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METHODS AND COMPOSITIONS FOR CANCER THERAPY USING A NOVEL ADENOVIRUS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority based on U.S. Provisional Patent Application No. 60/486,219, filed July 9, 2003, which is hereby incorporated by reference in full.

FIELD OF THE INVENTION

[0002] Generally, the present invention relates to a cancer therapy. More specifically, the present invention relates to an adenovirus-based cancer therapy.

BACKGROUND

[0003] Despite advances in both diagnosis and therapy, the annual number of cancer related deaths has not decreased during the past 60 years. Although conventional cancer therapies (surgery, radiotherapy, chemotherapy) produce a high rate of cure for patients with early stage disease, many cancers recur and the majority of patients with advanced cancer eventually succumb to the disease. The limitations of conventional cancer therapies do not derive from their inability to ablate tumor, but rather from limits on their ability to do so without excessively damaging the patient. It is this consideration that constrains the extent of surgical resection, the dose of radiation and volume to be irradiated, and the dose and combination of chemotherapeutic drugs. Improving the effectiveness of a treatment is of no clinical value if there is no significant increase in the differential response between tumor and normal tissue (i.e., therapeutic index).

[0004] Nonetheless, improved methods and novel agents for treating cancer have resulted in increased survival time and survival rate for patients with various types of cancer. For example, improved surgical and radiotherapeutic procedures result in more effective removal of localized tumors. Surgical methods, however, can be limited due, for example, to the location of a tumor or to dissemination of metastatic tumor cells. Radiotherapy also can be limited by other factors that limit the dose that can be administered. Tumors that are relatively radioresistant will not be cured at such a dose.

[0005] Although a single treatment modality such as radiation therapy, chemotherapy, surgery or immunotherapy can result in improvement of a patient, superior results can be achieved when such modalities are used in combination. In particular, treatment with a

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combination of radiotherapy, which can be directed to a localized area containing a tumor, and chemotherapy or immunotherapy, which provide a systemic mode of treatment, can be useful where dissemination of the disease has occurred or is likely to occur. Unfortunately, the therapeutic usefulness of radiation therapy can be limited where the tumor cells are relatively radioresistant, since the dose is limited by the tolerance of normal tissue in the radiation field. Thus, there exists a need to sensitize cancer tumors to the effects of radiotherapy so that it can more effectively reduce the severity of a tumor in a patient. Further, it would be useful to develop a treatment that more specifically isolates the location of the radiation, thus preventing the effects of radiation treatment on healthy cells.

[0006] In related fashion, to mitigate unwanted effects of some chemotherapies, adenovirus vectors have been used to transduce tumor cells with so-called "chemogenes" that convert a nontoxic substance, or "prodrug", into a toxic, therapeutically effective form. Several new approaches involving gene therapy are under consideration for improving the therapeutic index of cancer therapies.

[0007] One of these approaches, so-called "suicide gene therapy," involves the transfer and expression of non-mammalian genes encoding enzymes that convert non-toxic prodrugs into toxic anti-metabolites. Two "suicide genes" that are currently being evaluated in clinical trials are the *E. coli* cytosine deaminase (CD) and herpes simplex virus type-1 thymidine kinase (HSV-1 TK) genes, which confer sensitivity to 5-fluorocytosine (5-FC) and ganciclovir (GCV), respectively. Following targeted transfer of these genes to the tumor, the 5-FC and GCV prodrugs are converted locally into potent chemotherapeutic agents resulting in significant tumor cell death (see reference 1 (and the references cited therein) in the List of References Section below). Thus, the dose-limiting systemic toxicity associated with conventional chemotherapies is mitigated.

[0008] Previously, the bacterial CD and wild-type HSV-1 TK genes have been coupled to create a novel CD/HSV-1 TK fusion gene (see reference (hereinafter "ref.") 1 in the List of References Section). The CD/HSV-1 TK fusion gene allows for combined use of CD/5-FC and HSV-1 TK/GCV suicide gene therapies. It has been previously demonstrated that CD/5-FC and HSV-1 TK/GCV suicide gene therapies render malignant cells sensitive to specific pharmacological agents and importantly, sensitize them to radiation (see refs. 1-9). Using a novel, oncolytic, replication-competent adenovirus (Ad5-CD/TK*rep*) containing the prototype

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CD/HSV-1 TK fusion gene (ref. 10), the safety and efficacy of replication-competent adenovirus-mediated double suicide gene therapy without and with radiation therapy in several preclinical cancer models (refs. 10-13) and more recently, in human prostate cancer patients (refs. 14 and 15) have been demonstrated.

[0009] In these clinical trials targeting human prostate cancer, the Ad5-CD/TK*rep* virus proved to be safe up to a dose of 10^{12} Vp when combined with up to 3 weeks of 5-FC and GCV (vGCV) prodrug therapy without (ref. 14) and with (ref. 15) conventional dose (70 Gy) three dimensional conformal radiation therapy (3DCRT). Moreover, these treatment regimens have demonstrated signs of clinical activity (refs 14 and 15).

[0010] Nonetheless, despite these advances, a significant need remains for inventions that comprise effective methods and compositions for use in cancer therapies. The present invention was developed in light of these and other drawbacks.

SUMMARY OF THE INVENTION

[0011] The present invention comprises novel, improved methods and compositions for cancer therapy which comprise a novel virus that can kill mammalian cancer cells efficiently. The virus produces a novel protein that converts non-toxic prodrugs into potent chemotherapeutic agents. These chemotherapeutic agents are produced locally and help the virus kill the cancer cells as well as sensitize them to radiation. In preclinical studies, the virus has proven effective at killing a variety of human cancer cells either alone or when combined with prodrug therapy and/or radiation therapy.

[0012] The invention comprises a novel, "second-generation" adenovirus (designated "Ad5-yCD/*mut*TK_{SR39}*rep*-ADP") with at least two significant improvements relative to the previously disclosed prototype Ad5-CD/TK*rep* virus. Ad5-yCD/*mut*TK_{SR39}*rep*-ADP contains an improved yCD/*mut*TK_{SR39} fusion gene whose product is more efficient at converting the 5-FC and GCV prodrugs into their active chemotherapeutic agents. Moreover, Ad5-yCD/*mut*TK_{SR39}*rep*-ADP expresses the Ad5 ADP protein, which significantly increases the oncolytic activity of replication-competent adenoviruses. Relative to the prototype Ad5-CDITK*rep* virus, Ad5-yCD/*mut*TK_{SR39}*rep*-ADP has demonstrated greater viral oncolytic and chemotherapeutic activity in preclinical cancer models. The data suggest that the Ad5-yCD/*mut*TK_{SR39}*rep*-ADP virus

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comprising the present invention will exhibit low toxicity and significant anti-tumor activity clinically when combined with 5-FC and GCV prodrug therapy and radiation therapy.

[0013] Other aspects of the invention will be apparent to those skilled in the art after reviewing the drawings and the detailed description below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] The present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

[0015] FIG. 1 is a schematic representation of the Ad5-yCD/*mut*TK_{SR39}*rep*-ADP virus of the present invention.

[0016] FIG. 2 is a diagram showing an advantage of the ADP gene of the present invention.

[0017] FIGS. 3A and 3B are diagrams showing the advantage of the improved yCD/*mut*TK_{SR39} gene of the invention.

[0018] FIG. 4 is a diagram showing an advantage of the ADP gene of the present invention

[0019] FIG. 5 shows Kaplan-Meier plots with Ad5-yCD/*mut*TK_{SR39}*rep*-ADP in intraprostatic LNCaP C4-2 mouse model.

DETAILED DESCRIPTION OF THE INVENTION

[0020] Generally, the present invention comprises methods and compositions for the treatment for cancer. More specifically, the present invention provides a treatment that, when administered with prodrugs, can kill cancer cells and make the remaining cancer cells more sensitive to radiation.

[0021] Embodiments of the present invention include a novel virus that produces a protein that can convert non-toxic prodrugs into chemotherapeutic agents. The prodrugs can be produced locally or administered in conjunction with the treatment. Preferably, the virus is an oncolytic, replication-competent adenovirus such as, but not limited to, Ad5-yCD/*mut*TK_{SR39}*rep*-ADP. When administered to a patient in need of such treatment, the adenovirus converts at least two prodrugs into chemotherapeutic agents. These prodrugs can include, but are not limited to, 5-fluorocytosine (5-FC) and ganciclovir (GCV and derivatives thereof).

