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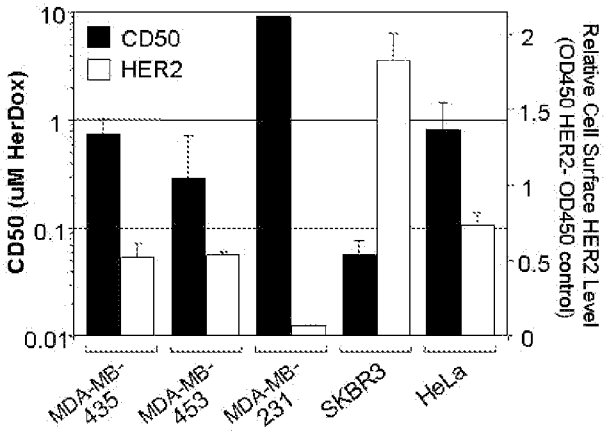
(54) Title: TARGETED DELIVERY SYSTEM

Figure 21.



(57) Abstract: The present invention relates a targeted delivery system for siRNA or antisense technology. In one embodiment, the invention provides for a method of treating cancer by administering a therapeutically effective dosage of HerPBK10 combined with siRNA, resulting in the inhibition of Her2 expression and cell death.

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TARGETED DELIVERY SYSTEM

GOVERNMENT RIGHTS

This invention was made with U.S. Government support on behalf of the NIH by NIH Grant W81XWH-06-1-0549. The U.S. Government may have certain rights in this invention.

FIELD OF THE INVENTION

The invention relates to the field of biotechnology; specifically, to methods of inhibiting sequence-specific gene expression.

BACKGROUND OF THE INVENTION

All publications herein are incorporated by reference to the same extent as if each individual publication or patent application was specifically and individually indicated to be incorporated by reference. The following description includes information that may be useful in understanding the present invention. It is not an admission that any of the information provided herein is prior art or relevant to the presently claimed invention, or that any publication specifically or implicitly referenced is prior art.

In the late 1970s oligonucleotides complementary to messenger RNA (mRNA) were shown to have the capability to knock down, partially or completely, sequence-specific gene expression (antisense technology, AS). The potential of AS seemed vast: in the lab, AS technology could be used to study gene function and complex regulatory pathways by knocking down expression of one gene, or multiple genes, at a time and location of the researcher's choosing; in the clinic, the possibility of shutting off expression of genes known to be involved in disease processes (e.g., oncogenes) beckoned as a new and exciting treatment modality. However, the lack of vectors that could stably, safely, accurately and efficiently deliver therapeutic AS molecules to the desired cell or tissue type was, in many ways, the single biggest hurdle to exploitation of AS technology in the therapeutics market. This dearth confined the market to diseases in which therapeutics could be administered locally, for example, the eye (injection), respiratory passages (inhalation), and the liver. The first, and only, FDA-approved AS drug did not reach the market until 1998; that drug, Isis Pharmaceutical's formivirsen (Vitravene), a 21-mer

oligonucleotide against cytomegalovirus (CMV) retinitis in AIDS patients, must be injected directly into the eye. It acts by specifically affecting CMV gene expression, shutting down the virus but not interfering with the normal functioning of human DNA.

Coincidentally, 1998 was the year in which Fire & Mello published their seminal work on RNA interference (RNAi), work that greatly accelerated advances in AS development and for which they were awarded the 2006 Nobel Prize in Physiology. RNAi is a naturally-occurring, evolutionarily conserved, cellular mechanism of gene regulation achieved through the action of sequence-specific short interfering RNA molecules (siRNA) of which there are several structural types.

Its advantages notwithstanding, use of RNAi presented its own drawbacks and shared with AS technology the lack of reasonably priced, non-toxic vectors that could deliver the nucleotide payload accurately and efficiently. This lack, as with AS technology, confined the development of RNAi therapeutics to those that could be administered locally (again, the eye, respiratory passages, and liver).

Thus, there is a need in the art for novel and effective means of targeted delivery of RNAi and AS therapeutics.

SUMMARY OF THE INVENTION

Various embodiments include a method of treating a disease in an individual, comprising providing a treatment delivery platform comprising a polypeptide sequence adapted to target and/or penetrate a type of cell, and a delivery molecule bound to the polypeptide sequence via electrostatic interactions, and administering a therapeutically effective amount of the treatment delivery platform to the individual to treat the disease. In another embodiment, the delivery molecule comprises siRNA. In another embodiment, the disease comprises cancer. In another embodiment, the polypeptide sequence comprises a decalysine motif. In another embodiment, the polypeptide sequence comprises a Her segment. In another embodiment, the polypeptide sequence comprises a penton base segment. In another embodiment, the polypeptide sequence comprises SEQ. ID. NO.: 5. In another embodiment, the type of cell comprises a HER2+ cancer cell. In another embodiment, the delivery molecule comprises a T7 transcribed siRNA. In another embodiment, the treatment delivery platform is administered to the individual

intravenously and/or by intratumoral injection. In another embodiment, the individual is a human. In another embodiment, the individual is a rodent.

Other embodiments include a treatment delivery platform, comprising a polypeptide sequence adapted to target and/or penetrate a type of cell, and a delivery molecule bound to the polypeptide sequence via electrostatic interactions. In another embodiment, the the polypeptide sequence comprises a decalysine motif. In another embodiment, the polypeptide sequence comprises a Her segment. In another embodiment, the polypeptide sequence comprises a penton base segment. In another embodiment, the polypeptide sequence comprises SEQ. ID. NO.: 5. In another embodiment, the type of cell comprises a HER2+ cancer cell. In another embodiment, the delivery molecule comprises siRNA. In another embodiment, the delivery molecule comprises a T7 transcribed siRNA.

Other embodiments include a pharmaceutical composition, comprising a treatment delivery platform comprising a polypeptide sequence adapted to target and/or penetrate a type of cell, and a delivery molecule bound to the polypeptide sequence via electrostatic interactions, and a pharmaceutically acceptable carrier. In another embodiment, the delivery molecule comprises siRNA. In another embodiment, the type of cell is a HER2+ cancer cell.

Various embodiments include a method of preparing a pharmaceutical composition, comprising combining a polypeptide sequence adapted to target and/or penetrate a type of cell, with a delivery molecule, wherein the polypeptide sequence binds to the delivery molecule via electrostatic interactions, and combining said treatment delilvery platform with a pharmaceutically acceptable carrier. In another embodiment, the delivery molecule comprises siRNA. In another embodiment, the combining of the polypeptide sequence with the delivery molecule comprises incubating the polypeptide sequence with the delivery molecule.

Other features and advantages of the invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, which illustrate, by way of example, various embodiments of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Exemplary embodiments are illustrated in referenced figures. It is intended that the embodiments and figures disclosed herein are to be considered illustrative rather than restrictive.

Figure 1 depicts on representation of an siRNA delivery system in accordance with an embodiment herein.

Figure 2 depicts, in accordance with an embodiment herein, an assembly of HER-targeted siRNA missile.

Figure 3 depicts, in accordance with an embodiment herein, HerPBK10 cell binding and entry. A, Relative cell surface levels of HER subunits on MDA-MB-435 (HER2+) and MDA-MB-231 (HER2-) human breast cancer cells. Cells growing on 96-well plates were incubated with anti-HER subunit antibodies followed by HRP-conjugated secondary antibodies using standard ELISA procedures. Relative cell numbers were measured by crystal violet staining and quantified by measuring crystal violet absorbance at 590 nm. Relative subunit levels are reported as the ELISA signal of each cell population normalized by the relative cell number, or Abs 450 nm/ 590 nm. B, Binding and uptake of HerPBK10 in HER2+ and HER2- cell lines. At 2 days after plating on coverslips in 24 well dishes, cells were incubated with 5 ug HerPBK10/well in Buffer A on ice for 1h to promote receptor binding but not internalization, then washed twice with buffer A to remove free protein, and incubated at 37°C for the indicated time points to promote endocytosis. At each time point, separate wells of cells were washed with PBS/Mg 3-times then fixed in 4% PFA for 15' at RT and processed for immunohistochemistry by standard methods. Images were captured using a Leica laser-scanning confocal fluorescence microscope (Leica Microsystems, Wetzlar, Germany) Red, actin; Blue, nucleus; Green, HerPBK10. Bar = ~10 microns.

Figure 4 depicts, in accordance with an embodiment herein, HerPBK10 transports a labeled oligonucleotide in MDA-MB-435 cells. A Cy3-labeled oligonucleotide (50 pmol) was incubated with either HerPBK10 (5 ug) or a commercial transfection reagent (Lipofectamine 2000; Invitrogen, Carlsbad, CA, USA) in 0.1 M HEPES/Optimem I (Invitrogen; Carlsbad, CA, USA) for 20 minutes at RT. The resulting mixture was added to MDA-MB-435 cells and incubated for 1h at 37°C. Cells were fixed in 4%PFA for 15' at

RT and processed for immunohistochemistry and confocal microscopy as described in Fig. 1.

Figure 5 depicts, in accordance with an embodiment herein, HerPBK10 directly interacts with siRNA via electrophilic binding. A, 50 pmol siRNA from Invitrogen (Carlsbad, CA, USA; ErbB2 RTF primer: TCTGGACGTGCCAGTGTGAA, and ErbB2 RTR primer: TGCTCCCTGAGGACACATCA) was incubated with 0, 5, 10 ug of protein (PB, PBK10 or HerPBK10) in 50ul of 0.1M Hepes/Optimem I buffer for 20' at RT, then subject to electrophoresis on a 2% agarose gel (1:1, agarose: SeaPlaqiue GTG, low melting agarose). After electrophoresis, the gel was stained ethidium bromide to visualize siRNA and siRNA-protein complexes. B, 50 pmol siRNA was incubated with 0, 2 and 6 ug HerPBK10 protein in 0.1MHepes/OptimemI buffer for 20' at RT, then subject to 6% PAGE under native (non-denaturing) conditions. The gel was stained with ethidium bromide to visualize siRNA and siRNA-protein complexes.

Figure 6 depicts, in accordance with an embodiment described herein, HerPBK10-siRNA form stable conjugates that can be isolated by ultrafiltration. Conjugates were made in 0.1M Hepes/OptimemI buffer for 20'-RT, as described above. The siRNA alone or HerPBK10-siRNA conjugates were applied 30K or 100K centrifugal filter devices (Nanosep; Pall Filtron, East Hills, NY, USA) following the manufacturer's protocol. Filtrates and retentates were collected and loaded onto either a 2% agarose (A and B, left panel) or 5% PAGE/native gel (B, right panel). Gels were stained for Et-Br to visualize siRNA and siRNA-protein complexes.

Figure 7 depicts, in accordance with an embodiment described herein, HerPBK10 facilitates siRNA-mediated knock-down in targeted HER2+ cells. At 2 days after plating, MDA-MB-435 cells were treated with either siRNA lipoplexes or HerPBK10-siRNA conjugates in complete media and incubated for 48h at 37°C, after which the media was exchanged for fresh media. At 96h after transfection, cells were analyzed for HER2 and/or HER3 subunit levels by Western blotting. Lipoplexes were formed by incubating 100 pmol siRNA with Lipofectamine 2000 in Optimem I, following the manufacturer's protocol. HerPBK10-siRNA conjugates were formed by incubating 100 pmol siRNA with 20 ug HerPBK10 at 1:2 or 1:4 (siRNA:protein) molar ratios in 100mM Hepes in Optimem I buffer, at RT for 20' before adding to cells in complete media. For Western blotting, cells

were lysed with RIPA buffer (150mM NaCl, 50mM Tris base pH 8.0, 1mM EDTA, 0.5% sodium deoxycholate, 1% NP40, 0.1% sodium dodecyl sulfate, 1mM DTT, 1mM PMSF, and 1mM Na3VO4) supplemented with complete Protease Inhibitor cocktail. Protein concentration was determined using a Bio-Rad protein assay reagent. The cell lysate proteins were separated by 10% PAGE (25 ug of total protein loaded per well), followed by electrotransfer (140 mA for 2 hours) to a nitrocellulose membrane (Hybond-ECL; Amersham Biosciences, Piscataway, NJ, USA). The membranes were blocked in PBS containing 3% dry milk for 1 h at room temperature with constant agitation. The blotted nitrocellulose was incubated with 1 ug/ml Anti-ErbB2/Her2 or Anti-erbB3/Her3 (Upstate/Millipore, Billerica, MA, USA) diluted in PBS-milk agitating at 4°C overnight. The membranes were washed twice with water, and incubated with secondary antibody for 1.5hours at room temperature. The membranes were washed twice with water, then with PBS-0.05% Tween for 3-5 minutes. The nitrocellulose was rinsed with water 4-5 times, and processed for chemiluminescence.

Figure 8 depicts, in accordance with an embodiment herein, HerPBK10 mediates siRNA delivery and knock-down to HER2+ but not HER2- cells. MDA-MB-435 and MDA-MB-231 cells were plated and treated with either siRNA lipoplexes or HerPBK10-conjugates as described in Fig. 5. At 96h after treatment, cells were fixed and processed for immunohistochemistry using a HER2 antibody. Significant differences were determined using two-tailed t tests with unequal variance. *, $P<0.00002$ (compared to untreated); **, $P<0.04$ (compared to untreated).

Figure 9 depicts, in accordance with an embodiment herein, HerPBK10 mediates siRNA delivery to high HER2-expressing cell lines, and augments lipoplex-mediated knock-down. A, HER2 levels of SKBR3 and SKOV3 cell lines in comparison to MDA-MB-435 and MDA-MB-231 cells. Cells were processed for immunohistochemistry using a HER2 antibody and scored for HER2 levels as described in Fig. 1. B, Immunofluorescence of HER2 protein after delivery of lipoplexes or targeted conjugates. SKBR3 and SKOV3 cells were plated and treated with either siRNA lipoplexes or HerPBK10-conjugates as described in Fig. 5. At 96h after treatment, cells were fixed and processed for immunohistochemistry using a HER2 antibody. Conjugates containing HerPBK10 with lipoplexes were formed by incubating either 1.5, 5, or 10 micrograms of HerPBK10 with

siRNA lipoplexes, equating a final molar ratio of either 1:1:1, 1:2:1, or 1:4:1 (siRNA:HerPBK10:Lipofectamine), respectively. These complexes were formed by incubating HerPBK10 with lipoplexes at RT for an additional 20 min after lipoplex formation, then complexes were added to the cells. Control cells were incubated in 100mM HEPES/Optimem I buffer alone, or with HerPBK10 only or siRNA only. Cells received either HER2/neu-specific or scrambled siRNA. C, Quantification of HER2 knock-down. Cells were scored for HER2 immunofluorescence as described in Fig. 1. Statistical significance was determined using a two-tailed t test at unequal variance. *, $P<0.00006$ (compared to untreated); **, $P<0.04$ (compared to untreated).

Figure 10 depicts, in accordance with an embodiment herein, HerPBK10 protects siRNA in serum. Free siRNA alone (60 pmoles) or pre-incubated with HerPBK10 (2 ug, for 30 min at RT) was incubated in either complete media (10% bovine serum) or whole (100%) serum at 37°C for 1h, then assessed by agarose gel electrophoresis.

Figure 11 depicts, in accordance with an embodiment herein, the effect of synthetic (Synth) vs T7-polymerized (T7) siRNA on cell survival. Indicated concentrations of anti-HER2 siRNA were transfected into MDA-MB-435 cells using (A) a commercial transfection agent (RNAimax) or (B) HerPBK10 (pre-assembled with siRNA at 4:1 charge ratio siRNA:protein), and assayed for cell survival using crystal violet stain at 96h after treatment. HerPBK10-siRNA complexes were assembled by co-incubating siRNA and HerPBK10 in 100mM Hepes in Optimem I buffer at RT for 30 min, then free siRNA removed by ultrafiltration through a 100 mwco membrane before adding to cells. Control cells were incubated in 100mM HEPES/Optimem I buffer alone. Un, untreated cells. P values reflect differences between synthetic vs T7 siRNA. Significant differences determined by 2-tailed t tests.

Figure 12 depicts, in accordance with an embodiment herein, survival (assessed by crystal violet stain) of MDA-MB-435 (HER2+) and MDA-MB-231 (HER2-) cells after receiving (A) dosed HerPBK10-siRNA conjugates, and (B) 50 pmoles siHER2 (anti-HER2 siRNA) by non-specific (Lipo-mediated) or targeted (3 ug HerPBK10) complexes in 100 uL complete media/well of a 96-well plate. Complexes were prepared as described in Fig. 2. Un, untreated. In A, *, $P<0.02$ (HER2+ vs HER2- cells). In B, *, $P<0.05$ (compared to untreated). Significant differences determined by 2-tailed t tests.

Figure 13 depicts, in accordance with an embodiment herein, cytokine induction. Cells growing in 96-well plates ($5x10^3$ cells/well) were treated with indicated concentrations (with respect to siRNA concentration) of HerPBK10-siRNA complexes or HerPBK10 (3ug per well, at equivalent concentration to HerPBK10 in the 50nM dose of complex). At 24h after treatment, media was collected from above the cells and assayed for (A) IFN-alpha, or (B) IFN-beta titer by sandwich ELISA following manufacturer's protocol (PBL Biomedical Laboratories). *, $P<0.01$ (compared to untreated); **, $P=0.01$ (HER2+ vs HER2- cells); †, $P<0.05$ (compared to untreated). Statistical significances determined by 2-tailed t tests.

Figure 14 depicts, in accordance with an embodiment herein, comparing of RNAi species. HerPBK10 was assembled with each RNAi species at a HerPBK10:nucleic acid molar ratio of 4 by co-incubation in 100mM Hepes+Optimem I buffer at RT for 30 min, then free RNAi species removed by ultrafiltration through a 100K mwco membrane before adding to separate wells of GFP-tagged MDA-MB-435 (HER2+; A & C) or MDA-MB-231 (HER2-; B & D) human cancer cells. Cells were assayed for GFP expression (A & B) and metabolic (MTT) activity (C & D) at 96h after treatment.

