(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
17 February 2011 (17.02.2011)

PCT

(10) International Publication Number
WO 2011/019630 A2

(51) International Patent Classification:
A01K 67/00 (2006.01) *A61K 31/506* (2006.01)
A61K 31/337 (2006.01) *C12N 5/00* (2006.01)
A61K 31/4188 (2006.01) *A61P 35/00* (2006.01)

(21) International Application Number:
PCT/US2010/044832

(22) International Filing Date:
9 August 2010 (09.08.2010)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/232,687 10 August 2009 (10.08.2009) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

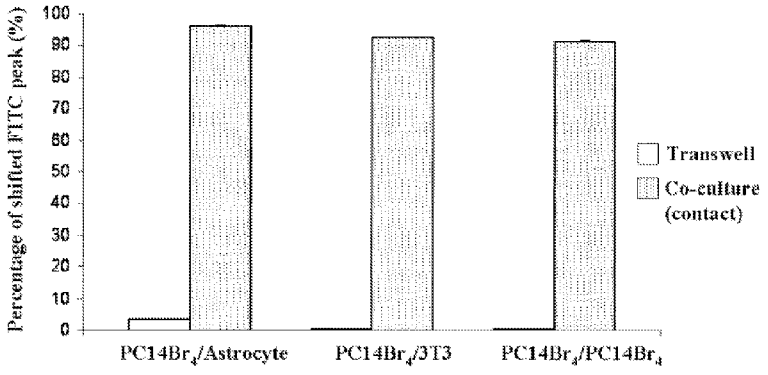
Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

WO 2011/019630 A2

(54) Title: TREATMENT OF ASTROCYTES-TUMOR CELLS WITH INHIBITORS OF ENDOTHELIN RECEPTORS

FIGURE 2



(57) Abstract: The disclosure relates to an endothelin receptor antagonist for use in the prevention or treatment of brain metastases in combination with a cytotoxic chemotherapy agent, radiotherapy or both. The endothelin receptor antagonist may for example be bosentan, macitentan or a mixture of bosentan and macitentan.

Treatment of Astrocytes-Tumor Cells with Inhibitors of Endothelin Receptors

Background

Brain metastasis is one of the most difficult challenges facing oncology. Metastatic tumors are resistant to most chemotherapy agents. The treatments for brain metastasis are primarily whole brain and focused radiotherapy, with surgical resection of tumors in a minority of cases. Most chemotherapy regimens involve 2-3 agents such as cisplatin, cyclophosphamide, etoposide, teniposide, mitomycin, irinotecan, vinorelbine, etoposide, ifosfamide, temozolomide and fluorouracil (5-FU). These are administered in combination with radiotherapy. The effect of these chemotherapies on prolonging survival is generally less than a year. A fairly new chemotherapy for brain tumors is temozolomide used with whole-brain irradiation. Results are preliminary but temozolomide appears to have some limited effect on the response rate compared to radiation alone and appears to have some clinical activity in combination with radiation in phase II trials.

Despite intense efforts, the limited medical options available for brain metastasis have remained poor and too often more palliative than therapeutically effective. This state of affairs has been long recognized but, to date, significant advances have not materialized. Consequently, there is a great and present medical need for new therapeutic approaches and pharmaceuticals effective at treating brain metastasis.

The disclosure below discusses endothelin receptor antagonists in relation to brain metastasis. Endothelin-1 (hereafter "ET-1"), a vasoactive peptide, is produced primarily in endothelial, vascular smooth muscle, and epithelial cells. ET-1 exerts its physiological effect via two high-affinity G-protein-coupled receptors, the endothelin-A (hereafter "ET_A") and the endothelin-B (hereafter "ET_B") receptors. Endothelin receptor antagonists (ERAs) are a well established class of compounds capable of inhibiting these endothelin receptors (hereafter "ETRs"). Within this class are subclasses of antagonists specific to ET_A or ET_B and a subclass effective against both (dual specificity). One member of the dual specificity subclass, bosentan, is currently approved for use in treating pulmonary arterial hypertension.

Certain ERAs have been investigated for use in cancer therapy. [Nelson JB, et al., Phase 3, randomized, controlled trial of atrasentan in patients with nonmetastatic, hormone-refractory prostate cancer. Cancer, 2008 Nov 1;113(9):2376-8.; Chiappori AA, et al. Phase I/II study of atrasentan, an ET_A receptor antagonist, in combination with paclitaxel and carboplatin as

first-line therapy in advanced non-small cell lung cancer. Clin Cancer Res, 2008 Mar 1;14(5):1464-9.] These studies have largely excluded patients with active brain metastasis. *Ibid.* This exclusion is done on the general view that existing brain metastases will not respond to treatment and, thus, morbidity and symptoms due to these metastases would mask the effects of the test treatment on the primary tumor. [Carden CP, et al., Eligibility of patients with brain metastases for phase I trials: time for a rethink? *The Lancet Oncology*, Vol 9, Issue 10, Pages 1012-1017, October 2008 doi:10.1016/S1470-2045(08)70257-2.] This standard clinical trial design strategy serves to emphasize the general expectation that therapies effective against primary tumors and even non-brain metastasis tumors will fail to effect brain metastasis tumors.

Brief Description of the Drawings

FIGURE 1: *In vitro* culture of MDA-MB-231 breast cancer cells (T) and murine astrocytes (A) were evaluated by scanning electron microscopy. Direct contact between the astrocytes (extending pods-feet) and tumor cells is evident;

FIGURE 2: The astrocyte-metastatic cancer cell co-cultures showed dye transfer between co-cultured cells;

FIGURE 3: Culturing of human MDA-MB-231 breast cancer cells or human PC14Br4 lung cancer cells with astrocytes (but not 3T3 fibroblasts) reduced the relative apoptotic index (increased resistance) of tumor cells incubated for 72 hours with paclitaxel (5 ng/ml) by 58.3 + 8.9% (mean ± S.D., $P<0.01$) and 61.8 ± 6.7% (mean ± S.D., $P<0.05$), respectively (the apoptotic index was compared by the Student's *t* test);

FIGURE 4: Human lung cancer PC14Br4 cells were cultured alone or with astrocytes (direct cell to cell contact) in medium containing P-glycoprotein-associated Adriamycin (200 ng/ml), paclitaxel (5 ng/ml), vinblastine (3 ng/ml), vincristine (8 ng/ml), and P-glycoprotein-dissociated 5-FU (500 ng/ml) or cisplatinum (2.4 μg/m1);

FIGURE 5: Astrocyte-mediated protection of brain metastasis cells from cytotoxic chemotherapy-induced cell death does not last longer than 72 hours after direct astrocyte-brain metastasis cell contact is lost;

FIGURE 6: Gene transcription profiling conditions distinguished between murine and human mRNA;

FIGURE 7: In the MDA-MB-231 cells, 1069 genes, and in the PC14Br4 cells, 594 genes were differentially expressed. A two-gene list comparison revealed increased expression of

several genes well known to be associated with anti-apoptosis and survival: glutathione S transferase 5 (*GSTA5*), *BCL2L1*, *TWIST*;

FIGURE 8: The expression of several anti-apoptosis and survival genes was confirmed at the protein level by Western blot analysis;

FIGURE 9: Gene transcription data were collected from two cycles of co-culture experiments;

FIGURE 10: Increased expression of ETA-R in MDA-MB-231 human breast cancer cells co-cultured with astrocytes but not with fibroblasts (3T3);

FIGURE 11: Expression of pAKT by MDA-MB-231 human breast cancer cells co-cultured with astrocytes/Taxol;

FIGURE 12: ACT-064992 added alone to MDA-MB-231 human breast cancer cells or with astrocytes or with 3T3 fibroblasts did not produce any measurable cytotoxic effects;

FIGURE 13: ACT-064992 added alone to PC14 lung cancer cells or with astrocytes or with 3T3 fibroblasts did not produce any measurable cytotoxic effects;

FIGURE 14A-D: Immunostaining for ET_AR and ET_BR in several in vivo experimental models for metastatic brain cancer shows relatively high expression associated specifically with tumors and not normal brain tissues;

FIGURE 15: Combination therapy of paclitaxel and ACT-064992 on MDA-MB-231 human breast cancer cells co-cultured with astrocytes or with 3T3 fibroblasts;

FIGURE 16: Combination therapy of paclitaxel and ACT-064992 on human lung cancer cells PC14Br4 co-cultured with astrocytes or with 3T3 fibroblasts;

FIGURE 17: The addition of ACT-064992 to co-cultures of astrocytes and tumor cells inhibited the expression of the survival factors pAKT and pMAPK;

FIGURE 18: Brain sections were fixed and stained for brain metastasis visualization. Control (vehicle) (FIG. 18A); temozolomide ("TMZ") 10mg/kg p.o., daily (FIG. 18B); ACT-064992 50 mg/kg, p.o. daily (FIG. 18C); or combination TMZ + ACT-064992 (FIG. 18D); combination TMZ + ACT-064992 at higher magnification (FIG. 18E);

FIGURE 19: Brain sections were fixed and stained for brain metastasis visualization. A. Control (injected with vehicle solution); B. Paclitaxel (8 mg/kg administered intraperitoneally once per week); C. ACT-064992 (50 mg/kg administered orally once per day); and D. Combination of ACT-064992 and paclitaxel;

FIGURE 20: Representative brain slices from the four treatment groups were stained for CD31 (endothelial cell marker) and Ki67 (cell proliferation marker): A. control mice; B. mice treated with only paclitaxel; C. ACT-064992; D. paclitaxel and ACT-064992;

FIGURE 21: Brain sices of mice from different treatment groups were analyzed by in situ Terminal deoxynucleotidyl transferase dUTP nick end labeling (TUNEL): A. control; B. paclitaxel-treated; C. ACT-064992-treated; D. Combination of ACT-064992 plus paclitaxel;

FIGURE 22: Brain slices of mice from the four treatment groups were immunostained for ET_A (red) and phosphoserine (green) colocalization produced orange-yellow color. A. Control brain; B. brain from mice treated with paclitaxel; C. brain from mice treated with ACT-064992 alone; D. brain from mice treated with ACT-064992 + paclitaxel.

Detailed Description

Definitions

As used herein, the use of the word "a" or "an" when used in conjunction with the term "comprising" in the claims and/or the specification may mean "one," but it is also consistent with the meaning of "one or more," "at least one," and "one or more than one." Still further, the terms "having", "containing", "including" and "comprising" are interchangeable and one of skill in the art is cognizant that these terms are open ended terms.

The term "treating" and "treatment" as used herein refers to administering to a subject a therapeutically effective medical intervention, such as chemotherapy, so that the subject has an improvement in the parameters relating to a cancer. The improvement is any observable or measurable improvement including changes in the size of a cancer tumor, reduction in the rate of growth of a cancer tumor, or subjective or objective measures of pain associated with a cancer tumor. Thus, one of skill in the art realizes that a treatment may improve the patient's condition but may not be a complete cure of the disease.

The term "effective amount" or "therapeutically effective amount" as used herein refers to an amount that results in an improvement or remediation of the symptoms of the disease or condition.

The term "existing brain metastasis tumor" as used herein refers to a multi-celled brain tumor and brain metastasis surrounded by and infiltrated with GFAP-positive astrocytes. Existing brain metastatic tumors are of two clinically distinct types, micrometastases, which are too small to be visualized by radiological means, and visible metastases, which are those tumors large enough to be discernable by clinical radiological means, such as magnetic resonance imaging, computerized tomography, or positron emission

tomography. These metastatic lesions are distinct from metastatic cancer cells in the systemic circulation and single cancer cells extravasating into brain tissue or quiescently residing therein. [See generally Johanna A. Joyce & Jeffrey W. Pollard, Microenvironmental regulation of metastasis, *Nat Rev Cancer* 9, 239-252 (April 2009) | doi:10.1038/nrc2618.] "Micrometastasis" as used herein is preferably defined as a group of confluent cancer cells measuring from greater than 0.2 mm and/or having greater than 200 cells to 2 mm in maximum width. More preferably "micrometastasis" is defined as a group of confluent cancer cells from 0.2 mm to 2 mm in maximum width. *See* The AJCC Cancer Staging Manual and Handbook, 7th ed. (2010), Edge, S.B.; Byrd, D.R.; Compton, C.C.; Fritz, A.G.; Greene, F.L.; Trotti, A. (Eds.), ISBN: 978-0-387-88440-0. An alternative preferred definition of "micrometastasis" is a confluent group of at least 1000 cancer cells and at least 0.1 mm in widest dimension up to 1 mm in widest dimension. Micrometastasis are generally not visible in standard contrast MRI imaging or other clinical imaging techniques. However, in certain cancers, radioactive antibodies directed to tumor selective antigens (e.g. Her2 for breast cancer metastasis) will allow visualization of micrometastasis. Other indirect detection methods include contrast media leakage at brain micrometastasis sites due to VEGF induced vascular leakage. Yano S; et al. (2000), Expression of vascular endothelial growth factor is necessary but not sufficient for production and growth of brain metastasis. Cancer research 2000;60(17):4959-67. More sensitive imaging techniques may also be applied to detect micrometastases. For example, blood volume may be imaged by MRI using the alternative contrast agent USPIO (Molday Iron, Biopal, Worcester, MA, sold as Molday ION™) to detect micrometastasis. JuanYin J, et al. Noninvasive imaging of the functional effects of anti-VEGF therapy on tumor cell extravasation and regional blood volume in an experimental brain metastasis model. Clin Exp Metastasis. 2009;26(5):403-14. Epub 2009 Mar 11.

The term "astrocyte mediated protection" as used herein refers to the ability of an astrocyte to reduce the cytotoxicity of a chemical for another cell type in direct physical contact with the astrocyte. This physical contact includes astrocytes connected to cancer cells, in particular via gap junction communication (GJC).

The term "cytotoxic chemotherapy induced cell death" as used herein refers to the induction of apoptosis or necrotic cell death by a cytotoxic chemical. Most medically used chemotherapy agents function to kill rapidly dividing tumor cells this way.

The term "endothelin receptor antagonist" as used herein refers to the class of compounds recognized in the art as such, and in particular to a compound that, when submitted to the "Test for the determination of ET_A or ET_B IC_{50}" described in the present patent application, has an IC_{50} equal or lower than 1 μM against ET_A, against ET_B or against both ET_A and ET_B. An ERA is a drug that blocks endothelin receptors from interaction with ET-1 or prevents an ETR from responding to bound ET-1. Two main kinds of ERAs exist: selective ERAs, such as sitaxentan, ambrisentan and atrasentan, which affect ET_A receptors, and dual ERAs, such as bosentan, which affect both ET_A and ET_B receptors. Exemplary members of the ERA class of compounds may be found in the patent literature cited in [HAM Mucke "Small-molecule endothelin receptor antagonists: A review of patenting activity across therapeutic areas" IDrugs 2009 12:366-375.] Representative ERAs which have already been investigated in human clinical trials or approved for medical use include sitaxentan, tezosentan, clazosentan, abbrisentan, bosentan, macitentan (also known as ACT-064992) and/or atrasentan.

The term "ET_A antagonist" as used herein refers a compound that, when submitted to the "Test for the determination of ET_A or ET_B IC_{50}" described in the present patent application, has an IC_{50} equal or lower than 1 μM against ET_A.

The term "ET_B antagonist" as used herein refers a compound that, when submitted to the "Test for the determination of ET_A or ET_B IC_{50}" described in the present patent application, has an IC_{50} equal or lower than 1 μM against ET_B.

The term "dual endothelin receptor antagonist" or "dual "ERAs" as used herein refers a compound that, when submitted to the "Test for the determination of ET_A or ET_B IC_{50}" described in the present patent application, has an IC_{50} equal or lower than 1 μM against ET_A and an IC_{50} equal or lower than 1 μM against ET_B. Dual ERAs include bosentan and macitentan.

The term "cytotoxic chemotherapy agent" as used herein refers to a substance inducing apoptosis or necrotic cell death. Examples of cytotoxic chemotherapy agents which may be used in combination with ERAs in accordance to the present invention include:

- alkylating agents (for example mechlorethamine, chlorambucil, cyclophosphamide, ifosfamide, streptozocin, carmustine, lomustine, melphalan, busulfan, dacarbazine, temozolomide, thiotepa or altretamine);

- platinum drugs (for example cisplatin, carboplatin or oxaliplatin);
- antimetabolite drugs (for example 5-fluorouracil, capecitabine, 6-mercaptopurine, methotrexate, gemcitabine, cytarabine, fludarabine or pemetrexed);
- anti-tumor antibiotics (for example daunorubicin, doxorubicin, epirubicin, idarubicin, actinomycin-D, bleomycin, mitomycin-C or mitoxantrone); and
- mitotic inhibitors (for example paclitaxel, docetaxel, ixabepilone, vinblastine, vincristine, vinorelbine, vindesine or estramustine); and
- topoisomerase inhibitors (for example etoposide, teniposide, topotecan, irinotecan, diflomotecan or elomotecan).

"Super-sensitization" or "Super-sensitize" is defined as a relative increase in cell death caused by cytotoxic chemotherapy agent(s) in physical contact with astrocytes over that seen in cells either in the absence of astrocytes or with no direct physical contact with astrocytes.

"Simultaneously" or "simultaneous", when referring to a therapeutic use, means in the present application that the therapeutic use concerned consists in the administration of two or more active ingredients by the same route and at the same time.

"Separately" or "separate", when referring to a therapeutic use, means in the present application that the therapeutic use concerned consists in the administration of two or more active ingredients at approximately the same time by at least two different routes.

By therapeutic administration "over a period of time" is meant in the present application the administration of two or more ingredients at different times, and in particular an administration method according to which the entire administration of one of the active ingredients is completed before the administration of the other or others begins. In this way it is possible to administer one of the active ingredients for several days, weeks or months before administering the other active ingredient or ingredients. In this case, no simultaneous administration occurs.