[0022] In addition to the ability to convert the prodrugs into chemotherapeutic agents, embodiments of the present invention sensitize the cells to radiation. By sensitizing the cells,

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lower doses of radiation can be used without limiting the benefits of radiation. Further, the radiation therapy is more effective because the cancer cells are more sensitive to the radiation, while normal cells are not more sensitive, thus limiting the side effects of cancer treatments. The treatment of the present invention can be used in conjunction with other therapies such as surgery, chemotherapy, hormone therapy, and immunotherapy.

[0023] In preferred embodiments, the present invention comprises a novel, oncolytic, replication-competent adenovirus (Ad5-yCD/*mut*TK_{SR39}*rep*-ADP) containing a yeast cytosine deaminase (yCD)/mutant SR39 herpes simplex virus type-1 thymidine kinase (*mut*TK_{SR39}) fusion gene and the adenovirus type 5 (Ad5) adenovirus death protein (ADP) gene. Ad5-yCD/*mut*TK_{SR39}*rep*-ADP replicates in and kills human cancer cells efficiently. Ad5-yCD/*mut*TK_{SR39}*rep*-ADP produces a novel yCD/*mut*TK_{SR39} fusion protein that can convert two prodrugs, 5-fluorocytosine (5-FC) and ganciclovir (GCV; and GCV derivatives), into potent chemotherapeutic agents (referred to as double suicide gene therapy). Both yCD/5-FC and HSV-1 TK_{SR39} suicide gene therapies exhibit potent chemotherapeutic activity and sensitize tumor cells to ionizing radiation.

[0024] By way of example only, preclinical studies show that the Ad5-yCD/*mut*TK_{SR39}*rep*-ADP virus is effective at killing a variety of human cancer cells when used by itself or when combined with double suicide gene therapy and/or radiation therapy. In a clinical setting, the Ad5-yCD/*mut*TK_{SR39}*rep*-ADP virus could be used as a monotherapy for its virus-mediated oncolytic effect, it could be coupled with yCD/5-FC and HSV-1 Ad5-TK_{SR39}/GCV suicide gene therapies for a combined viral oncolytic/chemotherapeutic effect, or it could be coupled with yCD/5-FC and HSV-1 TK_{SR39}/GCV suicide gene therapies and radiation therapy for a combined viral oncolytic/chemotherapeutic/radiosensitization effect (referred to as trimodal therapy). Trimodal therapy could be combined with other conventional cancer treatments such as surgery, chemotherapy, hormone therapy and immunotherapy in the management of human cancer.

[0025] To develop further this gene therapy-based approach as a cancer treatment, a novel, second-generation adenovirus (Ad5-yCD/*mut*TK_{SR39}*rep*-ADP) has been developed with two significant improvements relative to the prototype Ad5-CD/TK*rep* virus. Ad5-yCD/*mut*TK_{SR39}*rep*-ADP contains an improved yCD/*mut*TK_{SR39} fusion gene whose product is more efficient at converting the 5-FC and GCV prodrugs into their active chemotherapeutic agents. Moreover, Ad5-yCD/*mut*TK_{SR39}*rep*-ADP expresses the Ad5 ADP protein, which

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significantly increases the oncolytic activity of replication-competent adenoviruses. Relative to the prototype Ad5-CDITK*rep* virus, Ad5-yCD/*mut*TK_{SR39}*rep*-ADP has demonstrated greater viral oncolytic and chemotherapeutic activity in preclinical cancer models.

[0026] Introduction of nucleic acid of the present invention by viral infection offers several advantages over the other listed methods. Higher efficiency can be obtained due to virus' infectious nature. Moreover, viruses are very specialized and typically infect and propagate in specific cell types. Thus, their natural specificity can be used to target the vectors to specific cell types *in vivo* or within a tissue or mixed culture of cells. Viral vectors can also be modified with specific receptors or ligands to alter target specificity through receptor mediated events.

[0027] Also, additional features can be added to the vector to ensure its safety and/or enhance its therapeutic efficacy. Such features include, for example, markers that can be used to negatively select against cells infected with the recombinant virus. An example of such a negative selection marker is the TK gene described above that confers sensitivity to the antibiotic gancyclovir. Negative selection is therefore a means by which infection can be controlled because it provides inducible suicide through the addition of antibiotic. Such protection ensures that if, for example, mutations arise that produce altered forms of the viral vector or recombinant sequence, cellular transformation will not occur.

[0028] Features that limit expression to particular cell types can also be included in some embodiments. Such features include, for example, promoter and regulatory elements that are specific for the desired cell type.

[0029] In addition, recombinant viral vectors are useful for *in vivo* expression of the nucleic acids of the present invention because they offer advantages such as lateral infection and targeting specificity. Lateral infection is inherent in the life cycle of, for example, retrovirus and is the process by which a single infected cell produces many progeny virions that bud off and infect neighboring cells. The result is that a large area becomes rapidly infected, most of which was not initially infected by the original viral particles. This is in contrast to vertical-type of infection in which the infectious agent spreads only through daughter progeny. Viral vectors can also be produced that are unable to spread laterally. This characteristic can be useful if the desired purpose is to introduce a specified gene into only a localized number of targeted cells.

[0030] As described above, viruses are very specialized infectious agents that have evolved, in many cases, to elude host defense mechanisms. Typically, viruses infect and propagate in

specific cell types. The targeting specificity of viral vectors utilizes its natural specificity to specifically target predetermined cell types and thereby introduce a recombinant gene into the infected cell. The vector to be used in the methods of the invention will depend on desired cell type to be targeted and will be known to those skilled in the art. For example, if breast cancer is to be treated then a vector specific for such epithelial cells would be used. Likewise, if diseases or pathological conditions of the hematopoietic system are to be treated, then a viral vector that is specific for blood cells and their precursors, preferably for the specific type of hematopoietic cell, would be used.

[0031] The recombinant vector can be administered in several ways. For example, the procedure can take advantage of the target specificity of viral vectors and consequently do not have to be administered locally at the diseased site. However, local administration can provide a quicker and more effective treatment. Administration can also be performed by, for example, intravenous or subcutaneous injection into the subject. Following injection, the viral vectors will circulate until they recognize host cells with the appropriate target specificity for infection.

[0032] An alternate mode of administration can be by direct inoculation locally at the site of the disease or pathological condition or by inoculation into the vascular system supplying the site with nutrients. Local administration is advantageous because there is no dilution effect and, therefore, a smaller dose is required to achieve expression in a majority of the targeted cells. Additionally, local inoculation can alleviate the targeting requirement required with other forms of administration since a vector can be used that infects all cells in the inoculated area. If expression is desired in only a specific subset of cells within the inoculated area, then promoter and regulatory elements that are specific for the desired subset can be used to accomplish this goal. Such non-targeting vectors can be, for example, viral vectors, viral genome, plasmids, phagemids and the like. Transfection vehicles such as liposomes can also be used to introduce the non-viral vectors described above into recipient cells within the inoculated area. Such transfection vehicles are known by one skilled within the art.

[0033] The compound of the present invention is administered and dosed in accordance with good medical practice, taking into account the clinical condition of the individual patient, the site and method of administration, scheduling of administration, patient age, sex, body weight and other factors known to medical practitioners. The pharmaceutically "effective amount" for purposes herein is thus determined by such considerations as are known in the art. The amount

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must be effective to achieve improvement including but not limited to improved survival rate or more rapid recovery, or improvement or elimination of symptoms and other indicators as are selected as appropriate measures by those skilled in the art.

[0034] In the method of the present invention, the compound of the present invention can be administered in various ways. It should be noted that it can be administered as the compound and can be administered alone or as an active ingredient in combination with pharmaceutically acceptable carriers, diluents, adjuvants and vehicles. The compounds can be administered orally, subcutaneously or parenterally including intravenous, intraarterial, intramuscular, intraperitoneally, and intranasal administration as well as intrathecal and infusion techniques. Implants of the compounds are also useful. The patient being treated is a warm-blooded animal and, in particular, mammals including humans. The pharmaceutically acceptable carriers, diluents, adjuvants and vehicles as well as implant carriers generally refer to inert, non-toxic solid or liquid fillers, diluents or encapsulating material not reacting with the active ingredients of the invention.

[0035] It is noted that humans are treated generally longer than the mice or other experimental animals exemplified herein which treatment has a length proportional to the length of the disease process and drug effectiveness. The doses may be single doses or multiple doses over a period of several days. The treatment generally has a length proportional to the length of the disease process and drug effectiveness and the patient species being treated.

[0036] When administering the compound of the present invention parenterally, it will generally be formulated in a unit dosage injectable form (solution, suspension, emulsion). The pharmaceutical formulations suitable for injection include sterile aqueous solutions or dispersions and sterile powders for reconstitution into sterile injectable solutions or dispersions. The carrier can be a solvent or dispersing medium containing, for example, water, ethanol, polyol (for example, glycerol, propylene glycol, liquid polyethylene glycol, and the like), suitable mixtures thereof, and vegetable oils.