Figure 15 depicts, in accordance with an embodiment herein, effect on tumor growth. Female (6-8 week) nude mice were inoculated with human HER2+ MDA-MB-435 cancer cells by subcutaneous flank injections of 1x10^7 cells per injection. At 4-6 weeks after implant, weekly measurements were taken to quantify tumor volume and track growth. Each tumor received an IT injection of either T7 transcribed anti-HER2 siRNA or HerPBK10-siRNA (1.5 nmoles final siRNA dose) on the second and third weeks of tumor monitoring. Complex was prepared as described in Figure 14, A, representative mice at week 4 with tumors indicated by arrows. B, tumor volumes from mice receiving siRNA alone or HerPBK10-siRNA.

Figure 16 depicts, in accordance with an embodiment herein, in vivo cytokine induction. Blood was collected from the mice treated in Figure 15B at 24h after each IT injection and relative IFN-alpha levels quantified by sandwich ELISA following manufacturer's protocol (PBL Biomedical Laboratories). Control, tumors receiving saline injections. *, $P=0.05$ compared to control (as determined by 2-tailed unpaired T test).

Figure 17 depicts, in accordance with an embodiment herein,testing for neutralizing antibody induction. A, Immunocompetent (C57BL/6) mice received an initial subcutaneous inoculation of HerPBK10 protein (0.05 or 0.5 mg/kg) or Ad5-GFP (1.2x10^9 pfu/mouse) followed by blood collection scheduled every seven days up to day 35 after the initial inoculation, as summarized by the upper time chart. On day 21, respective mice received a second inoculation of each corresponding reagent. Sera isolated from bleeds were assessed by ELISA for relative antibody titer produced against HerPBK10 (lower graph). Arrows denote days of antigen inoculation. N=4 mice per treatment group dose. B, Effect of immune sera on target cell binding. Ligand-receptor binding was tested by measuring the level of cell attachment to HerPBK10-coated plates in immune or pre-immune serum collected from mice in *A*. Cells suspended in either pre-immune serum, immune serum from Ad5 or HerPBK10 –inoculated mice, or complete media containing 10% bovine serum but no mouse serum were incubated on HerPBK10-coated wells for 1 h at 37°C, followed by removal of free cells and measurement of attached cells by crystal violet assay. The level of receptor-specific binding was assessed on separate cells pre-incubated with competitive inhibitor (Her). Un, untreated mice. *, $P<0.01$ compared to cells attached in pre-immune serum, as determined by 2-tailed unpaired t test.

Figure 18 depicts, in accordance with an embodiment herein, external lesions in Ad vs. HerPBK10 treated mice. C57BL/6 mice inoculated with Ad or HerPBK10 as described in Figure 17, were observed for notable effects on eyes and periocular hair (arrows).

Figure 19 depicts, in accordance with an embodiment herein, preferential targeting to HER2+ tumors. Tumor-bearing mice were injected with 0.02 mg/kg (final Dox dose) of HerDox or Dox via the tail vein and imaged with a custom small animal imager. A, Imaging of live mice after IV delivery of HerDox. Time points are shown as minutes after injection. Tumors are indicated by arrows. B, Imaging of tumors and tissues harvested at 3h after injection of HerDox or Dox. Fluorescence signal from Dox is pseudo-colored according to the color bar, with a shift toward 100 indicating high fluorescence intensity.

Figure 20 depicts, in accordance with an embodiment herein, relative cell surface HER subunit levels as measured by ELISA. Cells were plated on a 96-well plate at $1x10^4$ cells/well and grown two days before 15 min fixation at RT with 4% paraformaldehyde in PBS, followed by rinsing 3x in PBS, and blocking with 1% BSA/PBS solution for 1h at

RT. Fixed cells were incubated with anti-HER subunit antibodies (1 ug/mL anti-erbB-2/Her-2 rabbit polyclonal IgG and anti-erbB-3/Her-3 mouse monoclonal IgG from Upstate Biotechnology Inc., Lake Placid, NY, USA; and 3 ug/mL mouse monoclonal [HFR1] to Her4 from Abcam Inc., Cambridge, MA, USA), followed by incubation with HRP-conjugated secondary antibodies and enzymatic assay using standard procedures (Agadjanian et al., 2009), with product formation quantified by absorbance at 450 nm. Relative cell numbers were quantified by crystal violet staining and absorbance at 590 nm. Relative subunit levels are reported as the ELISA signal of each cell population normalized by the relative cell number, or absorbance 450 nm/ 590 nm.

Figure 21 depicts, in accordance with an embodiment herein, toxicity to cells displaying differential HER2. Cytotoxicities from a range of HerDox doses were assessed on each cell line by metabolic assay and confirmed by crystal violet stain. CD50 values (shown in log scale) were determined by non-linear regression analyses of HerDox dose curves using a scientific graphing program (GraphPad Prism) and confirmed with an on-line calculator (Chang bioscience). The relative HER2 level of each cell line is shown next to each CD50 value.

Figure 22 depicts, in accordance with an embodiment herein, HerPBK10 binding to MDA-MB-435 cells in human serum from HER2+ or HER2- breast cancer patients. Cells were treated with HerPBK10 (1.2ug/well) in wells containing human serum from each of 5 HER2+ breast cancer patients or age matched HER2- controls, both obtained pre-chemotherapy treatment. Cells were processed for ELISA using an antibody directed at HerPBK10. Control (C) wells receiving HerPBK10 in media containing 10% bovine serum without or with 100x molar excess ligand inhibitor (+ Her) are indicated by open bars. Patient sera were provided by the WCRI tissue bank at Cedars-Sinai Medical Center. N=3 wells per treatment.

Figure 23 depicts, in accordance with an embodiment herein, monitoring in vivo tumor targeting. The inventors assembled HerPBK10 with Cy5-labeled HER2 siRNA (siRNA labeling kit, Mirus) and filtered the complex through a 50K MWCO ultrafiltration column to remove free label. A single tail vein injection of either (A) free siRNA or (B) HerPBK10-siRNA, equating ~40pmoles of Cy5 label, was each delivered into separate female nude mice bearing bilateral flank tumors of HER2+ (MDA-MB-435) cells. The

mice were immediately monitored by in vivo fluorescence intensity imaging through our collaborators' imaging facility (Farkas lab, Cedars-Sinai Medical Center). C, Analysis of the fluorescence intensity contrast between tumor and non-tumor areas of A and B (graphs).

DETAILED DESCRIPTION

All references cited herein are incorporated by reference in their entirety as though fully set forth. Unless defined otherwise, technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. Singleton et al., Dictionary of Microbiology and Molecular Biology 3rd ed., J. Wiley & Sons (New York, NY 2001); March, Advanced Organic Chemistry Reactions, Mechanisms and Structure 5th ed., J. Wiley & Sons (New York, NY 2001); and Sambrook and Russel, Molecular Cloning: A Laboratory Manual 3rd ed., Cold Spring Harbor Laboratory Press (Cold Spring Harbor, NY 2001), provide one skilled in the art with a general guide to many of the terms used in the present application.

One skilled in the art will recognize many methods and materials similar or equivalent to those described herein, which could be used in the practice of the present invention. Indeed, the present invention is in no way limited to the methods and materials described. For purposes of the present invention, the following terms are defined below.

"Beneficial results" may include, but are in no way limited to, preventing, reducing, preventing the increase of and inhibiting the proliferation or growth of cancer cells or tumors. Beneficial results may also refer to curing the cancer and prolonging a patient's life or life expectancy.

"Cancer" and "cancerous" refer to or describe the physiological condition in mammals that is typically characterized by unregulated cell growth. Examples of cancer include, but are not limited to, ovarian cancer, breast cancer, colon cancer, lung cancer, prostate cancer, hepatocellular cancer, gastric cancer, pancreatic cancer, cervical cancer, liver cancer, bladder cancer, cancer of the urinary tract, thyroid cancer, renal cancer, carcinoma, melanoma, head and neck cancer, and brain cancer.

"Curing" cancer includes degrading a tumor such that a tumor cannot be detected after treatment. The tumor may be reduced in size or become undetectable, for example, by

atrophying from lack of blood supply or by being attacked or degraded by one or more components administered according to the invention.

"Mammal" as used herein refers to any member of the class *Mammalia*, including, without limitation, humans and nonhuman primates such as chimpanzees and other apes and monkey species; farm animals such as cattle, sheep, pigs, goats and horses; domestic mammals such as dogs and cats; laboratory animals including rodents such as mice, rats and guinea pigs, and the like. The term does not denote a particular age or sex. Thus, adult and newborn subjects, as well as fetuses, whether male or female, are intended to be included within the scope of this term.

"Pathology" of cancer includes all phenomena that compromise the well-being of the patient. This includes, without limitation, abnormal or uncontrollable cell growth, metastasis, interference with the normal functioning of neighboring cells, release of cytokines or other secretory products at abnormal levels, suppression or aggravation of inflammatory or immunological response, neoplasia, premalignancy, malignancy, invasion of surrounding or distant tissues or organs, such as lymph nodes, etc.

"Prevention" as used herein refers to efforts undertaken to hinder the development or onset of a condition or cancer condition even if the effort is ultimately unsuccessful.

"Condition" as used herein refers to an illness or physical ailment.

"Therapeutically effective amount" as used herein refers to that amount which is capable of achieving beneficial results in a patient with cancer. A therapeutically effective amount can be determined on an individual basis and will be based, at least in part, on consideration of the physiological characteristics of the mammal, the type of delivery system or therapeutic technique used and the time of administration relative to the progression of the disease.

"Treatment" and "treating," as used herein refer to both therapeutic treatment and prophylactic or preventative measures, wherein the object is to achieve beneficial results even if the treatment is ultimately unsuccessful.

"Tumor," as used herein refers to all neoplastic cell growth and proliferation, whether malignant or benign, and all pre-cancerous and cancerous cells and tissues.

As used herein, "Her" refers to a segment obtained from the receptor binding domain of heregulin-α, which binds to HER2/HER3 or HER2/HER4 subunit heterodimers.

As used herein, "PB" refers to a penton base segment that normally mediates cell binding, entry, and cytosolic penetration of adenovirus serotype 5 during the early stages of infection. This penton base protein normally has an RGD motif (Arg-Gly-Asp). As used herein, "K10" refers to a decalysine motif that has the capacity to bind nucleic acids by electrophilic interaction. Similarly, a point mutation of the RGD motif may be used to create an EGD motif (Glu-Gly-Asp), resulting in a HerPBrgdK10 polypeptide molecule (rather than HerPBK10).

As readily apparent to one of skill in the art, any number of variations and examples of polynucleotide and polypeptide sequences described herein. For example, an example of HerPBK10, described herein as SEQ. ID. NO.: 1, may also include the complement polynucleotide sequence. Or, for example, it may include SEQ. ID. NO.: 5, a polypeptide penton base (PB) sequence. Similarly, SEQ. ID. NO.: 2, a 3' primer for PB, SEQ. ID. NO.: 3, a 3' primer for PBK10, and SEQ. ID. NO.: 4, a 3' primer for HerK10, may also be used to generate versions of the HerPBK10 construct in conjunction with various embodiments described herein.

As readily apparent to one of skill in the art, any number of antisense sequences or technology may be used in accordance with various embodiments described herein, including siRNA, triphosphate-capped siRNA, shRNA, dsRNA, double stranded nucleic acids, and RNAi. The invention is in no way limited to an siRNA molecule.

As known to one of skill in the art, any number of targeting ligands may be used in accordance with various embodiments described herein. For example, PB itself may act as a targeting ligand of PBK10 when targeting integrins such as $\alpha_v\beta_3$. As known by one of skill in the art, integrins are overly expressed in various types of metastatic tumors. Thus, in conjunction with various embodiments described herein, PBK10 may be used to target metastatic tumors and cells with a high expression of integrins.

As disclosed herein, the inventors tested whether a recombinant adenovirus (Ad) capsid protein, HerPBK10, which can selectively bind to HER2+ breast cancer, mediates missile-like targeted delivery of siRNA and induces tumor cell-specific death via siRNA-mediated "knock-down" of specific gene transcripts. The inventors designed HerPBK10 to penetrate HER2+ cells by combining the 'Her' domain for binding heregulin receptors, which have an increased ligand affinity on HER2+ tumor cells, and the membrane lysis and

intracellular trafficking features of the 'PB' domain, which is derived from the cell-entry functions of the Ad capsid. Binding and transport of nucleic acids can be mediated by the polylysine, 'K10' domain. To demonstrate that HerPBK10 can mediate targeted siRNA delivery, the inventors first used ELISA and/or immunofluorescence to establish the receptor profiles of frequently-used cell lines characterized by different levels of heregulin receptor subunits. It was observed that HerPBK10 underwent substantially greater cell binding and uptake in HER2+ human breast cancer cells while minimal to negligible levels of binding and uptake were detected from HER2- cells. Using in vivo fluorescence imaging, it was observed that the targeting ligand used here specifically accumulates at HER2+ tumor tissue in mice while evading accumulation in other tissues. It was also observed that HerPBK10 could mediate the uptake of a Cy3-labeled oligonucleotide in HER2+ cells. The formation of noncovalent conjugates resulting from incubating HerPBK10 with siRNA was verified by the observation that siRNA electromobility dose-dependently decreased as HerPBK10 concentration increased. Ultrafiltration of conjugates under high speed centrifugation demonstrated that free siRNA could be separated from siRNA bound to the HerPBK10, and also indicated that the conjugate can withstand high shear forces without releasing the siRNA molecule. Targeted conjugates delivering anti-Her2 siRNA were added to HER2+ human breast cancer cells in culture, and yielded specific gene "knock-down" in target cells. Associated with this reduction was substantial target cell death. Depending on the cell line, up to 85% reduction was observed in HER2+ cell survival whereas HER2- cells receiving the targeted conjugate were little affected. HerPBK10 also augmented liposomal delivery of siRNA: when combined with liposome-coated siRNA, HER2+ cell numbers were considerably reduced whereas HER2- cell numbers showed only slight to negligible reduction. SiRNA Lipoplexes alone (lacking HerPBK10) only modestly to negligibly reducted the survival of both HER2+ and HER2- cells. Altogether, these findings indicate that HerPBK10 enables missle-like delivery of siRNA, resulting in targeted cell death.

In one embodiment, this invention is designed to direct antisense and/or RNA interference (RNAi) to target cells. In another embodiment, the invention is comprised of two components that self-assemble into one targeted complex. In one form, the first component (Unit A) is a unique cell-penetrating carrier that can bind and enter target cells

(Fig. 1). The second component (Unit B) may be a double-stranded nucleic acid that binds to the first component via electrostatic interactions (Fig. 1).

In one embodiment, the carrier is comprised of three main segments: 1. a unit designed to bind to specific target cells (Fig. 1, "L"); 2. a unit designed to mediate penetration into the interior of target cells (Fig. 1, "MP"); 3. a unit that can interact with nucleic acids designed to mediate RNAi (Fig. 1, "D").

In another embodiment, the nucleic acid may be comprised of: small interfering RNA (siRNA) of any length made from either synthetic or biological sources, small hairpin RNA (shRNA) of any length, complimentary oligonucleotides of any length, etc., to mediate RNAi in target cells. The nucleic acid may also contain any type of modification (i.e. addition of phosphate groups, etc) that may enhance its therapeutic efficacy.

The feasibility of this new type of therapeutic has been tested on HER2+ breast cancer *in vitro* and *in vivo*. To target HER2+ breast cancer, Unit A may be comprised of a protein called HerPBK10 (Fig. 2). HerPBK10 may contain the receptor binding domain of heregulin fused to the cell penetrating adenovirus penton base protein modified by a carboxy (C) –terminal decalysine (Fig. 2). The 'Her' segment of HerPBK10 may be obtained from the receptor binding domain of heregulin which binds specifically to HER2/HER3 or HER2/HER4 subunit heterodimers. Although heregulin interacts directly with HER3 or HER4, but not HER2, ligand affinity is greatly enhanced by HER2. Thus, tumor cells that over-express HER2 (known as HER2+ tumor cells) are ideal candidates for heregulin-directed targeting.

The membrane penetrating activity of the adenovirus serotype 5 (Ad5) penton base protein is incorporated into the 'PB' segment of HerPBK10 to facilitate penetration into target cells. The 'K10' segment is comprised of 10 lysine residues, whose positive charge can facilitate the transport of negatively charged molecules, such as nucleic acids, by electrophilic interaction.

The targeted RNAi delivery system enables the utilization of recombinant pathogen proteins modified for missile-like delivery and penetration of the RNAi therapeutic into target cells. This system is modular in its design, thus the cell targeting ligand may be exchanged for other ligands, depending on the cell targeted. In its practically applied form for tumor targeting and treatment, siRNA containing secondary modifications may be used

to induce target cell induction of anti-tumor cytokines, and thus enhance tumor toxicity. The latter feature is unique to the method of use presented here, as sequence-independent cytotoxicity elicited by siRNA is currently considered an undesirable side effect by the research community at large. In one embodiment, this feature is exploited to enhance tumor toxicity by targeting the siRNA to tumor cells via the delivery agent.

The siRNA molecule delivery system includes a complex that can be administered to a mammal by various routes of administration, whereupon it hones in on target cells (*e.g.*, cancer cells) to deliver an siRNA molecule into the cells. In one embodiment, the complex provides for delivery of an siRNA molecule to cancer cells while sparing normal, healthy cells. Current methods of siRNA therapy fail due to the many off-target effects of the therapy and use of chemical modification strategies that impair therapeutic activity, in accordance with embodiments described herein, an advantage of the inventive siRNA molecule delivery system is its targeting effects.

In various embodiments, the siRNA molecule delivery system can be incorporated into a pharmaceutical composition, which may be formulated for delivery via any route of administration. "Route of administration" may refer to any administration pathway known in the art, including but not limited to aerosol, nasal, oral, transmucosal, transdermal or parenteral. "Parenteral" refers to a route of administration that is generally associated with injection, including intraorbital, infusion, intraarterial, intracapsular, intracardiac, intradermal, intramuscular, intraperitoneal, intrapulmonary, intraspinal, intrasternal, intrathecal, intrauterine, intravenous, subarachnoid, subcapsular, subcutaneous, transmucosal, or transtracheal. Via the parenteral route, the compositions may be in the form of solutions or suspensions for infusion or for injection, or in the form of lyophilized powders.

