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(54) Title: METHOD FOR COATING STENTS WITH DNA AND EXPRESSION OF RECOMBINANT GENES FROM DNA COATED STENT IN VIVO					
(57) Abstract					
The present invention describes DNA coated stents and methods of using the same to treat or prevent vascular diseases, such as restenosis.					

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METHOD FOR COATING STENTS WITH DNA AND EXPRESSION OF RECOMBINANT GENES FROM DNA COATED STENT IN VIVO

Field of the Invention:

5 This invention provides an intravascular DNA coated stent and methods for expressing recombinant genes *in vivo* using the DNA coated stent. DNA coated stents are useful for treating coronary and peripheral vascular diseases, particularly restenosis.

Background of the Invention:

10 Coronary and peripheral angioplasty is routinely performed to treat obstructive atherosclerotic lesions in the coronary and peripheral blood vessels. Following balloon dilation of these blood vessels, 30-40% of patients undergo restenosis.

Restenosis is the reclosure of a peripheral or coronary artery following trauma to that artery caused by efforts to open a stenosed portion of the artery, such as, for example, by balloon dilation, ablation, atherectomy or laser treatment of the artery. Restenosis is believed to be a natural healing reaction to the injury of the arterial wall. The healing reaction begins with the thrombotic mechanism at the site of the injury. The final result of the complex steps of the healing process can be intimal hyperplasia, the uncontrolled migration and proliferation of medial smooth muscle cells, combined with their extracellular matrix production, until the artery is again stenosed or occluded. Thus, restenosis is characterized by both elastic recoil or chronic constriction of the vessel in addition to abnormal cell proliferation.

20 Currently restenosis must be treated with subsequent angioplasty procedures. In an attempt to prevent restenosis, metallic intravascular stents have been permanently implanted in coronary or peripheral vessels. For example, U.S. 5,304,122 (Schwartz et al.) describe metal stents useful for treating restenosis after balloon angioplasty or other coronary interventional procedures. The stent is typically inserted by catheter into a vascular lumen and expanded into contact with the

diseased portion of the arterial wall, thereby providing mechanical support for the lumen. However, it has been found that restenosis can still occur with such stents in place; likely, because although the stent prevents elastic recoil of the artery, it fails to prevent the cell proliferation which leads to intimal hyperplasia. In addition, the stent itself can cause undesirable local thrombosis. To 5 address the problem of thrombosis, persons receiving stents also receive extensive systemic treatment with anticoagulant and antiplatelet drugs.

Stents coated with various compositions have been proposed. For example, Dichek et al. (Circulation **1989**, 80:1347-1353) describe coating stainless steel stents with sheep endothelial cells that had undergone retrovirus-mediated gene transfer for either bacterial β -galactosidase or human 10 tissue-type plasminogen activator. The stents were studied *ex vivo* in tissue culture dishes only. The feasibility of implanting the stents into arteries were not explored. This procedure of coating stents with cells is tedious, cumbersome and costly because cell have to be derived from a patient.

Other methods of providing therapeutic substances to the vascular wall by means of stents have also been proposed. For example, WO 91/12779, entitled "Intraluminal Drug Eluting 15 Prosthesis," and WO 90/13332, entitled "Stent With Sustained Drug Delivery," suggest coating stents with antiplatelet agents, anticoagulant agents, antimicrobial agents, anti-inflammatory agents, antimetabolic agents and other drugs to reduce the incidence of restenosis. Similarly, U.S. 5,571,166 and 5,554,182 (both to Dinh et al.) describe intraluminal stents coated with fibrin and heparin. The stent is used to treat restenosis.

20

SUMMARY OF THE INVENTION

Accordingly, one object of this invention is to provide an intravascular DNA coated stent.

A second object of this invention is to provide methods for expressing recombinant genes *in vivo* using the DNA coated stents.

A third object of this invention is to provide methods for treating coronary and peripheral vascular diseases, particularly restenosis and vein by-pass grafts, using the DNA coated stents.

The present inventors have now realized these and other objects through their discovery of methods for coating DNA on the outside surface of a stent.

5

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a restriction map of plasmid pCMV-CAT (VR1332).

