



(86) Date de dépôt PCT/PCT Filing Date: 2005/10/26

(87) Date publication PCT/PCT Publication Date: 2006/05/11

(45) Date de délivrance/Issue Date: 2014/05/13

(85) Entrée phase nationale/National Entry: 2007/04/19

(86) N° demande PCT/PCT Application No.: IB 2005/003435

(87) N° publication PCT/PCT Publication No.: 2006/048768

(30) Priorités/Priorities: 2004/11/08 (EP04360101.2);
2005/01/26 (US60/646,595)

(51) Cl.Int./Int.Cl. *C07K 14/47* (2006.01),
A61K 31/7052 (2006.01), *A61K 48/00* (2006.01),
A61P 31/12 (2006.01), *A61P 35/00* (2006.01),
C12N 15/861 (2006.01)

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(54) Titre : PEARMEASE ET GENES SUICIDE POUR UN TRAITEMENT ANTITUMORAL OU ANTIVIRAL

(54) Title: PEARMEASE AND SUICIDE GENES FOR ANTITUMORAL OR ANTIVIRAL TREATMENT

(57) **Abrégé/Abstract:**

The present invention relates to a kit of parts comprising a nucleic acid sequence encoding a permease and a drug comprising one nucleobase moiety or a precursor thereof. The present invention further relates to a kit of parts comprising a precursor of a drug comprising a gene coding a permease and a nucleic acid sequence comprising a suicide gene. The present invention also relates to a vector comprising a gene coding a permease and a suicide gene.

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

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
11 May 2006 (11.05.2006)

PCT

(10) International Publication Number
WO 2006/048768 A3

(51) International Patent Classification:

C07K 14/47 (2006.01) **A61P 31/12** (2006.01)
C12N 15/861 (2006.01) **A61K 31/7052** (2006.01)
A61P 35/00 (2006.01) **A61K 48/00** (2006.01)

(21) International Application Number:

PCT/IB2005/003435

(22) International Filing Date: 26 October 2005 (26.10.2005)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

04360101.2 8 November 2004 (08.11.2004) EP
60/646,595 26 January 2005 (26.01.2005) US

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM,

AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declaration under Rule 4.17:

— of inventorship (Rule 4.17(iv))

Published:

— with international search report
— before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments

(88) Date of publication of the international search report:

3 August 2006

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: KIT OF PARTS DESIGNED FOR IMPLEMENTING AN ANTITUMORAL OR ANTIVIAL TREATMENT IN A MAMMAL

(57) Abstract: The present invention relates to a kit of parts comprising a nucleic acid sequence encoding a permease and a drug comprising one nucleobase moiety or a precursor thereof. The present invention further relates to a kit of parts comprising a precursor of a drug comprising a gene coding a permease and a nucleic acid sequence comprising a suicide gene. The present invention also relates to a vector comprising a gene coding a permease and a suicide gene.



WO 2006/048768 A3

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CECI EST LE TOME 1 DE 2
CONTENANT LES PAGES 1 À 31

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NOTE: For additional volumes, please contact the Canadian Patent Office

NOM DU FICHER / FILE NAME :

NOTE POUR LE TOME / VOLUME NOTE:

Permease and suicide genes for antitumoral or antiviral treatment

The present invention relates to a kit of parts comprising a nucleic acid sequence encoding a permease and a drug comprising one nucleobase moiety or a precursor thereof. The present invention further relates to a kit of parts comprising a precursor of a drug comprising one nucleobase moiety, a nucleic acid sequence comprising a gene coding a permease and a nucleic acid sequence comprising a suicide gene. The present invention also relates to a vector comprising a gene coding a permease and a suicide gene. The present invention is particularly useful in the context of carrying out a gene therapy treatment of proliferative or infectious diseases.

Drugs comprising one nucleobase moiety are the most widely used drugs for the treatment of cancer or viral infection. Among them nucleoside analogues such as cytarabine, gemcitabine, fludarabine, cladribine, troxacitabine and clofarabine are currently used in cancer chemotherapy. Nucleoside analogues are antimetabolites which interfere with nucleic acid synthesis. These agents are generally S-phase specific, and can exert cytotoxic activity either by being incorporated and altering the DNA and RNA macromolecules themselves, and/or by interfering with various enzymes involved in nucleic acid synthesis, and/or by modifying the metabolism of physiologic nucleosides.

Nucleoside analogues were also among the first compounds shown to be effective against viral infections. For example, the first four anti-HIV drugs to be approved, AZT, ddI, ddC and D4T; were nucleoside analogues. All four of these drugs and other nucleoside analogues are believed to have a similar mechanism of HIV inhibition, in which the nucleosides are progressively phosphorylated to a 5'-triphosphate, which then acts as a chain terminator in a reverse transcriptase (RT) reaction.

Nucleobase analogues are also used in the treatment of cancer. For example fluorouracil (5-FU) is a fluorinated pyrimidine that is metabolized intracellularly to its active form, fluorodeoxyuridine monophosphate (FdUMP). The active form inhibits DNA synthesis by inhibiting the normal production of thymidine. Fluorouracil is given intravenously to treat colon, rectum, breast, stomach, and pancreas cancers. Fluorouracil is also available in creams and solutions for topical treatment of some skin cancers and genital warts.

The development of gene therapy has opened new possibilities for the use of drug comprising one nucleobase moiety. This particular domain of gene therapy which is called "suicide gene therapy" uses genes whose expression products are able to transform an inactive substance (a prodrug) into a cytotoxic substance, thereby giving rise to cell death.

The gene encoding the herpes simplex type 1 virus thymidine kinase (HSV-1 TK) constitutes the prototype of the suicide genes (Caruso et al., 1993, Proc. Natl. Acad. Sci. USA 90, 7024-7028; Culver et al., 1992, Science 256, 1550-1552; Ram et al., 1997, Nat. Med. 3, 1354-1361). While the TK polypeptide is not toxic as such, it catalyzes the transformation of nucleoside analogues such as acyclovir or ganciclovir (GCV). The modified nucleosides are incorporated into the DNA chains which are in the process of elongation, inhibiting cell division as a consequence. A large number of suicide gene/prodrug pairs are currently available. Those which may more specifically be mentioned Escherichia coli (E. Coli) purine nucleoside phosphorylase and 6-methylpurine deoxyribonucleoside (Sorscher et al., 1994, Gene Therapy 1, 223-238), E. coli guanine phosphoribosyl transferase and 6-thioxanthine (Mzoz and Moolten, 1993, Human Gene Therapy 4, 589-595) and cytosine deaminase (CDase) and 5-fluorocytosine (5FC).

In human, the transport of drugs comprising one nucleobase moiety across the cell membrane is passive or made by dedicated membraneous

transporter. For example, most of the nucleoside analogues are hydrophilic molecules and their transport through the cell membrane is regulated by membrane transporter. In mammalian cells, there are two major nucleoside transporter gene families: the equilibrative nucleoside 5 transporters (ENTs) and the concentrative nucleoside transporters (CNTs). The ENTs are facilitated carrier proteins and the CNTs are Na(+)-dependent secondary active transporters (Kong et al., 2004, Curr Drug Metab, 5,:63-84) The nucleoside transporters are implicated in resistance to anticancer nucleoside analogues. A single nucleotide polymorphisms 10 (SNPs) in drug transporters may contribute to interindividual variation in response to nucleoside analogues (Damaraju et al., Oncogene. 2003, 22: 7524-36). Therefore, there is need for a new therapeutic strategy which can circumvent a low or non-existent expression of the nucleoside transporters. Moreover, there is also a need to enhance the intracellular 15 concentration of drugs comprising one nucleobase moiety as the intracellular concentration is correlated with the therapeutic efficiency.

One of the goals of the present invention is to improve the intracellular concentration of drugs comprising one nucleobase moiety into cells (e.g. tumoral cells or virally infected cells). This goal is achieved by 20 the transfection of the target cells by a nucleic acid sequence comprising a gene coding a permease.

The present invention also aims to improve the efficacy of suicide gene therapy, by using in combination a nucleic acid sequence comprising a gene coding a permease and a nucleic acid sequence comprising a 25 suicide gene. This particular use improves the intracellular concentration of the prodrug (i.e. the precursor of a drug comprising a nucleobase moiety) which can be converted by the protein encoded by the suicide gene. This use may also improve the bystander effect by enhancing the transfer of the drug from the cells transfected by the suicide gene to the 30 cells expressing the permease.

With this respect, the present invention also allows to use lower amount of drugs or prodrugs and to reduce the side effects induced by such treatments.

For this purpose, the present invention provides a kit of parts 5 comprising:

- a drug comprising one nucleobase moiety or a precursor thereof, and
- a nucleic acid sequence comprising a gene coding a permease.