The pharmaceutical compositions according to the invention can also contain any pharmaceutically acceptable carrier. "Pharmaceutically acceptable carrier" as used herein refers to a pharmaceutically acceptable material, composition, or vehicle that is involved in carrying or transporting a compound of interest from one tissue, organ, or portion of the body to another tissue, organ, or portion of the body. For example, the carrier may be a liquid or solid filler, diluent, excipient, solvent, or encapsulating material, or a combination thereof. Each component of the carrier must be "pharmaceutically acceptable" in that it

must be compatible with the other ingredients of the formulation. It must also be suitable for use in contact with any tissues or organs with which it may come in contact, meaning that it must not carry a risk of toxicity, irritation, allergic response, immunogenicity, or any other complication that excessively outweighs its therapeutic benefits.

The pharmaceutical compositions according to the invention can also be encapsulated, tableted or prepared in an emulsion or syrup for oral administration. Pharmaceutically acceptable solid or liquid carriers may be added to enhance or stabilize the composition, or to facilitate preparation of the composition. Liquid carriers include syrup, peanut oil, olive oil, glycerin, saline, alcohols and water. Solid carriers include starch, lactose, calcium sulfate, dihydrate, terra alba, magnesium stearate or stearic acid, talc, pectin, acacia, agar or gelatin. The carrier may also include a sustained release material such as glyceryl monostearate or glyceryl distearate, alone or with a wax.

The pharmaceutical preparations are made following the conventional techniques of pharmacy involving milling, mixing, granulating, and compressing, when necessary, for tablet forms; or milling, mixing and filling for producing hard gelatin capsule forms. When a liquid carrier is used, the preparation will be in the form of a syrup, elixir, emulsion or an aqueous or non-aqueous suspension. Such a liquid formulation may be administered directly p.o. or filled into a soft gelatin capsule.

The pharmaceutical compositions according to the invention may be delivered in a therapeutically effective amount. The precise therapeutically effective amount is that amount of the composition that will yield the most effective results in terms of efficacy of treatment in a given subject. This amount will vary depending upon a variety of factors, including but not limited to, the characteristics of the therapeutic compound (including activity, pharmacokinetics, pharmacodynamics, and bioavailability), the physiological condition of the subject (including age, sex, disease type and stage, general physical condition, responsiveness to a given dosage, and type of medication), the nature of the pharmaceutically acceptable carrier or carriers in the formulation, and the route of administration. One skilled in the clinical and pharmacological arts will be able to determine a therapeutically effective amount through routine experimentation, for instance, by monitoring a subject's response to administration of a compound and adjusting the

dosage accordingly. For additional guidance, see Remington: The Science and Practice of Pharmacy (Gennaro ed. 20th edition, Williams & Wilkins PA, USA) (2000).

Typical dosages of the siRNA molecule delivery system as well as the siRNA molecule itself and additional compounds delivered by it such as therapeutical compounds and/or imaging agents, can be in the ranges recommended by the manufacturer where known therapeutic compounds or imaging agents are used, and also as indicated to the skilled artisan by the *in vitro* responses or responses in animal models. The actual dosage will depend upon the judgment of the physician, the condition of the patient, and the effectiveness of the therapeutic method.

The invention also relates to methods of treating diseases by administration to a mammal in need thereof of elimination of a specific target, such as a tumor, or to silence target genes. In one embodiment of the invention, the disease is cancer. In another embodiment of the invention, the disease is breast cancer and/or HER2+ breast cancer.

The invention also relates to methods of diagnosing and/or prognosing a disease in a mammal by administering to the mammal an effective amount of the delivery system of the invention including an imaging agent appropriate to enable the imaging of cells and/or tissues relevant to the disease. In one embodiment of the invention, the disease is cancer and an imaging agent is delivered to image cancerous cells or tissue. In another embodiment of the invention, the disease is breast cancer and/or HER2+ breast cancer. The methods may include administration of the delivery system with a suitable imaging agent and the use of conventional imaging techniques to thereafter image the target tissue or cells and thereby diagnose and/or prognose the disease condition.

In other embodiments, the aforementioned methods may be used as research tool to allow greater understanding of relevant pathways or the pathology of a disease. Researchers in the cancer field, for example, could silence specific genes, inducing cell death and/or mediate cellular intake and intracellular release of co-delivered compounds.

In still further embodiments of the present invention, the aforementioned methods may be used in concert to, for example, image cells or tissues to research the effect of silencing specific genes or eliminating specific target cells. For instance, in one embodiment of the present invention, an imaging agent such as a GFP may be delivered with the siRNA molecule delivery system.

The present invention is also directed to a kit to treat cancer, including, but in no way limited to, breast cancer and more particularly HER2+ breast cancer. The kit is useful for practicing the inventive method of treating such conditions. The kit is an assemblage of materials or components, including at least one of the components of the siRNA molecule delivery system.

The exact nature of the components configured in the inventive kit depends on its intended purpose. For example, some embodiments are configured for the purpose of treating the aforementioned conditions in a subject in need of such treatment. The kit may be configured particularly for the purpose of treating mammalian subjects. In another embodiment, the kit is configured particularly for the purpose of treating human subjects. In further embodiments, the kit is configured for veterinary applications, for use in treating subjects such as, but not limited to, farm animals, domestic animals, and laboratory animals.

Other embodiments are configured for the purpose of imaging particular cells or tissues in a subject after deliver of an siRNA molecule. The kit may be configured particularly for the purpose of imaging cells or tissues in mammalian subjects. In another embodiment, the kit is configured particularly for the purpose of imaging cells or tissues in human subjects, including, but in no way limited to, breast cancer cells and more particularly HER2+ breast cancer cells. In further embodiments, the kit is configured for veterinary applications, for use in imaging cells and tissues in subjects such as, but not limited to, farm animals, domestic animals, and laboratory animals.

Instructions for use may be included in the kit. "Instructions for use" typically include a tangible expression describing the technique to be employed in using the components of the kit to effect a desired outcome, such as to treat a disease condition (*e.g.*, cancer) or to image particular cells or tissues in a subject. Optionally, the kit also contains other useful components such as diluents, buffers, pharmaceutically acceptable carriers, syringes, catheters, applicators, pipetting or measuring tools, bandaging materials or other useful paraphernalia as will be readily recognized by those of skill in the art.

The materials or components assembled in the kit can be provided to the practitioner stored in any convenient and suitable ways that preserve their operability and utility. For example, the components can be in dissolved, dehydrated, or lyophilized form;

they can be provided at room, refrigerated or frozen temperatures. The components are typically contained in suitable packaging material(s). As employed herein, the phrase "packaging material" refers to one or more physical structures used to house the contents of the kit, such as inventive compositions and the like. The packaging material is constructed by well known methods, preferably to provide a sterile, contaminant-free environment. The packaging materials employed in the kit are those customarily utilized in treatment of pituitary disorders and/or tumors and/or cancer. As used herein, the term "package" refers to a suitable solid matrix or material such as glass, plastic, paper, foil, and the like, capable of holding the individual kit components. Thus, for example, a package can be one or more glass vials used to contain suitable quantities of the components of the inventive delivery system in an unassembled, a partially assembled, or a completely assembled form. The packaging material generally has an external label which indicates the contents and/or purpose of the kit and/or its components.

EXAMPLES

The following example is provided to better illustrate the claimed invention and are not to be interpreted as limiting the scope of the invention. To the extent that specific materials are mentioned, it is merely for purposes of illustration and is not intended to limit the invention. One skilled in the art may develop equivalent means or reactants without the exercise of inventive capacity and without departing from the scope of the invention.

Example 1

Generally

The inventors tested whether a recombinant adenovirus (Ad) capsid protein, HerPBK10, which can selectively bind to HER2+ breast cancer, mediates missile-like targeted delivery of siRNA and induces tumor cell-specific death via siRNA-mediated "knock-down" of specific gene transcripts. The inventors designed HerPBK10 to penetrate HER2+ cells by combining the 'Her' domain for binding heregulin receptors, which have an increased ligand affinity on HER2+ tumor cells, and the membrane lysis and intracellular trafficking features of the 'PB' domain, which is derived from the cell-entry functions of the Ad capsid. Binding and transport of nucleic acids can be mediated by the

polylysine, 'K10' domain. To demonstrate that HerPBK10 can mediate targeted siRNA delivery, the inventors first used ELISA and/or immunofluorescence to establish the receptor profiles of frequently-used cell lines characterized by different levels of heregulin receptor subunits. It was observed that HerPBK10 underwent substantially greater cell binding and uptake in HER2+ human breast cancer cells while minimal to negligible levels of binding and uptake were detected from HER2- cells. Using in vivo fluorescence imaging, it was observed that the targeting ligand used here specifically accumulates at HER2+ tumor tissue in mice while evading accumulation in other tissues. It was also observed that HerPBK10 could mediate the uptake of a Cy3-labeled oligonucleotide in HER2+ cells. The formation of noncovalent conjugates resulting from incubating HerPBK10 with siRNA was verified by the observation that siRNA electromobility dose-dependently decreased as HerPBK10 concentration increased. Ultrafiltration of conjugates under high speed centrifugation demonstrated that free siRNA could be separated from siRNA bound to the HerPBK10, and also indicated that the conjugate can withstand high shear forces without releasing the siRNA molecule. Targeted conjugates delivering anti-Her2 siRNA were added to HER2+ human breast cancer cells in culture, and yielded specific gene "knock-down" in target cells. Associated with this reduction was substantial target cell death. Depending on the cell line, up to 85% reduction was observed in HER2+ cell survival whereas HER2- cells receiving the targeted conjugate were little affected. HerPBK10 also augmented liposomal delivery of siRNA: when combined with liposome-coated siRNA, HER2+ cell numbers were considerably reduced whereas HER2- cell numbers showed only slight to negligible reduction. SiRNA Lipoplexes alone (lacking HerPBK10) only modestly to negligibly reducted the survival of both HER2+ and HER2- cells. Altogether, these findings indicate that HerPBK10 enables missle-like delivery of siRNA, resulting in targeted cell death.

Example 2

Description

This invention is designed to direct RNA interference (RNAi) to target cells. In one embodiment, the invention is comprised of two components that self-assemble into one targeted complex. In one form, the first component (Unit A) is a unique cell-penetrating

carrier that can bind and enter target cells (*Fig. 1*). The second component (Unit B) may be a double-stranded nucleic acid that binds to the first component via electrostatic interactions (*Fig. 1*).

In one embodiment, the carrier is comprised of three main segments: 1. a unit designed to bind to specific target cells (Fig. 1, "L"); 2. a unit designed to mediate penetration into the interior of target cells (Fig. 1, "MP"); 3. a unit that can interact with nucleic acids designed to mediate RNAi (Fig. 1, "D").

In another embodiment, the nucleic acid may be comprised of: small interfering RNA (siRNA) of any length made from either synthetic or biological sources, small hairpin RNA (shRNA) of any length, complimentary oligonucleotides of any length, etc., to mediate RNAi in target cells. The nucleic acid may also contain any type of modification (i.e. addition of phosphate groups, etc) that may enhance its therapeutic efficacy.

The feasibility of this new type of therapeutic has been tested on HER2+ breast cancer *in vitro* and *in vivo*. To target HER2+ breast cancer, Unit A may be comprised of a protein called HerPBK10 (Fig. 2). HerPBK10 may contain the receptor binding domain of heregulin fused to the cell penetrating adenovirus penton base protein modified by a carboxy (C) –terminal decalysine (Fig. 2). The 'Her' segment of HerPBK10 may be obtained from the receptor binding domain of heregulin-_lpha, which binds specifically to HER2/HER3 or HER2/HER4 subunit heterodimers. Although heregulin interacts directly with HER3 or HER4, but not HER2, ligand affinity is greatly enhanced by HER2. Thus, tumor cells that over-express HER2 (known as HER2+ tumor cells) are ideal candidates for heregulin-directed targeting.

The membrane penetrating activity of the adenovirus serotype 5 (Ad5) penton base protein is incorporated into the 'PB' segment of HerPBK10 to facilitate penetration into target cells. The 'K10' segment is comprised of 10 lysine residues, whose positive charge can facilitate the transport of negatively charged molecules, such as nucleic acids, by electrophilic interaction.

Example 3

Novel Embodiments

The targeted RNAi delivery system enables the utilization of recombinant pathogen proteins modified for missile-like delivery and penetration of the RNAi therapeutic into target cells. This system is modular in its design, thus the cell targeting ligand may be exchanged for other ligands, depending on the cell targeted. In its practically applied form for tumor targeting and treatment, siRNA containing secondary modifications may be used to induce target cell induction of anti-tumor cytokines, and thus enhance tumor toxicity. The latter feature is unique to the method of use presented here, as sequence-independent cytotoxicity elicited by siRNA is currently considered an undesirable side effect by the research community at large. Here, this feature is exploited to enhance tumor toxicity by targeting the siRNA to tumor cells via the delivery agent.

Example 4

The targeted carrier protein, HerPBK10, undergoes high cell binding and entry of HER2+ but not HER2- human breast cancer cells.

To verify the specificity and internalization activity of HerPBK10 on human breast cancer cells, we treated HER2+ (MDA-MB-435) and HER2- (MDA-MB-231) cells in culture with HerPBK10 and observed the cell binding, internalization, and intracellular trafficking activities using immunofluorescence and confocal microscopy. MDA-MB-435 cells display considerably higher cell surface levels of HER2/4 subunits compared to MDA-MB-231 cells, which display negligible to nearly undetectable HER2 levels (Fig. 3A). Accordingly, it was observed that MDA-MB-435 cells displayed substantially greater HerPBK10 bound to the cell surface than MDA-MB-231, while HerPBK10 fluorescence was minimal to negligible on MDA-MB-231 cells. (Fig. 3B). HerPBK10 internalization into each cell line likewise reflected the level of cell binding, with substantial protein uptake observed in MDA-MB-435 cells while minimal to negligible levels of uptake were detected in MDA-MB-231 cells (Fig. 3B).

Example 5

HerPBK10 transports labeled oligonucleotide into MDA-MB-435 cells.

To examine the capacity of HerPBK10 to facilitate direct transport of small nucleic acids into cells, a Cy3-labeled oligonucleotide (Cy3-oligo) was incubated with HerPBK10

to mediate assembly via electrophilic interaction, then the resulting complex was added to MDA-MB-435 cells in culture. Confocal fluorescence microscopy of treated cells shows that HerPBK10 and the Cy3-oligo colocalize after uptake (Fig. 4), demonstrating that the oligonucleotide is bound to HerPBK10 after cell entry. As it is possible that the oligo may enter cells by fluid-phase uptake with HerPBK10, the binding interaction between small nucleic acids and HerPBK10 was examined more closely.

Example 6

Recombinant targeted proteins form a stable assembly with siRNA.

One goal was to assemble a noncovalent siRNA conjugate. Thus, the interaction of a commercial siRNA duplex with HerPBK10 was examined by gel mobility shift assay. The duplex, which was obtained from Invitrogen (Carlsbad, CA, USA), has been established elsewhere to specifically eliminate HER2 transcripts and thus induce apoptosis (Choudhury et al., 2004; Faltus et al., 2004). Constant concentrations of the HER2 siRNA were incubated with increasing concentrations of HerPBK10 and each mixture was then analyzed on either an agarose or acrylamide gel. A dose-dependent decrease in siRNA electromobility was evident as HerPBK10 concentration increased (Fig. 5A and B). Likewise, the protein, PBK10, which lacks the Her domain, also dramatically decreased siRNA mobility, while PB did not (Fig. 5A), indicating that the decalysine, or 'K10', domain is responsible for binding the siRNA. As previously demonstrated using plasmid DNA and labeled oligonucleotides, both HerPBK10 and PBK10 can bind nucleic acids likely via electrophilic interactions between the positively charged polylysine and the negatively charged nucleic acid phosphate backbone (Medina-Kauwe et al., 2001a; Medina-Kauwe et al., 2001b).

To demonstrate that the protein-siRNA complex formed a stable assembly that could be separated from free siRNA, the mixture was subject to high speed centrifugation onto filter membranes with specified molecular weight exclusion ranges of either a 30K or 100K molecular weight cut-off (mwco). Both HerPBK10-siRNA and free siRNA are retained on 30K mwco filters (Fig. 6A and B) whereas the 100K filter retains the conjugate but allows the free siRNA to flow through (Fig. 6A). The ability of the conjugate to withstand high speed centrifugation, as determined by low to no detection of free siRNA in

100K filtrates (Fig. 6A), indicates that this conjugate can withstand high shear forces without releasing the siRNA molecule.

Example 7

siRNA missiles mediate knock-down in HER2+ but not HER2- cells in culture.

To determine whether the HerPBK10-siRNA conjugate is capable of mediating specific gene "knock-down" in target cells, the conjugate delivering HER2 siRNA was compared to a standard transfection agent (Lipofectamine 2000) on MDA-MB-435 cells in culture. Knock-down of HER2 was analyzed by immunoblotting of cell lysates. The transfection agent mediated very modest reductions of HER2 whereas the targeted conjugate reduced HER2 to undetectable levels (Fig. 7). A scrambled siRNA had no effect on HER2 levels when delivered by either the transfection agent or HerPBK10 (Fig. 7). Interestingly, HER3 levels were also nearly completely reduced by the targeted conjugate whereas the transfection agent had no detectable effect on this subunit (Fig. 7), raising the possibility that protein levels of HER2 may regulate those of HER3. HerPBK10 alone had no effect on HER2 and HER3 levels (Fig. 7), thus ruling out the possibility that HerPBK10 may somehow induce down-regulation of the receptor subunits by virtue of its binding and internalization through HER.