Disclosure

In the brain parenchyma, the role of astrocytes in maintaining homeostasis is well recognized. Astrocytes enwrap every blood vessel with specialized end-feet and communicate with other brain cells, such as neurons. This unique structure allows astrocytes to transport essential nutrients, such as glucose and amino acids, from the circulation to dependent neurons, and

glycolysis in astrocytes has been recently shown to regulate neuronal activity, the so called "neuron-astrocyte metabolic coupling." Under pathological conditions, such as hypoxia, ischemia, and degenerative conditions, astrocytes will become activated and express a protein designated GFAP. GFAP reactive astrocytes have been shown to protect neurons from various challenges and to rescue neurons from excitotoxicity produced by accumulation of glutamate. Activated astrocytes can also protect neurons from apoptosis produced by ethanol, hydrogen peroxide, and copper-catalyzed cysteine cytotoxicity.

Clinical brain metastases are commonly surrounded by and infiltrated by activated (GFAP-positive) astrocytes. [Yoshimine T, et al. (1985) Immunohistochemical study of metastatic brain tumors with astroprotein (GFAP), a glia-specific protein. Tissue architecture and the origin of blood vessels. J Neurosurg 62: 414–418.] The Inventors have confirmed this phenomenon is reproduced in a xenotransplantation model below.

Various embodiments of the present invention are presented thereafter:

1) The invention firstly relates to an endothelin receptor antagonist for use in the prevention or treatment of brain metastases in combination with a cytotoxic chemotherapy agent, radiotherapy or both.

2) According to one main variant of embodiment 1), the endothelin receptor antagonist will be for use in combination with a cytotoxic chemotherapy agent.

3) According to one sub-embodiment of embodiment 2), the cytotoxic chemotherapy agent will comprise (and in particular be) an alkylating agent.

4) In particular, the alkylating agent of embodiment 3) will be selected from the group consisting of mechlorethamine, chlorambucil, cyclophosphamide, iphosfamide, streptozocin, carmustine, lomustine, melphalan, busulfan, dacarbazine, temozolomide, thiotepa and altretamine.

5) According to another sub-embodiment of embodiment 2), the cytotoxic chemotherapy agent will comprise (and in particular be) a platinum drug.

6) In particular, the platinum drug of embodiment 5) will be selected from the group consisting of cisplatin, carboplatin and oxaliplatin.

7) According to yet another sub-embodiment of embodiment 2), the cytotoxic chemotherapy agent will comprise (and in particular be) an antimetabolite drug.

8) In particular, the antimetabolite drug of embodiment 7) will be selected from the group consisting of 5-fluorouracil, capecitabine, 6-mercaptopurine, methotrexate, gemcitabine, cytarabine, fludarabine and pemetrexed.

9) According to a further sub-embodiment of embodiment 2), the cytotoxic chemotherapy agent will comprise (and in particular be) an anti-tumor antibiotic.

10) In particular, the anti-tumor antibiotic of embodiment 9) will be selected from the group consisting of daunorubicin, doxorubicin, epirubicin, idarubicin, actinomycin-D, bleomycin, mitomycin-C and mitoxantrone.

11) According to another sub-embodiment of embodiment 2), the cytotoxic chemotherapy agent will comprise (and in particular be) a mitotic inhibitor.

12) In particular, the mitotic inhibitor of embodiment 11) will be selected from the group consisting of paclitaxel, docetaxel, ixabepilone, vinblastine, vincristine, vinorelbine, vindesine and estramustine.

13) According to yet another sub-embodiment of embodiment 2), the cytotoxic chemotherapy agent will comprise (and in particular be) a topoisomerase II inhibitor.

14) In particular, the topoisomerase II inhibitor of embodiment 13) will be selected from the group consisting of etoposide, teniposide, topotecan, irinotecan, diflomotecan and elomotecan.

15) In a preferred sub-embodiment of embodiment 2), the cytotoxic chemotherapy agent will be selected from the group consisting of paclitaxel, doxorubicin, vinblastine, vincristine, 5-fluorouracil, cisplatin, cyclophosphamide, etoposide, teniposide, mitomycin-C, irinotecan, vinorelbine, ifosfamide and temozolomide (and in particular from paclitaxel and temozolomide).

16) In particular, the cytotoxic chemotherapy agent of embodiment 15) will be selected from paclitaxel, temozolomide and a mixture of paclitaxel and temozolomide.

17) According to a preferred variant of embodiment 16), the endothelin receptor antagonist of embodiment 16) will be selected from the group consisting of bosentan, macitentan and a mixture of macitentan and bosentan (and will notably be macitentan).

18) The invention also relates to an endothelin receptor antagonist for use in combination with at least one of the cytotoxic chemotherapeutic agents mentioned in one of embodiments 2) to 17) and with radiotherapy.

19) According to a preferred embodiment of this invention, the endothelin receptor antagonist used in embodiments 1) to 18) will comprise (and in particular be) a dual endothelin receptor antagonist.

20) In particular, the dual endothelin receptor antagonist of embodiment 19) will be selected from the group consisting of bosentan, macitentan and a mixture of bosentan and macitentan.

21) In a particularly preferred embodiment, the dual endothelin receptor antagonist of embodiment 20) will be macitentan.

22) According to one variant of embodiments 1) to 21), the endothelin receptor antagonist and the cytotoxic chemotherapeutic agent will be administered separately.

23) According to another variant of embodiments 1) to 21), the endothelin receptor antagonist and the cytotoxic chemotherapeutic agent will be administered simultaneously.

24) According to yet another variant of embodiments 1) to 21), the endothelin receptor antagonist and the cytotoxic chemotherapeutic agent will be administered over a period of time.

25) According to yet another main variant of embodiment 1), the endothelin receptor antagonist will be for use in combination with radiotherapy (whereby this radiotherapy is preferably whole brain radiotherapy or stereotactic radiosurgery).

26) According to a preferred embodiment of this invention, the endothelin receptor antagonist used in embodiment 25) will comprise (and in particular be) a dual endothelin receptor antagonist.

27) In particular, the dual endothelin receptor antagonist of embodiment 26) will be selected from the group consisting of bosentan, macitentan and a mixture of bosentan and macitentan.

28) In a particularly preferred embodiment, the dual endothelin receptor antagonist of embodiment 27) will be macitentan.

29) In another main variant of this invention, the endothelin receptor antagonist for use with a cytotoxic chemotherapy agent according to one of embodiments 2) to 23) will be for use together with radiotherapy (whereby this radiotherapy is preferably whole brain radiotherapy or stereotactic radiosurgery).

30) Another main variant of this invention, combinable with any one or more of the foregoing embodiments 1) to 29), is an endothelin receptor antagonist for use in the treatment of an existing brain metastasis tumor in a subject wherein the existing brain metastasis tumor is a micrometastasis tumor such as micrometastasis tumor selected from the group consisting of a lung cancer, breast cancer, colon cancer, melanoma or renal carcinoma brain micrometastasis tumor.

31) The invention also relates to a method of inhibiting an astrocyte mediated protection of a brain metastasis cell, which method comprises administering an effective amount of an endothelin receptor antagonist to the brain metastasis cell and the astrocyte to inhibit the astrocyte mediated protection.

32) The invention further relates to the method of embodiment 31), which further comprises administering an effective amount of at least one cytotoxic chemotherapeutic agent to the brain metastasis cell.

33) The invention furthermore relates to the method of embodiment 31), which further comprises submitting the brain metastasis cell to radiotherapy (whereby this radiotherapy is preferably whole brain radiotherapy or stereotactic radiosurgery).

34) The invention moreover relates to the method of embodiment 31), which further comprises administering an effective amount of at least one cytotoxic chemotherapeutic agent to the brain metastasis cell and submitting the brain metastasis cell to radiotherapy (whereby this radiotherapy is preferably whole brain radiotherapy or stereotactic radiosurgery).

35) The invention furthermore relates to a method of manufacturing a medicament for use according to any of the foregoing 1) to 34) and any combinations thereof. Preferably, the

medicament produced by the foregoing is further packaged in a commercial package with instruction for carrying out one or more of 1)-34), and any combinations thereof.

36) The invention further relates to an endothelin receptor antagonist for use in the reduction of the risk of and/or reducing the rate of expansion of brain metastases, including brain micrometastasis, in combination with a cytotoxic chemotherapy agent, radiotherapy or both, according to one or more of 1)-34), and any combinations thereof.

EXPERIMENTAL SECTION

Experiment 1 – Immunofluorescent analysis of brain metastasis.

Materials and Methods

Experimental brain metastases were produced by the injection of human lung adenocarcinoma cells PC14Br4 into the internal carotid artery of nude mice (S1). Mice were killed 5 weeks later and tissue samples were processed in OCT compound for frozen section as previously described (S2). Tissues were sectioned (8-10 μm), mounted on positively charged slides, and air-dried for 30 minutes. Tissue fixation was performed using a protocol consisting of three sequential immersions in ice-cold solutions of acetone, 50:50 (v/v) acetone:chloroform, and acetone (5 minutes each). Samples were then washed three times with PBS, incubated with protein blocking solution containing 5% normal horse serum and 1% normal goat serum in PBS for 20 minutes at room temperature, and then incubated with a 1:400 dilution of rabbit anti-GFAP polyclonal antibody (Biocare Medical, Concord, CA) for 18 hours at 4°C. The samples were rinsed four times with PBS for 3 minutes each and then incubated for 1 hour with a 1:1500 dilution of goat anti-rabbit Cy5 antibody (Jackson ImmunoResearch Laboratories, West Grove, PA). Control samples were labeled with an identical concentration of isotype control antibody and goat anti-rabbit Cy5 antibody. All samples were rinsed and then briefly incubated with sytox green nucleic acid stain (Eugene, OR). The slides were mounted with a glycerol/PBS solution containing 0.1 mol/L propyl gallate (Sigma) to minimize fluorescent bleaching. Confocal images were collected on a Zeiss LSM 510 laser scanning microscope system (Carl Zeiss, Inc., Thornwood, NY) equipped with a motorized Axioplan microscope, argon laser, HeNe laser, LSM 510 control and image acquisition software, and appropriate filters (Chroma Technology Corp., Brattleboro, VT).

18 Composite images were constructed with Photoshop software (Adobe Systems, Inc., Mountain View, CA).

Results

The results were determined from color images (not shown) of immunohistochemically reacted samples. Tumor cells were surrounded by and infiltrated with GFAP-positive (red) astrocytes. This experiment confirmed prior observations of astrocyte infiltration of clinical brain metastasis samples. The same infiltration by GFAP-positive astrocytes were seen with a syngenic murine mouse model. Immunohistochemical analysis of mouse Lewis lung carcinoma (3LL) in the brain of a C57 mouse. Dividing 3LL cells (PCNA-positive, blue) were infiltrated and surrounded by activated astrocytes (GFAP-positive, brown). Together, these experiments validated the murine-human xenograft model which reproduced the phenomenon seen in clinical human samples and in the syngenic mouse model. One aspect of the present invention is therefore an *in vivo* mouse-human brain metastasis cell model which is useful, for example, in studying the phenomenon of human metastatic brain cancer.

Experiment 2 – Scanning electron microscopy studies

Having established that murine astrocytes interact *in vivo* with human tumor cells in the formation of brain metastasis in the same way as is seen in primary human clinical specimens, the Inventors examined the interactions of these two cell types *in vitro* in a simplified co-culture system. It was uncertain whether such a system would result in any cell-to-cell interaction, much less having direct physiological relevance to the *in vivo* situation described above. It was therefore a surprising discovery that intercellular interactions between human metastatic cancer cell lines and murine astrocytes were achieved *in vitro*.

Materials and Methods

Cell lines and culture conditions. Human breast cancer cell line, MDA-231 (S3), a brain metastatic variant of human lung adenocarcinoma cell line PC14Br4 (Si) and murine NIH 3T3 fibroblasts were maintained as monolayer cultures in a complete Eagle's minimum essential medium (CMEM) supplemented with 10% fetal bovine serum (FBS; HyClone, Logan, UT), L-glutamine pyruvate, nonessential amino acids, two-fold vitamin solution, and penicillin streptomycin (GIBCO/Invitrogen, Carlsbad, CA). All reagents used for tissue

culture were free of endotoxin as determined by the limulus amebocyte lysate assay (Associate of Cape Cod, Woodshole, MA), and the cell lines were free of the following murine pathogens: Mycoplasma spp, Hantan virus, hepatitis virus, minute virus, adenovirus (MAD1, MAD2), cytomegalovirus, ectromelia virus, lactate dehydrogenase-elevating virus, polyma virus, and Sendai virus (assayed by the Research Animal Diagnostic Laboratory, University of Missouri, Columbia, MO). Cells used in this study were from frozen stock and all experiments were carried out within 10 *in vitro* passages after thawing.

Isolation and maintenance of murine astrocytes. Neonatal mice homozygous for a temperature-sensitive SV40 large T antigen (H-2Kb-tsA58 mice; CBA/ca x C57BL/10 hybrid; Charles River Laboratories, Wilmington, MA) were euthanized in a carbon dioxide chamber, and the skin was prepared for surgery in standard fashion (S4). Sterile micro forceps (Roboz Surgical Instrument Co., Gaithersburg, MD) were used to remove the skin from the skull, and microscissors were used to create a circular posterior incision from the opening of the left ear to the opening of the right ear. Another incision was made along the brain midline, and the skull was divided to allow access to the cranial cavity. The optic nerves were clipped and the brain removed with blunt forceps and placed into 100-mm ice-cold phosphate buffered saline (PBS). Whole neocortices were dissected, and the hippocampus and internal structures were removed to leave only the cortical sheets. The meninges were stripped away, and the cortical sheets were minced with a scalpel and digested for 30 minutes at 37°C in Dulbecco's modified essential medium (DMEM) containing 0.1% collagenase (150 U/ml; Worthington Biochemical Corp., Lakewood, NJ) and 40 pg/m1 deoxyribonuclease (Sigma Chemical Co., St. Louis, MO). The cortical tissue was then triturated in DMEM containing 10% FBS and filtered through a 50-pm sterile mesh. The resulting single-cell suspension was plated onto 75-cm 2 tissue culture flasks that had been previously coated with 5 μg/m1 mouse laminin (Sigma). The cells were allowed to grow for 7 days in DMEM containing 10% FBS and supplements (see above) in an atmosphere of 8% carbon dioxide (to achieve a proper buffering of pH at 33°C). At this time, astroglial cells formed a confluent monolayer with neurons, oligodendrocytes, and fibroblasts growing on top. These contaminating cells were removed by rotary shaking the flasks overnight at 250 revolutions per minute in a warm room. The resulting cultures were composed of more than 95% astrocytes as determined by immunoreactivity with antibodies directed against GFAP. These cultures were expanded, the procedure was repeated, and the percentage of astrocytes in these cultures was determined to exceed 99%.

Scanning electron microscope imaging of cultured tumor cells and astrocytes. Human breast cancer MDA-MB-231 cells and murine astrocytes were plated in DMEM containing 5% FBS onto sterilized glass coverslips in 24 well plates at a density of 2.4 x 10^4 cells. After 48 hours, the coverslips were removed and fixed for 1 hour at room temperature in a solution containing 3% glutaraldehyde/2% parpformaldehyde/7.5% sucrose in 0.1 M cacodylate buffer (pH 7.3). The samples were then washed with 0.1 m cacodylate buffer and post-fixed for 1 hour with 1% cacodylate buffered osmium tetroxide containing 7.5% sucrose. The samples were washed with 0.1 M cacodylate buffer followed by distilled water and sequentially treated for 30 minutes in the dark with Millipore-filtered aqueous 1% tannic acid, washed in distilled water and Millipore-filtered 1% aqueous uranyl acetate for 1 hour in the dark. The samples were rinsed thoroughly with distilled water, dehydrated through an ascending series of ethanols, and then transferred for 5 minutes each to a graded series of increasing concentrations of hexamethyldisilazane and allowed to air dry overnight. Samples were mounted onto double-thick carbon tabs (Ted Pella, Inc., Redding, CA) that had previously been mounted onto aluminum specimen mounts (Electron Microscopy Sciences, Ft. Washington, PA). The samples were then coated under vacuum using a Balzer MED 010 evaporator (Technotrade International, Manchester, NH) with platinum alloy for a thickness of 25 nm and then immediately flash carbon coated under vacuum. The samples were transferred to a desiccator for examination at a later date. Samples were examined using a JSM-5910 scanning electron microscope (JEOL, Inc., Peabody, MA) at an accelerating voltage of 5 kV.

Results

The results are shown in Figure 1. *In vitro* culture of MDA-MB-231 breast cancer cells (T) and murine astrocytes (A) were evaluated by scanning electron microscopy. Direct contact between the astrocytes (extending pods-feet) and tumor cells is evident. A single astrocyte can contact multiple tumor cells. These appear to be fully formed gap junctions of the kind seen between astrocytes and neurons of the central nervous system. Similar results are seen with melanoma, breast cancer and lung cancer cell lines (not shown).

Experiment 3 – Gap Junction Assays

To further validate the functional nature of the gap junctions shown in Figure 1, The Inventors performed dye transfer experiments to ascertain whether the gap junction like structures seen in Experiment 2 were functional.