10 According to another embodiment, the present invention also provides a kit of parts comprising:

- a precursor of a drug comprising one nucleobase moiety, and
- a nucleic acid sequence comprising a gene coding a permease, and
- 15 - a nucleic acid sequence comprising a suicide gene.

In a preferred embodiment, the kit of parts according to the invention is intended to be used for the treatment of cancer and/or viral diseases in vertebrates and more particularly in humans.

As used herein a drug comprising one nucleobase moiety is a 20 molecule which comprise in its structure only one nucleobase moiety. According to a preferred embodiment of the invention, the drug comprising one nucleobase moiety is able to kill cells and more preferably to kill tumoral cells. According to another preferred embodiment, the drug comprising one nucleobase moiety is able to reduce or prevent the 25 replication of a virus in a cell.

According to the invention a nucleobase moiety is chosen from the group consisting in Adenine, Thymine, Guanine, Uracil, Cytosine and analogues thereof.

According to a preferred embodiment of the invention, a drug 30 comprising one nucleobase moiety is chosen from the group comprising :

- nucleoside analogues such as cytarabine, gemcitabine, capecitabine, fludarcibine, cladribine, troxacitabine, clofarabine, azidothymidine (AZT), didanosine (ddI), zalcitabine (ddC), stavudine (d4T), fluoromethylene deoxycytidine (FMdC) and lamivudine, floxuridine (FUdR) and
- Pyrimidine analogues such as 5-fluorouracil (5-FU), and
- Purine analogues such as thioguanine, mercaptopurine, acyclovir, valacyclovir, famcyclovir, ganciclovir.

As used herein, a precursor of a drug comprising one nucleobase moiety refers to a molecule which can be converted by one or more enzymatic reaction into a drug comprising one nucleobase moiety.

According to a preferred embodiment of the invention, a precursor of a drug comprising one nucleobase moiety is chosen from the group comprising azidothymidine (AZT), Gancyclovir (GCV), 5-Fluorocytosine (5-FC), 5-Fluorouracil (5-FU), 6-Methylpurine deoxyribonucleoside, Ganciclovir elaidic acid ester, penciclovir, Acyclovir, Valacyclovir, (E)-5-(2-bromovinyl)-2'-deoxyuridine, zidovudine, 2'-Exo-methanocarbathymidine.

As used herein, permease refers to transmembraneous protein involved in the transfer of a drug comprising one nucleobase moiety, or a precursor thereof through the cell membrane.

The permease according to the invention notably refers to purine permease, cytosine permease and nucleoside transporters.

According to a preferred embodiment of the invention, permease is a purine or a cytosine permease of *S. Cerevisiae*. The nucleobase transporters of *S. cerevisiae* consist of the purine-cytosine permease, known as FCY2, and the uracil permease, known as FUR4. According to a more preferred embodiment of the invention, the permease has an amino acid sequence chosen from the group comprising SEQ ID N0:1 and SEQ ID N0:2.

The purine-cytosine permease, FCY2 mediates symport of protons and adenine, guanine, hypoxanthine and cytosine across the yeast plasma membrane (Grenson 1969, Jund and Lacroute 1970, Polak and Grenson 1973, Chevallier *et al.* 1975, Hopkins *et al.* 1988). FCY2 protein
5 mediates also the transport of 5-fluorocytosine, an analogue of cytosine (Grenson 1969, Jund and Lacroute 1970). *FCY2* gene encodes a protein of 533 amino acids (58 kDa) initially predicted to have 10-12 transmembrane-spanning domains (Weber *et al.* 1990), with nine now favoured (Ferreira *et al.* 1999). FCY2 exhibits similar affinities for the
10 purine nucleobases and cytosine (Brethes *et al.* 1992). Uracil uptake into *S. cerevisiae* is mediated by the uracil permease, FUR4 (Jund and Lacroute 1970, Jund *et al.* 1977). FUR4 is a uracil-proton symporter (Hopkins *et al.* 1988) predicted to be a protein of 633 amino acids (71.7 kDa) with 10 transmembrane domains and long cytoplasmic hydrophilic
15 N- and C-terminal tails (Jund *et al.* 1988, Garnier *et al.* 1996). FUR4 protein can also mediate the transport of 5-fluorouracil, an analogue of uracil (Jund and Lacroute 1970).

With this respect, according to a preferred embodiment, the permease is chosen from the group comprising FCY2 and Fur4 and
20 analogues thereof. Amino acid sequences of FCY2 and Fur4 are notably available in the swissprot database (accession number P17064 and P05316 respectively). Analogues of Fur4 and FCY2 refers to polypeptide having an amino acid sequence which have at least a degree of identity greater than 70%, advantageously greater than 80%, preferably greater
25 than 90%, and most preferably greater than 95% with the amino acid sequence of the parent protein and which retains the ability to transport a drug comprising one nucleobase moiety through the cell membrane

According to another preferred embodiment, the permease is chosen from the group comprising hENT1, hENT2, hCNT1, hCNT2 and
30 hCNT3 and analogues thereof. The amino acid sequences of these

permeases are available to the one skilled in the art, notably in the swissprot database. Analogues of these polypeptides refers to a polypeptide having an amino acid sequence which have at least a degree of identity greater than 70%, advantageously greater than 80%, preferably
5 greater than 90%, and most preferably greater than 95% with the amino acid sequence of the parent polypeptide and which retains the ability to transport a drug comprising one nucleobase moiety through the cell membrane.

The one skilled in the art is able to choose the permease which will
10 be associated with the drug or the precursor of the drug comprising one nucleobase moiety. For example, FCY2 and Fur 4 are preferably associated with 5-FC.

Suicide gene refers to a gene coding a protein able to convert a precursor of a drug comprising one nucleobase moiety into a drug
15 comprising one nucleobase moiety.

Suicide genes comprised but are not limited to genes coding protein having a cytosine deaminase activity, a thymidine kinase activity, an uracil phosphoribosyl transferase activity, a purine nucleoside phosphorylase activity and/or a thymidylate kinase activity.

20 Preferably, the suicide gene comprised in the kit of parts according to the invention codes a proteinable to transform the precursor of the drug comprising one nucleobase moiety comprised in the same kit of parts. Examples of Suicide genes and corresponding precursors of a drug comprising one nucleobase moiety are disclosed in the following table:

25

Suicide gene	precursor of a drug comprising one nucleobase moiety
Thymidine Kinase	Ganciclovir; Ganciclovir elaidic acid ester; penciclovir; Acyclovir; Valacyclovir; (E)-5-(2-bromovinyl)-2'-deoxyuridine; zidovudine; 2'-Exo-methanocarbathymidine
Cytosine deaminase	5-Fluorocytosine
Purine nucleoside phosphorylase	6-Methylpurine deoxyriboside; Fludarabine
uracil phosphoribosyl transferase	5-Fluorocytosine; 5-Fluorouracil
thymidylate kinase.	Azidothymidine

According to a preferred embodiment of the invention, the suicide gene according to the invention codes a protein having at least a CDase activity. CDase is involved in the pyrimidine metabolic pathway by which

5 exogenous cytosine is transformed into uracil by means of a hydrolytic deamination. While CDase activities have been demonstrated in prokaryotes and lower eukaryotes (Jund and Lacroute, 1970, J. Bacteriol. 102, 607-615; Beck et al., 1972, J. Bacteriol. 110, 219-228; De Haan et al., 1972, Antonie van Leeuwenhoek 38, 257-263; Hoeprich et al., 1974, J.

10 Inf. Dis. 130, 112-118; Esders and Lynn, 1985, J. Biol. Chem. 260, 3915-3922), they are not present in mammals (Koechlin et al., 1966, Biochem Pharmacol. 15, 435-446; Polak et al., 1976, Chemotherapy 22, 137-153). The *Saccharomyces cerevisiae* (*S. cerevisiae*) FCY1 and the *E. coli* *codA* genes, which respectively encode the CDase of these two organisms, are

known and their sequences have been published (EP 402 108; Erbs et al., 1997, Curr. Genet. 31, 1-6; WO93/01281).

CDase also deaminates an analogue of cytosine, i.e. 5-fluorocytosine (5-FC), thereby forming 5-fluorouracil (5-FU), which is a
5 compound which is highly cytotoxic when it is converted into 5-fluoro-UMP (5-FUMP). Cells which lack CDase activity, either because of a mutation which inactivates the gene encoding the enzyme or because they are naturally deficient in this enzyme, as are mammalian cells, are resistant to 5-FC (Jund and Lacroute, 1970, J. Bacteriol, 102, 607-615; Kilstrup et al.,
10 1989, J. Bacteriol. 1989 171, 2124-2127). By contrast, mammalian cells into which the sequences encoding CDase activity were transferred became sensitive to 5-FC (Huber et al., 1993, Cancer Res. 53, 4619-4626; Mullen et al., 1992, Proc. Natl. Acad. Sci. USA 89, 33-37; WO 93/01281). In addition, the neighboring, untransformed cells also become sensitive to
15 5-FC (Huber et al., 1994, Proc. Natl. Acad. Sci. USA 91, 8302-8306). This phenomenon, which is termed a bystander effect, is due to the cells which are expressing the CDase activity secreting 5-FU, which then intoxicates the neighboring cells by straightforward diffusion across the plasma membrane. This property of 5-FU in diffusing passively represents an
20 advantage as compared with the tk/GCV reference system, where the bystander effect requires there to be contact with the cells which are expressing tk (Mesnil et al., 1996, Proc. Natl. Acad. Sci. USA 93, 1831-1835). All the advantages which CDase offers within the context of gene therapy, in particular anticancer gene therapy, can therefore be readily
25 understood.