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

10 DNA coated stents

Stents are devices which can be delivered percutaneously to treat coronary artery occlusions and to seal dissections or aneurysms of splenic, carotid, iliac and popliteal vessels. Suitable stents useful in the invention are polymeric or metallic. Examples of polymeric stents include stents made with biostable or bioabsorbable polymers such as poly(ethylene terephthalate), 15 polyacetal, poly(lactic acid), and poly(ethylene oxide)/poly(butylene terephthalate) copolymer. Examples of metallic stents include stents made from tantalum or stainless steel. Stents are available in myriad designs; all of which can be used in the present invention and are either commercially available or described in the literature. For example, a self-expanding stent of resilient polymeric material is described in WO 91/12779, entitled "Intraluminal Drug Eluting 20 Prosthesis." Alternatively, U.S. Pat. 4,886,062 describes a deformable metal wire stent. Commercial sources of stents include Johnson & Johnson, Boston Scientific, Cordis, Advanced Catheter Systems, and U. S. Catheter, Inc.

Suitable genes which encode for therapeutic proteins useful in the invention include genes which encode antiplatelet agents, anticoagulant agents, antimitotic agents, antioxidants, 25 antimetabolite agents, and anti-inflammatory agents. Preferred genes which encode therapeutic

proteins include proteins which can inhibit proliferation of cells (particular of vascular smooth muscle cells (vsmc), including:

HSV thymidine kinase (McKnight, 1980, Nucleic Acids Res. 8:5949; Mansour et al., 1988,

Nature 336:348-352),

5 β-galactosidase,

p16 (Chan et al., 1995, Mol. Cell. Biol. 15:2682-2688; Guan et al., Genes & Dev. 8:2939-

2952),

p21 (Harper et al., 1993, Cell 75:805; Xiong et al., 1993, Nature 366:701),

p27 (Toyoshima et al., 1994, Cell 78:67-74; Polyak et al., 1994, Cell 78:59-66),

10 p57 (Lee et al., 1995, Genes & Dev. 9:639-649; Matsuoka et al., 1995, Genes & Dev. 9:650-662),

retinoblastoma (Rb) (see Chang et al., 1995, Science, 267:518) or its mutants (see for example, Hamel et al., 1992, Mol. Cell. Biol. 12:3431), and

cytosine deaminase (WO 9428143; Wang et al., 1988, Can. Soc. Petrol. Geol. Mem.,

15 14:71).

The sequences of these gene products are known in the literature. Any DNA encoding these gene products can be used, including the cDNA sequences that are described in the literature.

Alternatively, fusion proteins of the above can be used. The preferred genes encode thymidine kinase (HSV-tk) or cytosine deaminase gene.

20 Any DNA encoding the above therapeutic proteins can be used. Preferably, the DNA sequence of the human cDNA encoding those proteins are used. The DNA can be naked or can be incorporated into a vector. Suitable vectors include shuttle vectors, expression vectors, retroviral vectors, adenoviral vectors, adeno-associated vectors and liposomes. Preferably a replication-defective adenovirus vector is used, such as pAd-BglII as described by Davidson et al. (1993, Nature Genet. 3:219-223). These vectors have been demonstrated to program high levels of

expression of genes in balloon-injured rat carotid, rabbit coronary and porcine femoral arteries (Ohno et al., Science 255:781 (1994); Guzman et al., Circulation 88:2838 (1993) and Barr et al., Gene Ther. 1:51 (1994)).

Various DNA constructs encoding HSV tk genes are available from American Type

5 Culture Collection, Rockville, MD, including ATCC 39371, ATCC 39369 and VR-2036.

Construction of adenoviral constructs containing HSV-tk is described in co-pending application 08/210,902, Example 1.

A list of preferred vectors is shown below in Table I.

Table 1

10 Plasmid	Description
CMVtkcitep27	CMVDSacIItk with cite-p27 (EcoRI-XbaI fragment from pcitep27) inserted at the BgIII site
CMVtkcitep27rev	CMVDSacIItk with CITE-p27rev (EcoRI-XbaI fragment from CITE p27rev) inserted into the BgIII site
CMVp27tk	pCMVp27citetk with the AatII-Ncol fragment (containing cite) deleted. Tk and p27 are still active
CMVp27citetk	plasmid resulting from the ligation of 3 fragments: (1) HindIII-EcoRI from 1332DSacII (=CMVtk DSacII) + (2) Sall-Ncol from p27 cite + (3) Ncol-HindIII from 1012-tk
CMVp27revcitetk	results from the ligation of 3 fragments: (1) HindIII-EcoRI from 1332 DSacII + (2) Sall-Ncol from p27revcite + (3) Ncol-HindIII from 1012-tk
CMVp27Sfcitetk	CMVp27citetk with the fragment SacII-FspI deleted. (region of p27 between the cdk2 binding site and the putative NLS)
CMVp27Nfcitetk	CMVp27 citetk with the fragment NarI-FspI deleted. (region of p27 between the cdk2 binding site and the putative NLS)
CMVp27Afcitetk	CMVp27citetk with the fragment Avall-FspI deleted. (region of p27 between the cdk2 binding site and the putative NLS)
CMVp27cdccitetk	CMVp27citetk with the cdc2 kinase consensus site mutated (TPKK to AAGG)
CMVp27SFtk	CMVp27tk with the SacII-FspI fragment deleted (that contains the region of p27 between the cdk2 binding site and the putative NLS)
CMVp27NFtk	CMVp27tk with the NarI-FspI fragment deleted (that contains the region of p27 between the cdk2 binding site and the putative NLS)