Materials and Methods

Gap junction communication. Gap junction communication between recipient tumor cells (MDA-MB-231) and donor cells (astrocytes, 3T3 cells, MDA-MB-231) was analyzed by flow cytometry measuring the transfer of dye. Briefly, recipient cells (300,000 cells/well) were plated into a 6-well plate and cultured overnight. At that time, donor cells were labeled for 45 minutes with 1 μg/ml green calcein-AM (Molecular Probes) followed by extensive washing. Donor cells (60,000 cells/well) were co-cultured for 5 hours with recipient cells either directly or in a transwell chamber (Transwell-Boyden Chamber, 0.4 p.m pore size; Costar, Corning, NY). Cells were harvested, washed, fixed in ethanol, and analyzed by flow cytometry. Gap junction formation was calculated as the percent of shifted FITC peak (S9-S11).

Results

As shown in Figure 2, the astrocyte-metastatic cancer cell co-cultures showed dye transfer between co-cultured cells. The Inventors' co-culture system thus results in active gap junctions forming between murine astrocytes and human metastatic cancer cell lines. The control transwell experiments demonstrate this to be a genuine cell-cell interaction. A second aspect of the present invention is therefore an *in vitro* mouse astrocyte-human metastasis cell co-culture system which is useful, for example, in studying the phenomenon of human metastatic brain cancer interaction with astrocytes in a manipulable *ex vivo* setting.

Experiment 4 – Chemoprotection Assays

Modeling of the chemoresistance of brain metastasis is and will be a major use for both the foregoing *in vivo* model system and the *in vitro* cell co-culture system. Because the cell based co-culture system is more amenable to experimental manipulation, it was further assessed to determine if the chemoresistance of brain metastases seen *in vivo* was replicated by the cell based culture system.

Material and Methods

In vitro co-culture chemoprotection assay. Astrocytes and NIH 3T3 fibroblasts were transfected with GFP genes as previously described (S5, S6). Target tumor cells, astrocytes, or 3T3 fibroblasts were harvested from a 60-70% confluent culture by a brief (2-minute) exposure to 0.25% trypsin in a 0.1% EDTA/PBS solution. The cells were dislodged by tapping the culture flasks briskly and resuspended in CMEM. The murine astrocytes, 3T3 fibroblasts, and tumor cells were plated alone or as co-culture at a tumor cell/astrocyte/3T3 cell ratio of 1:2 onto each of the 35-mm diameter well of the sterile 6-well tissue culture multi-well dish. The cells were allowed to adhere overnight in a humidified 37°C incubator in an atmosphere of 6.4% carbon dioxide plus air. The cultures were then washed and incubated with fresh CMEM (negative control) or medium containing various concentrations of TAXOL® (Paclitaxel; NDC 0015-3476-30, Bristol-Myers Squibb, Princeton, NJ) and other chemotherapeutic drugs (see below). After 72 hours, the GFP labeled astrocytes or NIH 3T3 cells were sorted out and the apoptotic fraction of tumor cells was determined by propidium iodide staining and FACS analysis (see below). To determine whether direct contact between tumor cells and astrocytes (or fibroblasts serving as control) was a prerequisite to produce induction of resistance to chemotherapy, we performed the co-culture assay using a Transwell-Boyden chamber, *i.e.*, plating the tumor cells in the chamber and the ImmortoAstrocytes (or fibroblasts) in the well. After 72 hours of incubation, the relative apoptotic index of the tumor cells was determined as described below.

In the second set of *in vitro* studies, we determined whether astrocyte-mediated induction of tumor cell resistance to chemotherapeutic drugs is transient or permanent. The human lung cancer PC14Br4 cells were co-cultured with either astrocytes or 3T3 fibroblasts in medium alone or medium containing 5 ng/ml paclitaxel. After 72 hours, the astrocytes or 3T3 cells were separated from tumor cells by FACS, and the relative apoptotic index of the tumor cells was determined in multiple wells by propidium iodide staining as described below. From parallel wells, we harvested surviving tumor cells and re-plated them on different monolayers of astrocytes or 3T3 cells. These co-cultures were of tumor cells first co-cultured with astrocytes and then with either astrocytes or 3T3 cells, or of tumor cells first cultured with 3T3 cells and then with either 3T3 cells or astrocytes. The second round of co-cultures then received media containing 5 ng/ml of paclitaxel. After 72 hours, the relative apoptotic index of tumor cells was determined by propidium iodide staining and FACS analysis.

Preparation for propidium iodide staining and FACS analysis. The supernatant medium containing floating cells were collected from each dish into a 15-ml conical centrifuge tube. The attached cells were harvested by briefly exposing the cells to 0.25% trypsin in a solution containing 0.1% EDTA/PBS. Cells were combined with the corresponding supernatant medium. The samples were pelleted by centrifugation at 100 g for 5 minutes. The pellets were resuspended in 10 ml of HBSS and further pelleted at 100 g for 5 minutes. The samples were resuspended by vortex and the cells fixed in 1 ml of 1% paraformaldehyde for 10 minutes at room temperature. The samples were then transferred into polypropylene microcentrifuge tubes and the fixed cells were washed in 1 ml of PBS and then pelleted at 10,000 g for 1 minute. The pellets were resuspended by vortex and the cells fixed overnight in 1 ml of ethanol at -20°C. The

cells were subsequently vortexed and pelleted by a microcentrifuge at 10,000 g for 1 minute. The samples were then vortexed and the pellets resuspended and stained in 300 of propidium iodide (50 μg/ml; Cat. P4864, Sigma) containing RNAse (15 μg/ml; Cat. A7973, Promega, Madison, WI) for 20-30 minutes at 37°C. The samples were finally transferred to 5-ml plastic culture tubes for FACS analysis using a Coulter EPICS Cytometer (Beckman Coulter, Inc., Fullerton, CA). Relative apoptotic index was determined by comparing the apoptotic index of tumor cells/apoptotic index of tumor cells and ImmortoAstrocytes or tumor cells and NIH 3T3 fibroblasts x 100 (%) (S7).

Results

Culturing of human MDA-MB-231 breast cancer cells or human PC14Br4 lung cancer cells with astrocytes (but not 3T3 fibroblasts) reduced the relative apoptotic index (i.e. increased chemoresistance) of tumor cells incubated for 72 hours with paclitaxel (5 ng/ml) by 58.3 + 8.9% (mean ± S.D., $P<0.01$) and 61.8 ± 6.7% (mean ± S.D., $P<0.05$), respectively (the apoptotic index was compared by the Student's *t* test) (FIG. 3). This reduction was dependent on direct contact between tumor cells and astrocytes. The Inventors base this conclusion on the data showing that when tumor cells and astrocytes were separated by a semi-permeable membrane (Transwell-Boyden Chamber, 0.4 pm pore size membrane; Costar, Corning, NY), the chemoprotective effect of astrocytes was not observed. Co-culture of tumor cells with 3T3 fibroblasts did not protect tumor cells from chemotherapy (FIG. 3). Co-culture of human tumor cells with an alternative control using fibroblasts isolated from the *H-2k^b-ts*A58 mouse

also did not protect the tumor cells from chemotherapeutic agents (data not shown). Analogous results were seen using standard MTT assays to determine the degree of cytotoxicity (data not shown). [Cory AH, Owen TC, Barltrop JA, Cory JG (July, 1991) "Use of an aqueous soluble tetrazolium/formazan assay for cell growth assays in culture." *Cancer Communications* 3 (7): 207–212.]

These data validate the cell based co-culture system disclosed herein as reproducing the phenomenon of brain metastasis chemoresistance. The unexpected ability of the co-culture system to replicate chemoresistance thus renders it well suited for use in studying the mechanism of chemoresistance and potential therapeutic interventions for abrogating chemoresistance in existing brain metastasis *in vivo*.

To expand upon these initial experiments, the Inventors have tested several additional chemotherapy agents, representative of the major classes of drugs in use to day. Human lung cancer PC14Br4 cells were cultured alone or with astrocytes (direct cell to cell contact) in medium containing P-glycoprotein-associated Adriamycin (200 ng/ml), paclitaxel (5 ng/ml), vinblastine (3 ng/ml), vincristine (8 ng/ml), and P-glycoprotein-dissociated 5-FU (500 ng/ml) or cisplatinum (2.4 μg/m1). Co-culture with astrocytes induced significant ($P<0.01$) protection against all drugs (FIG. 4). This unexpected finding further validates the cell based co-culture system. The cell culture system demonstrates the robustness of the chemoresistance induced by astrocytes in a manner which is directly comparable to brain metastasis chemoresistance seen *in vivo* in the clinical setting. A third aspect of the present invention is therefore an *in vitro* cell based chemoresistance assay which is useful, for example, in studying the phenomenon of astrocyte mediated protection of brain metastasis cells from cytotoxic chemotherapy induced cell death. In particular embodiments the *in vitro* cell based chemoresistance assay may be used to screen one or more candidate chemotherapy agents to assess the degree of astrocyte mediated protection against the cytotoxic effects of the chemotherapy agents.

Additional experiments summarized in Figure 5 demonstrate that astrocyte-mediated protection of brain metastasis cells from cytotoxic chemotherapy-induced cell death does not last longer than 72 hours after direct astrocyte-brain metastasis cell contact is lost. Further, cells having lost the protective effect afforded by prior astrocyte contact can be re-protected by a second co-culturing with astrocytes to reacquire astrocyte-mediated protection against the cytotoxic effects of the chemotherapy agents. This reflects the clinical observations of

primary tumors and even other non-brain metastasis being chemoresponsive while their derived brain metastasis are chemoresistant.

Experiment 5 – Mechanism of Astrocyte-Mediated Chemoresistance

The Inventors applied the above cell-based chemoresistance assay to investigate potential mechanisms underlying the phenomenon. Gene expression profiling plus Western blot confirmation of protein production were used to investigate astrocyte-mediated protection of brain metastasis cells from cytotoxic chemotherapy-induced cell death.

Materials and Methods

Gene expression profiles by RNA microarray analysis. In the first set of experiments, MDA-MB-231 or PC14Br4 cells were incubated alone, with murine astrocytes, or with NIH 3T3 fibroblasts in a 35-mm diameter 6-well plate (Cat. 353046, BD Falcon TM, San Jose, CA). To ascertain cell-to-cell contact, the ratio of tumor cells to murine astrocytes or NIH 3T3 cells was 1:2. After 72 hours, GFP-labeled murine astrocytes or fibroblasts were sorted out by FACS, and the tumor cells were processed for microarray analyses. In the second set of experiments, we determined whether the expression of genes associated with tumor cell resistance to chemotherapeutic drugs was dependent on a continuous contact with astrocytes. MDA-231 or PC14Br4 cells were co-cultured with either murine astrocytes or NIH 3T3 cells for 72 hours. The murine astrocytes or NIH 3T3 cells were sorted out, and tumor cells were either processed to determine gene expression profiles by microarray analyses or plated for a second round of co-culture with either murine astrocytes or fibroblasts. Thus, tumor cells first cultured with murine astrocytes were co-cultured again with murine astrocytes or with fibroblasts and, conversely, tumor cells initially cultured with fibroblasts were co-cultured again with fibroblasts or astrocytes. After a 72-hour incubation, murine astrocytes or fibroblasts were sorted out and the tumor cells were processed for microarray analyses.

Microarray Analyses. Total RNAs (500 ng) were used for labeling and hybridization according to the manufacturer's protocols (Illumina, Inc., San Diego, CA). Briefly, cDNA was generated from total RNA using IlluminaR Total Prep RNA Amplification Kit (Applied Biosystem, Austin, TX). Next, *in vitro* transcription was carried out to incorporate biotin-labeled nucleotides into cRNA for 4 hours at 37°C. A total of 1500 ng of biotin-labeled cRNA was hybridized to Illumina's SentrixR human 6-v2 Expression BeadChips at 58°C overnight (16 hours) according to the manufacturer's instructions. The hybridized biotinylated

cRNA was detected with 1 μg/ml cyanine 3-streptavidine (GE Healthcare, Piscataway, NJ), and the BeadChips were scanned with Illumina BeadArray Reader (Illumina, Inc.). The results of microarray data were extracted with Bead Studio 3.7 (Illumina, Inc.) without any normalization or background subtraction. Gene expression data were normalized using quantile normalization method in LIMMA package in R (www.r-project.org) (S12). The expression level of each gene was transformed into a log2 before further analysis. To select genes that are differentially expressed in two groups of tissues, we used a class comparison tool in BRB Array Tools (v 3.6; Biometrics Research Branch, National Cancer Institute, Bethesda, MD) as a method for two sample *t*-tests with the estimation of FDR.

Western blot analysis. The Western blot was used to confirm the results of the microarray. Briefly, whole-cell lysates of FACS-sorted tumor cells were prepared using 1 ml of lysis buffer (10 mM Tris [pH 8.0], 1 mM EDTA, 0.1% SDS, 1% deoxycholate, 1% NP40, 0.14 M NaC1, 1 μg/ml leupeptin, 1 μg/ml aprotinin, and 1 μg/ml pepstatin) containing a protease inhibitor mixture (Roche, Indianapolis, IN). Samples containing equal amounts of protein (30 fag) were separated by electrophoresis on 4-12% Nu-PAGE gels (Invitrogen) and transferred to nitrocellulose membranes. After blocking with TTBS (TBS + 0.1% Tween 20) containing 5% non-fat milk, the membranes were incubated at 4°C overnight with mouse monoclonal antibody against *BCL2* (1:1,000, BD PharMingen, San Diego, CA), rabbit polyclonal antibody against *BCL2L1* (1:1,000, Cell Signaling, Beverly, MA), rabbit polyclonal antibody against *TWIST* (1:1000, Cell Signaling), mouse monoclonal antibody against glutathione S-transferase (1:1,000, BD PharMingen), and mouse monoclonal antibody against I3-actin (Sigma). Blots were then exposed to horseradish peroxidase-conjugated secondary antibodies (1:3000) and visualized by the enhanced chemiluminescence system from Amersham (Piscataway, NJ). Equal protein loading was confirmed by stripping the blots and re-probing them with an anti-13-actin antibody.

Statistical analysis. For statistical analysis of gene expression profiles, the expression level of each gene was transformed into a log2 before further analysis. Class comparison tool in BRB Array Tools (v3.6; Biometrics Research Branch, National Cancer Institute, Baltimore, MD) for a two-sample *t* test with the estimation of FDR was the method used to determine the statistical significance of differentially expressed genes between tumor cells co-cultured with different host cells. Genes for Venn diagram were selected by univariate test (two-sample *t* test) with multivariate permutation test (10,000 random permutations). We applied a

cut-off *P*-value of less than 0.001 to retain genes whose expression is significantly different between two groups of tissues examined.

Results

The Inventors identified tumor cell genes whose expression is commonly altered subsequent to co-culture with astrocytes by applying two-sample *t* tests (P<0.001). Using this procedure, the Inventors identified in the MDA-MB-231 cells, 1069 genes, and in the PC14Br4 cells, 594 genes that were differentially expressed (FIG. 7). A two-gene list comparison revealed increased expression of several genes well known to be associated with anti-apoptosis and survival: glutathione S transferase 5 (*GSTA5*), *BCL2L1*, *TWIST* (Fig. 7). The expression of these genes was confirmed at the protein level by Western blot analysis (FIG. 8). The Inventors then determined whether the altered gene expression pattern in tumor cells co-cultured with astrocytes (but not fibroblasts) was permanent or transient. The Inventors co-cultured tumor cells for one cycle with astrocytes or fibroblasts, and then harvested the tumor cells and plated them in a second round on astrocytes or fibroblasts. When the gene expression data were collected from the two cycles of co-culture experiments, the influence of the second co-culture was dominant in gene expression patterns of the cancer cells. Regardless of the first co-culture condition, cancer cells co-cultured with astrocytes in the second cycle exhibited a distinctive gene expression signature that was detected in the first cycle culture experiments (high expression of *GSTA5, BCL2L1,* and *TWIST*), whereas cancer cells co-cultured with astrocytes in the first round lost the specific gene expression signatures when they were co-cultured with fibroblasts in the second round (FIG. 9). This result parallels that of the *in vitro* chemoprotection assay results summarized in Figure 5 and proves that the gene expression pattern in the tumor cells depends on constant contact with the astrocytes. Tumor cells co-cultured in the second round with astrocytes also expressed a high level of *TCF4, CD24, CARD14,* and *EFNB2* genes (data not shown). Clinical studies have shown that tumor cell expression of these genes is correlated with a poor prognosis. A fourth aspect of the present invention is therefore an *in vitro* cell based chemoresistance assay having a molecular diagnostic component which is useful, for example, in studying the phenomenon of astrocyte mediated protection of brain metastasis cells from cytotoxic chemotherapy induced cell death in an *ex vivo* setting. In certain embodiments, the molecular diagnostic component is one or more of a gene expression profiling step and an analysis of cellular protein concentrations. In specific embodiments, a predetermined gene expression signature is used to evaluate the effects of experimental interventions to, *e.g.*, abrogate

astrocyte mediated protection. A fifth aspect of the invention is a gene expression signature or a combination of protein level profiles indicative of astrocyte mediated protection of brain metastasis cells from cytotoxic chemotherapy induced cell death. A sixth aspect is the process of producing said gene signature or protein level profiles as described and exemplified above.

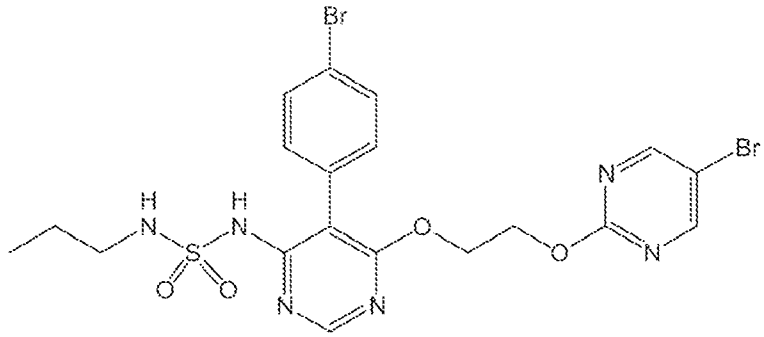
Experiment 6 – Expression of Endothelin Receptors by Tumor Cells and Astrocytes

300,000 MDA-MB-231 human breast cancer cells were cultured for 24 hours with 600,000 GFP-labeled astrocytes or with GFP-labeled 3T3 fibroblasts. The cells were then collected and sorted to isolate the MDA-MB-231 cells. Proteins were extracted, analyzed by Western blots, and hybridized with anti-ETAR antibody. The data shown in Figure 10 clearly demonstrate that tumor cells co-cultured with astrocytes express a higher level of ETAR.