With this respect, according to a more preferred embodiment of the invention, the gene coding a protein having a CDase activity is FCY1 or CodA or an analogue thereof. Analogues of these genes refers to a gene having an nucleic acid sequence which have at least a degree of identity
30 greater than 70%, advantageously greater than 80%, preferably greater

than 90%, and most preferably greater than 95% with the nucleic acid sequence of the parent gene Patent application FR2004/001657 discloses a gene coding a protein having an improved CDase activity. This polypeptide derives from a native CDase by addition of an amino acid
5 sequence. According to another preferred embodiment of the invention, the protein having a CDase activity is a polypeptide disclosed in FR2004/001657 and more preferably the polypeptide represented in the sequence identifier SEQ ID NO:1 of FR2004/001657.

In prokaryotes and lower eukaryotes, uracil is transformed into UMP
10 by the action of uracil phosphoribosyl transferase (UPRTase). This enzyme converts 5-FU into 5-FUMP. According to another preferred embodiment the suicide gene according to the invention code a protein having an UPRTase activity.

The UPRTase in question in the present invention may be of any
15 origin, in particular of prokaryotic, fungal or yeast origin. By way of illustration, the nucleic acid sequences encoding the UPRTases from *E. coli* (Anderson et al., 1992, Eur. J. Biochem 204, 51-56), from *Lactococcus lactis* (Martinussen and Hammer, 1994, J. Bacteriol. 176, 6457-6463), from *Mycobacterium bovis* (Kim et al., 1997, Biochem Mol.
20 Biol. Int 41, 1117-1124) and from *Bacillus subtilis* (Martinussen et al., 1995, J. Bacteriol. 177, 271-274) may be used in the context of the invention. However, it is most particularly preferred to use a yeast UPRTase and in particular that encoded by the *S. cerevisiae* *FUR1* gene whose sequence disclosed in Kern et al. (1990, Gene 88, 149-157) is
25 introduced here by way of reference. As a guide, the sequences of the genes and those of the corresponding UPRTases may be found in the literature and the specialist databanks (SWISSPROT, EMBL, Genbank, Medline and the like).

Moreover, application PCT/FR99/00904 describes an *FUR1* gene
30 lacking 105 nucleotides in 5' of the coding part allowing the synthesis of a

UPRTase from which the 35 first residues have been deleted at the N-terminal position and starting with the methionine at position 36 in the native protein. The product of expression of the mutant gene, designated *FUR1Δ105*, is capable of complementing an *fur1* mutant of *S. cerevisiae*.
5 In addition, the truncated mutant exhibits a higher UPRTase activity than that of the native enzyme. Thus, according to a particularly advantageous embodiment, the polypeptide encoded by the suicide gene according to the invention is a deletion mutant of a native UPRTase. The deletion is preferably located in the N-terminal region of the original UPRTase. It may
10 be complete (affecting all the residues of said N-terminal region) or partial (affecting one or more continuous or discontinuous residues in the primary structure). In general, a polypeptide consists of N-terminal, central and C-terminal parts, each representing about a third of the molecule. For example, since the *S. cerevisiae* UPRTase has 251 amino acids, its
15 N-terminal part consists of the first 83 residues starting with the so-called initiator methionine situated at the first position of the native form. As for the *E. coli* UPRTase, its N-terminal part covers positions 1 to 69.

A preferred protein having an UPRTase activity comprises an amino acid sequence substantially as represented in the sequence
20 identifier SEQ ID NO: 1 of PCT/FR99/00904, starting with the Met residue at position 1 and ending with the Val residue at position 216. The term "substantially" refers to a degree of identity with said sequence SEQ ID NO: 1 of PCT/FR99/00904 greater than 70%, advantageously greater than 80%, preferably greater than 90%, and most preferably greater than 95%.
25 More preferably still, it comprises the amino acid sequence represented in the sequence identifier SEQ ID NO: 1 of PCT/FR99/00904. As mentioned above, it may comprise additional mutations. There may be mentioned in particular the substitution of the serine residue at position 2 (position 37 in the native UPRTase) by an alanine residue.

According to another preferred embodiment, the suicide gene of the invention codes a protein having at least one Cdase and one UPRTase activity. Patent applications WO96/16183 and PCT/FR99/00904 describe the use of a fusion protein encoding an enzyme with two domains having
5 the CDase and UPRTase activities and demonstrate that the transfer of a hybrid gene *codA::upp* or *FCY1::FUR1* or *FCY1::FUR1 Δ 105* carried by an expression plasmid increases the sensitivity of the transfected B16 cells to 5-FC.

10

Although the fusion can take place at any site of the first polypeptide, the N- or C-terminal ends are preferred and in particular the N-terminal end. Advantageously, the fusion in phase uses a second polypeptide having a cytosine deaminase (CDase) activity and which is
15 derived from a native cytosine deaminase, such that the fusion polypeptide according to the invention exhibits the CDase and UPRTase activities. An *FCY1::FUR1* fusion is preferred. Such a bifunctional polypeptide makes it possible to improve the sensitivity of the target cells to 5-FC and to 5-FU.

20 A CDase of prokaryotic or lower eukaryotic origin is used. More preferably still, it is a yeast CDase, and in particular that encoded by the *Saccharomyces cerevisiae FCY1* gene. The cloning and the sequencing of the genes encoding CDases from various sources are available in the literature and specialist databanks. It should be mentioned that the
25 sequence of the *FCY1* gene is disclosed in Erbs et al. (1997, Curr. Genet. 31, 1-6). It is of course possible to use a mutant of CDase having a conversion capacity which is comparable to or greater than that of the native enzyme.

Persons skilled in the art are capable of cloning the CDase or
30 UPRTase sequences from the published data and of carrying out possible

mutations, of testing the enzymatic activity of the mutant forms in an acellular or cellular system according to the prior art technology or based on the protocol indicated in application PCT/FR99/00904, and of fusing, in particular in phase, the polypeptides with CDase and UPRTase activity, 5 and consequently all or part of the corresponding genes.

According to a more preferred embodiment of the invention, the suicide gene codes a polypeptide comprising an amino acid sequence substantially as represented in the sequence identifier SEQ ID NO: 2 of PCT/FR99/00904, starting with the Met residue at position 1 and ending 10 with the Val residue at position 373. The term "substantially" has the definition given above. A polypeptide comprising the amino acid sequence as represented in the sequence identifier SEQ ID NO: 2 of PCT/FR99/00904 is most particularly suitable for carrying out the invention.

15 Another preferred encoded polypeptide is disclosed in WO96/16183 and more preferably the polypeptide encoded by coda::upp or FCY1::FUR1.

The nucleic acid sequences may be easily obtained by cloning, by PCR or by chemical synthesis according to the conventional techniques in 20 use. They may be native genes or genes derived from the latter by mutation, deletion, substitution and/or addition of one or more nucleotides. Moreover, their sequences are widely described in the literature which can be consulted by persons skilled in the art.

The present invention also relates to a kit of parts as presented 25 above, characterized in that said nucleic acid sequences are inserted into one or more recombinant vectors of plasmid or viral origin, and to such recombinant vectors carrying such nucleotide sequences placed under the control of the elements necessary for their expression in a host cell.

More particularly, the kit of parts of the invention may comprise said 30 nucleic acid sequence comprising a gene coding a permease and said

nucleic acid sequence comprising a suicide gene inserted into the same recombinant vector or into distinct recombinant vectors. According to a preferred embodiment, the nucleic acid sequences are comprised into the same recombinant vector.

5 The present invention also relates to a recombinant vector which carries at least one of the nucleotide acid sequences according to the invention which is placed under the control of the elements which are required for expressing it in a host cell. More particularly, the present invention relates to a recombinant vector comprising a nucleic acid
10 sequence coding a permease.