HER2 immunofluorescence was compared between MDA-MB-435 cells and MDA-MB-231 cells when each was treated with either the targeted conjugate or transfection reagent. MDA-MB-231 are not HER2 deficient but rather express HER2 intracellularly but not on the cell surface. Whereas the transfection reagent delivering HER2 siRNA mediated 50-60% reduction of HER2 in both cell lines, the targeted conjugate reduced HER2 nearly 60% in MDA-MB-435 cells but had little to no effect on HER2 in MDA-MB-231 cells (Fig. 8). HerPBK10 alone and targeted conjugate delivering scrambled siRNA had little to no effect on either cell line. Importantly, all siRNA delivery experiments in culture were performed in complete (i.e. serum-containing) media, thus demonstrating that serum will not have an inhibitory effect on the conjugate.

Example 8

HerPBK10 augments lipoplex-mediated siRNA delivery in high HER2-expressing cells.

The inventors also examined whether conjugate activity could be expanded to other HER2+ cell lines. Using immunofluorescence, it was determined that SKBR3 and SKOV3 cell lines expressed nearly 3-times higher HER2 compared to MDA-MB-435 cells (Fig. 9A). Whereas a transfection reagent delivering HER2 siRNA had no detectable effect on HER2 levels in SKBR3 cells, the targeted conjugate reduced levels nearly 50% (Fig. 9B). The transfection reagent used here is specified for siRNA delivery (Silentfect; Bio-Rad Laboratories, Hercules, CA, USA). To see if HerPBK10 could improve delivery by the transfection reagent, increasing concentrations of HerPBK10 were incubated with the lipoplex, resulting in a dose-dependent decrease (up to 80-85% reduction) in HER2 when added to SKBR3 cells (Fig. 9B). The transfection reagent fared better in SKOV3 cells, resulting in nearly 50-55% reduction of HER2 whereas the targeted conjugate mediated nearly 50% reduction (Fig. 9C). Combining HerPBK10 with the lipoplex augmented HER2 reduction, resulting in nearly a 70% HER2 knock-down (Fig. 9C).

Example 9

Serum stability: HerPBK10 protects the siRNA from serum nucleases.

Nucleases present in serum and cells can degrade nucleic acid payloads and thus potentially reduce siRNA delivery (Medina-Kauwe et al., 2005). We examined the stability of siRNA conjugates in whole serum. HerPBK10-siRNA or siRNA alone were incubated in either 100% bovine serum or cell culture media (containing 10% serum) for 1h at 37°C and then assessed by agarose gel electrophoresis to examine the state of the siRNA. Ethidium bromide staining of the agarose gel identifies the siRNA molecular size and relative concentration. Ethidium bromide staining is nearly absent from samples in which the free siRNA was incubated with 100% serum, suggesting that the siRNA molecule is degraded by serum nucleases (Fig. 10). The same samples in which the siRNA is complexed with HerPBK10 shows that the siRNA molecule is intact and appears to be protected from serum nucleases (Fig. 10).

Example 10

T7-transcribed siRNA induces higher breast cancer cell cytotoxicity than synthetic siRNA.

Previously, it was found that HerPBK10-siRNA complexes induce cell-specific silencing of target HER2 gene transcripts. The siRNA used in those studies were obtained from a commercial source as pre-made, synthetic molecules (Dharmacon). As published findings indicate that T7 transcribed siRNA induce non-specific but potent cytokine-mediated cytotoxicity (Kim et al., 2004), the inventors compared the cytotoxicity of T7 transcribed vs synthetic anti-HER2 siRNA on HER2+ cells. The inventors acquired a 21 nucleotide (nt) synthetic anti-HER2 (ErbB2) siRNA and also produced a T7-transcribed molecule (Silencer siRNA construction kit; Ambion) using the same sequence. Both were transfected into MDA-MB-435 human breast cancer cells in vitro at 1, 10, and 50 nM final siRNA concentrations and the cells assayed for survival at 96h after treatment. Whereas the synthetic siRNA had no effect on cell survival, the 10 and 50 nM concentrations induced substantial cell death (Fig. 11A). Similarly, when each siRNA is pre-assembled with HerPBK10, treated cells undergo significantly reduced cell survival after receiving the T7-transcribed siRNA compared to the synthetic siRNA (Fig. 11B).

Example 11

SiRNA-facilitated cytotoxicity can be targeted to HER2+ but not HER2- cells by HerPBK10-mediated delivery.

As the cytotoxicity induced by T7-transcribed siRNA is thought to be non-sequence specific, the inventors explored whether this effect could be targeted using the HerPBK10 protein. Previous studies show that HerPBK10 binds and enters MDA-MB-435 but not MDA-MB-231 cells, whereas commercial transfection reagents are not expected to be as discriminating with respect to receptor-targeting capacity. Several different doses of HerPBK10-siRNA complexes added to MDA-MB-435 (HER2+) and MDA-MB-231 (HER2-) cells produced a dose-dependent reduction in survival of the HER2+ cells (Fig. 12A) but had little to no effect on HER2- cells (Fig. 12, A & B). In contrast, siRNA delivered by a liposomal transfection reagent (Lipo-siHER2) significantly reduced the survival of both HER2+ and HER2- cells (Fig. 12B). Transfection reagent alone (Lipo), siRNA alone (siHER2), and HerPBK10 alone (0.03 mg/mL) had negligible effect on both cell lines (Fig. 12B).

Example 12

Ligand-directed siRNA carrier vehicle, HerPBK10, targets HER2+ tumors in mice.

To get a sense of the targeting ability of the ligand *in vivo* and establish an index of *in vivo* targeting, the inventors used a green fluorescent protein (GFP)-tagged ligand (GFP-Her), which has been used previously to demonstrate targeted receptor binding and endocytosis in HER2+ cells (Medina-Kauwe and Chen, 2002; Medina-Kauwe et al., 2000). Importantly, this ligand is identical to the 'Her' domain of HerPBK10. The inventors established HER2+ tumors in 6-8 week female nude mice via bilateral flank injections of MDA-MB-435 cells. When the tumors reached 250-300 mm^3 (~3-4 weeks after tumor cell implant), 3 nmoles of GFP-Her was injected via the tail vein. Mock injected mice received saline alone. Indicated tissues were harvested at 3.5 h after injection and imaged for GFP using a Xenogen IVIS three-dimensional small-animal *in vivo* imaging system (Xenogen, Alameda, CA). Preferential accumulation of GFP fluorescence was detected in the tumors over the other tissues. Low to negligible levels of fluorescence were detected in the liver and muscle, while GFP fluorescence was undetectable in the other tissues, including the heart. Tissues from mock-treated animals showed no fluorescence. To further assess the in vivo targeting capacity of HerPBK10, tumor-bearing mice received systemic administration of HerPBK10 labeled with a fluorescent molecule (S2Ga; (Agadjanian et al., 2006)). Mice were monitored for label circulation and biodistribution in real time using a small animal image acquisition system through the assistance of the Minimally Invasive Surgical Technologies Institute (MISTI) directed by Dr. Daniel Farkas at Cedars-Sinai Medical Center. Whereas the free, untargeted label exhibits distribution throughout most of the mouse (and, interestingly, appeared to be excluded from the tumors), labeled HerPBK10 exhibited preferential tumor accumulation in comparison to other regions of the body (except for the injection site). The occasional high retention of injected material at the injection site of the tail vein is mostly due to technical complications in which some of the material is accidentally injected into the tail muscle rather than wholly in the vessel. This effect can be alleviated as injection technique improves.

Example 13

The targeted siRNA complex as well as carrier protein alone induce interferon (IFN) – alpha secretion from HER2+ but not HER2- breast cancer cells.

The mechanism of T7-transcribed siRNA cytotoxicity is thought to be via the induced secretion of cytotoxic cytokines as a cellular response (Kim et al., 2004). To examine whether cytokines contribute to the targeted toxicity observed earlier, the media of HerPBK10-siRNA (T7-transcribed) –treated HER2+ MDA-MB-435 and HER2- MDA-MB-231 cells were collected and assayed by ELISA for interferons alpha and beta. Our findings show that IFN-alpha secretion from MDA-MB-435 cells is substantially elevated after treatment with HerPBK10-siRNA complex (at 10 and 50 nM siRNA dose) as well as HerPBK10 alone (at equivalent concentration to the 50 nM dose) (Fig. 13A). Whether the effect produced by the protein is elicited by receptor signaling remains to be seen, though it is interesting that despite the high IFN-alpha secretion in response to HerPBK10, the protein alone does not induce substantial cell death (Fig. 13B). MDA-MB-231 cells are little affected by either HerPBK10 or the complex (Fig. 13A). Both cell lines showed little to no sign of IFN-beta secretion regardless of treatment, though significant differences between HER2+ and HER2- cells were observed, especially after 10 nM HerPBK10-siRNA treatment (Fig. 13B). Given the overall low level of cytokine detected in the medium by all treatments, these differences are likely to have little relevance.

Example 14

Advantages

This invention enables direct RNA interference (RNAi) to target cells.

Targeting and Penetration: Most current therapeutics affect the body globally because they are not targeted to the specific tissue or cell that is meant to be treated. Moreover, if such therapeutics can be targeted to the desired tissue or cell type, delivery does not necessarily entail efficient penetration of the therapeutic into the desired tissue or cell type. Thus, the two main problems of therapeutic delivery addressed here are: 1. targeting, and 2. penetration.

Overcoming complicated formulations and high cost of production: Another general problem of therapeutic development is complexity and cost of production when the therapeutic is a synthetic molecule or combination of covalently bonded molecules.

Production of the delivery agent as a recombinant fusion protein as described here enables pharmaceutical quantities to be generated by large-scale fermentation with facile quality control. Noncovalent assembly of the targeted missile avoids the need for complex chemical bonding reactions and additional processing steps to check the purity and integrity of the final product. Altogether, these practical features entail a lower cost of production compared to completely synthetic reagents.

Non-specific cytotoxicity of siRNA: With respect to the delivery of siRNA and similar nucleic acids encoding RNAi, cell specific targeting is necessary to ensure that the RNAi effect is imparted at the desired cell type, as some siRNA molecules can have a generalized cytotoxicity due to the cytokine-inducing effect of the molecule itself, irrespective of the sequence being delivered. The general scientific community has seen this as a pitfall of RNAi, given that the RNAi technology was originally intended to silence specific genes at which the RNAi sequence is targeted. The inventors have exploited this feature by combining it with cell-targeted proteins to target this cytotoxic effect to cancer cells, as an improved means of tumor toxicity. In the practical examples provided herein, the inventors delivered siRNA carrying sequences known elsewhere to induce cell death after gene silencing, thus the combination of both gene-specific silencing and molecule-induced toxicity should entail high potency, especially when combined with the targeting and efficient penetration imparted by the recombinant carrier protein.

Example 15

Flawed alternatives

HER2+ breast tumors, which over-express subunit 2 of the human epidermal growth factor receptor (HER), comprise a significant subset of breast cancers that are recalcitrant to standard methods of treatment, and predict a high mortality. The abnormally high level of HER on the surface of these tumor cells may enable targeted therapeutics to home in on these cells, thus making HER2+ tumors ideal candidates for targeted therapy. The current strategies for targeting therapy to these tumors include *antibody-targeted chemotherapy agents (immunoconjugates), targeted toxins, signal-blocking antibodies, and antibody-targeted liposomes (immunoliposomes).*

Immunoconjugates: Immunoconjugate therapies rely on the chemical coupling of single-chain antibodies to drugs, whereby the antibody directs the drug to specific cells by recognizing certain cell surface proteins or receptors (Chester et al., 2000; Frankel et al., 2000). Studies have shown, however, that such antibodies can unfold and aggregate at physiological temperature, which would impede binding to target cells, and result in low therapeutic efficacy (Glockshuber et al., 1990; Schmidt et al., 1999). Moreover, covalent linkage of drug to carrier can impair the activity of both molecules, as well as entail high production cost.

Targeted toxin: An alternative approach to tumor targeting has been the development of toxic proteins, such as plant or bacterial toxins, that are modified by appendage to a targeting peptide (or ligand) (Frankel et al., 2000). Such proteins are produced by recombinant methods (i.e. genes are engineered to produce the proteins in a cell system, from which the proteins can then be isolated), and the resulting protein is a fusion of the toxin to the ligand. While fusion toxin proteins can be produced by large scale fermentation as a more efficient and lower cost alternative to antibody generation, the toxin requires special processing to be active, thus limiting potency (Jeschke et al., 1995; Schmidt et al., 1999). For example, the activity of recombinant diptheria toxin transmembrane domain, used to enhance non-viral gene transfer, is reduced by as much as 75% when fused to a foreign peptide, indicating that appending a peptide to a toxin disables toxin activity (Fisher and Wilson, 1997).

Signal blocking antibodies: Antibodies directed at the extracellular domain of HER2 have been used to target drug complexes to the HER2 subunit, but have not necessarily induced internalization of the drug complex, thus limiting potency (Goren et al., 1996). Such findings illustrate that targeting is not enough, as a lack of targeted uptake can limit efficacy. Alternatively, signal blocking antibodies have been developed to inhibit the proliferative signal transduced through overexpression and high cell surface display of HER2 (Baselga et al., 1996; Cobleigh et al., 1998). The currently used targeted therapy, trastuzumab (Herceptin), an antibody directed against the HER2 subunit, blocks normal signaling but has been ineffective in about 70% of treated patients, possibly due to aberrant intracellular pathways in tumor cells that may not respond to signal inhibition (Vogel et al., 2002) (Kute et al., 2004). More importantly, an ongoing concern with trastuzumab is the

exquisite sensitivity of heart tissue to HER2 signal inhibition, which is further exacerbated by anthracycline chemotherapy agents (Slamon et al., 2001).

While targeted uptake facilitates drug entry into target cells, the intracellular disposition of the drug can still affect potency. Targeting antibodies delivering covalently linked drugs can be trafficked to lysosomes, thus sequestering the drug from subcellular targets and limiting potency. Approaches to circumventing this include linking the drug to a targeting antibody via an acid labile bond to facilitate release into the endocytic compartment (Braslawsky et al., 1990; Trail et al., 2003; Trail et al., 1992; Trail et al., 1993). However, bond instability can reduce in vivo potency, likely by causing premature drug release and thus delivery to non-target tissue.

Immunoliposomes: Immunoliposomes, carrying doxorubicin (Dox) and targeted to HER2, have been developed and can accumulate in tumor tissue in animal models (Park et al., 2002), likely due to the leaky tumor vasculature (Drummond et al., 1999). Release of Dox from these liposomes is thought to occur via the acidic tumor environment, lipase release from dying cells, and enzyme and oxidizing agent release from infiltrating inflammatory cells (Minotti et al., 2004). These conditions may induce premature drug release and nonspecific delivery, though the accumulation of immunoliposomes at tumor sites may tend to favor drug uptake at the tumor. Studies using the trastuzumab Fab fragment for liposome targeting of Dox have demonstrated antitumor efficacy (Park et al., 2002), though the effect on cardiac tissue was not reported in that study.

In general: Problems with the current tumor targeting strategies include: requirement for chemical modification, which can be costly and impair activity of drug and/or carrier; use of recombinant antibodies that can lose structure in physiological conditions and thus result in impaired targeting activity; inability to penetrate into the cell; need to modulate receptor signaling, which can be impaired in tumor cells and thus ineffective; and, importantly, off-target effects, including toxicity to the heart.

Example 16

Advantages over flawed alternatives

Advantage over immunoconjugates: Whereas covalent linkage of drug to carrier can impair the activity of both molecules, as well as entail high production cost, our studies

show that our targeted carrier protein, HerPBK10, retains receptor targeting under physiological conditions in the presence of serum, indicating that our targeted carrier does not unfold or lose receptor binding. Furthermore, embodiments of the invention is engineered so that the drug self-assembles with the carrier molecule and thus does not require chemical modifications to covalently link the molecules together. This noncovalent assembly would thus allow both the targeted carrier and drug to remain unmodified and thus preserve structure and activity. Finally, recombinant proteins such as HerPBK10 can be produced in bulk quantities by large-scale fermentation for a lower cost compared to monoclonal antibody generation and production.

Advantage over targeted toxins: As most toxins require special processing to be active, producing these as fusions can limit potency. Thus, delivery by noncovalent means (i.e. self-assembly) as proposed herein is likely to be advantageous in terms of retaining drug potency.

Advantage over signal blocking antibodies: Antibodies generated to recognize a specific epitope have the potential to direct therapies to normal cells presenting normal levels of the epitope being targeted. In conjunction with various embodiments described herein, the inventors take advantage of the binding interaction of the natural ligand for HER, which have a greatly increased ligand affinity when HER2 is overexpressed. This is likely to translate to lower, and thus safer, doses of drug when targeted, thus avoiding the likelihood of cardiac damage. Accordingly, the targeting approach should avoid binding to tissues displaying low to normal receptor subunit levels but exhibit preferential binding to HER2+ tumor cells. Moreover, the inventors have shown that the receptor binding domain of heregulin that is incorporated into HerPBK10 induces rapid internalization after binding to the heregulin receptor (Medina-Kauwe and Chen, 2002; Medina-Kauwe et al., 2000), enabling uptake of DNA (Medina-Kauwe et al., 2001b) and fluorescent compounds (Agadjanian et al., 2006). Antibodies generally do not induce receptor-mediated uptake. Our approach, therefore, circumvents the need to modulate receptor signaling, by exploiting the rapid receptor endocytosis induced by ligand binding and the cytosolic penetration features of viral capsid protein to directly transport drugs into the cell and induce cytotoxicity from within. Additionally, the endosomal disruption feature of various embodiments described herein has the advantage of endosomal escape, thus facilitating

release of the therapeutic into the cell cytoplasm and access to intracellular targets, including gene transcripts.

Advantage over immunoliposomes: The inventors believe that the system will yield effective targeted drug delivery due to high affinity receptor-ligand binding and rapid endocytosis coupled with the membrane-penetrating activity of the viral penton base protein to ensure efficient delivery into target cells.