In the next set of studies, 10,000 GFP-labeled MDA-MB-231 cells were co-cultured with 20,000 astrocytes in chamber slides. Twenty-four hours later, the cultures were treated for 24 hours with Taxol (15 ng/ml) and then stained for phosphorylated pAKT (4% PFA fixation). As shown in Figure 11, tumor cells co-cultured with astrocytes (and Taxol) expressed high levels of pAKT. Hence, co-culture with astrocytes produces increased expression of ETR and survival factors by tumor cells which are correlated with tumor cell increased resistance to chemotherapeutic drugs. Similar studies with an anti-ETBR antibody revealed ETBR expression.

Experiment 7 – Endothelin Receptor Antagonists Do Not Produce Cytotoxic Effects Against Tumor Cells

Using the *in vitro* cell based chemoresistance assay scheme described above, the Inventors tested two endothelin receptor antagonists having dual ETAR and ETBR affinity to assess the degree of astrocyte-mediated protection against the cytotoxic effects of the chemotherapy agent. One ETR antagonist tested was Bosentan which is approved by the EMEA for use in the treatment of pulmonary artery hypertension (PAH). The second drug tested was designated ACT-064992 and is a derivative of Bosentan also having dual ETAR/ETBR affinity. ACT-064992 is formally designated Macitentan, and has the structure [*N*-[5-(4-bromophenyl)-6-(2-(5-bromopyrimidin-2-yloxy)ethoxy)-pyrimidin-4-yl]-*N*'-propylaminosulfonamide]:



Macitentan

Iglarz M, et al., Pharmacology of macitentan, an orally active tissue-targeting dual endothelin receptor antagonist, J Pharmacol Exp Ther. 2008 Dec;327(3):736-45. Epub 2008 Sep 9. The original disclose of the ACT-064992 molecule, its synthesis and its pharmacological activity may be found in WO02/053557. ACT-064992 is roughly three times more pharmaceutically active than Bosentan (i.e. it requires 1/3 the dose). The detailed data herein refer to the ACT-064992 experiments, however analogous results are achieved by higher dose Bosentan experiments.

ACT-064992 (100 nM) was added to the cell-based co-culture assay described above with a tumor cell:astrocyte cell ratio of 1:2 or tumor cell:3T3 fibroblasts for 48 hours, and the degree of apoptosis was measured as described above. As shown in Figure 12 (MDA-231 breast cancer) and Figure 13 (PC14 lung cancer), ACT-064992 added alone or with astrocytes or with 3T3 fibroblasts did not produce any measurable cytotoxic effects.

Experiment 8 – Endothelin Receptor Antagonists in Combination with Chemotherapeutic Agents

ETR antagonists as shown above were ineffective as a single agent chemotherapy. This negative result made the dramatic effect seen with ETR antagonists as a component of combination therapies highly unexpected. In co-culture experiments, cell culture ratios were 1:2 tumor cell:astrocyte cell (50,000:100,000), and treatments were using paclitaxel (TAXOL®) (6 ng/ml) and/or ACT-064992 (100 nM) for 48 hours (FIG. 15; $*p<0.01$). For the control experiments using MDA-MB-231 cells, the same astrocyte-mediated protection from paclitaxel occurred as in prior experiments. There were two surprising results from these combination experiments. First, the combination of paclitaxel and ACT-064992 in the controls lacking astrocytes did not yield a significant increase in cell death over paclitaxel alone. This was seen in at least three independent experiments (FIG. 15). These results were

reproduced using human lung cancer cells PC14Br4 (FIG. 16). Thus, under the conditions tested, ETR antagonists were also ineffective in combination as was observed in Experiment 6 as a single agent. In the tumor cell-astrocyte co-cultures, ACT-064992 showed the unexpected ability to negate the astrocyte-mediated protection from paclitaxel. Even more surprising, ACT-064992 actually enhanced the efficacy of paclitaxel, as compared to control experiments without astrocytes, to super-sensitize the metastatic tumor cells to paclitaxel. The addition of ACT-064992 to co-cultures of astrocytes and tumor cells inhibited the expression of the survival factors pAKT and pMAPK (FIG. 17). This inhibition was directly correlated with the increased tumor cell death mediated by the chemotherapeutic drug. This synergism is made even more surprising because the experiments lacking astrocytes did not demonstrate even additive effects. These dramatic results demonstrate the importance of the new co-culture screening methods disclosed herein because the effects of ETR antagonists in combination therapy would not have been seen in a standard tumor cell line assay scheme lacking co-cultured astrocytes. A seventh aspect of the present invention is thus the use of endothelin receptor antagonists in combination with one or more other cytotoxic chemotherapy agents and/or radiation therapy to treat an existing brain metastasis tumor in a subject. In particular embodiments, this combination therapy super-sensitizes the existing brain metastasis to the cytotoxic chemotherapy agents and/or radiation therapy co-administered with the ETR antagonist.

In vivo Endothelin Receptor Antagonist Therapy for Existing Brain Metastasis

In vivo delivery of endothelin receptor antagonist(s) and co-administered chemotherapy agents may be achieved by the same oral and or systemic delivery already developed and used in prior clinical trials for various members of this class of compounds. The development and optimization of such therapeutic regimens is routine in the art. [Clinical trials: a practical guide to design, analysis and reporting Edited by Ameet Bakhai and Duolao Wang. Remedica, London 2005.] One issue specific to brain cancers is the impact of the blood brain barrier. While this has been long cited as a technical problem precluding systemic treatments for brain metastasis, the art has now recognized that even in micrometastasis, the blood brain barrier is partially disrupted. [Cavaliere R. and Schiff D., Chemotherapy and cerebral metastases: misperception or reality? *Neurosurg Focus*. 2007 Mar 15;22(3):E6.] Thus it is reasonable to expect that systemic delivery of endothelin receptor antagonist(s) will penetrate and have therapeutic effect in brain metastasis tumors. In addition, certain members of the endothelin receptor antagonist(s) family have the ability

to cross even intact blood brain barrier, thus rendering them particularly suited for use in brain metastasis tumor therapy *in vivo*. [Vatter H, et al., Cerebrovascular characterization of clazosentan, the first nonpeptide endothelin receptor antagonist shown to be clinically effective for the treatment of cerebral vasospasm. Part II: effect on endothelin(B) receptor-mediated relaxation. *J Neurosurg.* 2005 Jun;102(6):1108-14.] Finally, direct tumor infusion or injection of endothelin receptor antagonist(s) may be suitable where the size of metastatic tumors render such an approach feasible.

In vivo therapy for brain metastasis in mice

To further validate the efficacy of endothelin receptor antagonist therapy for existing brain metastasis, the Inventors performed exemplary *in vivo* experiments using mice. Nude mice were injected with 10,000 viable MDA231 cells mice by way of the internal carotid artery. Preliminary pathology work revealed that visible established metastases formed two weeks, post injection (data not shown). The Inventors thus started treatments at this time point.

Experiment 9 – ACT-064992 and temozolomide effects on *in vivo* tumor growth

Nude mice were injected into the internal carotid artery with 10,000 viable MDA231 cells. The treatment groups at two weeks post injection were: Control (vehicle) (FIG. 18A); temozolomide ("TMZ") 10mg/kg p.o., daily (FIG. 18B); ACT-064992 50 mg/kg, p.o. daily (FIG. 18C); or combination TMZ + ACT-064992 (FIG. 18D).

All mice were killed on day 28 of treatment. Brain sections were fixed and stained. Brain metastases were evaluated visually. Exemplary specimens are shown in FIG. 18A-D at the same magnifications. As can be seen in more detail in FIG 18E, the combination TMZ and ACT-064992 dramatically reduced the size and density of metastasis tumors compared to TMZ alone. This demonstrates that the above described cell culture system results correlate directly with the observed effects *in vivo*.

Experiment 10 – ACT-064992 and Paclitaxel effects on *in vivo* tumor growth

Female nude mice (10-12 weeks old) were injected in the internal carotid artery with 10,000 viable MDA231 cells. Two weeks after the injection when brain metastases were established, the mice were randomized into 4 treatment groups (n=10): 1) Control (injected with vehicle solution); 2) Paclitaxel (8 mg/kg administered intraperitoneally once per week);

3) ACT-064992 (50 mg/kg administered orally once per day); and 4) Combination of ACT-064992 and Paclitaxel. All mice were euthanized after 28 days of treatment and autopsied. The brains were collected for histologic study and immunohistochemistry. Exemplary results are shown in FIG 19. A. Control (19A), ACT-064992 (19B) and Paclitaxel (19C) all have well defined metastatic tumors. The ACT-064992 + Paclitaxel group (19D) in contrast had much smaller colonies of tumor cells.

The results with temozolomide and paclitaxel demonstrate that endothelin receptor antagonist therapy sensitizes brain metastasis to chemotherapy agents generally.

Experiment 11 – ACT-064992 and Paclitaxel effects on *in vivo* tumor cell proliferation

Representative brain slices from the four treatment groups were stained for CD31 (endothelial cell marker) and Ki67 (cell proliferation marker). The brains of control mice, mice treated with only paclitaxel, or only ACT-064992 contained a large number of proliferating cells. In sharp contrast, the brains of mice treated with both paclitaxel and ACT-064992 contained only a few dividing cells. FIG. 20A, B , C and D, respectively.

Experiment 12 – ACT-064992 and Paclitaxel effects on *in vivo* tumor cell apoptosis

Brain slices of mice from different treatment groups were analyzed by in situ Terminal deoxynucleotidyl transferase dUTP nick end labeling (TUNEL). Negoescu A, et al., J Histochem Cytochem. 1996 Sep;44(9):959-68. The brains of control, Taxol-treated, and ACT-064992-treated mice had few to no apoptotic cells. FIG. 21 A-C. In sharp contrast, the brains of mice treated with the combination of ACT-064992 plus Taxol had a large number of apoptotic tumor cells (green) and endothelial cells (yellow) (FIG. 21 D).

Experiment 13

Brain slices of mice from the four treatment groups were immunostained for ET_AR (red) and phosphoserine (green) colocalization produced orange-yellow color. Control brains expressed phosphorylated ET_AR as did brains from mice treated with paclitaxel (FIG. 22A-B). Treatment with ACT-064992 alone, and with ACT-064992 + paclitaxel, prevented phosphorylation of the ET_AR. (FIG. 22C-D). This result confirms the correlation of

endothelin receptor antagonist activity and the sensitization metastatic tumors to chemotherapy agents.

Experiment 14

Survival Study for Treatment of Experimental Human MDA231 Breast Cancer Brain Metastasis with ACT064992 and Taxol

Experimental Details

5 x 10^3 MDA231 cells were injected according to the protocol in Experiment 10. Treatment began on day 14 after injection according to the protocol in Experiment 10. A Survival curve is drawn and the p-value derived to compare the statistical significance among treatment groups.

Treatment Groups

Control (vehicle): daily oral administrations and once weekly i.p. injections.

Paclitaxel (5 mg/kg): daily oral vehicle administrations and once weekly i.p. injection of Paclitaxel.

ACT064992 (10 mg/kg): daily oral ACT064992 administrations and once weekly i.p. injections of Paclitaxel.

Results

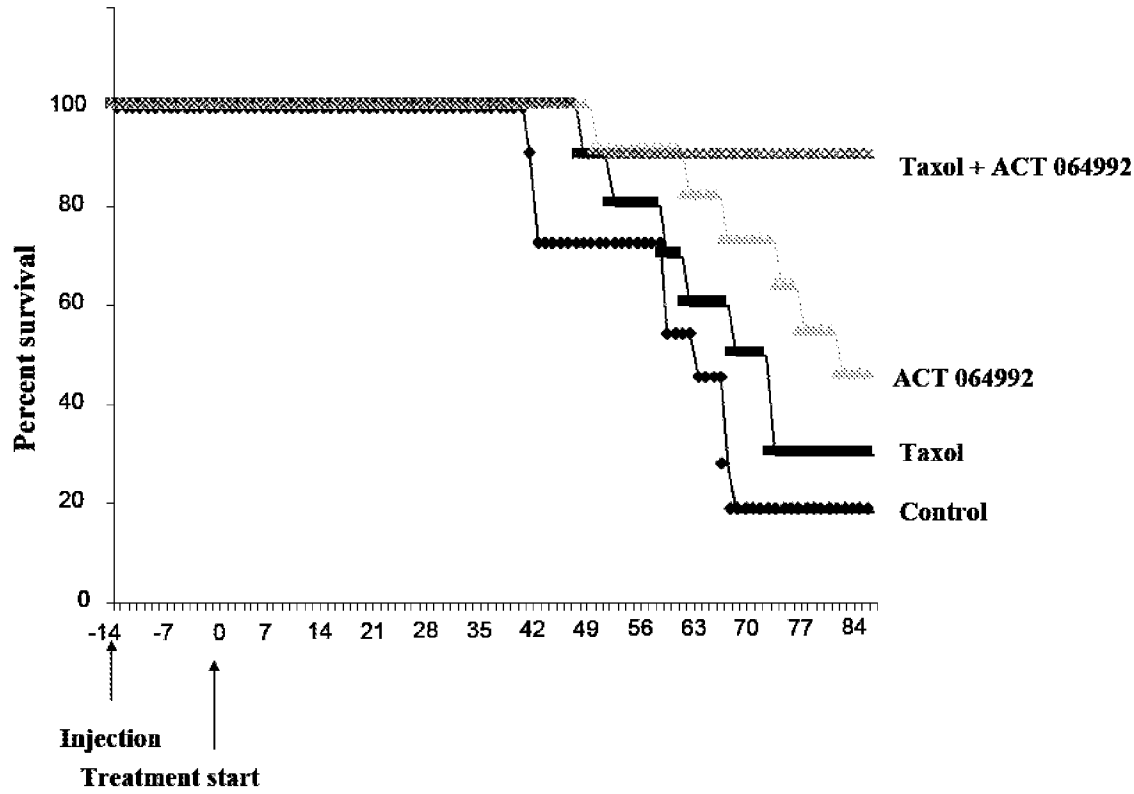
Day of death (after treatment)

Control: 42, 43, 53, 60, 64, 68, 68, 69, 69

Paclitaxel: 49, 53, 60, 63, 74, 74, 78

ACT064992: 51, 63, 68, 75, 78, 82

Paclitaxel + ACT: 48



Test for the determination of ET_A or ET_B IC_{50}:

For competition binding studies, membranes of CHO cells expressing human recombinant ET_A or ET_B receptors are used. Microsomal membranes from recombinant CHO cells are prepared and the binding assay made as previously described (Breu V., et al, *FEBS Lett.* (1993), **334**, 210).

The assay is performed in 200 µL 50 mM Tris/HCl buffer, pH 7.4, including 25 mM $MnCl_2$, 1 mM EDTA and 0.5% (w/v) BSA in polypropylene microtiter plates. Membranes containing 0.5 ug protein were incubated for 2 h at 20°C with 8 pM [^{125}I]ET-1 (4000 cpm) and increasing concentrations of unlabelled antagonists. Maximum and minimum binding are estimated in samples without and with 100 nM ET-1, respectively. After 2 h, the membranes are filtered on filterplates containing GF/C filters (Unifilterplates from Canberra Packard S.A. Zürich, Switzerland). To each well, 50 µL of scintillation cocktail is added (MicroScint 20, Canberra Packard S.A. Zürich, Switzerland) and the filter plates counted in a microplate counter (TopCount, Canberra Packard S.A. Zürich, Switzerland).

All the test compounds are dissolved, diluted and added in DMSO. The assay is run in the presence of 2.5% DMSO which is found not to interfere significantly with the binding. IC_{50} is calculated as the concentration of antagonist inhibiting 50 % of the specific binding of ET-1.

Background References:

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10. WO 02/053557

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D. Fan et al. Cancer Res. 50, 3619-3626 (1990).

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P. C. Fonseca et al. Cytometry 69A, 487-493 (2006).

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Clinical trials: a practical guide to design, analysis and reporting Edited by Ameet Bakhai and Duolao Wang. Remedica, London 2005.

Negoescu A, et al., J Histochem Cytochem. 1996 Sep;44(9):959-68.

All References cited or otherwise identified herein are hereby incorporated by reference in their entireties and particularly for any specific information for which they are cited.

We claim:

1. An endothelin receptor antagonist for use in the prevention or treatment of brain metastases in combination with a cytotoxic chemotherapy agent, radiotherapy or both.

2. An endothelin receptor antagonist for use in the prevention or treatment of brain metastases according to claim 1, which is a dual endothelin receptor antagonist.

3. An endothelin receptor antagonist for use in the prevention or treatment of brain metastases according to claim 1 or 2, which is selected from the group consisting of bosentan, macitentan and a mixture of bosentan and macitentan.

4. An endothelin receptor antagonist for use in the prevention or treatment of brain metastases according to one of claims 1 to 3, whereby the endothelin receptor antagonist is selected from the group consisting of bosentan, macitentan and a mixture of them and is intended to be used with a cytotoxic chemotherapy agent.

5. An endothelin receptor antagonist for use in the prevention or treatment of brain metastases according to claim 4, wherein the cytotoxic chemotherapy agent is selected from the group consisting of paclitaxel, temozolomide and a mixture of paclitaxel and temozolomide.