The recombinant vector can be of plasmid or viral origin and can, where appropriate, be combined with one or more substances which improve the transfectional efficiency and/or stability of the vector. These substances are widely documented in the literature which is available to
15 the skilled person (see, for example, Feigner et al., 1987, Proc. West. Pharmacol. Soc. 32, 115-121; Hodgson and Solaiman, 1996, Nature Biotechnology 14, 339-342; Remy et al., 1994, Bioconjugate Chemistry, 5, 647-654). By way of non-limiting illustration, the substances can be polymers, lipids, in particular cationic lipids, liposomes, nuclear proteins or
20 neutral lipids. These substances can be used alone or in combination. A combination which can be envisaged is that of a recombinant plasmid vector which is combined with cationic lipids (DOGS, DC-CHOL, spermine-chol, spermidine-chol, etc.), lysophospholipides (for example Hexadecylphosphocholine) and neutral lipids (DOPE).

25 According to a preferred embodiment, the cationic lipids which can be used in the present invention are the cationic lipids describes in EP901463B1 and more preferably pcTG90.

The choice of the plasmids which can be used within the context of the present invention is immense. They can be cloning vectors and/or
30 expression vectors. In a general manner, they are known to the skilled

person and, while a number of them are available commercially, it is also possible to construct them or to modify them using the techniques of genetic manipulation. Examples which may be mentioned are the plasmids which are derived from pBR322 (Gibco BRL), pUC (Gibco BRL),
5 pBluescript (Stratagene), pREP4, pCEP4 (Invitrogene) or p Poly (Lathe et al., 1987, Gene 57, 193-201). Preferably, a plasmid which is used in the context of the present invention contains an origin of replication which ensures that replication is initiated in a producer cell and/or a host cell (for example, the ColE1 origin will be chosen for a plasmid which is intended
10 to be produced in E. coli and the oriP/EBNA1 system will be chosen if it desired that the plasmid should be self-replicating in a mammalian host cell, Lupton and Levine, 1985, Mol. Cell. Biol. 5, 2533-2542; Yates et al., Nature 313, 812-815). The plasmid can additionally comprise a selection gene which enables the transfected cells to be selected or identified
15 (complementation of an auxotrophic mutation, gene encoding resistance to an antibiotic, etc.). Naturally, the plasmid can contain additional elements which improve its maintenance and/or its stability in a given cell (cer sequence, which promotes maintenance of a plasmid in monomeric form (Summers and Sherrat, 1984, Cell 36, 1097-1103, sequences for
20 integration into the cell genome).

With regard to a viral vector, it is possible to envisage a vector which is derived from a poxvirus (vaccinia virus, in particular MVA, canarypoxvirus, etc.), from an adenovirus, from a retrovirus, from a herpesvirus, from an alphavirus, from a foamy virus or from an
25 adenovirus-associated virus. It is possible to use replication competent or replication deficient viral vectors. Preference will be given to using a vector which does not integrate. In this respect, adenoviral vectors and MVA are very particularly suitable for implementing the present invention.

According to a preferred embodiment, the viral vector according to
30 the invention derives from a Modified Vaccinia Virus Ankara (MVA). MVA

vectors and methods to produce such vectors are fully described in European patents EP83286 and EP206920, as well as in Mayr et al. (1975, Infection 3, 6-14) and Sutter et Moss (1992, Proc. Natl. Acad. Sci. USA 89, 10847-10851). According to a more preferred embodiment, the
5 nucleotide sequence according to the invention may be inserted in deletion I, II, III, IV, V and VI of the MVA vector and even more preferably in deletion III (Meyer et al., 1991, J. Gen. Virol. 72, 1031-1038; Sutter et al., 1994, Vaccine 12, 1032-1040).

Retroviruses have the property of infecting, and in most cases
10 integrating into, dividing cells and in this regard are particularly appropriate for use in relation to cancer. A recombinant retrovirus according to the invention generally contains the LTR sequences, an encapsidation region and the nucleotide sequence according to the invention, which is placed under the control of the retroviral LTR or of an internal promoter such as
15 those described below. The recombinant retrovirus can be derived from a retrovirus of any origin (murine, primate, feline, human, etc.) and in particular from the M0MuLV (Moloney murine leukemia virus), MVS (Murine sarcoma virus) or Friend murine retrovirus (Fb29). It is propagated in an encapsidation cell line which is able to supply in trans the viral
20 polypeptides gag, pol and/or env which are required for constituting a viral particle. Such cell lines are described in the literature (PA317, Psi CRIP GP + Am-12 etc.). The retroviral vector according to the invention can contain modifications, in particular in the LTRs (replacement of the promoter region with a eukaryotic promoter) or the encapsidation region
25 (replacement with a heterologous encapsidation region, for example the VL3O type) (see French applications 94 08300 and 97 05203)

Preference will be also given to using an adenoviral vector which lacks all or part of at least one region which is essential for replication and which is selected from the EI, E2, E4 and L1-L5 regions in order to avoid
30 the vector being propagated within the host organism or the environment.

A deletion of the EI region is preferred. However, it can be combined with (an)other modification(s)-/deletion(s) affecting, in particular, all or part of the E2, E4 and/or L1-L5 regions, to the extent that the defective essential functions are complemented in trans by means of a complementing cell line and/or a helper virus. In this respect, it is possible to use second-generation vectors of the state of the art (see, for example, international applications WO-A-94/28152 and WO-A-97/04119). By way of illustration, deletion of the major part of the EI region and of the E4 transcription unit is very particularly advantageous. For the purpose of increasing the cloning capacities, the adenoviral vector can additionally lack all or part of the nonessential E3 region. According to another alternative, it is possible to make use of a minimal adenoviral vector which retains the sequences which are essential for encapsidation, namely the 5' and 3' ITRs (Inverted Terminal Repeat), and the encapsidation region. The various adenoviral vectors, and the techniques for preparing them, are known (see, for example, Graham and Prevec, 1991, in *Methods in Molecular Biology*, Vol 7, p 109-128; Ed: E.J. Murey, The Human Press mc).

Furthermore, the origin of the adenoviral vector according to the invention can vary both from the point of view of the species and from the point of view of the serotype. The vector can be derived from the genome of an adenovirus of human or animal (canine, avian, bovine, murine, ovine, porcine, simian, etc.) origin or from a hybrid which comprises adenoviral genome fragments of at least two different origins. More particular mention may be made of the CAV-1 or CAV-2 adenoviruses of canine origin, of the DAV adenovirus of avian origin or of the Bad type 3 adenovirus of bovine origin (Zakharchuk et al., *Arch. Virol.*, 1993, 128: 171-176; Spibey and Cavanagh, *J. Gen. Virol.* 1989, 70: 165-172; Jouvenne et al., *Gene*, 1987, 60: 21-28; Mittal et al., *J. Gen. Virol.*, 1995, 76: 93-102). However, preference will be given to an adenoviral vector of

human origin which is preferably derived from a serotype C- adenovirus, in particular a type 2 or 5 serotype C adenovirus.

The term "replication-competent" as used herein refers to a viral vector capable of replicating in a host cell in the absence of any trans-
5 complementation. In the context of the present invention, this term also encompasses replication-selective or conditionally-replicative adenoviral vectors which are engineered to replicate better or selectively in cancer or hyperproliferative host cells.

According to a preferred embodiment of the invention, the
10 replication competent vector is a replication competent adenoviral vector. These replication competent adenoviral vectors are well known by the one skilled in the art. Among these, adenoviral vectors deleted in the E1b region coding the 55kD P53 inhibitor, as in the ONYX-015 virus (Bischoff et al, 1996; Heise et al., 2000; WO 94/18992), are particularly preferred.
15 Accordingly, this virus can be used to selectively infect and kill p53-deficient neoplastic cells. A person of ordinary skill in the art can also mutate and disrupt the p53 inhibitor gene in adenovirus 5 or other viruses according to established techniques. Adenoviral vectors deleted in the E1A Rb binding region can also be used in the present invention. For
20 example, Delta24 virus which is a mutant adenovirus carrying a 24 base pair deletion in the E1A region (Fueyo et al., 2000). Delta24 has a deletion in the Rb binding region and does not bind to Rb. Therefore, replication of the mutant virus is inhibited by Rb in a normal cell. However, if Rb is inactivated and the cell becomes neoplastic, Delta24 is no longer inhibited.
25 Instead, the mutant virus replicates efficiently and lyses the Rb-deficient cell.

An adenoviral vector according to the present invention can be generated in vitro in *Escherichia coli* (*E. coli*) by ligation or homologous recombination (see, for example, international application WO-A-
30 96/17070) or else by recombination in a complementing cell line.