[0037] Proper fluidity can be maintained, for example, by the use of a coating such as lecithin, by the maintenance of the required particle size in the case of dispersion and by the use of surfactants. Nonaqueous vehicles such a cottonseed oil, sesame oil, olive oil, soybean oil, corn oil, sunflower oil, or peanut oil and esters, such as isopropyl myristate, may also be used as solvent systems for compound compositions. Additionally, various additives which enhance the

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stability, sterility, and isotonicity of the compositions, including antimicrobial preservatives, antioxidants, chelating agents, and buffers, can be added. Prevention of the action of microorganisms can be ensured by various antibacterial and antifungal agents, for example, parabens, chlorobutanol, phenol, sorbic acid, and the like. In many cases, it will be desirable to include isotonic agents, for example, sugars, sodium chloride, and the like. Prolonged absorption of the injectable pharmaceutical form can be brought about by the use of agents delaying absorption, for example, aluminum monostearate and gelatin. According to the present invention, however, any vehicle, diluent, or additive used would have to be compatible with the compounds.

[0038] Sterile injectable solutions can be prepared by incorporating the compounds utilized in practicing the present invention in the required amount of the appropriate solvent with various of the other ingredients, as desired.

[0039] A pharmacological formulation of the present invention can be administered to the patient in an injectable formulation containing any compatible carrier, such as various vehicle, adjuvants, additives, and diluents; or the compounds utilized in the present invention can be administered parenterally to the patient in the form of slow-release subcutaneous implants or targeted delivery systems such as monoclonal antibodies, vectored delivery, iontophoretic, polymer matrices, liposomes, and microspheres. Many other such implants, delivery systems, and modules are well known to those skilled in the art.

[0040] In one embodiment, the compound of the present invention can be administered initially by intravenous injection to bring blood levels to a suitable level. The patient's levels are then maintained by an oral dosage form, although other forms of administration, dependent upon the patient's condition and as indicated above, can be used. The quantity to be administered will vary for the patient being treated.

DEFINITIONS

[0041] Unless stated otherwise or suggested by context, the following terms and phrases have the meaning provided below.

[0042] The term "gene therapy" as used herein refers to the transfer of genetic material (e.g. DNA or RNA) of interest into a host to treat or prevent a genetic or acquired disease or condition phenotype. The genetic material of interest encodes a product (e.g. a protein, polypeptide,

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peptide, functional RNA, antisense) whose production in vivo is desired. For example, the genetic material of interest can encode a hormone, receptor, enzyme, polypeptide or peptide of therapeutic value. The genetic material of interest can also encode a suicide gene. For a review see, in general, the text "Gene Therapy" (Advances in Pharmacology 40, Academic Press, 1997).

[0043] The phrase "*in vivo* gene therapy" refers to when the genetic material to be transferred is introduced into the target cells of the recipient organism *in situ*, which is within the recipient. After therapy, the genetically altered target cells express the transfected genetic material *in situ*. Such therapy also includes repairing the gene *in situ*, if the host gene is defective.

[0044] The phrase "gene expression vehicle" refers to any vehicle capable of delivery/transfer of heterologous nucleic acid into a host cell. The expression vehicle may include elements to control targeting, expression and transcription of the nucleic acid in a cell selective manner as is known in the art. It should be noted that often the 5'UTR and/or 3'UTR of the gene may be replaced by the 5'UTR and/or 3'UTR of the expression vehicle. Therefore, as used herein the expression vehicle may, as needed, not include the 5'UTR and/or 3'UTR of the actual gene to be transferred and only include the specific amino acid coding region. The expression vehicle can include a promoter for controlling transcription of the heterologous material and can be either a constitutive or inducible promoter to allow selective transcription. Enhancers that may be required to obtain necessary transcription levels can optionally be included. Enhancers are generally any non-translated DNA sequence which works contiguously with the coding sequence (in cis) to change the basal transcription level dictated by the promoter. The expression vehicle can also include a selection gene.

EXAMPLES

1. Description of the Ad5-yCD/*mut*TK_{SR39}*rep*-ADP adenovirus

[0045] The complete and partial DNA and translated protein sequences of the Ad5-yCD/*mut*TK_{SR39}*rep*-ADP adenovirus, yCD/*mut*TK_{SR39} fusion gene and ADP gene (SEQ ID NOs. 1-5) are disclosed following the List of References Section. The following examples are presented in view of such sequences.

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[0046] The Ad5-yCD/*mut*TK_{SR39}*rep*-ADP virus (*SEQ ID NO. 1*) of the examples is a replication-competent, type 5 adenovirus (the sequence of which is readily known and obtainable to one skilled in the art) that contains an improved yCD/*mut*TK_{SR39} fusion gene in the El region and the Ad5 ADP gene in the E3 region. A schematic representation of Ad5-yCD/*mut*TK_{SR39}*rep*-ADP is provide in Figure 1 (in Figure 1, "CMV" = human cytomegalovirus promoter; "SV40" = simian virus 40 polyadenylation sequences; and "mu" = map units.) As shown in Figure 1, the CMV-yCD/*mut*TK_{SR39}-SV40 expression cassette is located in the E1 region in place of the deleted 55 kDa E1B gene. The CMV-ADP-SV40 expression cassette is located in the E3 region in place of the deleted E3 genes.

[0047] Ad5-yCD/*mut*TK_{SR39}*rep*-ADP contains a 1,255 base pair (bp) deletion (bases 2,271 to 3,524) in the 55 kDa E1B gene (*see SEQ ID NO. 2*). Using methods known to those of ordinary skill in the art, two premature translation stop codons were engineered into the 55 kDa E1B gene resulting in the production of a truncated, non-functional, 78 amino acid E1B protein. Ad5-yCD/*mut*TK_{SR39}*rep*-ADP expresses the wild-type Ad5 E1A and 19 kDa E1B proteins. The yCD/*mut*TK_{SR39} fusion gene (*SEQ ID NO. 4*) was inserted in place of the deleted 55 kDa E1B gene. Expression of the yCD/*mut*TK_{SR39} fusion gene is driven by the human cytomegalovirus (CMV) promoter and utilizes simian virus 40 (SV40) polyadenylation elements. The yCD/*mut*TK_{SR39} fusion gene codes for a 59 kDa yCD/*mut*TK_{SR39} fusion protein, which is capable of enzymatically converting 5-flurocytosine (5-FC) into fluorouracil (5-FU) and ganciclovir (GCV) and its derivatives into their corresponding monophosphates (e.g. GCV-MP). The downstream metabolic products of 5-FU and GCV-MP are potent inhibitors of DNA replication and result in the death of dividing cells. These downstream metabolic products are also potent radiosensitizers and can markedly increase the therapeutic effect of radiation therapy (see refs. 1-14). Cells that express the yCD/*mut*TK_{SR39} fusion protein, as well as neighboring cells via the bystander effect, are killed by yCD/5-FC and HSV-1 TK_{SR39}/GCV suicide gene therapies and are sensitized to the killing effects of ionizing radiation.

[0048] Ad5-yCD/*mut*TK_{SR39}*rep*-ADP also contains a 2.68 kb deletion in the E3 region (bases 28,133 to 30,181), which affects genes that suppress the host immune response but are unnecessary for virus replication (*see SEQ ID NO. 3*). Ad5-yCD/*mut*TK_{SR39}*rep*-ADP contains an Ad5 ADP expression cassette in place of the natural Ad5 E3 genes. Expression of the ADP gene (*SEQ ID NO. 5*) is driven by the human cytomegalovirus (CMV) promoter and utilizes simian

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virus 40 (SV40) polyadenylation elements. The authentic 111.6 kDa Ad5 ADP protein is produced, which significantly increases the oncolytic activity of replication-competent adenoviruses. Ad5-yCD/*mut*TK_{SR39}*rep*-ADP lacks all other known Ad5 E3 genes (gp19, 10.4 kDa, 14.5 kDa and 14.7 kDa genes).