Advantage over gene therapy: While gene therapy approaches are a possibility, the inventors have found that the large size of a DNA plasmid complicates vector assembly by requiring that additional DNA condensing molecules be incorporated into the vector to reduce the size of the plasmid. Such agents not only add to the complexity of the overall vector system but can also hamper targeting and gene expression by binding DNA well(Medina-Kauwe et al., 2001a; Medina-Kauwe et al., 2001b) but releasing DNA poorly (Zabner et al., 1995). Because siRNA molecules are 200-300 times smaller than the average DNA vehicle for gene therapy, development of siRNA missiles involves much simpler and more streamlined procedures compared to non-viral gene therapy vector development. Adding to the benefits of this system is that fewer barriers would need to be overcome compared to gene therapy systems: the siRNA molecule need only be delivered to the cytoplasm as opposed to translocating through the cytosol and being transported into the nucleus.

Toxicity advantage: Cell death can be induced by certain modifications carried by siRNA molecules. Kim et al (2004) reported that siRNA molecules carrying a 5' triphosphate stimulate interferon alpha and beta (IFNalpha and IFNgamma) secretion from siRNA-transfected cells, inducing cell death in culture (Kim et al., 2004). Such modifications are introduced into siRNA produced from bacteriophage T7 RNA polymerase, but siRNA produced synthetically do not carry such modifications, and likewise do not induce cytokine secretion. Removal of the 5' triphosphate completely eliminated IFN induction. The induction of IFN correlated with cell death by 5 days after siRNA transfection, and the effect could be transferred with the medium from transfected cells.

Example 17

Comparing various RNAi species

The inventors wanted to determine what type of RNAi species delivered the most potent cytotoxicity in order to incorporate it into the targeted complex and test it in vivo. They compared HER2-silencing siRNA produced either synthetically by a commercial vendor (Dharmacon), or from a T7 transcription kit (Ambion), and shRNA, which is reportedly a more effective substrate for the dicer mechanism in RNAi. Targeted complexes or the equivalent concentration of HerPBK10 alone were added to separate sets of triplicate wells containing GFP-tagged MDA-MB-435 (HER2+) or MDA-MB-231 (HER2-) human cancer cells. At 96 hours after treatment, cell survival was assessed by convalidating assays: GFP fluorescence and metabolic activity (MTT). Both assays confirmed that the T7 transcribed siRNA is the most potent cytotoxic species. Moreover, the HER2+ cells exhibit substantially greater sensitivity to the targeted complexes compared to the HER2- cells, providing further evidence that the complex is targeted to HER2+ cells.

Example 18

Reduction in tumor growth from intratumoral injection

Before testing for targeted toxicity of HerPBK10-siRNA, the inventors assessed cytotoxic potential in vivo after intratumoral (IT) injection of complexes in tumor-bearing mice. Tumor bearing nude mice received two IT injections, each a week apart from one another, of either T7 transcribed siRNA alone or HerPBK10-siRNA, and tumor volumes were measured weekly before, during, and after injections. Blood was also collected after each injection to assess cytokine levels. Mice receiving HerPBK10-siRNA exhibited an average reduction in tumor growth whereas tumor growth in mice receiving siRNA alone was unaffected. Even though the complex was not delivered intravenously but rather by IT injection, there still appears to be an advantage to the targeted complex with regard to tumor toxicity.

Example 19

Destruction of tumor cells via cytokine-mediated cytotoxicity

The mechanism of non-specific T7-transcribed siRNA cytotoxicity is thought to be via the induced secretion of cytotoxic cytokines as a cellular response to secondary modifications introduced onto the siRNA as a side-product of the T7 transcription. To examine whether cytokines contribute to the tumor reduction observed and described herein, blood was collected from the same mice at 24h after each IT injection and assayed for interferon (IFN) –alpha. While overall cytokine levels remained low, HerPBK10-siRNA injection yielded elevated circulating IFN-alpha compared to IT saline injections (control). The trend from the first set of IT injections indicates that siRNA alone tends to elevate circulating IFN-alpha over the controls, though not to statistically significant levels. While previous studies show that HerPBK10 alone has no effect on HER2+ tumor cell growth, the inventors have yet to determine whether the carrier protein contributes directly to cytokine elevation. It is possible that its indirect contribution results from enhanced tumor delivery, penetration, retention. Together with the tumor-shrinkage observed from these injections, these findings provide additional evidence that the targeted carrier, HerPBK10, can deliver both siRNA-mediated silencing and cytokine-mediated cytotoxicity to induce two-pronged targeted destruction to tumor cells.

Example 20

Evidence targeted carrier HerPBK10 does not induce neutralizing antibodies

To address concerns regarding the use of an Ad capsid protein-derived carrier for siRNA, the inventors examined whether HerPBK10 induced neutralizing antibody formation. A single inoculation of Ad can produce a long-lasting humoral response in patients and animals, and prevent subsequent administration, thus reducing overall therapeutic efficacy of Ad-mediated therapies. Here the inventors tested the antibody formation potential of HerPBK10 under the same conditions that produce an Ad capsid-elicited immune response.

Immunocompetent (C57BL/6) mice were inoculated with HerPBK10 at 0.05 mg/kg (with regard to protein dose) as well as a 10-fold higher dose (0.5 mg/kg). As a comparison, mice were also inoculated with Ad5 at a dose established elsewhere to induce neutralizing antibodies ($1.2x10^9$ pfu/mouse). Blood was collected from mice before initial antigen injection, followed by blood collections every 7 days up to 35 days post- initial

inoculation, while mice received a second inoculation of the same antigens on day 21 to boost any existing immunity.

ELISA of blood serum from treated mice showed that both doses of HerPBK10 produced no significant induction of anti-HerPBK10 antibodies in comparison to untreated mice, whereas the dose of Ad5 used here triggered secretion of antibodies that recognize HerPBK10. As the latter result may simulate the presence of pre-existing antibodies from a previous Ad infection or exposure, it would be critical to determine whether such antibodies could prevent the binding of HerPBK10 to target cells. To test this, the inventors assessed ligand-receptor binding by measuring the attachment capacity of MDA-MB-435 cells to HerPBK10-coated plates in immune serum. In the absence of serum, the cells readily attach to HerPBK10-coated wells, while the heregulin receptor-blocking ligand, Her, significantly reduces this binding, thus confirming that the cells undergo heregulin receptor-specific attachment ($P<0.05$ compared to binding without serum or competitive inhibitor, as determined by 2-tailed unpaired t test). The level of cell attachment in sera from Ad5-treated mice was comparable to that in the absence of serum and in pre-immune serum. Likewise, sera from mice treated with 0.05 and 2.5 mg/kg HerPBK10 did not reduce attachment, and while 0.5 mg/kg HerPBK10 appeared to slightly reduce attachment, this was not significant ($P<0.05$ compared to binding without serum or competitive inhibitor, as determined by 2-tailed unpaired t test) (Fig. 4B). Altogether, these findings indicate that the targeted carrier, HerPBK10, does not induce neutralizing antibodies, which would otherwise be inhibitory to therapeutic efficacy.

Additionally, Ad-treated mice showed signs of inflammation and fur loss around the eye area, whereas HerPBK10-treated mice showed no such damage, and appeared similar to mock-treated mice. Whereas such hair loss can be attributed to dominant mouse barbering or cage lesions, all Ad treated mice showed this phenotype and were continuously kept separately from other mice, whereas none of the other mice showed any such phenotype. Acute periocular hair loss and corneal damage can result from herpes simplex virus infection in mice and may involve viral-induced autoimmunity. It is worth noting the correlation between Ad infection, which can induce T-cell immunity and inflammation, and the phenotype observed here.

Example 21

Additional evidence of HerPBK10 directed systemic targeting of small nucleic acids such as siRNA

The inventors used the fluorescent DNA intercalator, doxorubicin (Dox), to tag a double-stranded oligonucleotide mimicking an siRNA molecule to track its biodistribution after systemic delivery in mice bearing 4-week old tumors (~700-800 mm^3). The Dox-intercalated nucleic acid was complexed with HerPBK10 using equivalent conditions for HerPBK10-siRNA assembly. Mice received a single tail vein injection of Dox alone or the complex (HerDox) (0.02 mg/kg with respect to Dox conc) and were imaged live using a customized macro-illumination and detection system. Fluorescence was evident throughout the body at 10 min after HerDox injection, then quickly accumulated at the tumors by 20 min and remained detectable in the tumors up to 100 min after injection. Tissues and tumors harvested at ~3h after HerDox injection showed intense fluorescence in the tumors while substantially lower levels of fluorescence were detectable in the liver. Some fluorescence was barely detectable in the kidneys while other tissues, including the heart, spleen, lungs, and skeletal muscle, did not exhibit any fluorescence. In contrast, tissues harvested from mice injected with the equivalent dose of Dox exhibited detectable fluorescence in the liver, tumor, and kidneys. Lower levels of fluorescence were also detectable in the lungs and skeletal muscle. Overall, these findings indicate that HerPBK10 directs systemic targeting of small nucleic acids (similar to siRNA) to HER2+ tumors in vivo.

Example 22

Additional evidence of targeting efficacy

To assess whether targeting and potency corresponds to HER2 levels, the inventors selected lines displaying HER2 at relatively high (SKBR3), moderate (MDA-MB-435, MDA-MB-453, HeLa), and low to undetectable (MDA-MB-231) levels, according to receptor subunit profiling of a panel of cell lines disclosed herein, and performed cytotoxicity dose curves using the HerDox complex previously used. The inventors observed that HerDox CD50 inversely correlates with cell surface HER2 level on these selected lines: the cell line displaying relatively high HER2 shows a relatively higher

sensitivity to HerDox whereas the cell line displaying low HER2 exhibits low sensitivity, and the lines displaying intermediate HER2 levels likewise exhibit intermediate sensitivities. Altogether, these findings indicate that tumor-targeting correlates with HER2 cell surface display levels, supporting the targeting efficacy of the complex.

Example 23

Evidence human sera does not interfere with targeted binding

To determine whether HerPBK10 can compete with circulating ligand that may be present in serum, the inventors tested HerPBK10 binding to HER2+ breast cancer cells in human serum obtained from HER2+ patients. The Women's Cancer Research Institute at Cedars-Sinai occasionally acquires limited quantities of patient serum, of which sera from HER2+ patients comprises an even smaller minority. Notably, the human serum used here is from collected whole blood of HER2+ and age-matched HER2- patients. The inventors ensured that cells received considerable exposure to the human sera (2 hours, which provides ample time for receptor binding of any circulating ligand) prior to treatment. Head-to-head comparisons of cell binding in serum from either HER2+ patients, HER2- patients, or bovine serum show no significant differences, indicating that the human sera tested here did not interfere with HerPBK10 binding to target cells. Pre-blocking receptors with 100x competitive ligand (+Her) confirms that binding is specific to heregulin receptors.

Example 24

Tumor targeting of siRNA in vivo

To assess *in vivo* tumor-targeting ability for the delivery of siRNA, the inventors imaged HER2+ tumor-bearing mice after tail vein injection of fluorescently-labeled siRNA or HerPBK10-siRNA complex. Based on analysis of the fluorescence intensity contrast between tumors and non-tumor areas, HerPBK10-siRNA exhibits preferential tumor accumulation compared to the free siRNA at all time points monitored. Moreover, HerPBK10-siRNA displays tumor retention whereas the free siRNA clears from the tumors by 24h after tail vein injection. Altogether, these results suggest that HerPBK10 facilitates

tumor targeting and tumor retention of siRNA, likely due to the cell binding and penetration capacity of the HerPBK10 protein.

While the description above refers to particular embodiments of the present invention, it should be readily apparent to people of ordinary skill in the art that a number of modifications may be made without departing from the spirit thereof. The presently disclosed embodiments are, therefore, to be considered in all respects as illustrative and not restrictive. One skilled in the art will recognize many methods and materials similar or equivalent to those described herein, which could be used in the practice of the present invention. Indeed, the present invention is in no way limited to the methods and materials described. For example, various agents may be delivered in conjunction with embodiments described herein and the invention should not be merely limited to siRNA. Similarly, various motifs could be used interchangeably with or in addition to those described herein and the invention should not be construed as limited to only polylysine motifs and/or RGD motifs. Finally, as recognized by one of skill in the art, the invention can be applied to any number of conditions, disorders and/or diseases where it is advantageous to target delivery of an agent to a cell and/or cell nucleus and the present invention should not be construed in any way as limited to the treatment of breast cancer.

Various embodiments of the invention are described above in the Description of the Invention. While these descriptions directly describe the above embodiments, it is understood that those skilled in the art may conceive modifications and/or variations to the specific embodiments shown and described herein. Any such modifications or variations that fall within the purview of this description are intended to be included therein as well. Unless specifically noted, it is the intention of the inventor that the words and phrases in the specification and claims be given the ordinary and accustomed meanings to those of ordinary skill in the applicable art(s).

The foregoing description of various embodiments of the invention known to the applicant at this time of filing the application has been presented and is intended for the purposes of illustration and description. The present description is not intended to be exhaustive nor limit the invention to the precise form disclosed and many modifications and variations are possible in the light of the above teachings. The embodiments described

serve to explain the principles of the invention and its practical application and to enable others skilled in the art to utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. Therefore, it is intended that the invention not be limited to the particular embodiments disclosed for carrying out the invention.

While particular embodiments of the present invention have been shown and described, it will be obvious to those skilled in the art that, based upon the teachings herein, changes and modifications may be made without departing from this invention and its broader aspects and, therefore, the appended claims are to encompass within their scope all such changes and modifications as are within the true spirit and scope of this invention. Furthermore, it is to be understood that the invention is solely defined by the appended claims. It will be understood by those within the art that, in general, terms used herein, and especially in the appended claims (*e.g.*, bodies of the appended claims) are generally intended as "open" terms (*e.g.*, the term "including" should be interpreted as "including but not limited to," the term "having" should be interpreted as "having at least," the term "includes" should be interpreted as "includes but is not limited to," etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, as an aid to understanding, the following appended claims may contain usage of the introductory phrases "at least one" and "one or more" to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles "a" or "an" limits any particular claim containing such introduced claim recitation to inventions containing only one such recitation, even when the same claim includes the introductory phrases "one or more" or "at least one" and indefinite articles such as "a" or "an" (*e.g.*, "a" and/or "an" should typically be interpreted to mean "at least one" or "one or more"); the same holds true for the use of definite articles used to introduce claim recitations. In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should typically be interpreted to mean at least the recited number (*e.g.*, the bare recitation of "two recitations," without other modifiers, typically means at least two recitations, or

two or more recitations).

Accordingly, the invention is not limited except as by the appended claims.

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CLAIMS

1. A method of treating a disease in an individual, comprising:

providing a treatment delivery platform comprising

a polypeptide sequence adapted to target and/or penetrate a type of cell, and

a delivery molecule bound to the polypeptide sequence via electrostatic interactions; and

administering a therapeutically effective amount of the treatment delivery platform to the individual to treat the disease.

2. The method of claim 1, wherein the delivery molecule comprises siRNA.

3. The method of claim 1, wherein the disease comprises cancer.

4. The method of claim 1, wherein the polypeptide sequence comprises a decalysine motif.

5. The method of claim 1, wherein the polypeptide sequence comprises a Her segment.

6. The method of claim 1, wherein the polypeptide sequence comprises a penton base segment.

7. The method of claim 1, wherein the polypeptide sequence comprises SEQ. ID. NO.: 5.

8. The method of claim 1, wherein the type of cell comprises a HER2+ cancer cell.

9. The method of claim 1, wherein the delivery molecule comprises a T7 transcribed siRNA.

10. The method of claim 1, wherein the treatment delivery platform is administered to the individual intravenously and/or by intratumoral injection.

11. The method of claim 1, wherein the individual is a human.

12. The method of claim 1, wherein the individual is a rodent.

13. A treatment delivery platform, comprising:

a polypeptide sequence adapted to target and/or penetrate a type of cell; and

a delivery molecule bound to the polypeptide sequence via electrostatic interactions.

14. The treatment delivery platform of claim 13, wherein the polypeptide sequence comprises a decalysine motif.

15. The treatment delivery platform of claim 13, wherein the polypeptide sequence comprises a Her segment.

16. The treatment delivery platform of claim 13, wherein the polypeptide sequence comprises a penton base segment.

17. The treatment delivery platform of claim 13, wherein the polypeptide sequence comprises SEQ. ID. NO.: 5.

18. The treatment delivery platform of claim 13, wherein the type of cell comprises a HER2+ cancer cell.

19. The treatment delivery platform of claim 13, wherein the delivery molecule comprises siRNA.

20. The treatment delivery platform of claim 13, wherein the delivery molecule comprises a T7 transcribed siRNA.

21. A pharmaceutical composition, comprising:

a treatment delivery platform comprising

a polypeptide sequence adapted to target and/or penetrate a type of cell, and

a delivery molecule bound to the polypeptide sequence via electrostatic interactions; and

a pharmaceutically acceptable carrier.

22. The pharmaceutical composition of claim 21, wherein the delivery molecule comprises siRNA.

23. The pharmaceutical composition of claim 21, wherein the type of cell is a HER2+ cancer cell.

24. A method of preparing a pharmaceutical composition, comprising:

combining a polypeptide sequence adapted to target and/or penetrate a type of cell, with a delivery molecule, wherein the polypeptide sequence binds to the delivery molecule via electrostatic interactions; and

combining said treatment delilvery platform with a pharmaceutically acceptable carrier.

25. The method of claim 24, wherein the delivery molecule comprises siRNA.

26. The method of claim 24, wherein the combining of the polypeptide sequence with the delivery molecule comprises incubating the polypeptide sequence with the delivery molecule.

Figure 1.