The elements required for expression consist of all the elements which enable the nucleotide sequence to be transcribed into RNA and the mRNA to be translated into polypeptide. These elements comprise, in particular, a promoter which may be regulable or constitutive. Naturally, the promoter is suited to the chosen vector and the host cell. Examples which may be mentioned are the eukaryotic promoters of the PGK (phosphoglycerate kinase), MT (metallothionein; McIvor et al., 1987, Mol. Cell Biol. 7, 838-848), α -1 antitrypsin, CFTR, surfactant, immunoglobulin, β -actin (Tabin et al., 1982, Mol. Cell Biol. 2, 426-436) and SRa (Takebe et al., 1988, Mol. Cell Biol. 8, 466-472) genes, the early promoter of the SV40 virus (Simian virus), the LTR of RSV (Rous sarcoma virus), the HSV-I TK promoter, the early promoter of the CMV virus (Cytomegalovirus), the p7.5K pH5R, pK1L, p28 and p11 promoters of the vaccinia virus, and the E1A and MLP adenoviral promoters. The promoter can also be a promoter which stimulates expression in a tumor or cancer cell. Particular mention may be made of the promoters of the MUC-I gene, which is overexpressed in breast and prostate cancers (Chen et al., 1995, J. Clin. Invest. 96, 2775-2782), of the CEA (standing for carcinoma embryonic antigen) gene, which is overexpressed in colon cancers (Schrewe et al., 1990, Mol. Cell. Biol. 10, 2738-2748) of the tyrosinase gene, which is overexpressed in melanomas (Vile et al., 1993, Cancer Res. 53, 3860-3864), of the ERBB-2 gene, which is overexpressed in breast and pancreatic cancers (Harris et al., 1994, Gene Therapy 1, 170-175) and of the α -fetoprotein gene, which is overexpressed in liver cancers (Kanai et al., 1997, Cancer Res. 57, 461-465). The cytomegalovirus (CMV) early promoter is very particularly preferred.

However, when a vector deriving from a Vaccinia Virus (as for example an MVA vector) is used, the promoter of the thymidine kinase 7.5K gene is particularly preferred.

The necessary elements can furthermore include additional elements which improve the expression of the nucleotide sequence according to the invention or its maintenance in the host cell. Intron sequences, secretion signal sequences, nuclear localization sequences, 5 internal sites for the reinitiation of translation of IRES type, transcription termination poly A sequences, tripartite leaders and origins of replication may in particular be mentioned. These elements are known to the skilled person.

The recombinant vector according to the invention can also 10 comprise one or more additional genes of interest, with it being possible for these genes to be placed under the control of the same regulatory elements (polycistronic cassette) or of independent elements. Genes which may in particular be mentioned are the genes encoding interleukins IL-2, IL-4, IL-7, IL-10 and IL-12, interferons, tumor necrosis factor (TNF), 15 colony stimulating factors (CSF), in particular GM-CSF, and factors acting on angiogenesis (for example PAI-1, standing for plasminogen activator inhibitor). In one particular embodiment, the recombinant vector according to the invention comprises the gene of interest encoding IL-2 or encoding interferon γ (INF γ). It is also possible to envisage combining the nucleotide 20 sequence according to the invention with other suicide genes such as the HSV-1 TK gene, the ricin gene, the cholera toxin gene, etc.

The present invention also relates to a viral particle which comprises a recombinant vector according to the invention. Such a viral particle can be generated from a viral vector using any technique which is 25 conventional in the field of the art. The viral particle is propagated in a complementing cell which is suited to the deficiencies of the vector. With regard to an adenoviral vector, use will, for example, be made of the 293 cell line, which was established using human embryonic kidney cells and which efficiently complements the E1 function (Graham et al., 1977, J. 30 Gen. Virol. 36, 59-72), of the A549-E1 cell line (Imler et al., 1996, Gene

Therapy 3, 75-84) or of a cell line which permits double complementation (Yeh et al., 1996, J. Virol. 70, 559-565; Krougliak and Graham, 1995, Human Gene Therapy 6, 1575-1586; Wang et al., 1995 Gene Therapy 2, 775-783; international application WO 97/04119). It is also possible to
5 employ helper viruses to at least partially complement the defective functions. A complementing cell is understood as being a cell which is able to supply in trans the early and/or late factors which are required for encapsidating the viral genome in a viral capsid in order to generate a viral particle which contains the recombinant vector. Said cell may not be able
10 to complement all the defective functions of the vector on its own and, in this case, can be transfected/transduced with a vector/helper virus which supplies the additional functions.

The invention also relates to a process for preparing a viral particle, in which process:

- 15 (i) a recombinant vector according to the invention is introduced into a complementing cell which is able to complement said vector in trans, so as to obtain a transfected complementing cell,
- (ii) said transfected complementing cell is cultured under conditions which are appropriate for enabling said viral particle to be
20 produced, and
- (iii) said viral particle is recovered from the cell culture.

While the viral particle can of course be recovered from the culture supernatant, it can also be recovered from the cells. One of the commonly employed methods consists in lysing the cells by means of consecutive
25 freezing/thawing cycles in order to collect the virions in the lysis supernatant. The virions can then be amplified and purified using the techniques of the art (chromatographic method, method of ultra-centrifugation, in particular through a cesium chloride gradient, etc.).

The present invention, also relates to a composition which
30 comprises a kit of parts, a recombinant vector or a viral particle according

to the invention in combination with a pharmaceutically acceptable excipient

A kit of parts according to the invention is more specifically intended for the preventive or curative treatment of diseases by means of gene therapy and is more specifically aimed at proliferative diseases (cancers, tumors, restenosis, etc.) and at diseases of infectious origin, in particular of viral origin (induced by hepatitis B or C viruses, HIV, herpes, retroviruses, etc.).

A kit of parts according to the invention can be made conventionally with a view to administering it locally, parenterally or by the digestive route. In particular, a therapeutically effective quantity of the therapeutic or prophylactic agent is combined with a pharmaceutically acceptable excipient. It is possible to envisage a large number of routes of administration. Examples which may be mentioned are the intragastric, subcutaneous, intracardiac, intramuscular, intravenous, intraperitoneal, intratumor, intranasal, intrapulmonary and intratracheal routes. In the case of these three latter embodiments, it is advantageous for administration to take place by means of an aerosol or by means of instillation. The administration can take place as a single dose or as a dose which is repeated on one or more occasions after a particular time interval. The appropriate route of administration and dosage vary depending on a variety of parameters, for example the individual, the disease to be treated or the gene(s) of interest to be transferred. The preparations based on viral particles according to the invention can be formulated in the form of doses of between 10^4 and 10^{14} pfu (plaque-forming units), advantageously 10^5 and 10^{13} pfu, preferably 10^6 and 10^{12} pfu, more preferably 10^9 and 10^{10} when adenoviral particles are used and 10^6 and 10^7 when MVA particles are used. As far as the recombinant vector according to the invention is concerned, it is possible to envisage doses comprising from

0.01 to 100 mg of DNA, preferably from 0.05 to 10 mg, very particularly preferably from 0.5 to 5 mg.

The formulation can also include a diluent, an adjuvant or an excipient which is acceptable from the pharmaceutical point of view, as well as solubilizing, stabilizing and preserving agents. In the case of an injectable administration, preference is given to a formulation in an aqueous, non-aqueous or isotonic solution. It can be presented as a single dose or as a multidose, in liquid or dry (powder, lyophilizate, etc.) form which can be reconstituted at the time of use using an appropriate diluent.

10 The formulation can also comprise appropriate quantities of prodrugs.

The present invention also relates to the therapeutic or prophylactic use of a kit of parts, of a recombinant vector or of a viral particle according to the invention for preparing a medicament which is intended for treating the human or animal body by gene therapy. According to a first possibility,

15 the medicament can be administered directly in vivo (for example by intravenous injection, into an accessible tumor, into the lungs by means of an aerosol, into the vascular system using an appropriate catheter, etc.). It is also possible to adopt the ex vivo approach, which consists in removing cells from the patient (bone marrow stem cells, peripheral blood

20 lymphocytes, muscle cells, etc.), transfecting or infecting them in vitro in accordance with the techniques of the art and then readministering them to the patient. A preferred use consists in treating or preventing cancers, tumors and diseases which result from unwanted cell proliferation. Conceivable applications which may be mentioned are cancers of the

25 breast, of the uterus (in particular those induced by papilloma viruses), of the prostate, of the lung, of the bladder, of the liver, of the colon, of the pancreas, of the stomach, of the esophagus, of the larynx, of the central nervous system (e.g. glioblastoma) and of the blood (lymphomas, leukemia, etc.). It can also be used in the context of cardiovascular

30 diseases, for example in order to inhibit or retard the proliferation of the

smooth muscle cells of the blood vessel wall (restenosis). Finally, in the case of infectious diseases, it is possible to conceive of the medicament being applied to AIDS.

The invention also extends to a method for treating diseases by gene therapy, characterized in that a kit of parts, a recombinant vector, a viral particle or a host cell according to the invention is administered to an host organism or cell which is in need of such treatment.