2. Construction of the Ad5-yCD/*mut*TK_{SR39}*rep*-ADP adenovirus

[0049] Plasmids containing adenoviral sequences used in the construction of Ad5-yCD/*mut*TK_{SR39}*rep*-ADP were obtained from Microbix (Toronto, Canada). To generate the pCMV-yCD/*mut*TK_{SR39} expression plasmid (left-end vector), the mutant SR39 HSV-1 TK gene (ref. 16) was generated by the polymerase chain reaction (PCR) using linearized pET23d:HSVTK_{SR39} as template. The following primer pair was used to generate the *mut*TK_{SR39} PCR product:

5'-GATCGGATCCCTCGAGATC2CTAGCATGGCTTCGTACCCCGGC-3

5'-GATCGAATTCTTCCGTGTTTCAGTTAGCCTC-3

[0050] The resulting 1,128 bp fragment was digested with *BamHI* (GGATCC) + *EcoRI* (GAATTC) and cloned between the *BamHI* + *EcoRI* sites of pCA14-CDglyTK-E1aE1b (ref. 10) after removal of the prototype CD/HSV-1 TK fusion gene generating pCA14-CMV-*mut*TK_{SR39}-E1aE1b. The yCD gene (ref. 17) was generated by PCR using linearized pBAD-ByCD as template. The following primer pair was used to generate the yCD PCR product:

5'-GATCCTCGAGCCACCATGGTGACAGGGGGAATG-3'

5'-GATCGCTAGCACCTCCCCCACCGCCTCtCCCTCCACCCTCACCAATATCTTC-3'

[0051] The resulting 526 bp fragment was digested with *XhoI* (CTCGAG) + *NheI* (GCTAGC) and cloned between the *XhoI* + *NheI* sites of pCA14-CMV-*mut*TK_{SR39}-E1aE1b generating pCA14-CMV-yCD/*mut*TK^{SR39}-E1aE1b.

[0052] To generate pBHG10-PacImod-CMV-ADP (right-end vector), the ADP gene was generated by PCR and cloned between the *PacI* and *SwaI* sites of pBHG10-*PacImod*. pBHG10-*PacImod* is a derivative of pBHG10 (Microbix; Toronto, Canada) and contains *PacI* and *SwaI* sites in the E3 region to facilitate directional cloning.

[0053] pBHG10 is a plasmid that contains the entire adenovirus type 5 genome minus bases 188 to 1,339 in the El region and bases 28,133 to 30,818 in the E3 region. Using wild-type Ad5

DNA as template, a 333 bp PCR product containing the ADP gene was generated. The following primer pair was used to generate the ADP PCR product:

5'-GATCGGATCCCCTGCTCCAGAGATGACCGGC.3'

5'-GATCAAGCTTGGAATCATGTCTCAMAATC-3'

[0054] The resulting 333 bp PCR product was digested with *BamHI* (GGATCC) + *HindIII* (AAGCTT) and cloned into *BamHI-HindIII* digested pCA14 (Microbix; Toronto, Canada) generating pCA14-ADP. The entire CMV-ADP-SV40 polyA expression cassette was generated by PCR using the following primer pair:

5'-GATCATTTAAATAATTCCCTGGCATTATGCCCAGTA-3'

5'-GATCTTAATTAATCGATGCTAGACGATCCAGACATG-3'

[0055] A *SwaI* restriction site (ATTTAAAT) was introduced upstream of the CMV promoter in the 5' primer and a *PacI* restriction site (TTAATTAA) was introduced downstream of the SV40 poly A region with the 3' primer. The PCR product was digested with *SwaI* and *PacI* and cloned into *SwaI-PacI* digested pBGH10-*PacImod* generating pBGH10-*PacImod*-CMV-ADP.

[0056] To generate Ad5-yCD/*mut*TK_{SR39}*rep*-ADP virus, pCA14-CMV-yCD/*mut*TK_{SR39}-E1aE1b (10 μg) was linearized by *PvuI* digestion and co-transfected with *ClaI*-linearized pBHG10-*PacImod*-CMV-ADP (30 μg) into HEK 293 cells (Microbix) using the $CaP0_4$-DNA precipitation method. Isolated plaques were harvested 7 - 14 days later and plaque-purified a second time on HEK 293 cells. Virus form twice purified plaques was used to infect HEK 293 cells to generate crude viral supernatants and CsCl gradient-purified adenovirus.

3. Advantage of the ADP gene contained in Ad5-yCD/*mut*TK_{SR39}*rep*-ADP *in vitro*

[0057] Human DU145 prostate adenocarcinoma cells were plated in a 24-well plate at a concentration of 5 x 10^4 cells/well and were infected with graded amounts of thee Ad5-CD/TK*rep* (lane 1) and Ad5-yCD/*mut*TK_{SR39}*rep*-ADP viruses (lane 2). Five days later, cells were fixed and stained with crystal violet. The results (as shown in Figure 2, "Vp" = viral particles) clearly demonstrate that replication-competent adenoviruses containing the Ad5 ADP gene and expressing the ADP protein (i.e. Ad5-yCD/*mut*TK_{SR39}*rep*-ADP) possess significantly greater oncolytic activity than adenoviruses that lack ADP. In other words, the presence of the Ad5 ADP gene significantly increased the oncolytic activity of replication competent

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adenoviruses. These results demonstrate, *in vitro*, the advantage of the ADP gene contained in Ad5-yCD/*mut*TK_{SR39}*rep*-ADP.

4. Advantage of the yCD/*mut*TK_{SR39} gene contained in Ad5-yCD/*mut*TK_{SR39}*rep*-ADP *in vitro*

A. CD Assays

[0058] LNCaP C4-2 cells were mock-infected (lanes 1 & 5), or infected with Ad5-CD/TK*rep* (lanes 2 & 6), Ad5-yCD/*mut*TK_{SR39}*rep*-ADP (lanes 3 & 7), Ad5-yCD/*mut*TK_{SR39} *rep*-hNIS (lanes 4 & 8) at a MOI of 10. Seventy two hours later, cells were examined for CD activity using [^{14}C]-cytosine (lanes 1-4) and [^{3}H]-5-FC (lanes 4-8) as substrates. The results are shown in Figure 3A [(Cytosine (lower left arrow), uracil (upper left arrow), 5-FC (upper right arrow), 5-FU (lower right arrow)]. As shown by Figure 3A, recombinant adenoviruses that express the improved yCD/*mut*TK_{SR39}*rep* gene, such as Ad5-yCD/*mut*TK_{SR39}*rep*-ADP, demonstrate greater conversion of 5-FC into 5-FU, but not cytosine into uracil, than viruses expressing the CD/HSV-1 TK fusion gene contained in the prototype Ad5-CD/TK*rep* virus.

B. Cytopathic Effect Assay

[0059] Cells (10^6 cells, 60 mm dish) were mock-infected or infected with Ad5-CD/TK*rep* or Ad5-yCD/*mut*TK_{SR39}*rep*-ADP at an MOI of 3. The next day, cells were replated (24 well plate) in medium containing varying concentrations of 5-FC (wells 3 - 7 and 15 - 19, going left to right, top to bottom) or GCV (wells 8 – 12 and 20 - 24, going left to right, top to bottom) in μg/ml. Cells were stained with crystal violet 9 days later. The results (as shown in Figure 3B) demonstrate that recombinant adenoviruses expressing the improved yCD/*mut*TK*rep* gene, such as Ad5-yCD/*mut*TK_{SR39}*rep*-ADP, achieve greater cell kill when combined with 5-FC prodrug therapy than viruses expressing the CD/HSV-1 TK fusion gene contained in the prototype Ad5-yCD/TK*rep* virus. Together, the results of Figures 3A and 3B show, *in vitro*, the advantage of the yCD/*mut*TK_{SR39} gene, which is contained in Ad5-yCD/*mut*TK_{SR39}*rep*-ADP.

[0060] The results of this example also demonstrate that yCD/5-FC and HSV-1 TK_{SR39}/GCV suicide gene therapies can be used to increase the therapeutic effect of the Ad5-yCD/*mut*TK_{SR39}*rep*-ADP virus itself. Ad5-yCD/*mut*TK_{SR39}*rep*-ADP contains a novel yCD/*mut*TK_{SR39} fusion gene whose product has improved catalytic activity relative to the

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CD/HSV-1 TK fusion protein produced by the prototype Ad5-CD/TK*rep* virus. Recombinant adenoviruses that express the improved yCD/*mut*TK_{SR39} fusion protein demonstrate significantly greater conversion of 5-FC into 5-FU, and possibly GCV into GCV-MP, than viruses that express the prototype CD/HSV-1- TK fusion protein. Thus, yCD/5-FC and HSV-1 TK_{SR39}/GCV suicide gene therapies can be used independently and together to augment the tumor destructive effects of the Ad5-yCD/*mut*TK_{SR39}*rep*-ADP virus.