6. An endothelin receptor antagonist for use in the prevention or treatment of brain metastases according to claim 4, wherein the endothelin receptor antagonist is selected from the group consisting of bosentan, macitentan and a mixture of bosentan and macitentan.

7. A method of inhibiting an astrocyte mediated protection of a brain metastasis cell from a cytotoxic chemotherapy induced cell death, the method comprising the step of administering an effective amount of an endothelin receptor antagonist to the brain metastasis cell and the astrocyte to inhibit the astrocyte mediated protection.

8. A method of inhibiting an astrocyte mediated protection of a brain metastasis cell from a cytotoxic chemotherapy induced cell death, the method comprising the step of administering an effective amount of an endothelin receptor antagonist to the brain metastasis cell and the astrocyte to inhibit the astrocyte mediated protection

and further to super-sensitize the brain metastasis cell to the cytotoxic chemotherapy induced cell death.

9. The method of claim 7 or 8, further comprising the step of administering at least one cytotoxic chemotherapeutic agent to the brain metastasis cell.

10. The method of claim 9, wherein the brain metastasis cell is comprised in either an existing brain metastasis tumor in a subject or the brain metastasis cell is an isolated cell.

11. The method of claim 9 or 10 wherein the cytotoxic chemotherapy agent is at least one of paclitaxel, doxorubicin, vinblastine, vincristine, 5-fluoro-uracil, cisplatin, cyclophosphamide, etoposide, teniposide, mitomycin, irinotecan, vinorelbine, ifosfamide, and/or temozolomide.

12. The method of one of claims 7 to 11 wherein the endothelin receptor antagonist is one ore more of macitentan, sitaxentan, tezosentan, clazosentan, abbrisentan, bosentan and/or atrasentan.

13. The method of claim 11 or 12, wherein the subject is a human and optionally further comprising a step of administering a standard of care palliative and/or therapeutic treatment of the existing brain metastasis tumor in the human subject.

14. The method of claim 13, wherein the standard of care therapeutic treatment is given and the standard of care therapeutic treatment is one or both of whole brain radiotherapy or stereotactic radiosurgery.

15. A method of treating an existing brain metastasis tumor in a subject comprising administering to said subject a combination of an endothelin receptor antagonist and at least one cytotoxic chemotherapy agent.

16. A mouse having a human cancer metastasis cell brain tumor, the mouse further comprising a) at least one cytotoxic chemotherapeutic agent in a therapeutically effective amount to treat the human cancer metastasis brain tumor and b) at least one endothelin receptor antagonist in an amount sufficient to inhibit an astrocyte mediated protection of the human cancer metastasis brain tumor.

17. An isolated astrocyte cell-cancer cell complex wherein an isolated astrocyte cell is in gap junction communication with an isolated cancer cell.

18. The isolated astrocyte cell-cancer cell complex of claim 17 wherein the isolated astrocyte cell is a murine astrocyte and the isolated cancer cell is a human cancer cell.

19. The isolated astrocyte cell-cancer cell complex of claim 18, wherein the isolated cancer cell line cell is MDA-MB-231 or PC14Br4.

20. A method of forming an isolated astrocyte cell-cancer cell complex comprising the steps of a) providing an isolated astrocyte cell, b) providing a cancer cell, c) co-culturing the provided cells for a time sufficient for a gap junction form between the cells thereby forming the astrocyte cell-cancer cell complex.

21. The method of claim 20 wherein the isolated astrocyte cell is a murine astrocyte and the isolated cancer cell is a human cancer cell.

22. The method of claim 21 wherein the isolated cancer cell line is MDA-MB-231 or PC14Br4.

23. The method of claim 20, 21 or 22, further comprising the step of adding one or more candidate chemotherapy agents to assess the degree of astrocyte mediated protection against the cytotoxic effects of the chemotherapy agents.

24. The method of claim 23, further comprising the step of performing a molecular diagnostic step to provide an identifying molecular profile corresponding to the astrocyte mediated protection against the cytotoxic effects of the chemotherapy agent.

25. The method of claim 24 wherein the molecular diagnostic step is one or more of a differential gene expression measurement or a differential cellular protein concentration measurement.

26. The method of claim 25 wherein the differential gene expression measurement is performed using a gene chip.

FIGURE 1

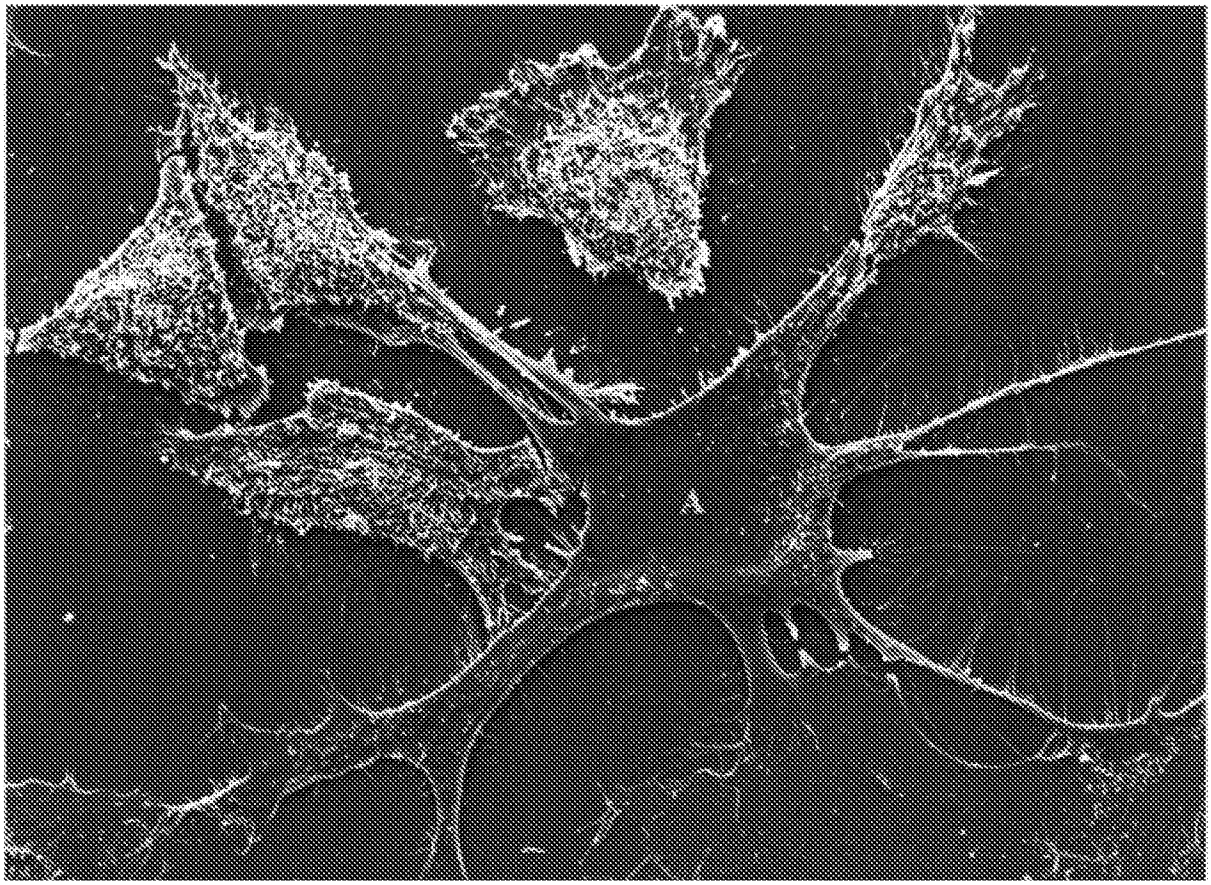


FIGURE 2

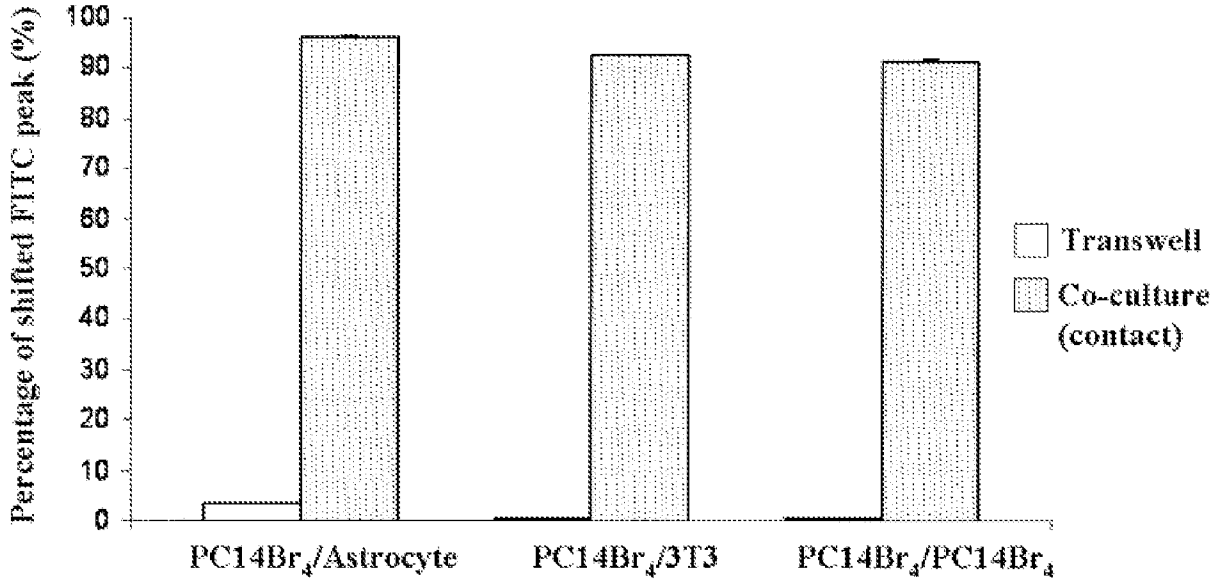


FIGURE 3

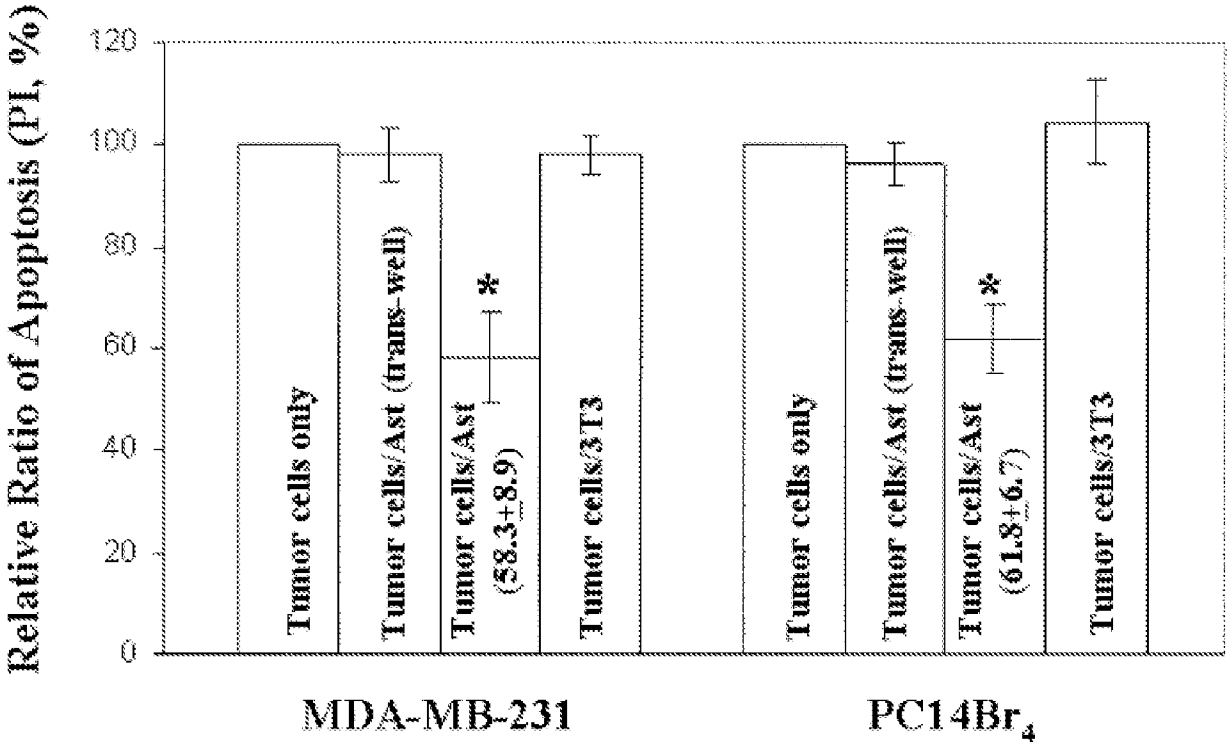


FIGURE 4

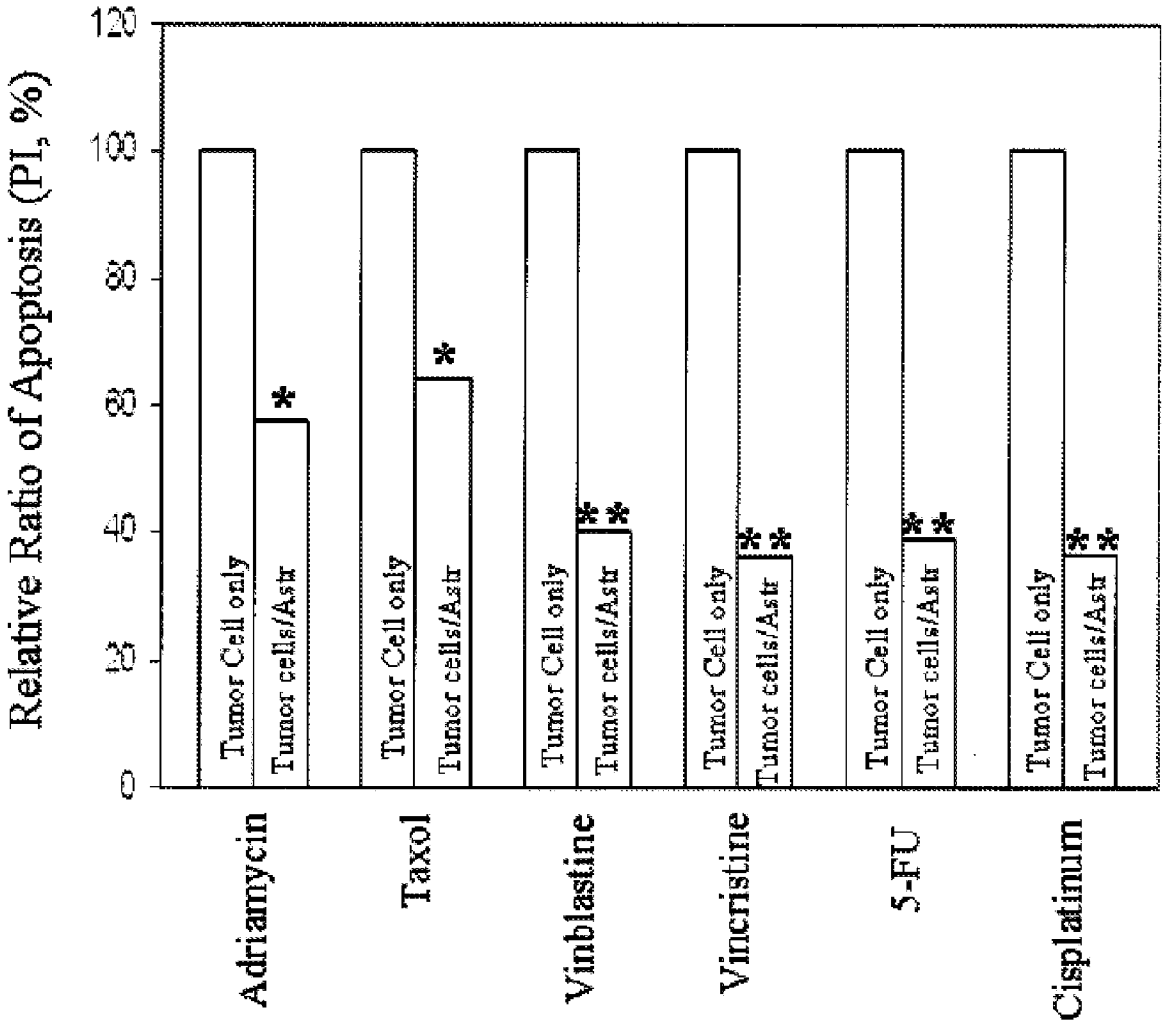

Relative Ratio of Apoptosis (PI, %)
120
100
80
60
40
20
0
Tumor Cell only
Tumor cells/Astr
*
Adriamycin
Taxol
Vinblastine
Vincristine
5-FU
Cisplatinum