The drug comprising one nucleobase moiety or a precursor thereof can be administered in accordance with standard practice (e.g. per os, systematically). By way of illustration, regarding 5-FU, it is possible to use a dose of from 50 to 500 mg/kg/day, with a dose of 200 mg/kg/day being preferred. Within the context of the present invention, the prodrug is administered in accordance with standard practice (e.g. per os, systematically), with the administration taking place prior to, concomitantly with or else subsequent to the administration of a nucleic acid sequence according to the invention. The oral route is preferred. It is possible to administer a single dose of prodrug or doses which are repeated for a time which is sufficiently long to enable the toxic metabolite to be produced within the host organism or cell.

Furthermore, the kit of parts or method according to the invention can be combined with one or more substances which potentiate the cytotoxic effect of the drug comprising one nucleobase moiety. Mention may in particular be made of drugs which inhibit the enzymes of the pathway for the de novo biosynthesis of the pyrimidines (for example those mentioned below), drugs such as Leucovorin (Waxman et al., 1982, Eur. J. Cancer Clin. Oncol. 18, 685-692), which, in the presence of the product of the metabolism of 5-FU (5-FdUMP), increases the inhibition of thymidylate synthase, resulting in a decrease in the pool of dTMP, which is required for replication, and finally drugs such as methotrexate (Cadman et al., 1979, Science 250, 1135-1137) which, by inhibiting dihydrofolate

reductase and increasing the pool of PRPP (phosphoribosylpyrophosphate), brings about an increase in the incorporation of 5-FU into the cellular RNA.

The kit of parts or method according to the invention can be combined with one or more substances effective in anticancer therapy. The kit of parts or methods according to the invention can also be use in combination with a radiotherapy.

Figure 1 Antitumor activity of the combination of adenovirus and 5-FC at 125 and 50 mg/kg/day on the growth of LoVo colon cancer xenograft in Swiss nude mice. Tumors were established by s.c. implantation of 5×10^6 cells into nude mice. When the tumors were palpable, the animals were intratumorally inoculated 3 times with Ad-empty (A) Ad-FCU1 (B) and Ad-FCY2FCU1 (C), and treated for 3 weeks with per os administrations of 5-FC. Using Ad-empty (A), no differences in growth curves between absence and presence of 5-FC ($P > 0.05$). Using Ad-FCU1 (B), there is a significant difference in the growth curves between presence and absence of 5-FC only at 125 mg/kg/day ($P < 0.05$). Using Ad-FCY2FCU1 (C), there is a significant difference in the growth curves between without 5-FC and systemic 5-FC at 125 and 50 mg/kg/day ($P < 0.05$).

Examples:

Construction of an adenovirus expressing FCY2 from the E1 region:

Complete yeast purine-cytosine permease gene (FCY2, 1599 bp) was amplified from the plasmid pAJ14 (Bloch *et al.* 1992) as template using polymerase chain reaction (PCR). Oligonucleotides SEQ ID N° 3 :

5'-

TAACGATCTCGAGCCATGGTGGGAAGAGGGAAATAATGTTTACG-3'

(OTG14626, corresponding to the 5' end of the FCY2 coding sequence

but introducing a Kozak consensus sequence replacing Leu in position 2 by a Val and incorporating an *Xho*I restriction site upstream of the start codon) and SEQ ID N° 4 : 5'-CCCTAATCACGCGTTCCTAACGACCGAAGTATTTTAAT-3' (OTG14627, 5 corresponding to the 3' end and inserting a *Mlu*I restriction site downstream of the stop codon) were used as primers. The PCR product was digested by *Xho*I and *Mlu*I and subcloned into the corresponding sites of the mammalian expression vector pCIneo (Promega) generating the plasmid pTG15829. Sequences from pTG15829 revealed a silent mutation 10 at nucleotide +1272 (G to A) in the open reading frame of *FCY2* gene. From plasmid pTG15829, the *Xho*I-*Mlu*I fragment containing the *FCY2* gene was inserted into the transfer vector pTG13387 cleaved by the same enzymes, generating the transfer vector pTG15857. The adenoviral vector Ad-*FCY2* (pTG15895) was generated by homologous recombination in the 15 BJ5183 *E. coli* strain between the fragment *Pac*I-*Bst*EII of pTG15857 and the vector pTG6624 linearized by *Cla*I. Final construction Ad-*FCY2* (pTG15895) contains a deletion in E3 (nucleotides 28592 to 30470), whereas the E1 region (nucleotides 459 to 3510) was replaced by the expression cassette containing, from 5' to 3', the CMV immediate-early 20 enhancer/promoter, a chimeric human β -globin/IgG intron, the *FCY2* gene, and the bGH polyadenylation signal. The adenoviral particles expressing *FCY2* (AdTG15895) were generated by transfection in a cell line complementing the E1 function (for example line PERC6).

25 **Construction of an adenovirus expressing a bicistronic unit *FCY2* IRES *FCU1* from the E1 region:**

The *Nhe*I-*Not*I fragment of the plasmid pTG15829 containing the *FCY2* gene was isolated and introduced into the vector pTG14347 (plasmid pTG4369p53FCU1 described in p53FCU1 patent) linearized with 30 *Nhe*I-*Not*I. The plasmid pTG16055 thus obtained contains, from 5' to 3',

the *FCY2* gene, the IRES (Internal Ribosome Entry Site) sequence of ECMV (encephalomyocarditis virus), and the *FCU1* gene. From plasmid pTG16055, the *NheI*-*Bam*HI fragment was inserted into the transfer vector pTG14799 (plasmid described in FCU1-8 patent) cleaved by the same 5 enzymes, generating the transfer vector pTG16066. The adenoviral vector Ad-FCY2FCU1 (pTG16079) was generated by homologous recombination in the BJ5183 *E. coli* strain between the fragment *PacI*-*Bst*EII of pTG 16066 and the vector pTG6624 linearized by *Cla*I. Final construction Ad-FCY2FCU1 (pTG16079) contains a deletion in E3 (nucleotides 28592 to 10 30470), whereas the E1 region (nucleotides 459 to 3510) was replaced by the expression cassette containing, from 5' to 3', the CMV immediate-early enhancer/promoter, a chimeric human β -globin/IgG intron, the *FCY2* IRES *FCU1* bicistronic unit, and the bGH polyadenylation signal. The adenoviral particles expressing *FCY2* IRES *FCU1* (AdTG16079) were generated by 15 transfection in a cell line complementing the E1 function (for example line PERC6).

5-fluorocytosine uptake assays:

The human tumoral cell line A549 (ATCC CCL-185) was infected 20 with Mock, an empty adenovirus (AdTG15149), an adenovirus expressing *FCU1* (AdTG14800 described in FCU1-8 patent) or *FCY2* (AdTG15895) or *FCY2* and *FCU1* (AdTG16079). The cells ($5 \cdot 10^6$) were infected at MOI 20 and plated on 60-mm plates. After 24 hours, uptake of 5-FC into transfected cells was measured by conventional tracer techniques. The 25 initial rate of 5-FC (10 μ M, room temperature) was measured using a 1-min incubation period and was traced with [^{3} H]5-FC at a concentration of 0.15 μ Ci/ml.

Briefly, 24 hours after infection, cells were washed once with the transport buffer (100 mM NaCl, 2 mM KCl, 1 mM CaCl_2 , 1mM MgCl_2 and 30 10 mM HEPES, pH 7.5). Uptake assays were started by adding 2 ml of

transport buffer containing 5-FC at 10 μM ($[^3\text{H}]5\text{-FC}$ at 0.15 $\mu\text{Ci/ml}$). At the end of the incubation, extracellular label was removed by three rapid washes with ice-cold transport buffer. The cells were solubilized in 1 ml of 5% SDS for quantification of radioactivity by liquid scintillation counting.

5

Table 1: Uptake of 5-FC into transfected A549 cells:

Uptake of 5-FC was measured using transport buffer containing 10 μM of 5-FC.

Each values represents the average of three independent 10 experiments $\pm$ SD.

Vector	Uptake of 5-FC (pmol/min/5.10 ⁶ cells)
Mock	7.97 $\pm$ 3.76
Ad-empty (AdTG15149)	9.74 $\pm$ 3.31
Ad-FCU1 (AdTG14800)	13.28 $\pm$ 5.74
Ad-FCY2 (AdTG15895)	38.94 $\pm$ 7.61
Ad-FCY2FCU1 (AdTG16079)	77 $\pm$ 28.7

The results presented in Table 1 demonstrate an increase in 5-FC transport in cells infected by Adenoviruses expressing FCY2 (AdFCY2 and 15 AdFCY2FCU1). Such results indicate that the yeast *FCY2*, expressed in human cells, encodes a functional 5-FC transporter.

***In vitro* cell sensitivity to 5-FC:**

Tumor cells infected with the different adenoviruses were compared for their sensitivity toward 5-FC. The human tumor cell line A549 (ATCC CCL-185) was infected with Mock, an empty adenovirus (AdTG15149), an adenovirus expressing *FCU1* (AdTG14800 described in FCU1-8 patent) or *FCY2* (AdTG15895) or *FCY2* and *FCU1* (AdTG16079). The cells were infected at an MOI of 1 and then cultured in the presence of different concentrations of 5-FC. After 6 days of culture, the viability of the cells was determined using trypan blue. The LD₅₀ values for 5-FC listed in Table 2 are the means of four counts.