5. Advantage of the ADP gene contained in Ad5-yCD/*mut*TK_{SR39}*rep*-ADP *in vivo*

[0061] Intramuscular (leg) C33A tumors (150 – 200 mm^3) were injected with 10^{10} vp of Ad5-CD/TK*rep* or Ad5-CD/TK*rep*-ADP on Days 0, 2 and 4 (arrowheads in Figure 4). 5-FC (500 mg/kg/day) and GCV (30 mg/kg/day) were administered on Days 5 – 11 (hatched bar in Figure 4). Tumor volume was monitored every other day. The predetermined endpoint was 500 mm^3. Survival is defined as an animal having no tumor (cure) or a tumor < 500 mm^3 on Day 90. The results (as shown in Figure 4 and Table 1 below) show greater destruction of tumor cells *in vivo* and thus demonstrate the advantage of the ADP gene, which is contained in Ad5-yCD/*mut*TK_{SR39}*rep*-ADP. In other words, the presence of the Ad5 ADP gene significantly increased the oncolytic activity of replication competent adenoviruses *in vivo* as well as *in vitro*.

Table 1. Summary of Results with Ad5-CD/TK*rep*-ADP in C33A Tumor Model.

Group	Median Survival	Tumor Care (%)	Pvalue	
			Log Rank (Survival)	Fisher Exact (Tumor Cure)
PBS	17	0(0/13)		
Ad5-CD/TK*rep*	26	0(0/12)		
Ad5-CD/TK*rep* + 5-FC + GCV	33	9(1/11)		
Ad5-CD/TK*rep*-ADP	>90	8(1/12)	0.022[b]	1.000[b]
Ad5-CD/TK*rep*-ADP + 5-FC + GCV	>90	70(7/10)	0.026[c]	.008[c]

[a]Median survival is in days.
[b]Ad5-CD/TK*rep*-ADP vs. Ad5-CD/TK*rep*
[c]Ad5-CD/TK*rep*-ADP + 5-FC + GCV vs. Ad5-CD/TK*rep* + 5-FC + GCV

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6. Effectiveness of Ad5-yCD/*mut*TK$_{SR39}$*rep*-ADP *in vivo* in Mouse Model

[0062] Male SCID mice bearing intraprostatic LNCaP C4-2 tumors (~25 - 50 mm^3 in size) were injected with about 10^9 vp of Ad5-yCD/*mut*TK$_{SR39}$*rep*-ADP on Day 0 (arrowhead in Figure. 5). 5-FC (500 mg/kg/day) and GCV (30 mg/kg/day) were administered on Days 3 - 9 (hatched bar in Figure 5). Serum PSA was measured weekly. The predetermined endpoint was PSA = 500 ng/ml. The results (as shown in Figure 5 and Table 2) show an increase in median survival time and/or tumor cure in mouse model using Ad5-yCD/*mut*TK$_{SR39}$*rep*-ADP of the present invention.

Table 2 - Results with Ad5-yCD/*mut*TK$_{SR39}$*rep*-ADP in LNCaP C4-2 Tumor Model.

Group	Median Survival (days)	Tumor cure (%)	P value	
			Log Rank (Survival)	Fisher Exact (Tumor Cure)
PBS	5	0 (0/8)		
Ad5-yCD/*mut*TK$_{SR39}$*rep*-ADP	17	0 (0/11)	.038[a]	NA[a]
Ad5-yCD/*mut*TK$_{SR39}$*rep*-ADP + 5-FC + GCV	> 90	80 (8/10)	<0.001[b]	<0.001[b]

[a]Ad5-yCD/*mut*TK$_{SR39}$*rep*-ADP vs. PBS;
[b]Ad5-yCD/*mut*TK$_{SR39}$*rep*-ADP + 5-FC + GCV vs. PBS.

7. Radiosensitized Human Cancer Cells using yCD/5-FC and HSV-1 TK$_{SR39}$/GCV

[0063] As shown in previous experiments by the inventors (see refs. 1-14), yCD/5-FC and HSV-1 TK$_{SR39}$/GCV suicide gene therapies can also be used to radiosensitize human cancer cells. Ad5-yCD/*mut*TK$_{SR39}$*rep*-ADP contains a novel yCD/*mut*TK$_{SR39}$ fusion gene whose product has improved catalytic activity relative to the CD/HSV-1 TK fusion protein produced by the prototype Ad5-CD/TK*rep* virus. The previous studies demonstrated that CD/5-FC and HSV-1 TK/GCV suicide gene therapies can sensitize human tumor cells to ionizing radiation. Thus, since Ad5-yCD/*mut*TK$_{SR39}$*rep*-ADP expresses an improved yCD/*mut*TK$_{SR39}$ fusion protein, it may result in greater tumor cell radiosensitization *in vivo*.

[0064] Throughout this application, various references are noted by reference numbers. A numbered list of these references with their full citations is provided below. The disclosures of these references in their entireties are hereby incorporated by reference into this application in order to more fully describe the state of the art to which this invention pertains.

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[0065] While the present invention has been particularly shown and described with reference to the foregoing preferred and alternative embodiments, and examples, it should be understood by those skilled in the art that various alternatives to the embodiments of the invention described herein may be employed in practicing the invention without departing from the spirit and scope of the invention as defined in the following claims. It is intended that the following claims define the scope of the invention and that the method and composition within the scope of these claims and their equivalents be covered thereby. This description of the invention should be understood to include all novel and non-obvious combinations of elements described herein, and claims may be presented in this or a later application to any novel and non-obvious combination of these elements. The foregoing embodiments are illustrative, and no single feature or element is essential to all possible combinations that may be claimed in this or a later application. Where the claims recite "a" or "a first" element of the equivalent thereof, such claims should be understood to include incorporation of one or more such elements, neither requiring nor excluding two or more such elements.

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Complete DNA Sequence of Ad5-yCD/*mut*TK$_{SR39}$*rep*-ADP Virus (SEQ. ID NO. 1)

TCCCTTCCAGCTCTCTGCCCCTTTGGATTGAAGCCAATATGATAATGAGGGGGTGGAGTTTGTGACGTGGCGCGGGGCGTGGGAACGG
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Partial DNA sequence of Ad5-yCD/*mut*TK_{SR39}*rep*-ADP (base 1 → 5100) (E1 Region)
(SEQ ID NO. 2)

yCD sequence is italicized; glycine polylinker is bolded; *mut*TK_{SR39} sequence is regular text; mutations in *mut*TK_{SR39} are indicated

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90        100
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190       200
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GGTGTACACAG

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290       300
GAAGTGACAATTTTCGCGCGGTTTTAGGCGGATGTTGTAGTAAATTTGGGCGTAACCGAGTAAGATTTGGCCATTTTCGCGGGAAAACT
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                                                    BglII/Bam HI
       310         320         330         340         350         360         370         380
390       400
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E1A

TATA

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490 500

ACTCGCCCAGGTGTTTTTCTCAGGTGTTTTCCGCGTTCCGGGTCAAAGTTGGCGTTTTATTATAGTCAGCTGACGTGTAGTGTATT

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+1 E1A mRNA E1A start

510 520 530 540 550 560 570 580

590 600

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ATCTGCCACGG

610 620 630 640 650 660 670 680

690 700

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710 720 730 740 750 760 770 780

790 800

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890 900

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E1A SD

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990   1000
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1090  1100
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                    E1A SD
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1190  1200
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                                  E1A SA
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1290  1300
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GCCTGCAAGAC

      1310      1320      1330      1340      1350      1360      1370      1380
1390  1400
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1490  1500
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E1A stop

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1590 1600
GAGGACTTGCTTAACGAGCCTGGGCAACCTTTGGACTTGAGCTGTAAACGCCCCAGGCCATAA GGTGTAAACCTGTGATTGCGTGTGTG
GTTAACGCCTT

E1A polyadenylation E1A mRNA 3' terminus

1610 1620 1630 1640 1650 1660 1670 1680
1690 1700
TGTTTGCTGAATGAGTTGATGTAAGTTTAATAAA GGGTGAGATAATGTTTA ACTTGCATGGCGTGTTAAATGGGGCGGGGCTTAAAGGG
TATATAATGCG

+1 E1B mRNA 19 kDa E1B start

1710 1720 1730 1740 1750 1760 1770 1780
1790 1800
CCGTGGGCTAATCTTGGTTA CATCTGACCTCATG GAGGCTTGGGAGTGTTTGGAAGATTTTTCTGCTGTGCGTAACTTGCTGGAACAGA
GCTCTAACAGT

1810 1820 1830 1840 1850 1860 1870 1880
1890 1900
ACCTCTTGGTTTTGGAGGTTTCTGTGGGGCTCATCCCAGGCAAAGTTAGTCTGCAGAATTAAGGAGGATTACAAGTGGGAATTTGAAGA
GCTTTTGAAAT