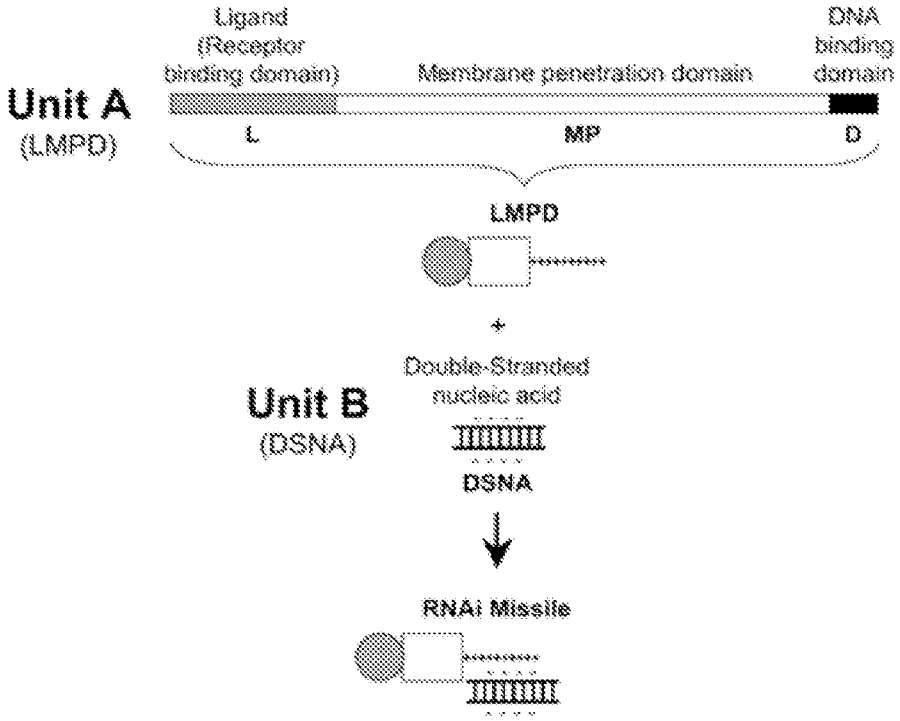


Figure 2.

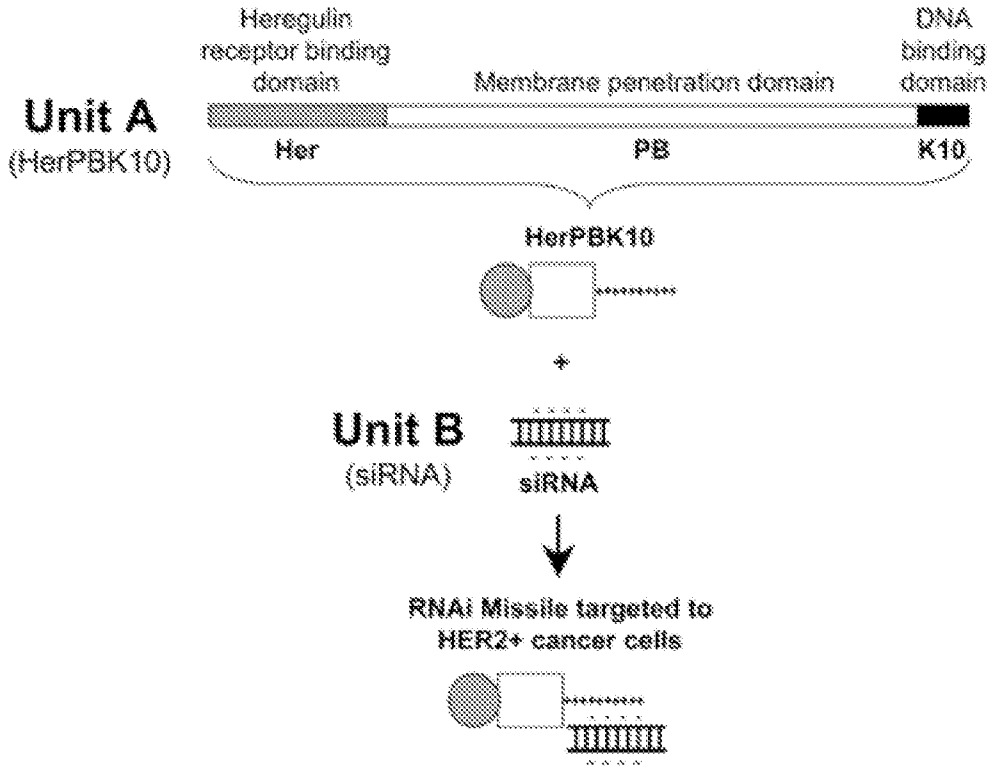


Figure 3 (A).

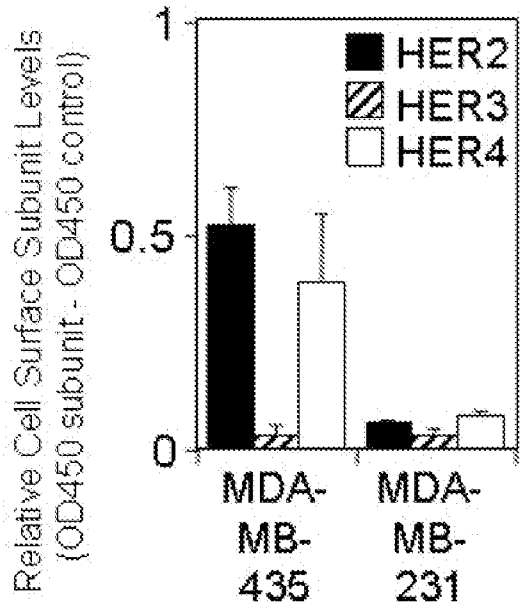

Relative Cell Surface Subunit Levels
(OD450 subunit - OD450 control)
1
0.5
0
HER2
HER3
HER4
MDA-MB-435
MDA-MB-231

Figure 3 (B).

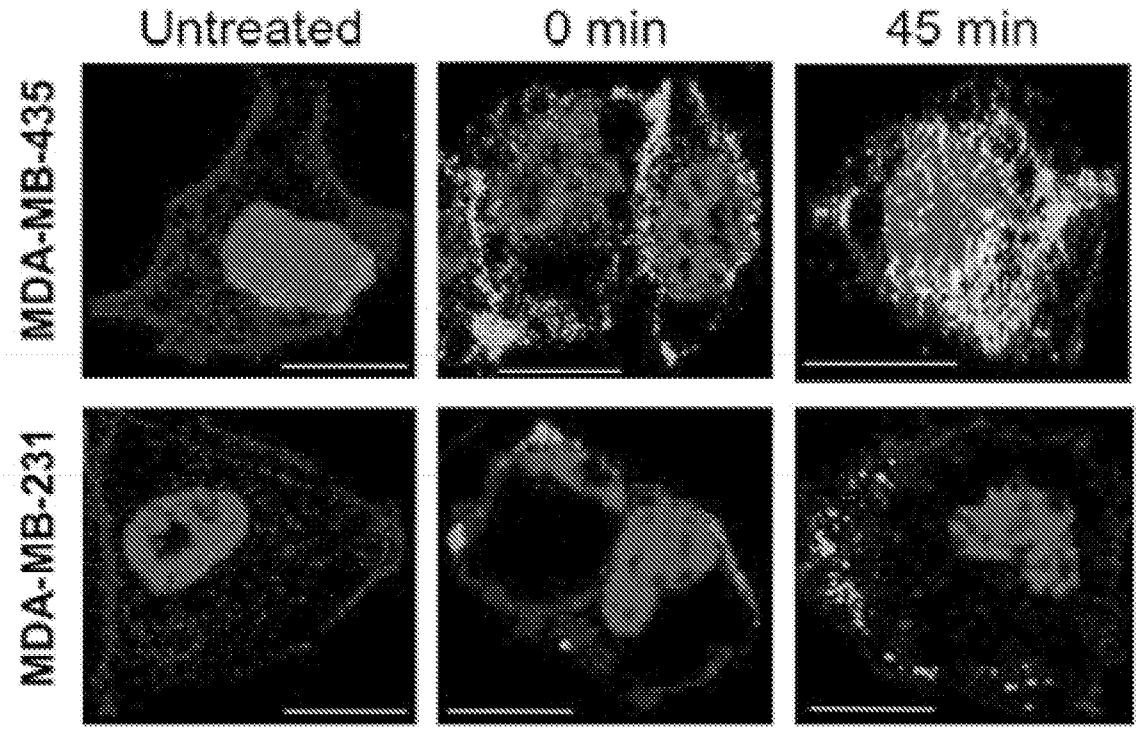


Figure 4.

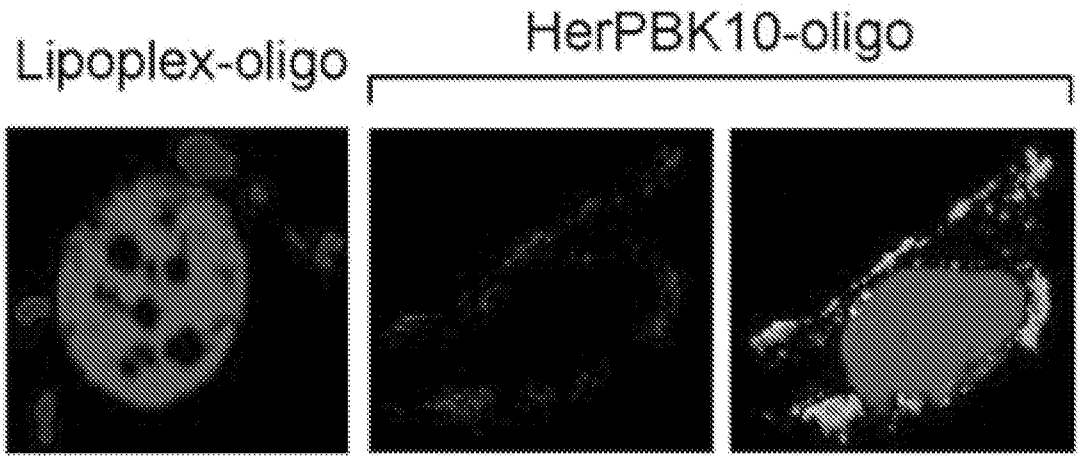


Figure 5.

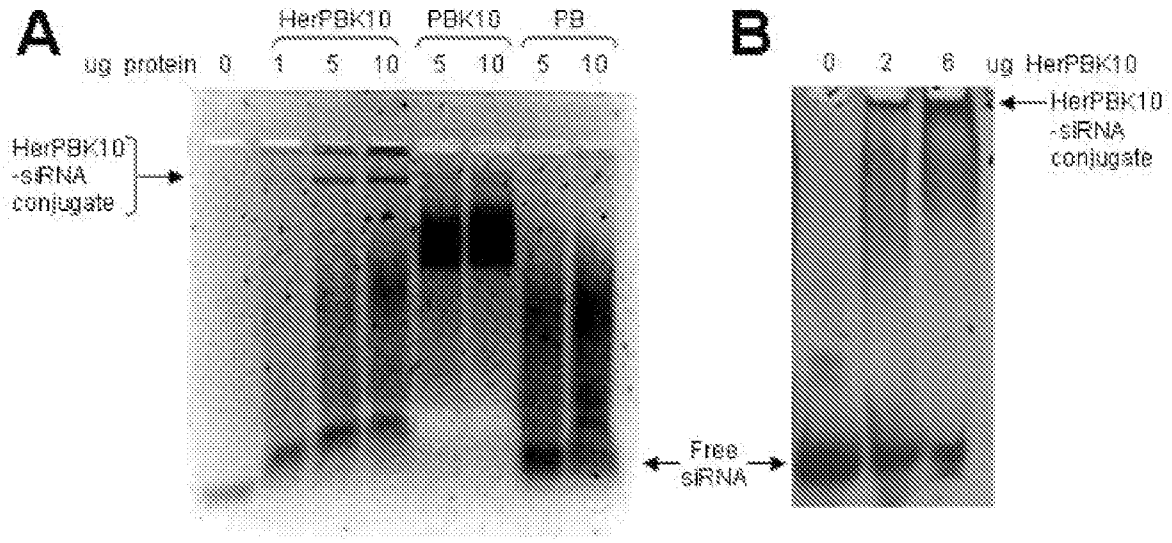


Figure 6.

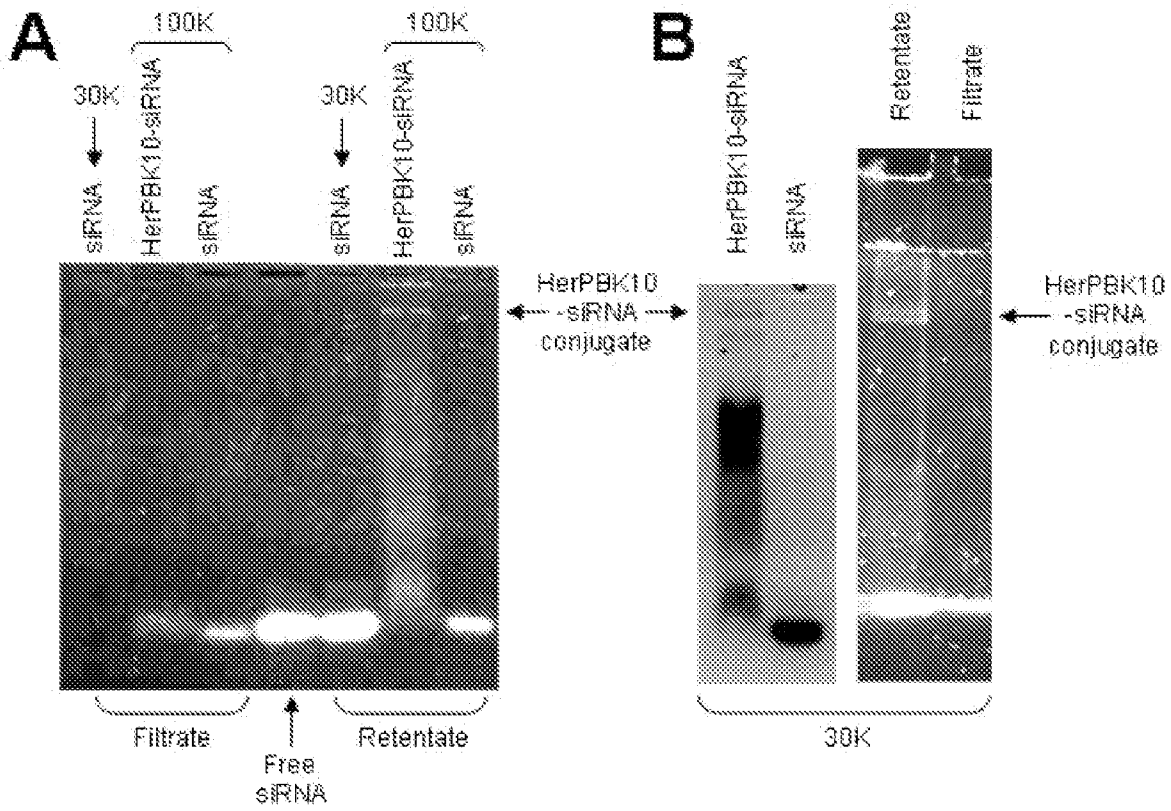


Figure 7.

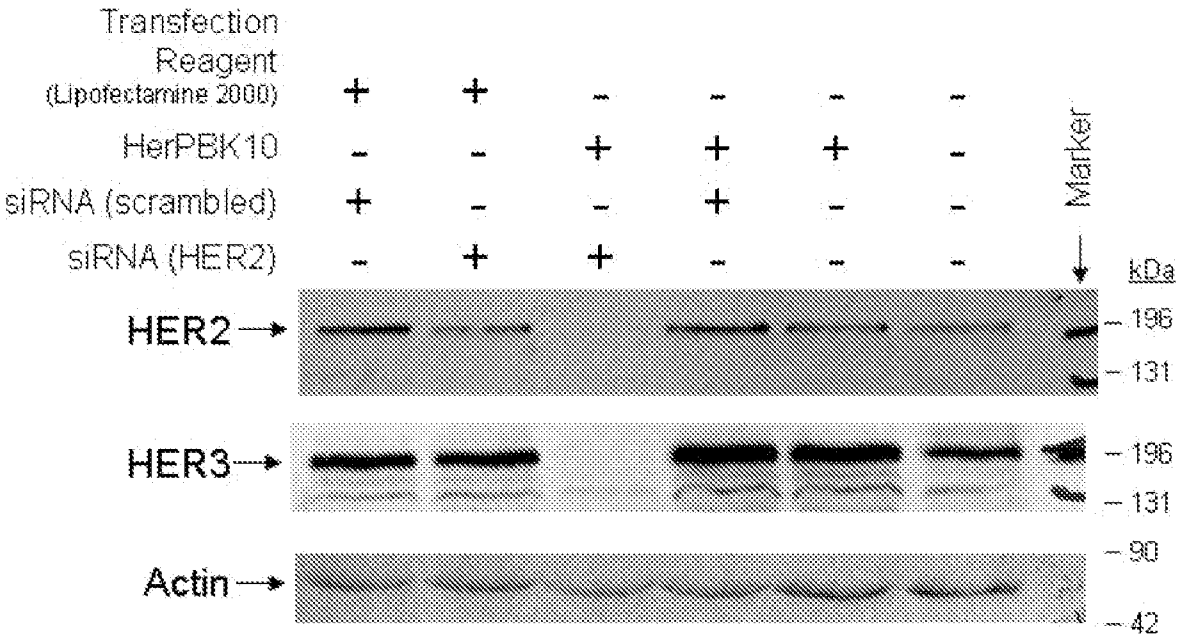


Figure 8.

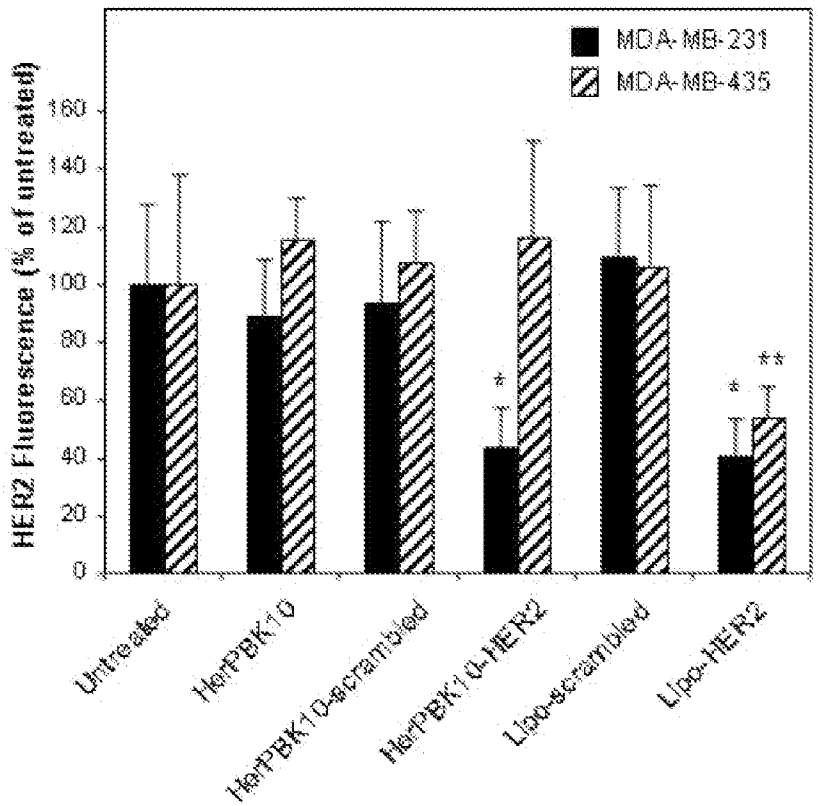


Figure 9 (A).