***In vivo* experiments:**

The objective of this study is to compare the antitumor activity of the recombinant Ad-FCU1 and Ad-FCY2FCU1 in combination with per os administration of 5-fluorocytosine (5-FC) at 125 or 50 mg/kg/day in nude mice bearing LoVo human colon tumors.

LoVo cells were injected subcutaneously (s.c.) into the flanks of Swiss nude mice. Each animal was implanted with 5x10⁶ LoVo cells suspended in 100 µl of PBS. When tumors had reached 30-50 mm³, the mice were randomized in a blinded manner and treated with the indicated vectors at dose of 1.108IU. The vectors (suspended in 100 µl of 10mM Tris-HCl, pH7.5, 1mM MgCl₂) were directly injected into the tumor at days 12, 15 and 18 after tumor implantation. From day 12 on, 5-FC was given by oral gavage at 62.5 mg/kg/day (0.6 ml 5-FC 0.25% in water) or at 25 mg/kg/day (0.6 ml 5-FC 0.1% in water) twice a day during 3 weeks. Tumor size was measured in two dimensions using calipers. Tumor volume were calculated in mm³ using the formula (p 6)(length x width²).

Statistical analyses were performed using the non-parametric Mann-Whitney U test and Statistica 6.1 software (StatSoft, Inc.). A P<0.05 was considered to be statistically significant.

Using administration of 5 FC at 125 mg/kg/day, injection of Ad-FCU1 and Ad-FCY2FCU1 resulted in a statistically significant suppression of tumor growth (Fig.1B,C). This antitumor effect was specific of FCU1/5-FC because infection Ad-empty, which does not induce FCU1 activity, did not significantly reduce tumor size in presence of 5-FC (Fig.1A). At a lower dose of 5-FC (50 mg/kg/day), a significant inhibition of tumor growth was observed after delivery of Ad-FCY2FCU1 (Fig.1C), whereas no modification in tumor growth was observed using Ad-FCU1. This result indicates that the combination of FCY2 and FCU1 is significantly more effective than FCU1 alone and suggests that the FCY2FCU1/5-FC system is more efficient than the FCU1/5-FC system in a cancer gene therapy approach.

Table 2: LD₅₀ values for 5-FC of adenovirus-transduced A549 cells:

Vector	LD ₅₀ (μM)
Mock	> 1000
Ad-empty (AdTG15149)	> 1000
Ad-FCU1 (AdTG14800)	50
Ad-FCY2 (AdTG15895)	> 1000
Ad-FCY2FCU1 (AdTG16079)	20

These results demonstrate that coexpression of the *FCY2* and *FCU1* genes from adenoviral vector (AdTG16079) sensitizes the cells to 5-FC more strongly than does the expression of the *FCU1* gene

(AdTG14800). This greater sensitivity to 5-FC results from the uptake of 5-FC encoded by the *FCY2* gene. Using cells infected with Ad-FCY2 (AdTG15895), no antiproliferative effect was observed, this indicates that the sole administration of *FCY2*, in absence of cytosine deaminase 5 activity, is insufficient for an effective antitumor therapy protocol.

DEMANDE OU BREVET VOLUMINEUX

LA PRÉSENTE PARTIE DE CETTE DEMANDE OU CE BREVET COMPREND PLUS D'UN TOME.

CECI EST LE TOME 1 DE 2
CONTENANT LES PAGES 1 À 31

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THIS IS VOLUME 1 OF 2
CONTAINING PAGES 1 TO 31

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Claims

1. A kit of parts for the treatment of cancer and/or viral diseases in vertebrates comprising:

10 - a precursor of a drug comprising one nucleobase moiety, selected from the group consisting of azidothymidine (AZT), Gancyclovir (GCV), 5-Fluorocytosine (5-FC), 5-Fluorouracil (5-FU), 6-Methylpurine deoxyribonucleoside, Ganciclovir elaidic acid ester, penciclovir, Acyclovir, Valacyclovir, (E)-5-(2-bromovinyl)-2'-deoxyuridine, zidovudine, and 2'-Exo-methanocarbathymidine,

15 - a nucleic acid molecule comprising a gene coding a permease involved in the transfer of said precursor thereof through the cell membrane, said permease being selected from the group consisting of *S. Cerevisiae* FCY2, Fur4, and analogues thereof having at least a degree of identity of 90% with the full length amino acid sequence of FCY2 or Fur4 and retaining the ability to transport said precursor through the cell membrane, and,

20 - a nucleic acid molecule comprising a suicide gene coding a protein able to convert said precursor into a drug comprising one nucleobase moiety, wherein said suicide gene is selected from the group consisting of genes coding proteins having at least one of a cytosine deaminase activity, a thymidine kinase activity, an uracil phosphoribosyl transferase activity, a purine nucleoside phosphorylase activity, and a
25 thymidylate kinase activity.

2. The kit of parts according to claim 1, wherein said permease is chosen from the group consisting of FCY2 and Fur4.

30 3. The kit of parts according to claim 1, wherein said permease is FCY2.

4. The kit of parts according to one of claims 1 to 3, wherein said suicide gene codes a protein having a cytosine deaminase activity.

- 5 5. The kit of parts according to one of claims 1 to 4, wherein said suicide gene codes a protein having at least a cytosine deaminase activity and an uracil phosphoribosyl transferase activity.
- 10 6. The kit of parts according to claim 4, wherein the suicide gene is selected from the group consisting of CodA, upp, FUR1, FCY1 and FUR1Δ105.
- 15 7. The kit of parts according to claim 5, wherein said protein is a fusion protein in which:
a) a first polypeptide exhibiting a UPRTase activity is fused in phase with at least a second polypeptide, said second polypeptide exhibiting a CDase activity, or
b) a first polypeptide exhibiting a CDase activity is fused in phase with at least a second polypeptide, said second polypeptide exhibiting a UPRTase activity.
- 20 8. The kit of parts according to claim 5, wherein said suicide gene comprises a first nucleic acid sequence selected from the group consisting of upp, FUR1 and FUR1Δ105, and a second nucleic acid sequence selected from the group consisting of CodA and FCY1.
- 25 9. The kit of parts according to one of claims 1 to 8, wherein said nucleic acid molecules are inserted into a recombinant vector of plasmid or viral origin.
- 30 10. The kit of parts according to claim 9, wherein said nucleic acid molecules are inserted into the same recombinant vector.
- 35 11. The kit of parts according to claim 9, wherein said nucleic acid molecules are inserted into distinct recombinant vectors.
12. A recombinant vector comprising a gene coding a permease involved in the transfer of a precursor of a drug comprising one nucleobase moiety through the cell membrane and a suicide gene coding a protein able to convert said precursor into a drug comprising one nucleobase moiety, wherein:

- 5 a) said permease is selected from the group consisting of *S. Cerevisiae* FCY2, Fur4, and analogues thereof having at least a degree of identity of 90% with the full length amino acid sequence of FCY2 or Fur4 and retaining the ability to transport said precursor through the cell membrane, and
- 10 b) said precursor is selected from the group consisting of azidothymidine (AZT), Gancyclovir (GCV), 5-Fluorocytosine (5-FC), 5-Fluorouracil (5-FU), 6-Methylpurine deoxyribonucleoside, Ganciclovir elaidic acid ester, penciclovir, Acyclovir, Valacyclovir, (E)-5-(2-bromovinyl)-2'-deoxyuridine, zidovudine, and 2'-Exo-methanocarbathymidine, and
- 15 c) said suicide gene is selected from the group consisting of genes coding proteins having at least one of a cytosine deaminase activity, a thymidine kinase activity, an uracil phosphoribosyl transferase activity, a purine nucleoside phosphorylase activity, and a thymidylate kinase activity.
- 20 **13.** The recombinant vector according to claim 12, characterized in that said vector is selected from the group consisting of plasmid and viral vectors.
- 14.** The recombinant vector according to claim 13, characterized in that said plasmid or viral vector is combined with one or more substances which improve(s) the
- 25 transfectional efficacy, the stability, or both the transfectional efficacy and the stability of the vector.
- 15.** The recombinant vector according to claim 13 or claim 14, wherein said substance which improves the transfectional efficacy, the stability, or both the transfectional
- 30 efficacy and the stability of the vector is selected from the group consisting of cationic lipids, cationic polymers, lysophospholipides and polypeptides.
- 16.** The recombinant vector according to any one of claims 13 to 15, wherein said vector is a viral vector which is derived from a pox virus, from an adenovirus, from a
- 35 retrovirus, from a herpes virus, from an alphavirus, from a foamyvirus or from an adenovirus associated virus.