1910 1920 1930 1940 1950 1960 1970 1980
1990 2000
CCTGTGGTGAGCTGTTTGATTCTTTGAATCTGGGTCACCAGGCGCTTTTCCAAGAGAAGGTCATCAAGACTTTGGATTTTTCCACACCG
GGGCGCGCTGC

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55 kDa E1B start

2010 2020 2030 2040 2050 2060 2070 2080

2090 2100

GGCTGCTGTTGCTTTTTTGAGTTTTATAAAGGATAAATG GAGCGAAGAAACCCATCTGAGCGGGGGGGTACCTGCTGGATTTTCTGGCCA

TGCATCTGTGG

2110 2120 2130 2140 2150 2160 2170 2180

2190 2200

AGAGCGGTTGTGAGACACAAGAATCGCCTGCTACTGTTGTCTTCCGTCCCGCCGGCGATAATACCGACGGAGGAGCAGCAGGCAGCA

GGAGGAAGCCA

55 kDa premature

stops

19 kDa E1B stop

BglII

2210 2220 2230 2240 2250 2260 2270 2280

2290 2300

GGCGGCGGCGGCAGGAGCAGAGCCCATGGAACCCGAGAGCCGGCCTGGACCCTCGGGAATGA ATGTTGTATAGGTGGCTTAACTGTATA

GATCTAATTCC

2310 2320 2330 2340 2350 2360 2370 2380

2390 2400

CTGGCATTATGCCCAGTACATGACCTTATGGGACTTTCCTACTTGGCAGTACATCTACGTATTAGTCATCGCTATTACCATGGTGATGC

GGTTTTGGCAG

2410 2420 2430 2440 2450 2460 2470 2480

2490 2500

TACATCAATGGGCGTGGATAGCGGTTTGACTCACGGGGATTTCCAAGTCTCCACCCCATTGACGTCAATGGGAGTTTGTTTTGGCACCA

AAATCAACGGG

CMV TATA

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```
      2510        2520        2530        2540        2550        2560        2570        2580
2590        2600
ACTTTCCAAAATGTCGTAACAACTCCGCCCCATTGACGCAAATGGGCGGTAGGCGTGTACGGTGGGAGGTCTATATAA GCAGAGCTCGT
TTAGTGAACCG

+1                                                                                      CMV
BamHI XhoI
      2610        2620        2630        2640        2650        2660        2670        2680
2690        2700
TCAGATCGCCTGGAGACGCCATCCACGCTGTTTTGACCTCCATAGAAGACACCGGGACCGATCCAGCCTGGGGATCTTCGAGTCGAGGG
ATCCCTCGAGC

   CD start
      2710        2720        2730        2740        2750        2760        2770        2780
2790        2800
CACCATGGGACAGGGGAATGGCAAGCAAGTGGATCAGAAGGGTATGGACATTGCCTATGAGGAGGCGGCCTTAGGTTACAAAGAGG
GTGGTGTTCCT

      2810        2820        2830        2840        2850        2860        2870        2880
2890        2900
ATTGGCGGATGTCTTATCAATAACAAAGACGGAAGTGTTCTCGGTCGTGGTCACAACATGAGATTTCAAAAGGGATCCGCCACACTACA
TGGTGAGATCT

      2910        2920        2930        2940        2950        2960        2970        2980
2990        3000
CCACTTTGGAAAACTGTGGGAGATTAGAGGGCAAAGTGTACAAAGATACCACACTTTGTATACGACGCTGTCTCCATGCGACATGTGTACA
GGTGCCATCAT
```

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      3010      3020      3030      3040      3050      3060      3070      3080
3090      3100
CATGTATGGTATTCCACGCCTGTGTTGTCGGTGAGAACGTTAATTTCAAAAGTAAGGGCGAGAAATATTTACAAACTAGAGGTCACGAGG
TTGTTGTTGTT

                                                                  end  of  yCD
polylinker
      3110      3120      3130      3140      3150      3160      3170      3180
3190      3200
GACGATGAGAGGTGTAAAAAGATCATGAAACAATTTATCGATGAAAGACCTCAGGATTGGTTTGAAGATATTGGTGAGGGTGGAGGGGG
AGGCGGTGGGG

   NheI  TK start
      3210      3220      3230      3240      3250      3260      3270      3280
3290      3300
GAGGTGCTAGCATGGCTTCGTACCCCTGCCATCAACACGCGTCTGCGTTCGACCAGGCTGCGCGTTCTCGCGGCCATAGCAACCGACGT
ACGGCGTTGCG

      3310      3320      3330      3340      3350      3360      3370      3380
3390      3400
CCCTCGCCGGCAGCAAGAAGCCACGGAAGTCCGCCTGGAGCAGAAAATGCCCACGCTACTGCGGGTTTATATAGACGGTCCTCACGGGA
TGGGGAAAACC

      3410      3420      3430      3440      3450      3460      3470      3480
3490      3500
ACCACCACGCAACTGCTGGTGGCCCTGGGTTCGCGCGACGATATCGTCTACGTACCCGAGCCGATGACTTACTGGCAGGTGCTGGGGGC
TTCCGAGACAA

      3510      3520      3530      3540      3550      3560      3570      3580
3590      3600
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TCGCGAACATCTACACCACACAACACCGCCTCGACCAGGGTGAGATATCGGCCGGGGACGCGGCGGTGGTAATGACAAGCGCCCAGATA
ACAATGGGCAT

                                                                                mutTKSR39
mutations
      3610      3620      3630      3640      3650      3660      3670      3680      3690      3700
GCCTTATGCCGTGACCGACGCCGTTCTGGCTCCTCATGTCGGGGGGGAGGCTGGGAGTTCACATGCCCCGCCCCCGGCCCTCACCA_TCT
TCCTCGACCGC

          mutTKSR39 mutations
      3710      3720      3730      3740      3750      3760      3770      3780      3790      3800
CATCCCATCGCCTTCATGCTGTGCTACCCGGCCGCGCGGTACCTTATGGGCAGCATGACCCCCCAGGCCGTGCTGGCGTTCGTGGCCCT
CATCCCGCCGA

      3810      3820      3830      3840      3850      3860      3870      3880      3890      3900
CCTTGCCCGGCACAAACATCGTGTTGGGGCCCTTCCGGAGGACAGACACATCGACCGCCTGGCCAAACGCCAGCGCCCCGGCGAGCGG
CTTGACCTGGC

      3910      3920      3930      3940      3950      3960      3970      3980      3990      4000
TATGCTGGCCGCGATTCGCCGCGTTTACGGGCTGCTTGCCAATACGGTGCGGTATCTGCAGGGCGGCGGGTCGTGGTGGAGGATTGGG
GACAGCTTTCG

      4010      4020      4030      4040      4050      4060      4070      4080      4090      4100
GGGACGGCCGTGCCGCCCCAGGGTGCCGAGCCCCAGAGCAACGCGGGCCCACGACCCCATATCGGGACACGTTATTTACCCTGTTTCG
GGCCCCCGAGT
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                                                                    4110        4120        4130        4140        4150        4160        4170        4180
4190        4200
TGCTGGCCCCCCAACGGCGACCCTGTATAACGTGTTTGCCTGGGCCTTGGACGTCTTGGCCAAACGCCTCCGTCCCATGCACGTCTTTATC
CTGGATTACGA

                                                                    4210        4220        4230        4240        4250        4260        4270        4280
4290        4300
CCAATCGCCCGCCGGCTGCCGGGACGCCCTGCTGCAACTTACCTCCGGGATGGTCCAGACCCACGTCACCACCCCAGGCTCCATACCGA
CGATCTGCGAC

                                                                                TK stop     EcoRI Hind III
                                                                    4310        4320        4330        4340        4350        4360        4370        4380
4390        4400
CTGGCGCGCACGTTTGCCCGGGAGATGGGGGAGGCTAACTGA AACACGGAAGAATTCAAGCTT GTCGACTTCGAGCAACTTGTTTATTG
CAGCTTATAAT

                                                                    SV40 polyadenylation SV40 3' terminus
                                                                    4410        4420        4430        4440        4450        4460        4470        4480
4490        4500
GGTTACAAATAAAGCAATAGCATCACAAATTTCACAAATAAAGCATTTTTTTCACTGCATTCTAGTTGTGGTTTGTCCAAACTCATCAA
TGTATCTTATC

                                                                    BglII BamHI/Bgl II
                                                                    4510        4520        4530        4540        4550        4560        4570        4580
4590        4600
ATGTCTGGATCGTCTAGCATCGAAGATCTGGATCT GGGCGTGGTTAAGGGTGGGAAAGAATATATAAGGTGGGGGTCTTATGTAGTTTT
GTATCTGTTTT

E1B SA
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```
    4610      4620      4630      4640      4650      4660      4670      4680
4690      4700
GCAGCAGCCGCCGCCATGAGCACCAACTCGTTTGATGGAAGCATTGTGAGCTCATATTTGACAACGCGCATGCCCCCATGGGCCGG
GGTGCGTCAGA

    4710      4720      4730      4740      4750      4760      4770      4780
4790      4800
ATGTGATGGGCTCCAGCATTGATGGTCGCCCCGTCCTGCCCGCAAACTCTACTACCTTGACCTACGAGACCGTGTCTGGAACGCCGTTG
GAGACTGCAGC

    4810      4820      4830      4840      4850      4860      4870      4880
4890      4900
CTCCGCCGCCGCTTCAGCCGCTGCAGCCACCGCCCGCGGGATTGTGACTGACTTTGCTTCCTGAGCCCGCTTGCAAGCAGTGCAGCTT
CCCGTTCATCC

    4910      4920      4930      4940      4950      4960      4970      4980
4990      5000
GCCCGCGATGACAAGTTGACGGCTCTCTTTGGCACAATTGGATTCTTTGACCCGGGAACTTAATGTCGTTTCTCAGCAGCTGTTGGATCT
GCGCCAGCAGG

                                    E1B polyadenylation                 E1B mRNA
3' terminus
    5010      5020      5030      5040      5050      5060      5070      5080
5090      5100
TTTCTGCCCTGAAGGCTTCCTCCCCCTCCCAATGCGGTTTAAAACATAAATAAA AAACCAGACTCTGTTTGGATTTGGATCA AGCAAGTG
TCTTGCTGTCT
```