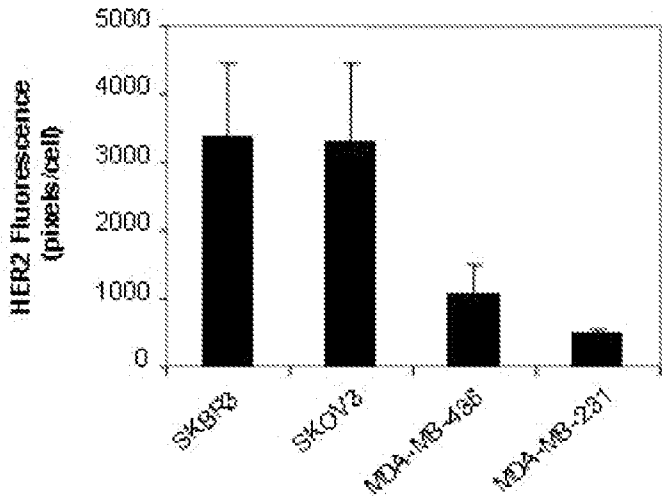


Figure 9 (B).

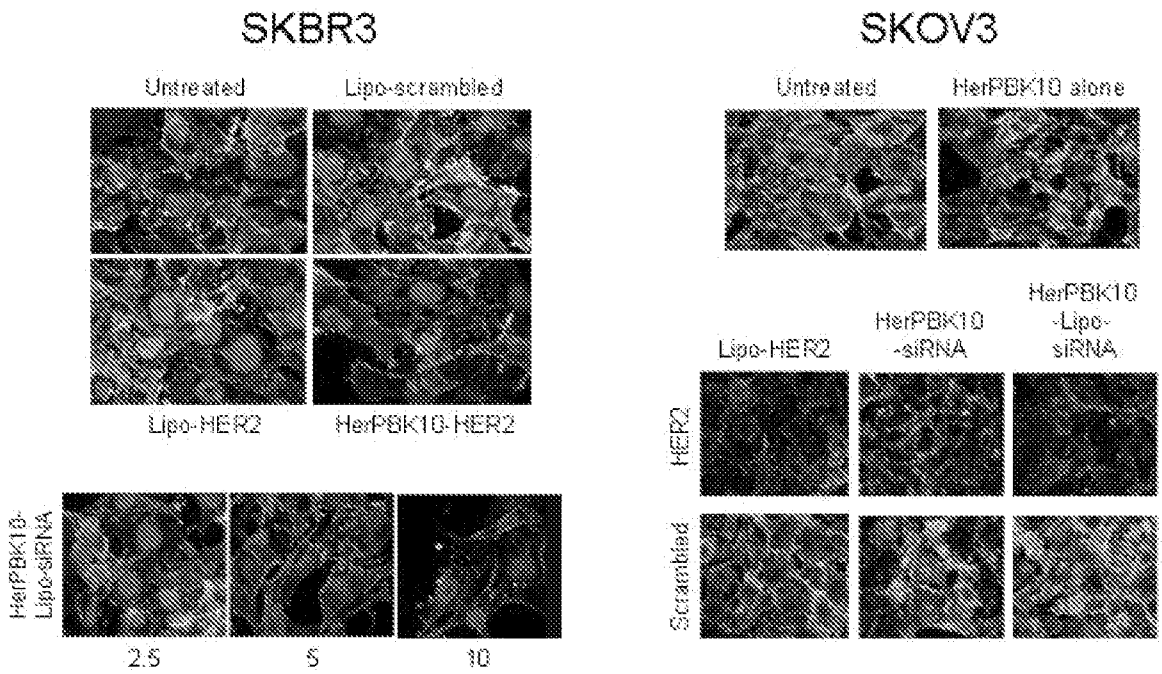


Figure 9 (C).

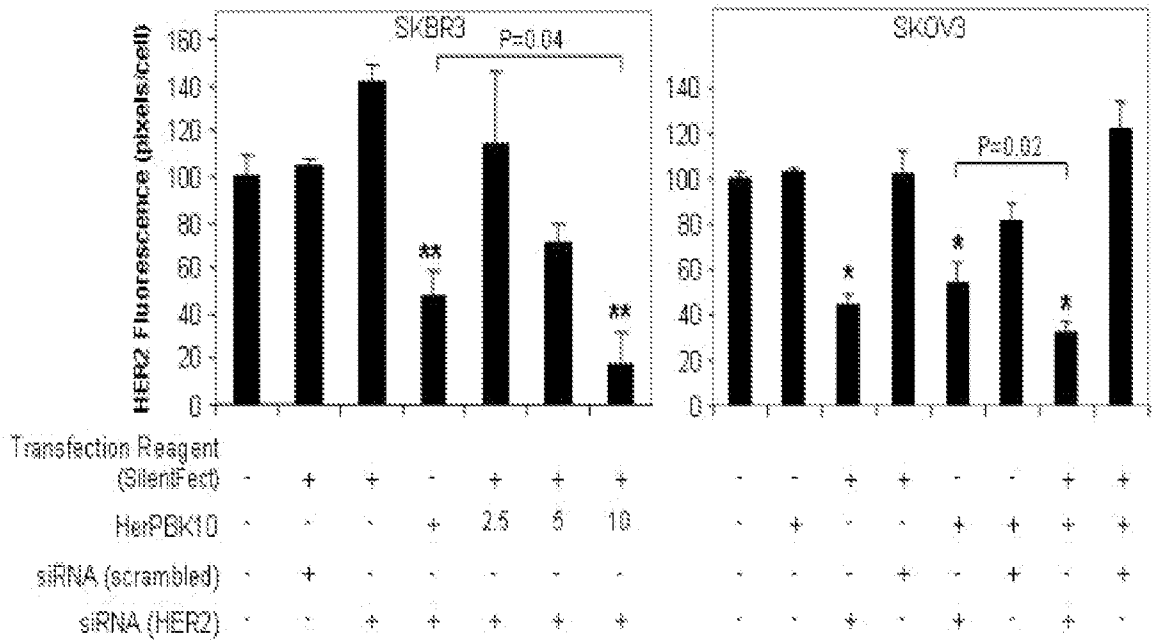


Figure 10.

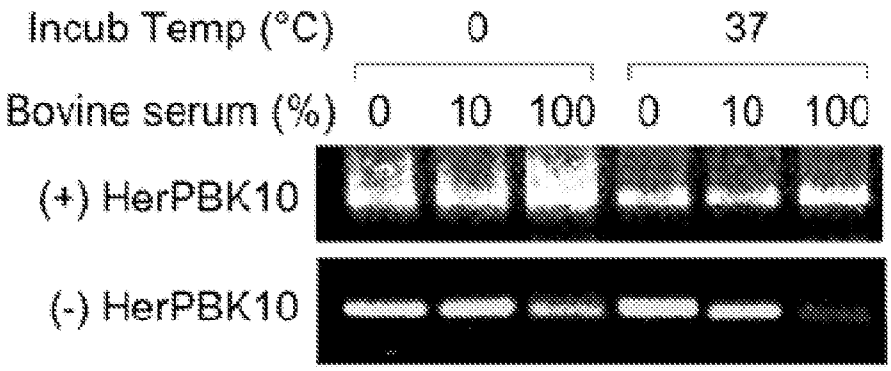


Figure 11.

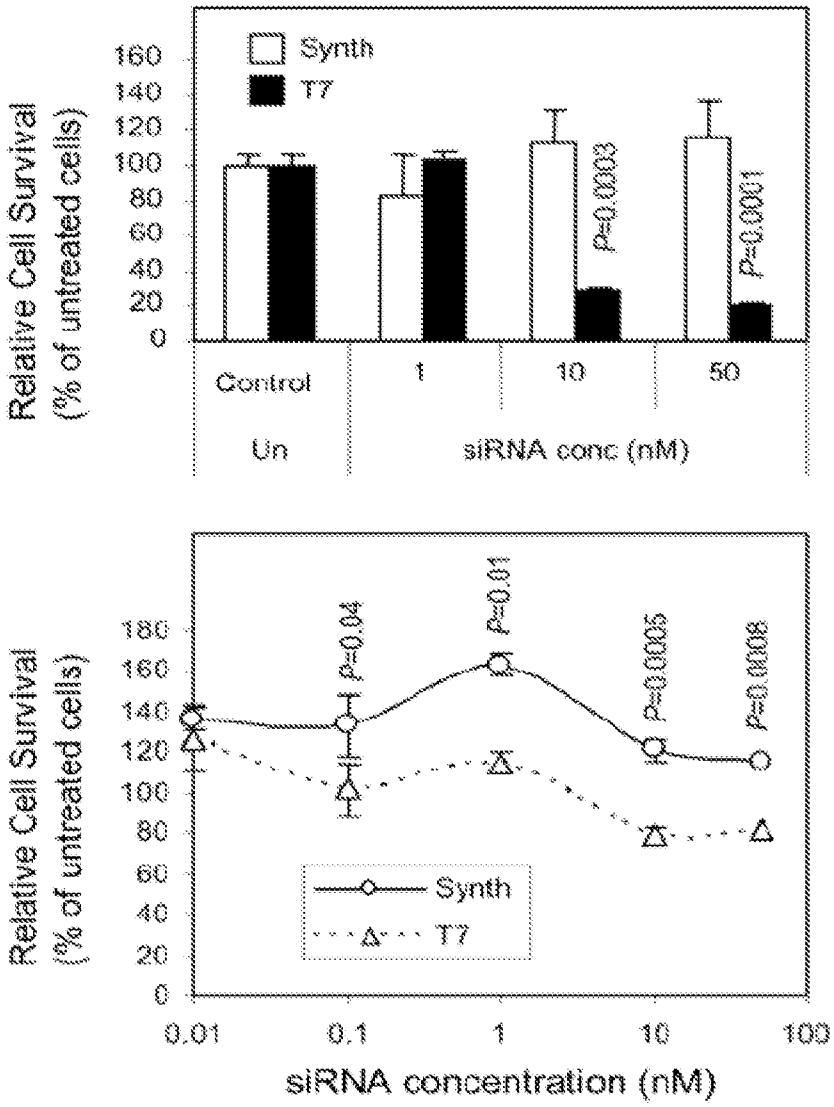

Relative Cell Survival
(% of untreated cells)
160
140
120
100
80
60
40
20
0
Synth
T7
P=0.0003
P=0.0001
Control
1
10
50
Un
siRNA conc (nM)
Relative Cell Survival
(% of untreated cells)
180
160
140
120
100
80
60
40
20
0
P=0.04
P=0.01
P=0.0005
P=0.0008
Synth
T7
0.01
0.1
1
10
100
siRNA concentration (nM)

Figure 12.

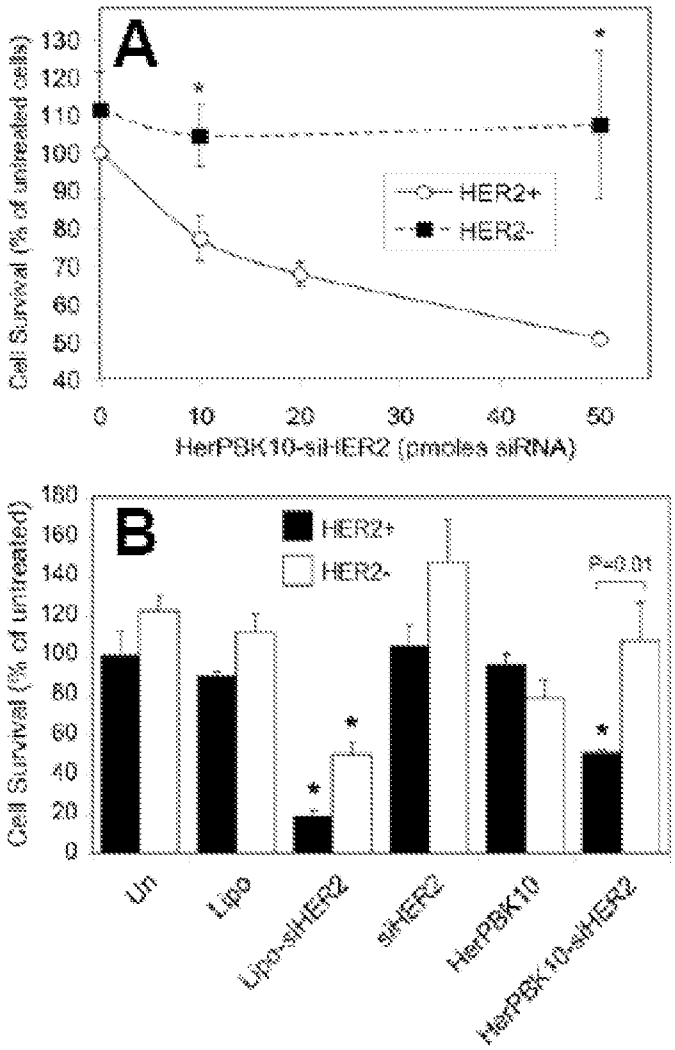

A
Cell Survival (% of untreated cells)
130
120
110
100
90
80
70
60
50
40
HER2+
HER2-
0
10
20
30
40
50
HerPBK10-siHER2 (pmoles siRNA)
B
Cell Survival (% of untreated)
180
160
140
120
100
80
60
40
20
0
HER2+
HER2-
P=0.01
Un
Lipo
Lipo-siHER2
siHER2
HerPBK10
HerPBK10-siHER2

Figure 13.

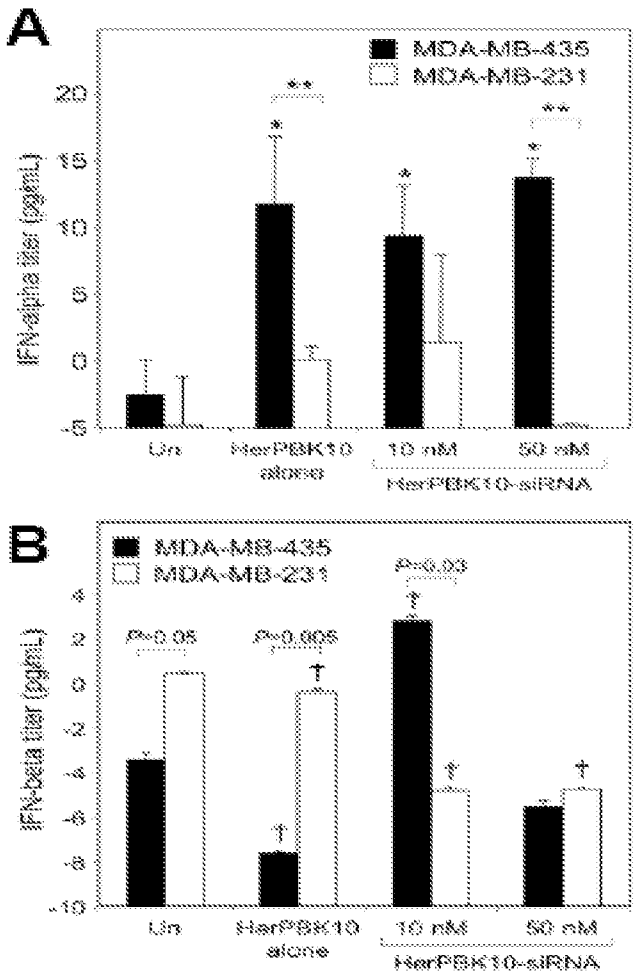

A
MDA-MB-435
MDA-MB-231
IFN-alpha titer (pg/mL)
20
15
10
5
0
-5
**
*
*
**
*
†
†
†
Un
HerPBK10 alone
10 nM
50 nM
HerPBK10-siRNA
B
MDA-MB-435
MDA-MB-231
IFN-beta titer (pg/mL)
4
2
0
-2
-4
-6
-8
-10
P=0.05
P=0.005
P=0.03
†
†
†
†
†
Un
HerPBK10 alone
10 nM
50 nM
HerPBK10-siRNA

Figure 14.