FIGURE 5

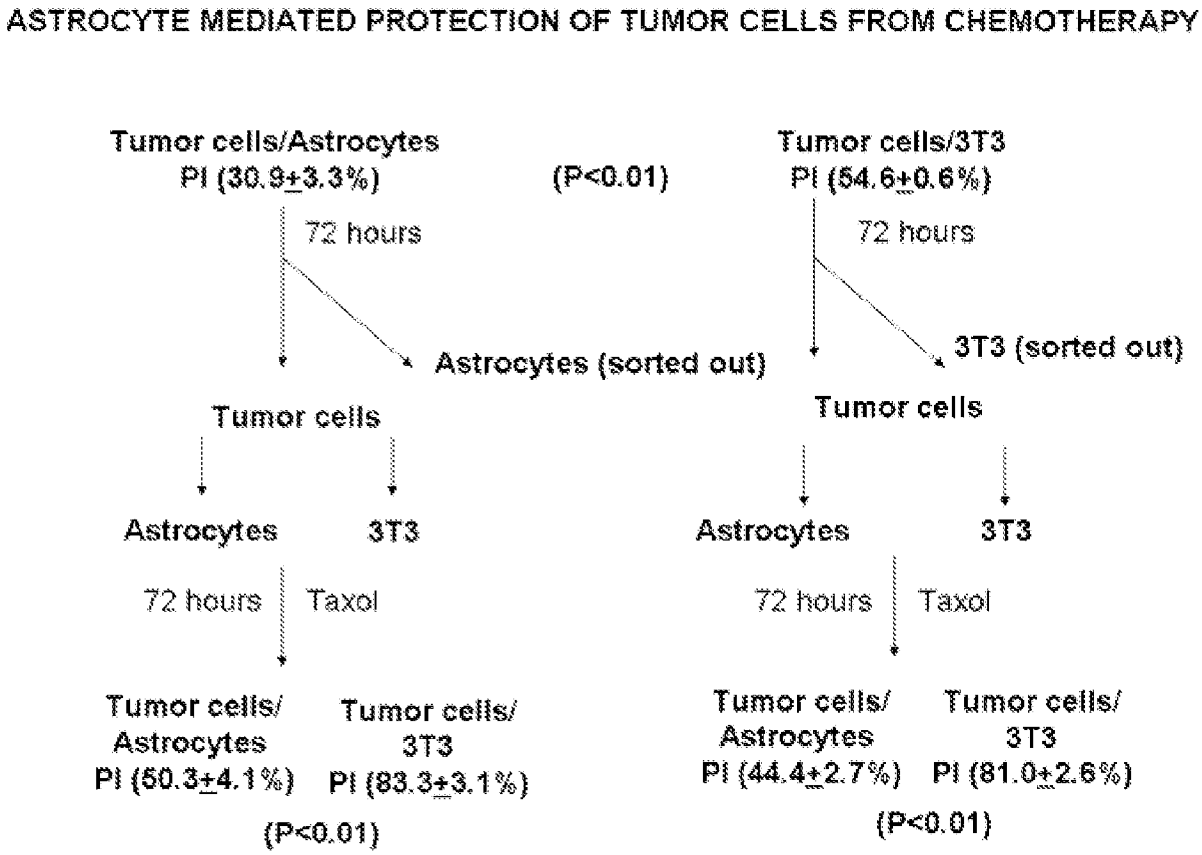

ASTROCYTE MEDIATED PROTECTION OF TUMOR CELLS FROM CHEMOTHERAPY
Tumor cells/Astrocytes
PI (30.9±3.3%)
(P<0.01)
Tumor cells/3T3
PI (54.6±0.6%)
72 hours
72 hours
Astrocytes (sorted out)
3T3 (sorted out)
Tumor cells
Tumor cells
Astrocytes
3T3
Astrocytes
3T3
72 hours
Taxol
72 hours
Taxol
Tumor cells/
Astrocytes
PI (50.3±4.1%)
Tumor cells/
3T3
PI (83.3±3.1%)
(P<0.01)
Tumor cells/
Astrocytes
PI (44.4±2.7%)
Tumor cells/
3T3
PI (81.0±2.6%)
(P<0.01)

FIGURE 6

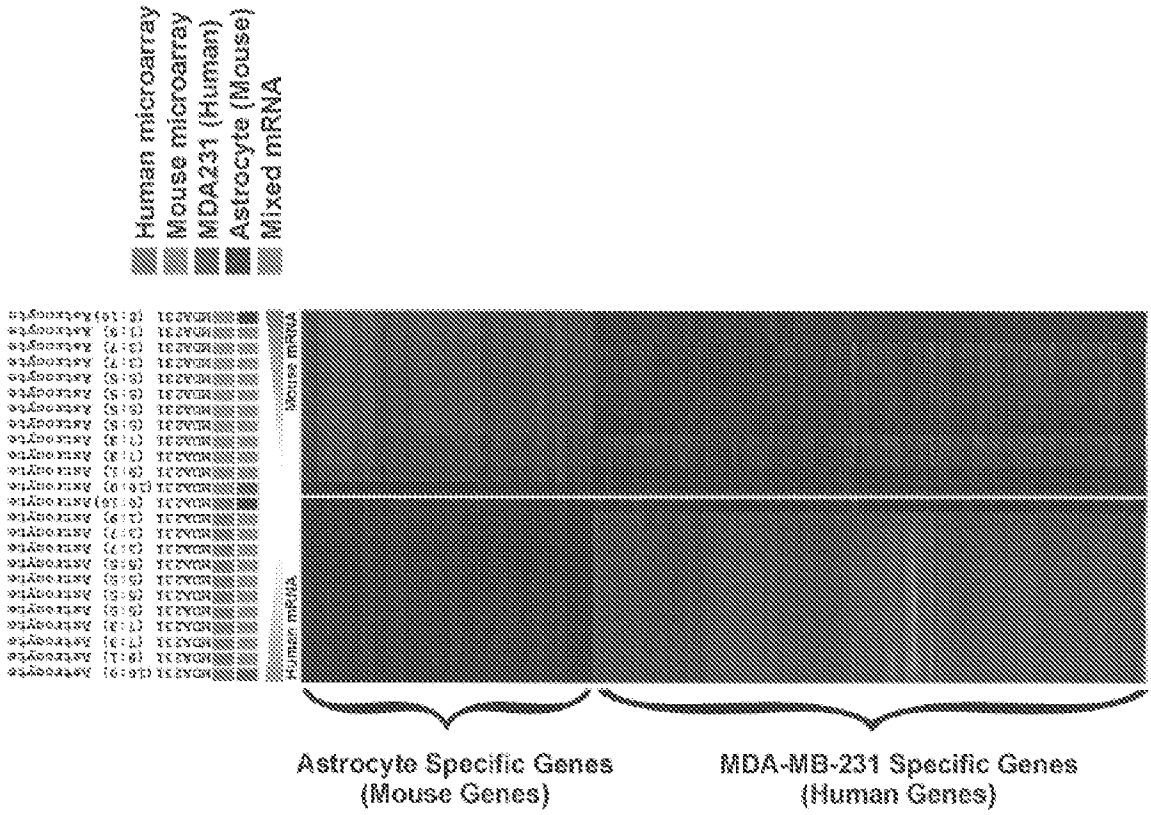


FIGURE 7

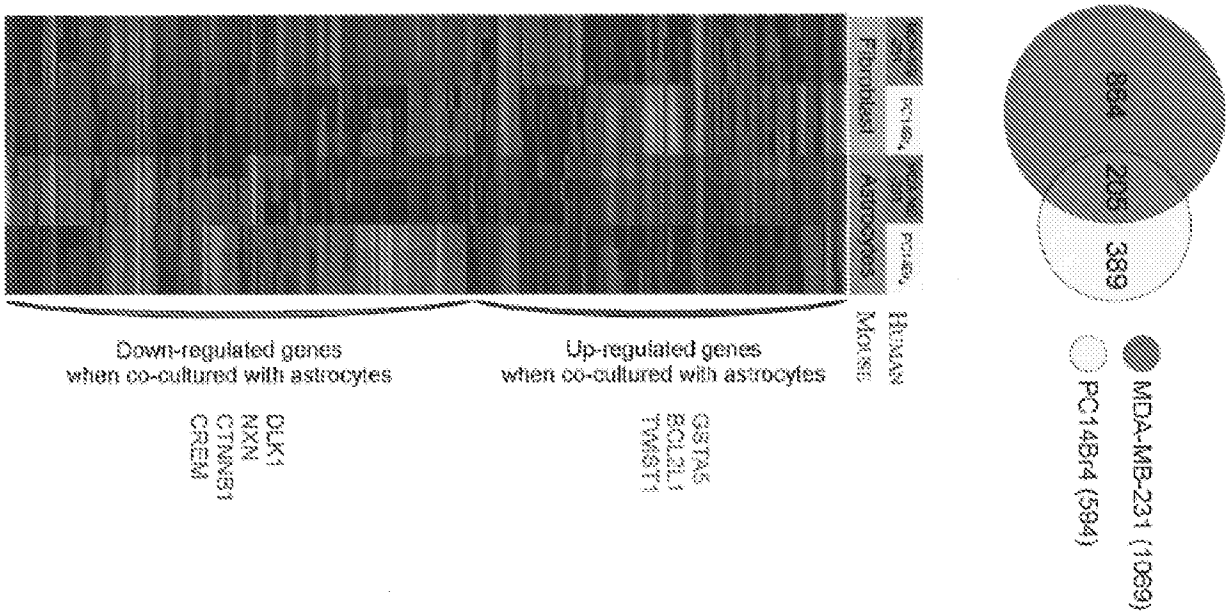


FIGURE 8

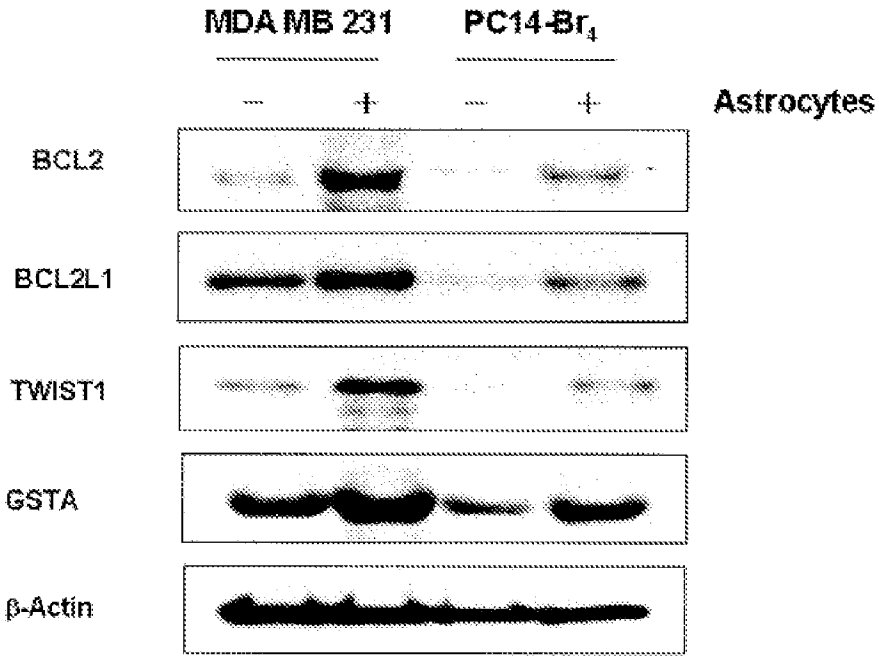


FIGURE 9

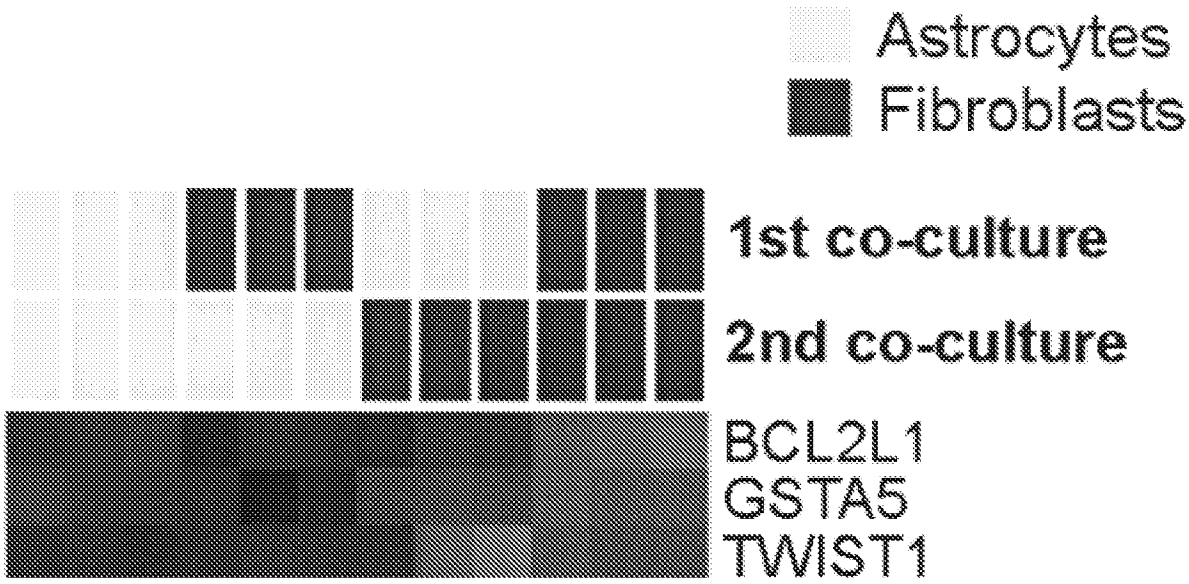


FIGURE 10

Increased expression of ET_A-R in MDA231 human breast cancer cells co-cultured with astrocytes but not with fibroblasts (3T3)

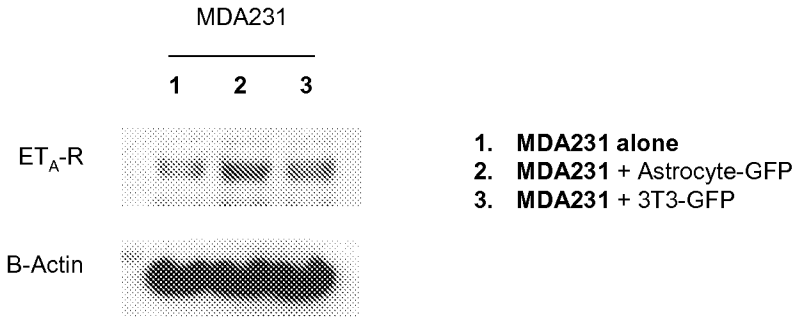


FIGURE 11

Expression of pAKT by MDA231 human breast cancer cells co-cultured with astrocytes/Taxol