Partial DNA sequence of Ad5-yCD/*mut*TK_{SR39}*rep*-ADP (base 29,163 → 30,079) (E3 Region)
(SEQ ID NO. 3)

ADP sequence is bolded

*Swa*I

```
        10          20          30          40          50          60          70          80
90       100
ATTTAAATAATTCCCTGGCATTATGCCCAGTACATGACCTTATGGGACTTTCCTACTTGGCAGTACATCTACGTATTAGTCATCGCTAT
TACCATGGTGA

       110         120         130         140         150         160         170         180
190       200
TGCGGTTTTGGCAGTACATCAATGGGCGTGGATAGCGGTTTGACTCACGGGGATTTCCAAGTCTCCACCCCATTGACGTCAATGGGAGT
TTGTTTTGGCA

CMV TATA
       210         220         230         240         250         260         270         280
290       300
CCAAAATCAACGGGACTTTCCAAAATGTCGTAACAACTCCGCCCCATTGACGCAAATGGGCGGTAGGCGTGTACGGTGGGAGGTCTATA
TAAGCAGAGCT

              +1 CMV
       310         320         330         340         350         360         370         380
390       400
CGTTTAGTGAACCGTCAGATCGCCTGGAGACGCCATCCACGCTGTTTTGACCTCCATAGAAGACACCGGGACCGATCCAGCCTGGGGAT
CAGTCTTCGAG
```


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BamHI ADP start

410 420 430 440 450 460 470 480

490 500

TCGAGGATCCCCTGCTCCAGAGATGACCGGCTCAACCATCGCGCCCACAACGGACTATCGCAACACCACTGCTACCGGACTAACATCTG

CCCTAAATTTA

510 520 530 540 550 560 570 580

590 600

CCCCAAGTTCATGCCTTTGTCAATGACTGGGCGAGCTTGGACATGTGGTGGTTTTCCATAGCGCTTATGTTTGTTTGCCTTATTATTAT

GTGGCTTATTT

610 620 630 640 650 660 670 680

690 700

GTTGCCTAAAGGCGCAGACGCGCCAGACCCCCCATCTATAGGCCTATCATTGTGCTCAACCCACACAATGAAAAAATTCATAGATTGGAC

GGTCTGAAACC

ADP stop HindIII

SV40 poly A

710 720 730 740 750 760 770 780

790 800

ATGTTCTCTTCTTTTTACAGTATGATTAAATGAGACATGATTCCAAGCTT GTCGACTTCGAGCAACTTGTTTATTGCAGCTTATAATGGT

TACAAATAAAG

SV40 3' terminus

810 820 830 840 850 860 870 880

890 900

CAATAGCATCACAAATTTCACAAATAAAGCATTTTTTTCACTGCATTCTAGTTGTGGTTTGTCCAAACTCATCAATGTATCTTATCATG

TCTGGATCGTC

PacI

910

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TAGCATCGATTAATTAA

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DNA Sequence and Translation of yCD/*mut*TK$_{SR39}$ Fusion Gene (SEQ ID NO. 4)

yCD sequence is italicized; glycine polylinker is bolded; *mut*TK$_{SR39}$ sequence is regular text; mutations in *mut*TK$_{SR39}$ are indicated

```
                                                                  10                  20                  30
                M  G  T  G  G  M  A  S  K  W  D  Q  K  G  M  D  I  A  Y  E  E  A  A  L  G  Y  K  E  G  G  G
ATGGGGACAGGGGGAATGGCAAGCAAGTGGGATCAGAAGGGTATGGACATTGCCTATGAGGAGGCGGCCTTAGGTTACAAAGAGGGTGG
T
          10                  20                  30                  40                  50                  60                  70                  80
90

                                                                  40                  50                  60
                V  P  I  G  G  C  L  I  N  N  K  D  G  S  V  L  G  R  G  H  N  M  R  F  Q  K  G  S  A  T
GTTCCTATTGGCGGATGTCTTATCAATAACAAAGACGGAAGTGTTCTCGGTCGTGGTCACAACATGAGATTTCAAAGGGATCCGCCAC
A
          100                 110                 120                 130                 140                 150                 160                 170
180

                                                                  70                  80                  90
                L  H  G  E  I  S  T  L  E  N  C  G  R  L  E  G  K  V  Y  K  D  T  T  L  Y  T  T  L  S  P
CTACATGGTGAGATCTCCACTTTGGAAAACTGTGGGAGATTAGAGGGCAAAGTGTACAAAGATACCACTTTGTATACGACGCTGTCTCC
A
          190                 200                 210                 220                 230                 240                 250                 260
270

                                                                 100                 110                 120
                C  D  M  C  T  G  A  I  I  M  Y  G  I  P  R  C  V  V  G  E  N  V  N  F  K  S  K  G  E  K
TGCGACATGTGTACAGGTGCCATCATGTATGGTATTCCACGCTGTGTTGTCGGTGAGAACGTTAATTTCAAAAGTAAGGGCGAGAA
A
          280                 290                 300                 310                 320                 330                 340                 350
360
```