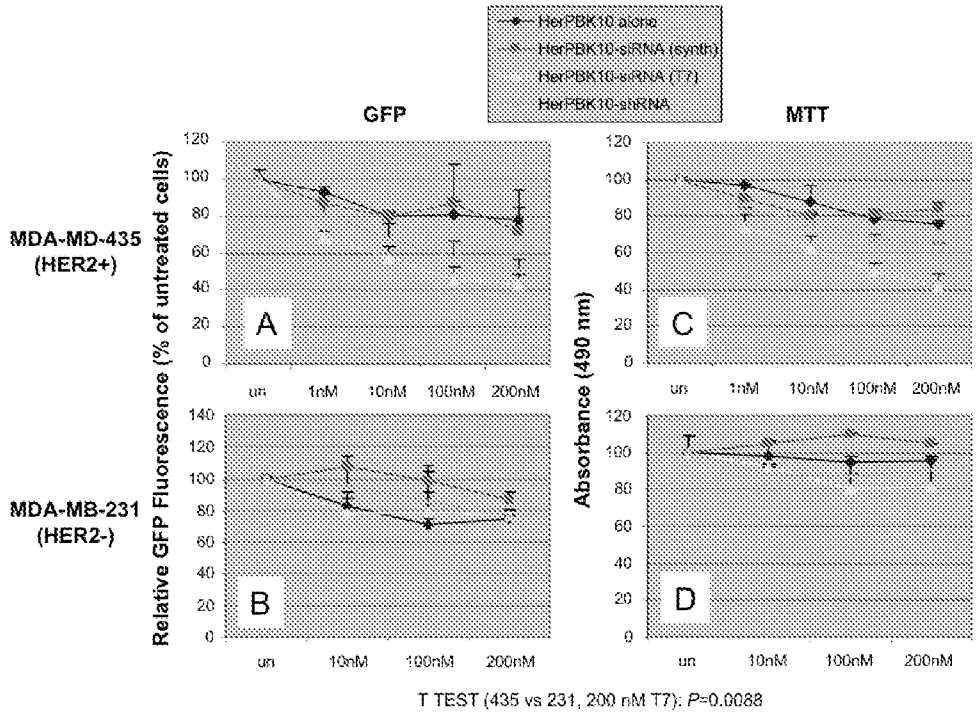

HerPBK10 alone
HerPBK10-siRNA (synth)
HerPBK10-siRNA (T7)
HerPBK10-shRNA
GFP
MTT
MDA-MD-435 (HER2+)
MDA-MB-231 (HER2-)
Relative GFP Fluorescence (% of untreated cells)
Absorbance (490 nm)
A
B
C
D
un
1nM
10nM
100nM
200nM
T TEST (435 vs 231, 200 nM T7): P=0.0088

Figure 15.

Figure 15(A)

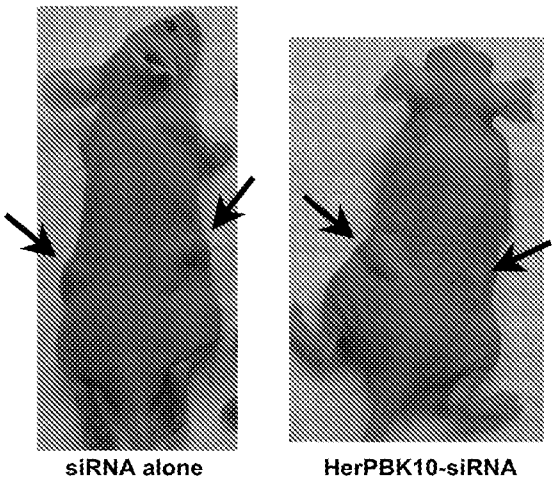


Figure 15(B)

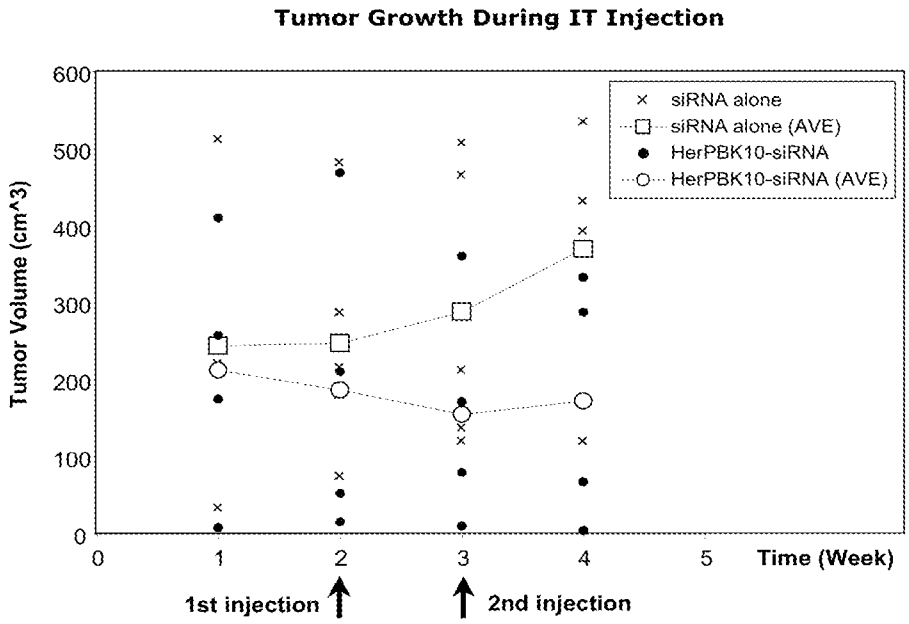


Figure 16.

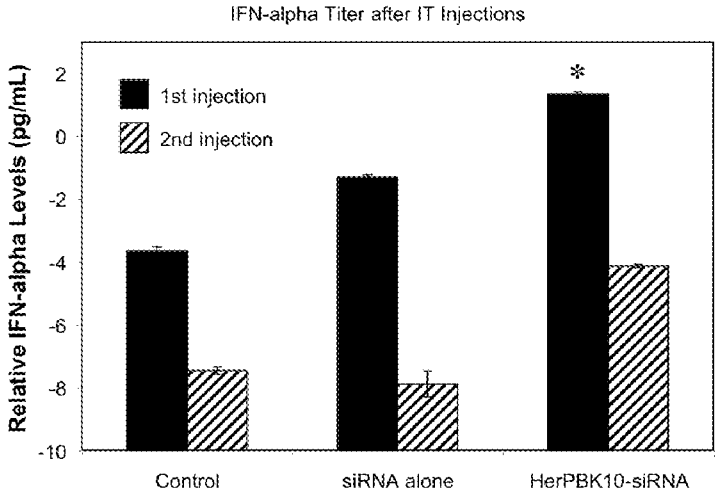

IFN-alpha Titer after IT Injections
Relative IFN-alpha Levels (pg/mL)
2
0
-2
-4
-6
-8
-10
1st injection
2nd injection
*
Control
siRNA alone
HerPBK10-siRNA

Figure 17.

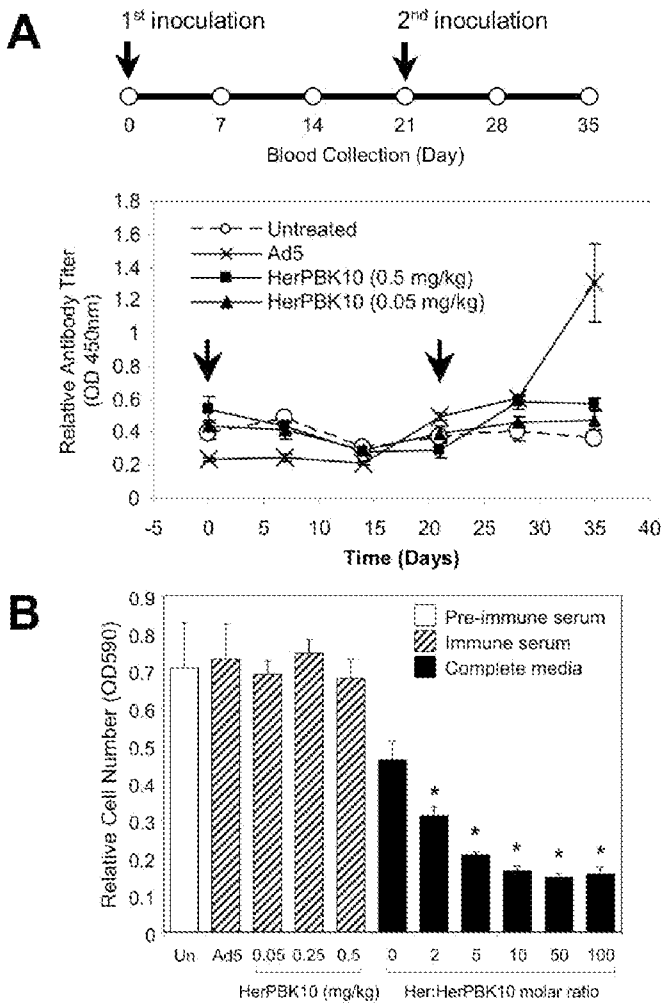

A
1st inoculation
2nd inoculation
0
7
14
21
28
35
Blood Collection (Day)
Relative Antibody Titer (OD 450nm)
Untreated
Ad5
HerPBK10 (0.5 mg/kg)
HerPBK10 (0.05 mg/kg)
Time (Days)
B
Relative Cell Number (OD590)
Pre-immune serum
Immune serum
Complete media
Un
Ad5
0.05
0.25
0.5
0
2
5
10
50
100
HerPBK10 (mg/kg)
Her:HerPBK10 molar ratio

Figure 18.

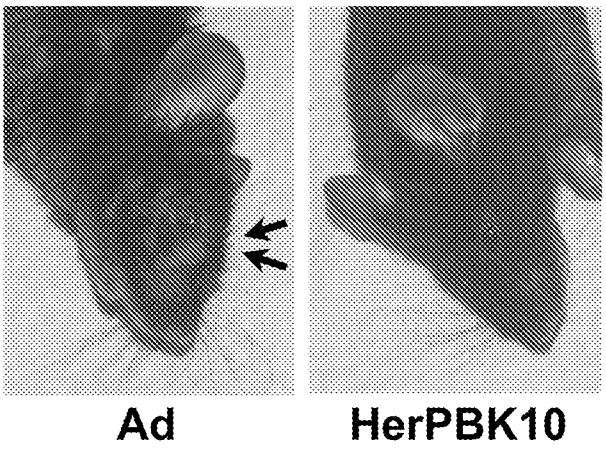


Figure 19.

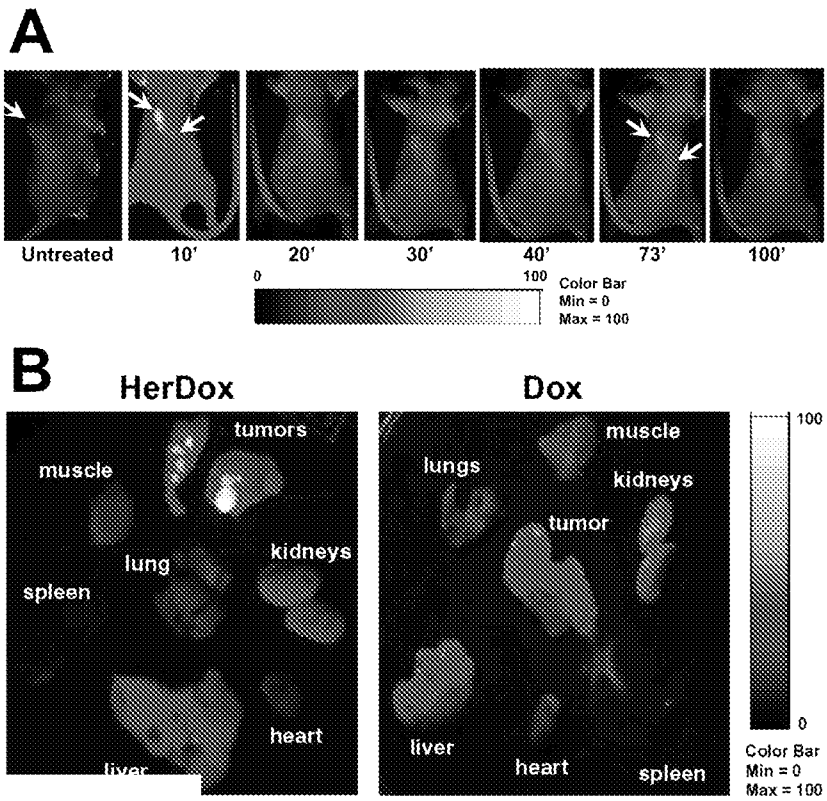


Figure 20.

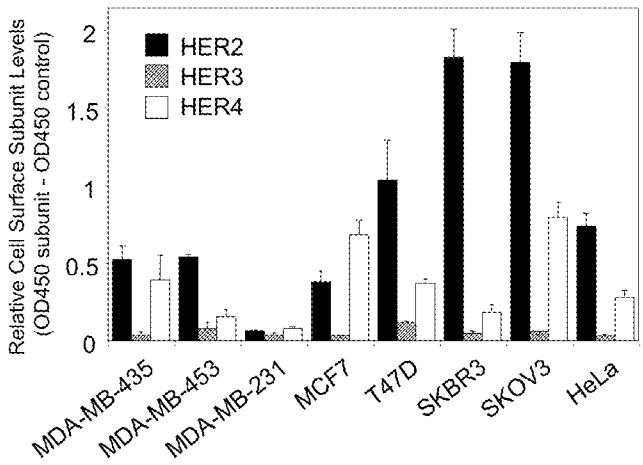


Figure 21.

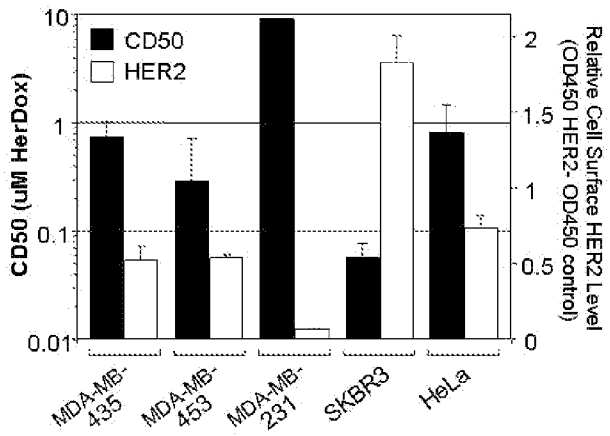


Figure 22.

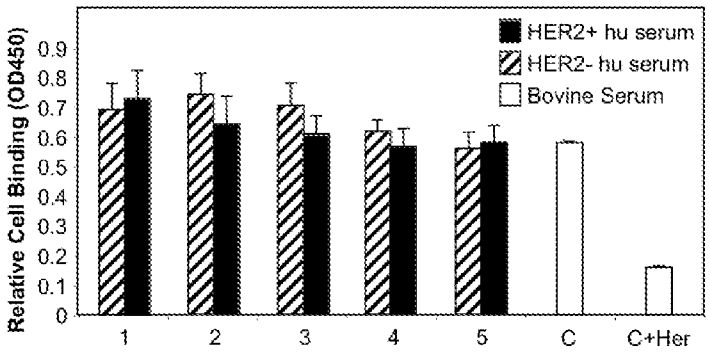

HER2+ hu serum
HER2- hu serum
Bovine Serum
Relative Cell Binding (OD450)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2
3
4
5
C
C+Her

Figure 23.

Figure 23(A).

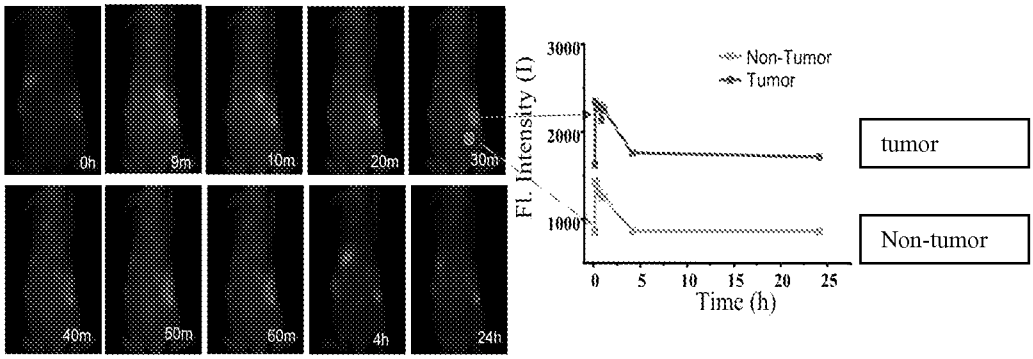


Figure 23(B)

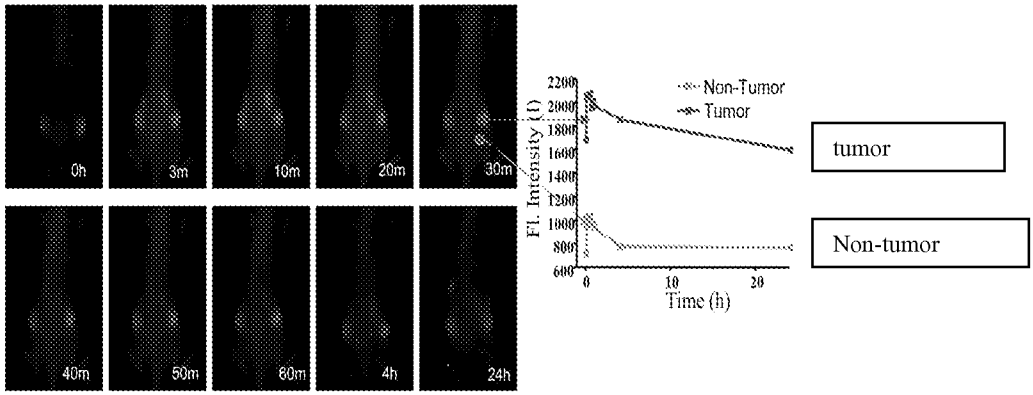
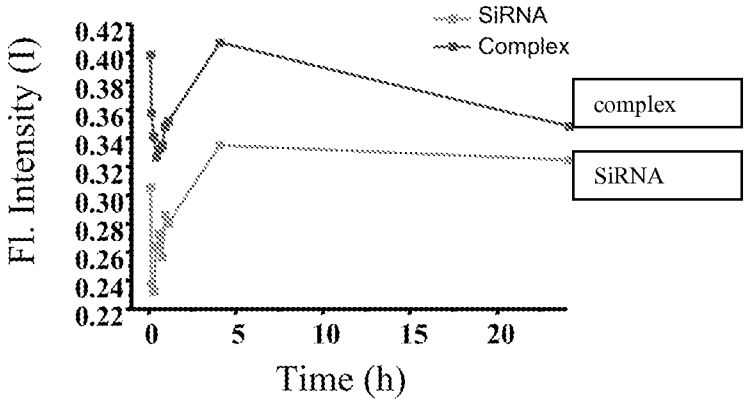


Figure 23(C).


SiRNA
Complex
complex
SiRNA
Fl. Intensity (I)
0.42
0.40
0.38
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0
5
10
15
20
Time (h)