Green = MDA231
Red = pAkt
Blue = nucleus

FIGURE 12

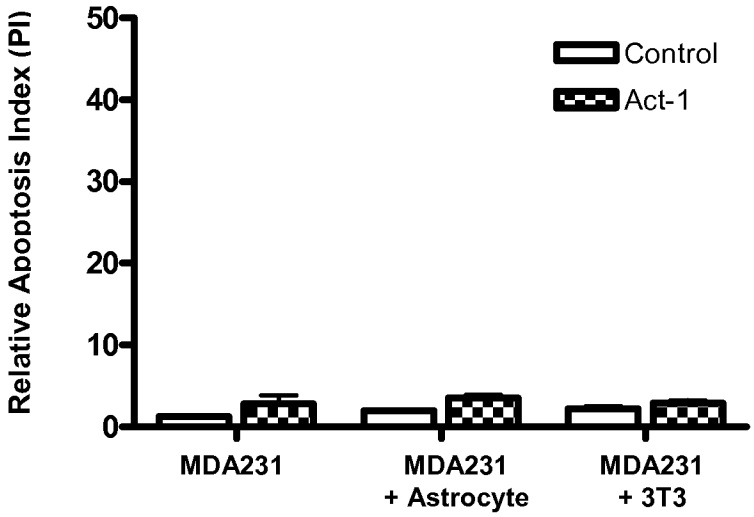


FIGURE 13

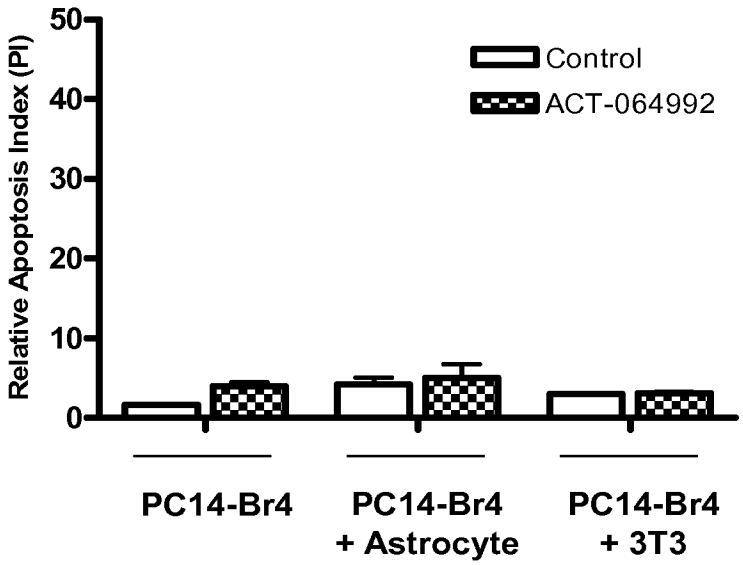


FIGURE 14A

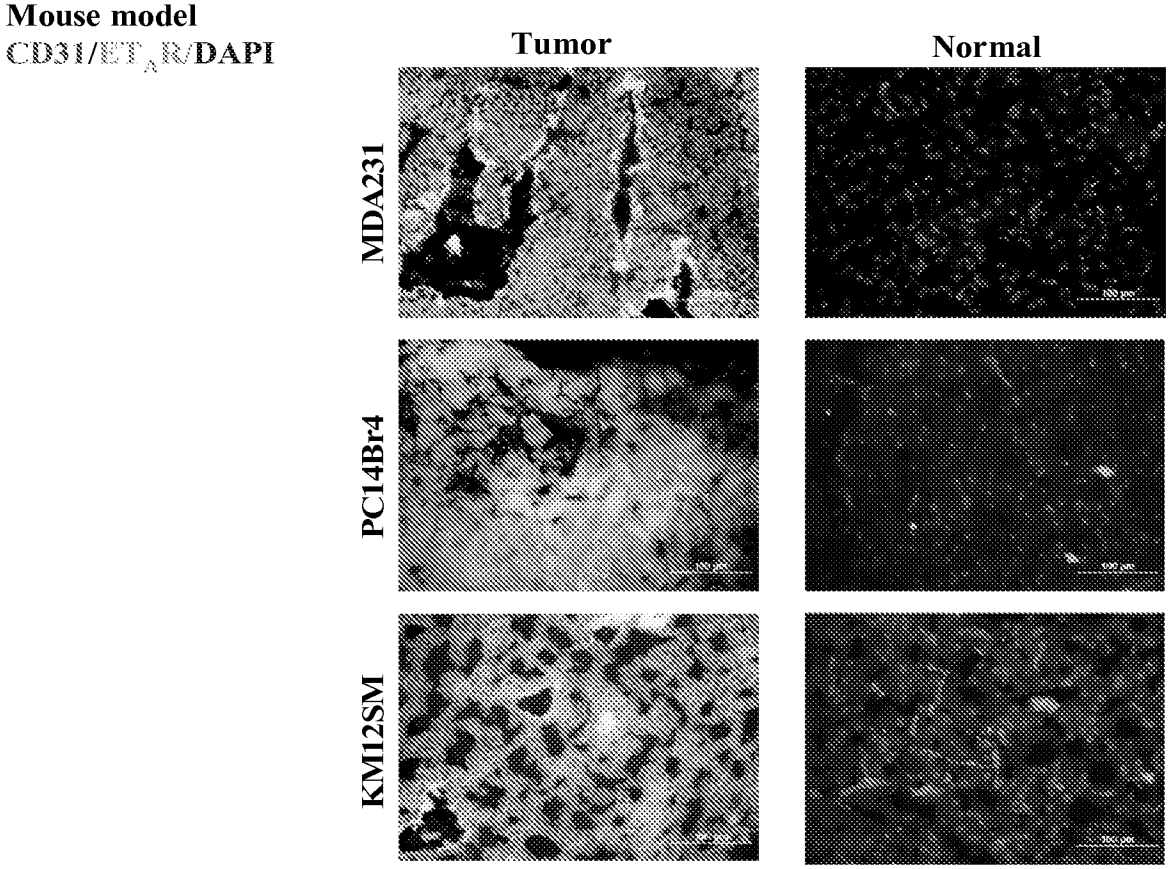

Mouse model
CD31/ETAR/DAPI
Tumor
Normal
MDA231
PC14Br4
KM12SM

FIGURE 14B

Mouse model
CD31/ET_AR/DAPI

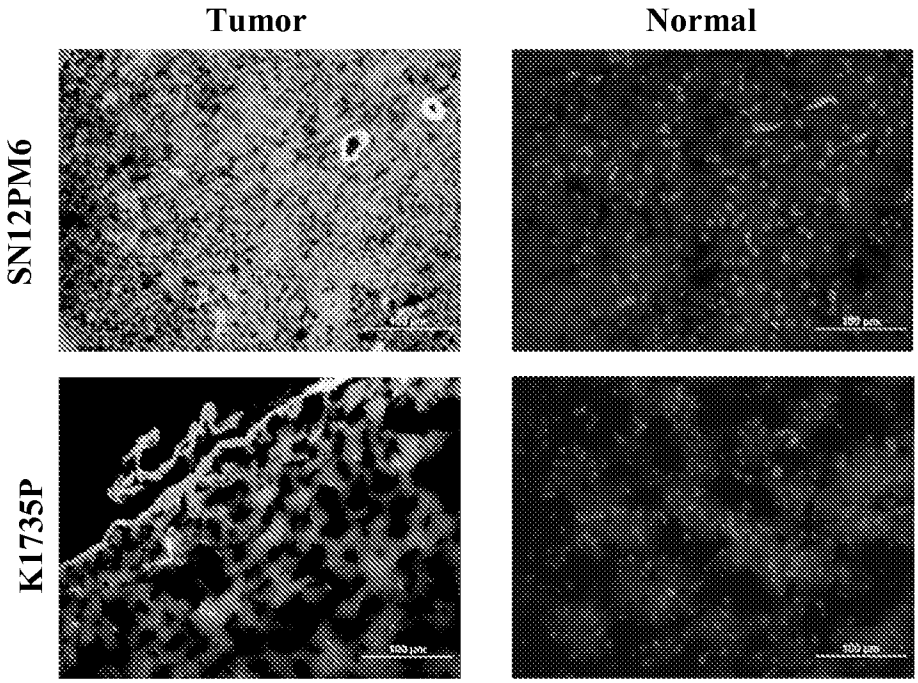


FIGURE 14C

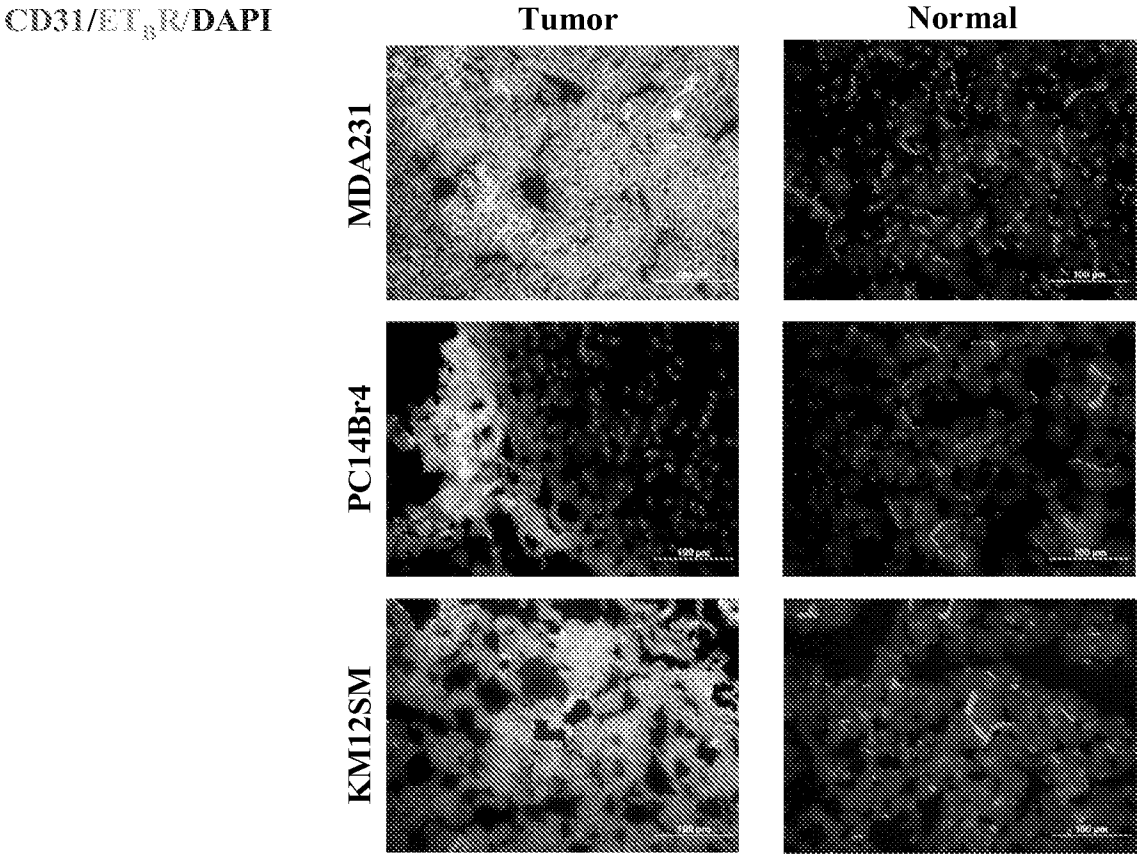

Mouse model
CD31/ETBR/DAPI
Tumor
Normal
MDA231
PC14Br4
KM12SM

FIGURE 14D

Mouse model
CD31/ET_BR/DAPI

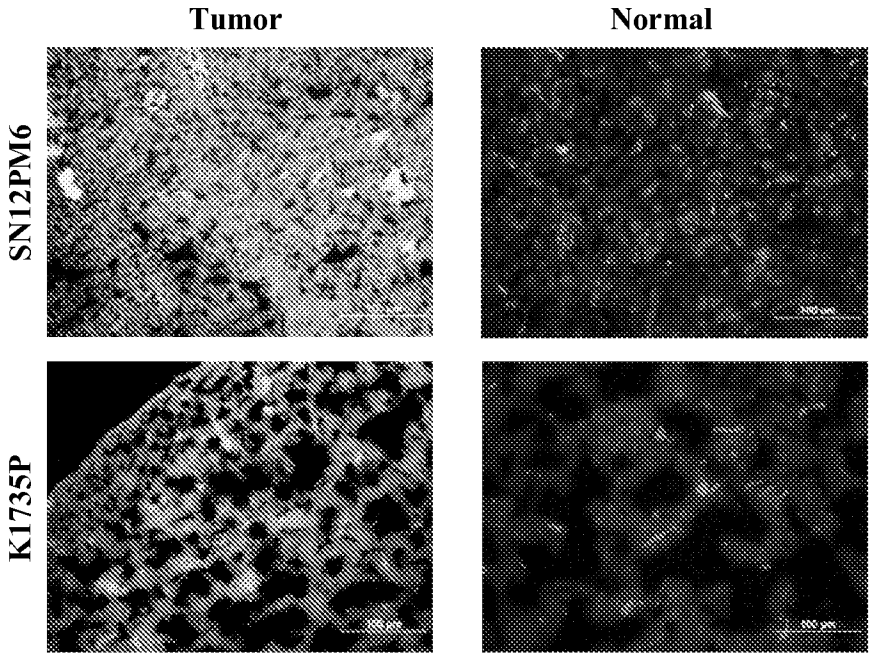


FIGURE 15

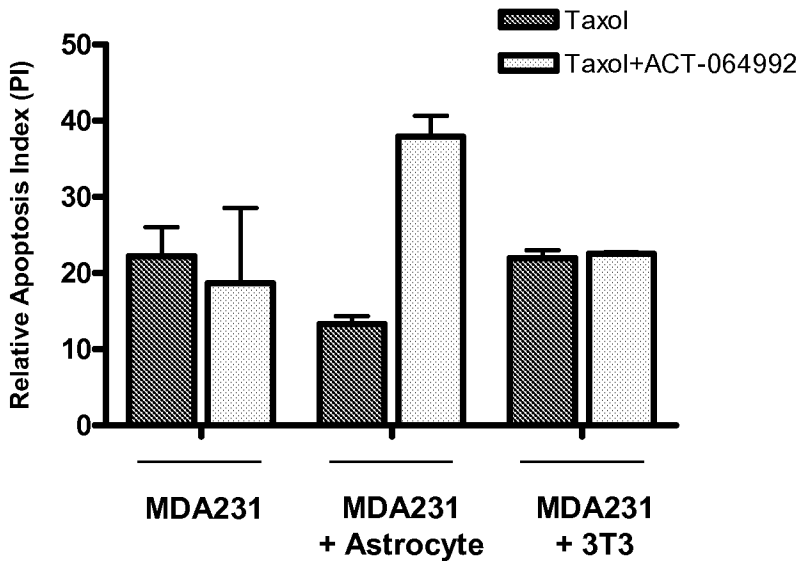


FIGURE 16

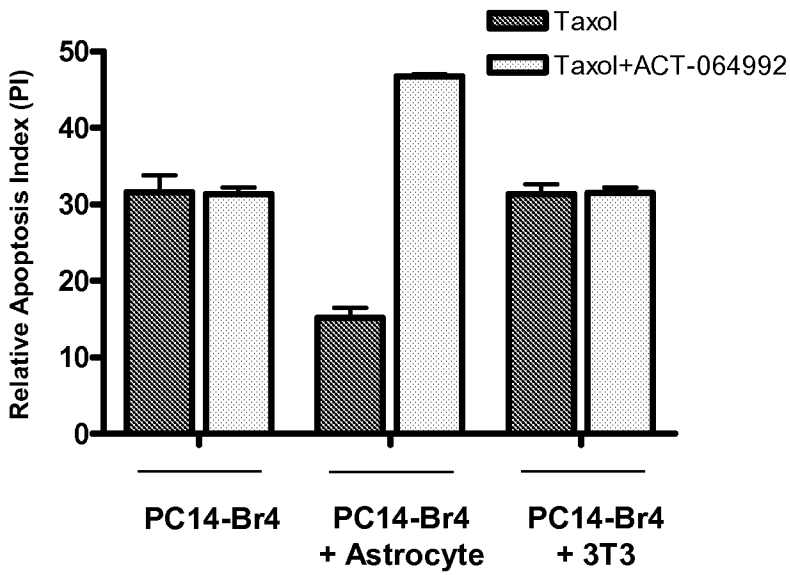
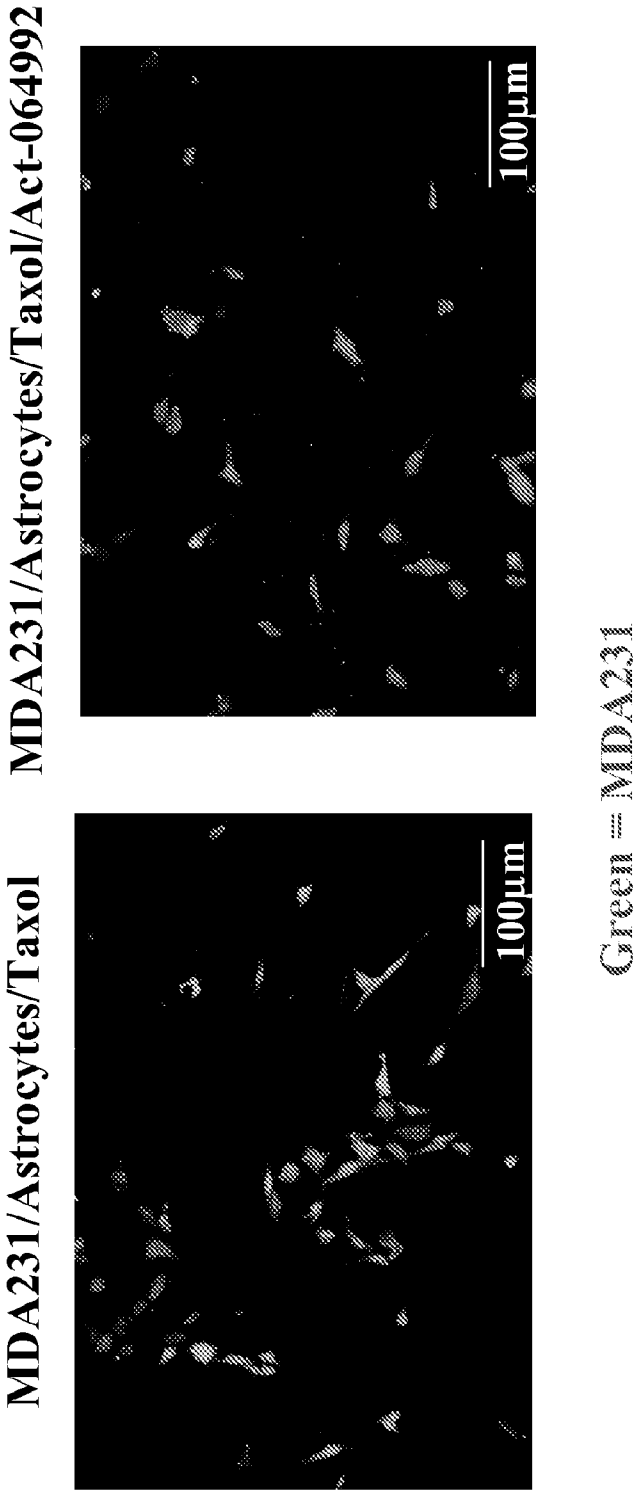


FIGURE 17


Immunohistochemical Analysis
MDA231/Astrocytes/Taxol
MDA231/Astrocytes/Taxol/Act-064992
100μm
100μm
Green = MDA231
Red = pAkt
Blue = nucleus