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```
                                                                  130
  Y  L  Q  T  R  G  H  E  V  V  V  V  D  D  E  R  C  K  K  I  M  K  Q  F  I  D  E  R  P  Q
TATTTACAAACTAGAGGTCACGAGGTTGTTGTTGACGATGAGAGGTGTAAAAAGATCATGAAACAATTTATCGATGAAAGACCTCA
G
      370        380        390        400        410        420        430        440
450
                                                                  160
  D  W  F  E  D  I  G  E  G  G  G  G  G  G  G  G  A  S  M  A  S  Y  P  C  H  Q  H  A  S
GATTGGTTTTGAAGATATTGGTGAGGGTGGGGAGGCGGTGGGGGAGGTGCTAGCATG GCTTCGTACCCCTGCCATCAACACGCGTC
T
      460        470        480        490        500        510        520        530
540
                                                                  190
  A  F  D  Q  A  A  R  S  R  G  H  S  N  R  R  T  A  L  R  P  R  R  Q  Q  E  A  T  E  V  R
GCGTTCGACCAGGCTGCGCGTTCTCGCGGCCATAGCAACCGACGTACGGCGTTGCGCCCTCGCCGGCAGCAAGAAGCCACGGAAGTCCG
C
      550        560        570        580        590        600        610        620
630
                                                                  220
  L  E  Q  K  M  P  T  L  L  R  V  Y  Y  I  D  G  P  H  G  M  G  K  T  T  T  T  Q  L  L  V  A
CTGGAGCAGAAAATGCCCACGCTACTGCGGGTTTATATAGACGGTCCTCACGGGATGGGGAAAACCACCACGCAACTGCTGGTGGC
C
      640        650        660        670        680        690        700        710
720
                                                                  250
  L  G  S  R  D  D  I  V  Y  V  P  E  P  M  T  Y  W  Q  V  L  G  A  S  E  T  I  A  N  I  Y
CTGGGTTCGCGCGACGATATCGTCTACGTACCCGAGCCGATGACTTACTGGCAGGTGCTGGGGGCTTCCGAGACAATCGCGAACATCTA
C
```

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```
      730       740       750       760       770       780       790       800
810
                                  280                                       290                                       300
  T T Q H R L D Q G E I S A G D A A V V M T S A Q I T M G M P
ACCACACAACACCGCCTCGACCAGGGTGAGATATCGGCCGGGACGCGGCGGTGGTAATGACAAGCGCCCAGATAACAATGGCATGCC
T
      820       830       840       850       860       870       880       890
900
                                  310                                       320                                       330
WT HSV-1 TK                                                                                                   L I F
WT HSV-1 TK                                                                                                   C A T
  Y A V T D A V L A P H V G G E A G S S H A P P P A L T I F L
TATGCCGTGACCGACGCCGTTCTGGCTCCTCATGTCGGGGGGAGGCTGGGAGTTCACATGCCCCGGCCCCTCACCA_TCTTCCT
C
      910       920       930       940       950       960       970       980
990
                                  340                                       350                                       360
WT HSV-1 TK         A L
WT HSV-1 TK         GC C C
  D R H P I A F M L C Y P A A R Y L M G S M T P Q A V L A F V
GACCGCCATCCCATCGCCTTCATGCTGTGCTACCCGGCCGCGGTACCTTATGGGCAGCATGACCCCCCAGGCCGTGCTGGCGTTCGT
G
      1000      1010      1020      1030      1040      1050      1060      1070
1080
                                  370                                       380                                       390
  A L I P P T L P G T N I V L G A L P E D R H I D R L A K R Q
GCCCTCATCCCGCCGACCTTGCCCGGCACAAACATCGTGTTGGGGGCCCTTCCGGAGGACAGACACATCGACCGCCTGGCCAAACGCCA
G
```

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```
    1090        1100        1110        1120        1130        1140        1150        1160
1170

                                  400                 410                 420
  R  P  G  E  R  L  D  L  A  M  L  A  A  I  R  R  V  Y  G  L  L  A  N  T  V  R  Y  L  Q  G
CGCCCCGGCGAGCGGCTTGACCTGGCTATGCTGGCCGCGATTCGCCGCGTTTACGGGCTGCTTGCCAATACGGTGCGGTATCTGCAGGG
C

    1180        1190        1200        1210        1220        1230        1240        1250
1260

                                  430                 440                 450
  G  G  S  W  W  E  D  W  G  Q  L  S  G  T  A  V  P  P  Q  G  A  E  P  Q  S  N  A  G  P  R
GGCGGGTCGTGGTGGGAGGATTGGGGACAGCTTTCGGGGACGGCCGTGCCGCCCCAGGGTGCCGAGCCCCAGAGCAACGCGGGCCCACG
A

    1270        1280        1290        1300        1310        1320        1330        134C
1350

                                  460                 470                 480
  P  H  I  G  D  T  L  F  T  L  F  R  A  P  E  L  L  A  P  N  G  D  L  Y  N  V  F  A  W  A
CCCCATATCGGGGACACGTTATTTACCCTGTTTCGGGCCCCCGAGTTGCTGGCCCCCAACGGCGACCTGTATAACGTGTTTGCCTGGGC
C

    1360        1370        1380        1390        1400        1410        1420        1430
1440

                                  490                 500                 510
  L  D  V  L  A  K  R  L  R  R  M  H  V  E  L  L  D  Y  D  Q  S  P  A  G  C  R  D  A  L  L
TTGGACGTCTTGGCCAAACGCCTCCGTCCCATGCACGTCTTTATCCTGGATTACGACCAATCGCCCGCCGGCTGCCGGGACGCCCTGCT
G

    1450        1460        1470        1480        1490        1500        1510        1520
1530
```

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```
                                                                  520
                                                                  530                                                 540
 Q  L  T  S  G  M  V  Q  T  H  V  T  T  P  G  S  I  P  T  I  C  D  L  A  R  T  F  A  R  E
CAACTTACCTCCGGGATGGTCCAGACCCACGTCACCACCCCAGGCTCCATACCGACGATCTGCGACCTGGCGCGCACGTTTGCCCGGGA
G
      1540        1550        1560        1570        1580        1590        1600        1610        1620

                  545
 M  G  E  A  N
ATGGGGGAGGCTAAC
      1630
```

DNA Sequence and Translation of ADP gene (SEQ ID NO. 5)

```
                                10                                  20                                  30
 M  T  G  S  T  I  A  P  T  T  D  Y  R  N  T  T  A  T  G  L  T  S  A  L  N  L  P  Q  V  H
ATGACCGGCTCAACCATCGCGCCCACAACGGACTATCGCAACACCACTGCTACCGGACTAACATCTGCCCTAAATTTACCCCAAGTTCA
T
        10          20          30          40          50          60          70          80
90

                                40                                  50                                  60
 A  F  V  N  D  W  A  S  L  D  M  W  W  F  S  I  A  L  M  F  V  C  L  I  I  M  W  L  I  C
GCCTTTGTCAATGACTGGGCGAGCTTGGACATGTGGTGGTTTTCCATAGCGCTTATGTTTGTTTGCCTTATTATTATGTGGCTTATTTG
T
        100         110         120         130         140         150         160         170
180

                                70                                  80                                  90
 C  L  A  R  R  R  A  R  P  P  I  Y  R  P  I  I  V  L  N  P  H  N  E  K  I  H  R  L  D  G
TGCCTAAAGCGCAGACGCGCCAGACCCCCCATCTATAGGCCTATCATTGTGCTCAACCCACACAATGAAAAAATTCATAGATTGGACGG
T
        190         200         210         220         230         240         250         260
270

                                100
 L  K  P  C  S  L  L  L  Q  Y  D
CTGAAACCATGTTCTCTTCTTTTACAGTATGAT
        280         290         300
```


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CLAIMS

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1. An isolated polynucleotide comprising a nucleotide sequence of a yeast cytosine deaminase/mutant SR 39 herpes simplex virus type 1 thymidine kinase fusion gene.

2. An isolated polypeptide comprising an amino acid sequence encoded by the polynucleotide of claim 1, which converts prodrugs, 5 fluorocytosine and ganciclovir, into active chemotherapeutic agents.

3. A recombinant adenovirus comprising the polynucleotide according to claim 1.

4. The recombinant adenovirus according to claim 3, further comprising an adenovirus type 5 adenovirus death protein gene.

5. The recombinant adenovirus according to claim 3, wherein the adenovirus is a replication-competent, type 5 adenovirus.

6. The polynucleotide according to claim 1, further comprising an adenovirus type 5 adenovirus death protein gene.

7. The polynucleotide according to claim 1, which comprises the nucleotide sequence of SEQ ID NO. 4.

8. The recombinant adenovirus according to claim 4, wherein the adenovirus type 5 adenovirus death protein gene comprises the nucleotide sequence of SEQ ID NO. 5.

9. The isolated polypeptide according to claim 2, which comprises an amino acid sequence of SEQ ID NO. 4.

10. The recombinant adenovirus according to claim 4, which comprises the nucleotide sequence of SEQ ID NO. 1.

11. A pharmaceutical composition comprising the recombinant adenovirus according to claim 3 or claim 4, and a pharmaceutically acceptable carrier.

12. The pharmaceutical composition according to claim 11, wherein the pharmaceutical composition is administered locally to a tumor site.

13. The pharmaceutical composition according to claim 11, wherein the pharmaceutical composition is administered by direct injection to a tumor.

14. The pharmaceutical composition according to claim 11, wherein the pharmaceutical composition is administered by intravenous injection.

15. The pharmaceutical composition according to claim 11, wherein the pharmaceutical composition is administered at two or more separate times.

16. A pharmaceutical composition comprising

(i) the first pharmaceutical composition according to claim 11; and
(ii) the second pharmaceutical composition comprising one or more ingredients selected from the group consisting of (a) 5-fluorocytosine, (b) ganciclovir and (c) derivatives thereof,

wherein the first pharmaceutical composition is administered before administration of the second pharmaceutical composition.

17. The pharmaceutical composition according to claim 16, wherein the first pharmaceutical composition and the second pharmaceutical composition are administered before radiation therapy.

18. A method of converting 5 fluorocytosine and/or ganciclovir into active chemotherapeutic agents comprising contacting the polypeptide according to claim 2 with 5 fluorocytosine and/or ganciclovir.