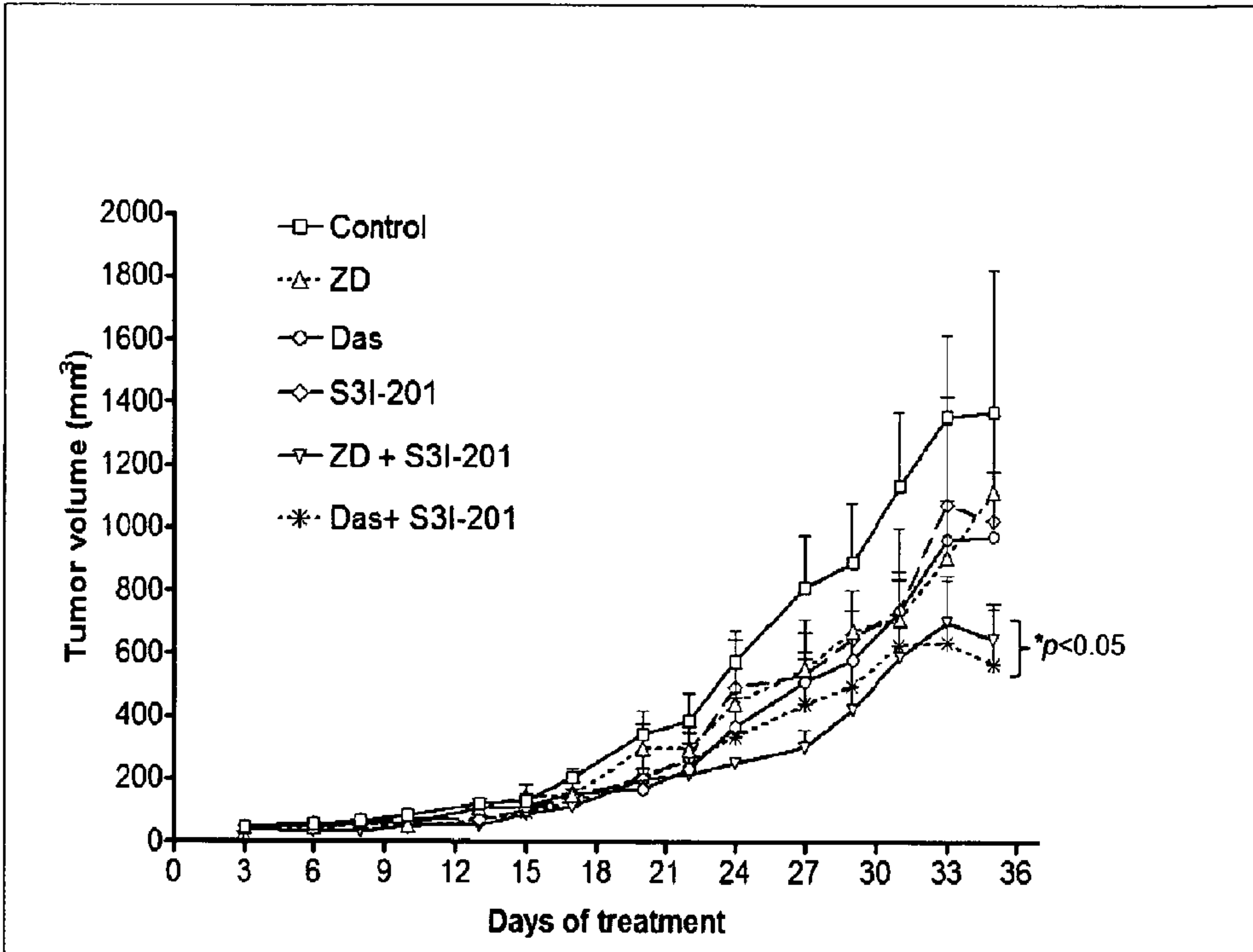
Control
ZD
Das
S3I-201
ZD + S3I-201
Das+ S3I-201
Tumor volume (mm3)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
3
6
9
12
15
18
21
24
27
30
33
36
Days of treatment
*p<0.05

FIG. 6