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17. The recombinant vector according to claim 16, wherein said vector is derived from a Modified Vaccinia Ankara (MVA) virus.

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18. The recombinant vector according to claim 17, wherein said gene coding a permease and said suicide gene are inserted at a site of a naturally occurring deletion within the MVA genome selected from the group consisting in deletion I, II, III, IV, V and VI.

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19. The recombinant vector according to claim 18, wherein said naturally occurring deletion within the MVA genome is deletion III.

20. The recombinant vector according to claim 16, wherein said vector is an adenoviral vector which additionally lacks fully or partially the E3 region.

20

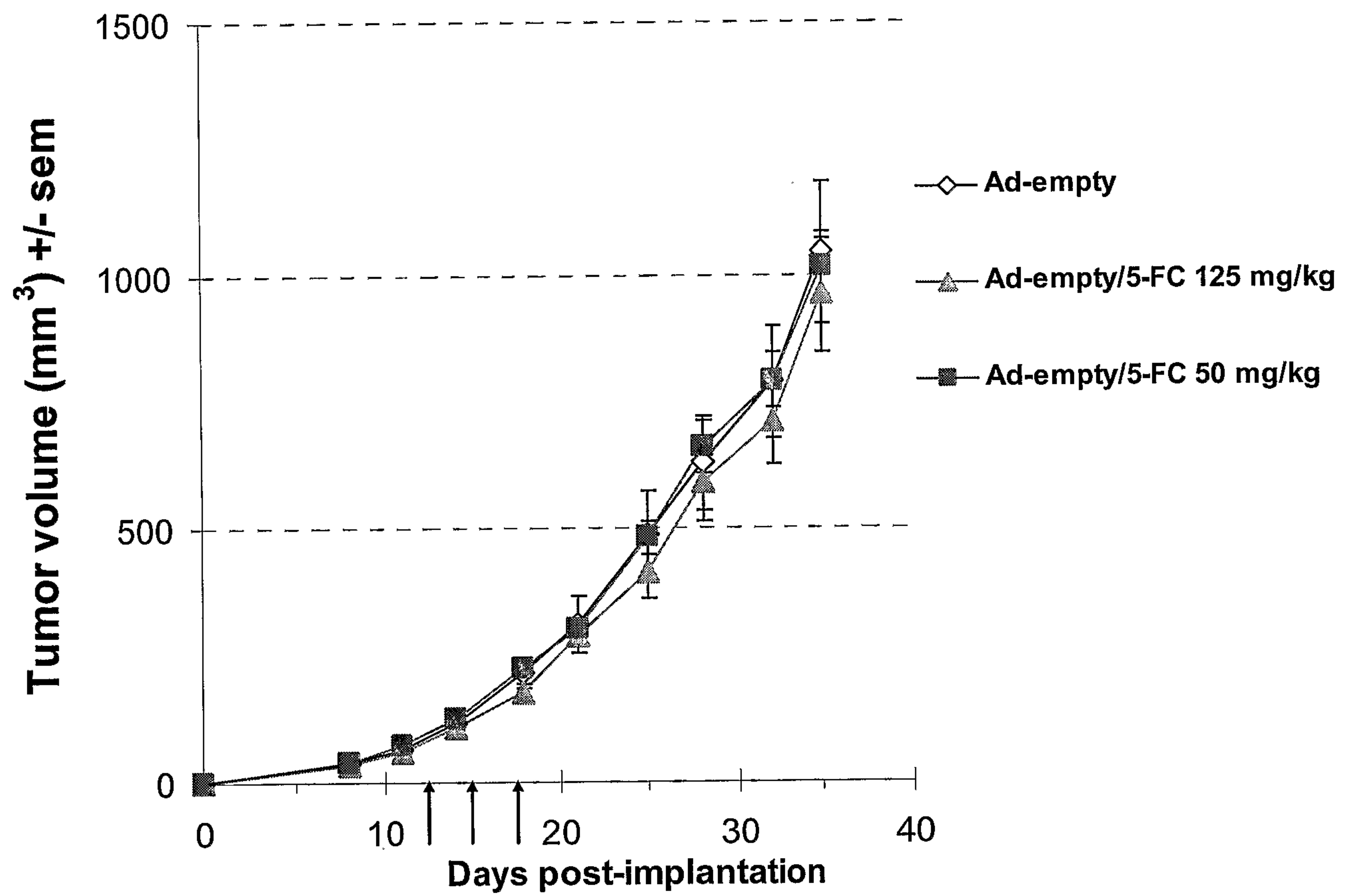
21. A pharmaceutical composition comprising the kit of parts according to one of claims 1 to 11 or the recombinant vector according to one of claims 12 to 20, in combination with a pharmaceutically acceptable excipient.

25

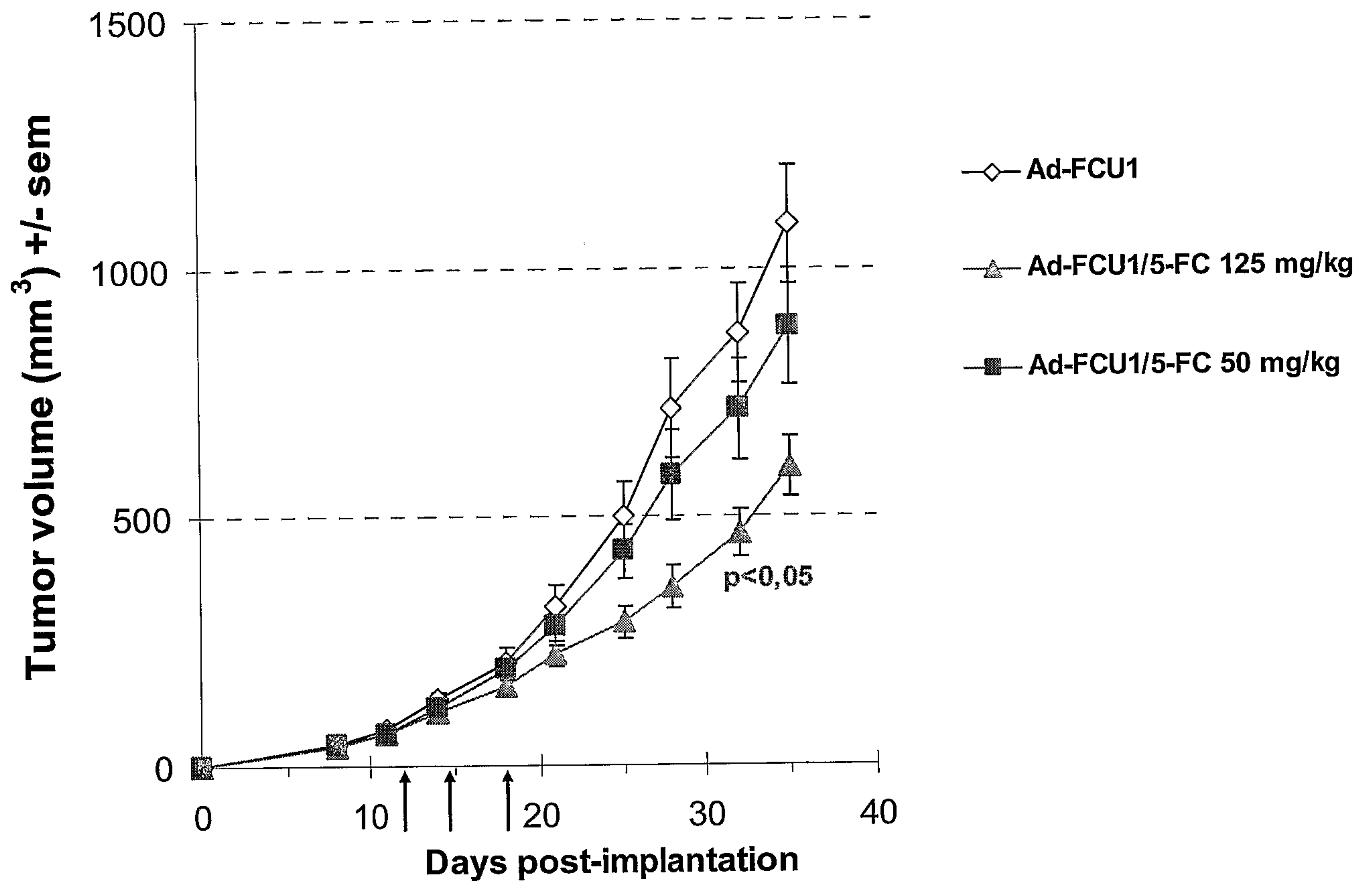
22. Use of the pharmaceutical composition according to claim 21 for the preparation of a medicament for the treatment of cancer.

1/3

Fig. 1 A



2/3

Fig. 1 B

3/3

Fig. 1 C