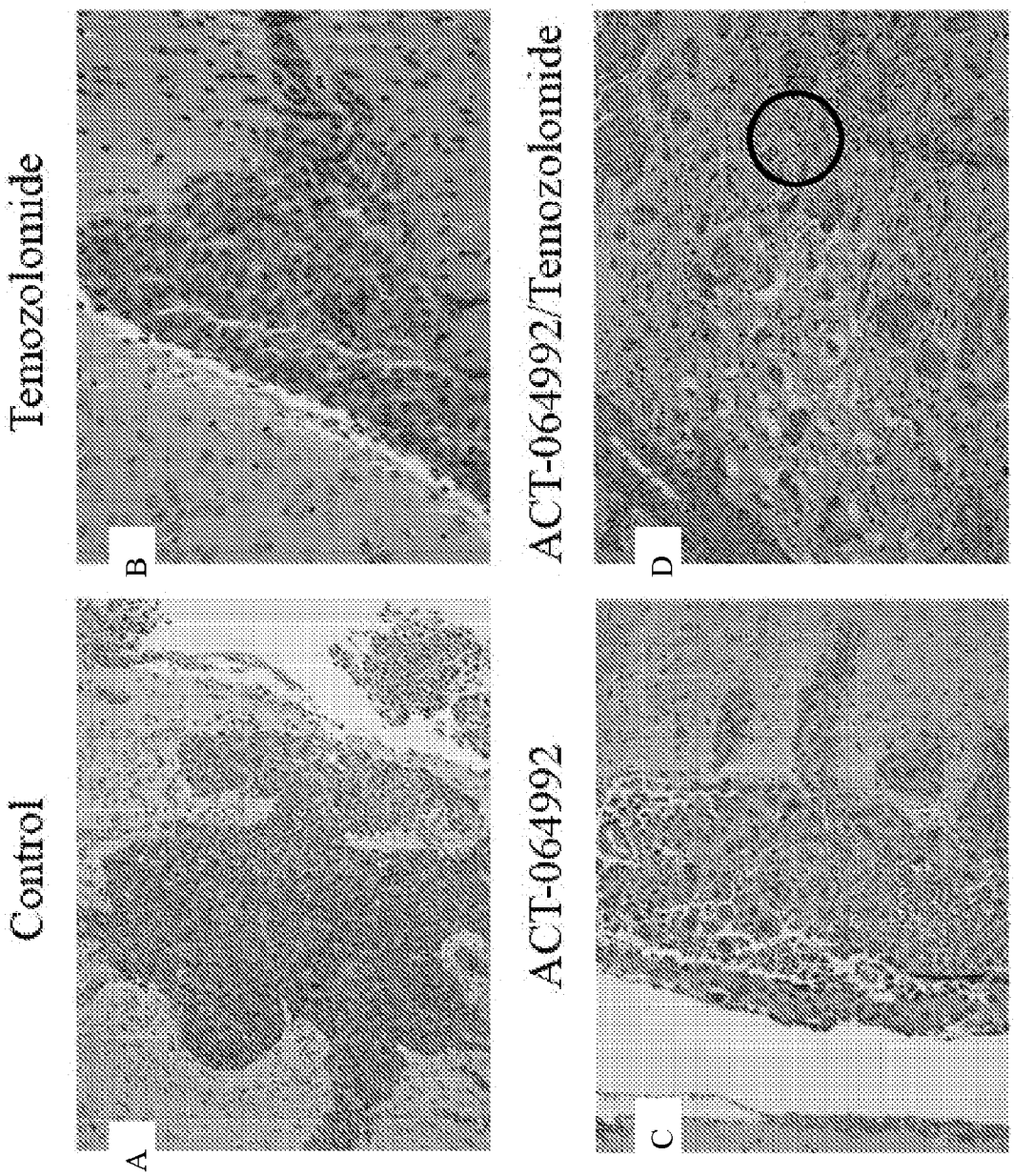

Control
Temozolomide
ACT-064992
ACT-064992/Temozolomide
A
B
C
D

FIGURE 18 A-D

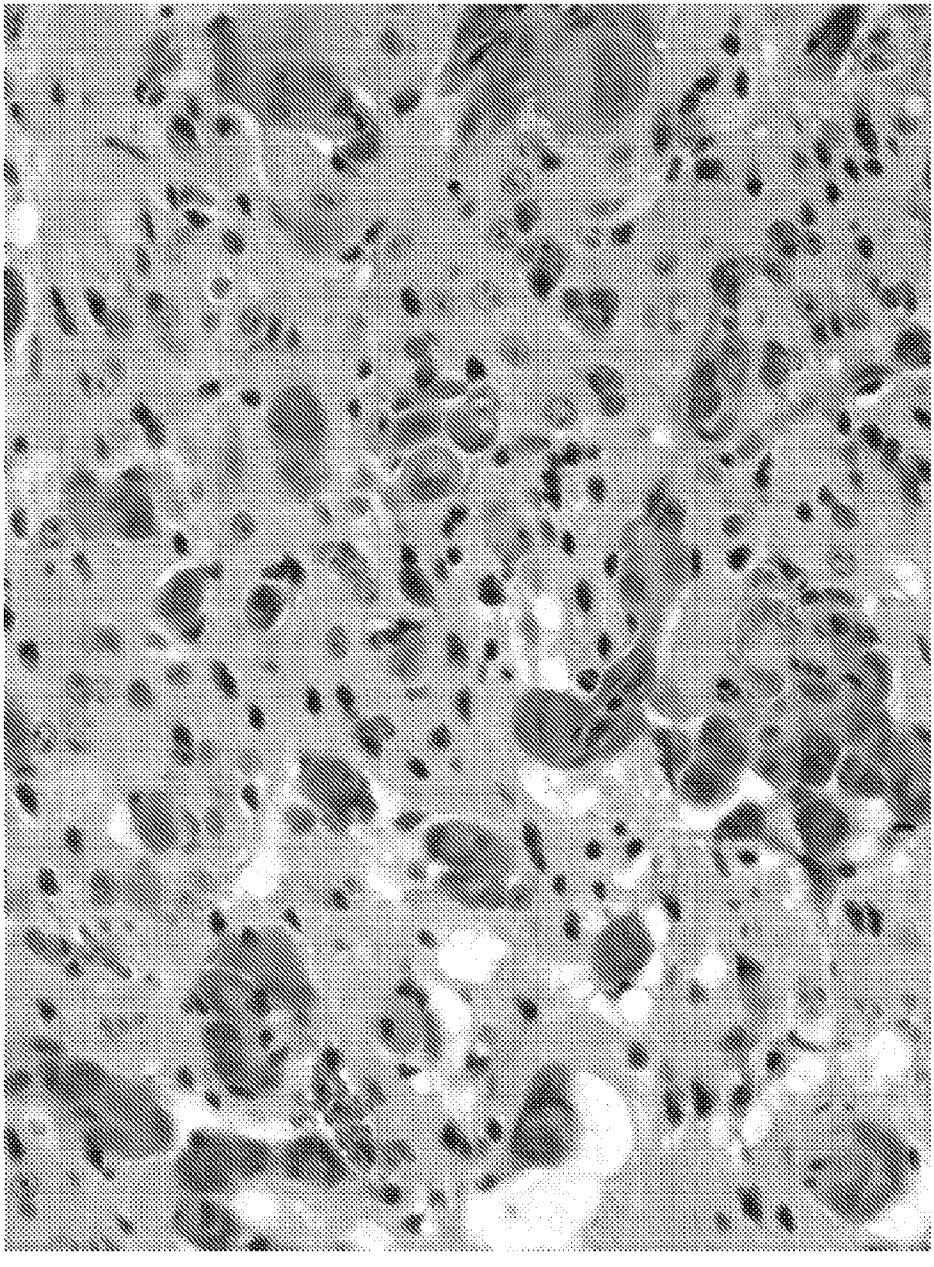


FIGURE 18E

FIGURE 19

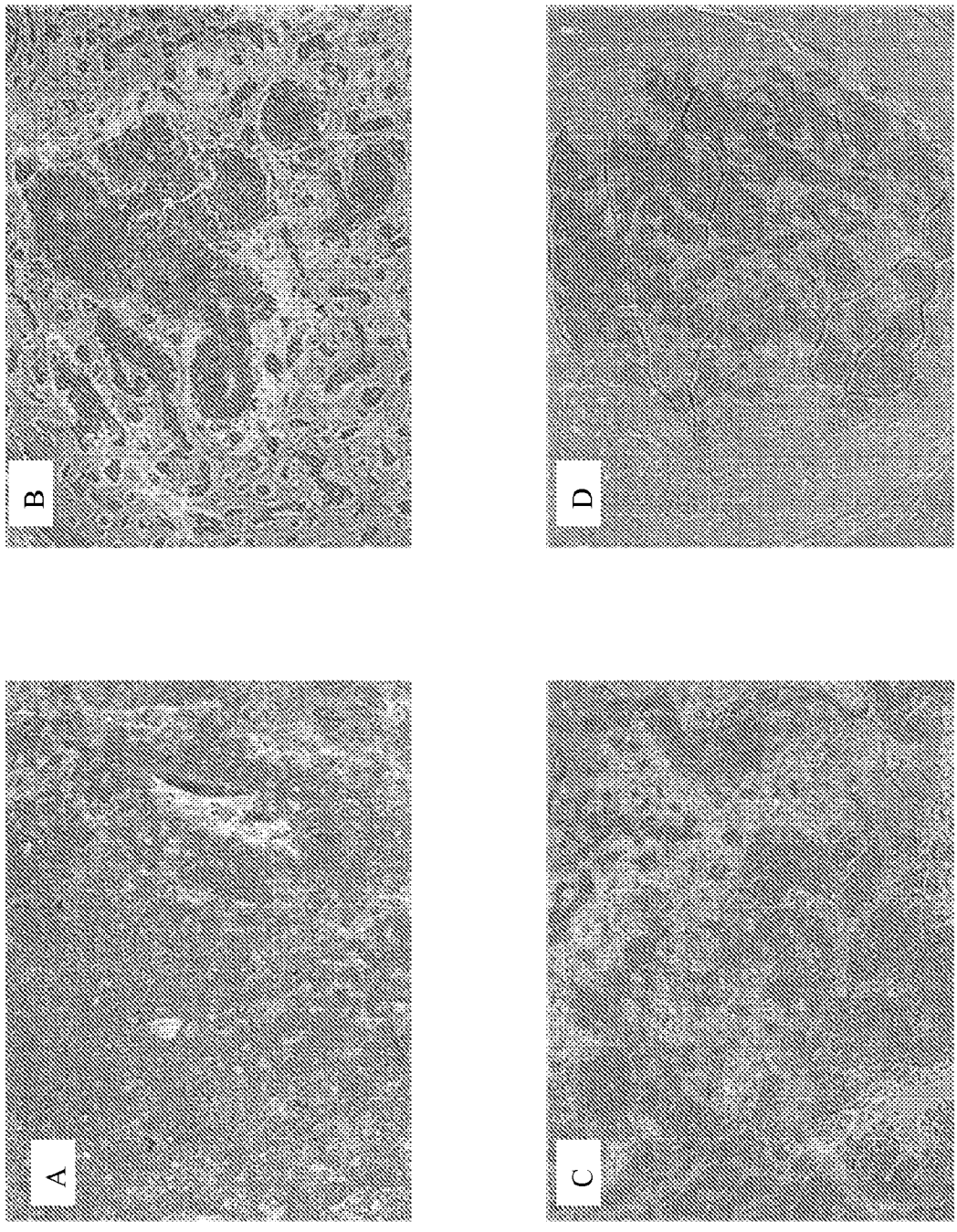


FIGURE 20

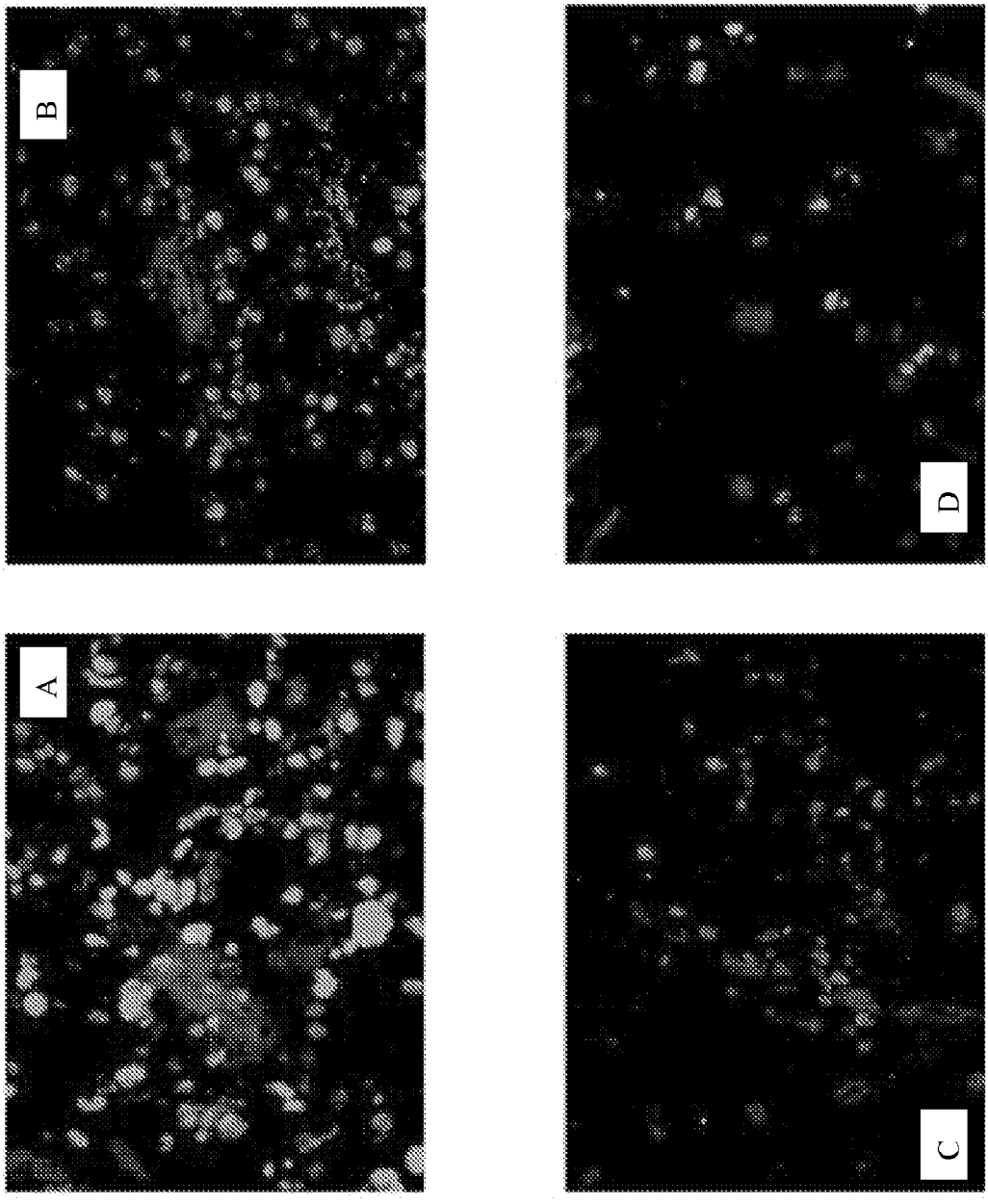


FIGURE 21

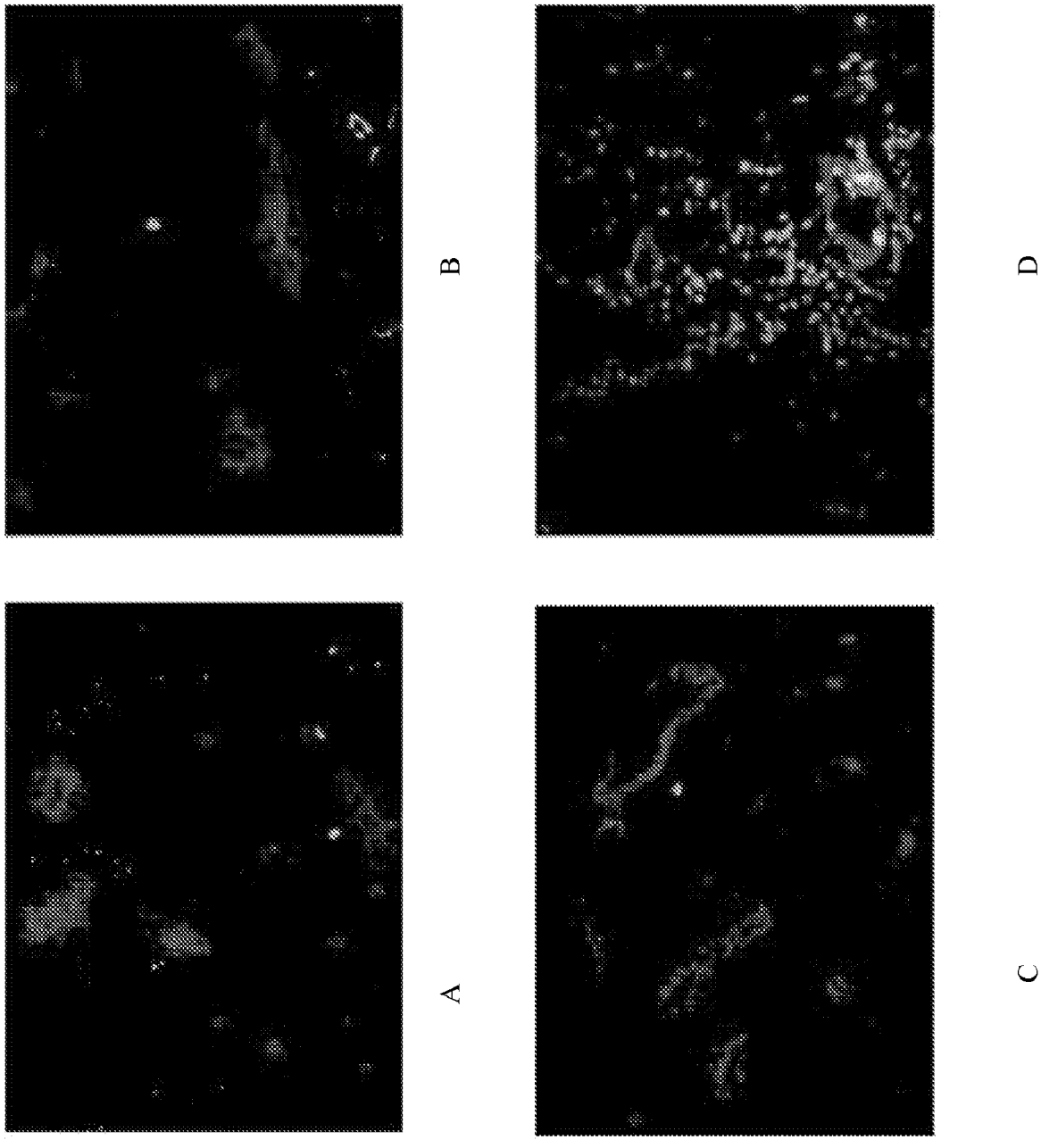


FIGURE 22