Plasmid	Description
CMVp27Aftk	CMVp27tk with the Avall-Fspl fragment deleted (that contains the region of p27 between the cdk2 binding site and the putative NLS)
CMVp27SNtk	CMVp27citetk with the SacII-Ncol fragment deleted (containing the C-terminus of p27)
CMVp27Sp21Ftk	CMVp27tk with the HindIII-Ncol fragment from 1012-p21N inserted between the SacII and FspI sites
CMVp27Np21Ftk	CMVp27tk with the HindIII-Ncol fragment from 1012-p21N inserted between the NarI and FspI sites
CMVp27Sp21Fcitetk	CMVp27citetk with the HindIII-Ncol fragment from 1012-p21N (containing the N-terminal part of p21 coding sequence) inserted between the SacII and FspI sites in the p27 coding region
CMVp27Np21Fcitetk	CMVp27citetk with the HindIII-Ncol fragment from 1012-p21N inserted between the NarI and FspI sites
CMVp27Sp21	Clal-SacII fragment from CMVp27citetk fused to the Ncol-Clal fragment of VR 1012-p21N (giving a fusion between p27N and p21N)
CMVp27Np21	Clal-NarI fragment from CMVp27 citetk fused to the Ncol-Clal fragment of VR 1012-p21N (giving a fusion between p27N and p21N)
CMVp27Dkcitetk	CMVp27citetk with all K mutated to R between ATG and SacII of p27. There is an additional 'c' before the SacII site
CMVp27Ncitetk	CMVp27citetk with a stop codon between SacII and XbaI in p27 (only the N-terminus of p27 remains)
CMVp27NLScitetk	CMVp27citetk with a NLS (GRRRRA = ATF2 NLS) and a stop codon between SacII and XbaI in p27 (only the N-terminus of p27 remains)
CMVp27DKNcitetk	CMVp27Dkcitetk with a stop codon between SacII and XbaI in p27 (only the N-terminus of p27 remains)
CMVp27DKNLScitetk	CMVp27Dkcitetk with a NLS (GRRRRA = ATF2 NLS) and a stop codon between SacII and XbaI in p27 (only the N-terminus of p27 remains)

The stent can optionally be coated with other therapeutic proteins such as heparin, hirudin, angiopeptin, ACE inhibitors, growth factors (such as IL₂₋₁₀), nitric oxide or with DNA encoding the same.

5 Suitable polymerizable matrix useful for binding the DNA to the stent include any monomeric biocompatible material which can be suspended in water, mixed with DNA and

subsequently polymerized to form a biocompatible solid coating. Thrombin polymerized fibrinogen (fibrin) is preferred.

The stent is preferably coated with about 50 μ g to about 5 mg of DNA. The thickness of the polymerizable matrix containing the DNA is typically about 5-500 μ m. The matrix preferably 5 covers the entire surface of the stent.

Methods for coating a stent with DNA

Methods for coating surfaces are well known in the art and include, for example, spray coating, immersion coating, etc. Any of these methods can be used in the invention. For example, 10 a liquid monomeric matrix can be mixed with the DNA and polymerization initiated. The stent can then be added to the polymerizing solution, such that polymer forms over its entire surface. The coated stent is then removed and dried. Multiple application steps can be used to provide improved coating uniformity and improved control over the amount of DNA applied to the stent.

In a preferred embodiment, an aqueous mixture of DNA and human thrombin is added to 15 an aqueous suspension of fibrinogen. The fibrinogen concentration of the suspension is typically between about 10-50, preferably about 20-40, more preferably about 30 mg/ml. The concentration of the DNA in the aqueous mixture is typically about 1-20, preferably about 5-15, more preferably about 10 μ g/ml. The amount of human thrombin in the aqueous mixture about 0.5 to 5, preferably about 1 U. The DNA and human thrombin are first added together to form a mixture and that 20 mixture is then added to the fibrinogen suspension. Thereafter, a stent is dipped into the polymerizing solution. After the mixture solidifies, the stent is removed.

Methods for placing the DNA coated stent within the vasculature

The stent can be placed onto the balloon at a distal end of a balloon catheter and delivered 25 by conventional percutaneous means (e.g. as in an angioplasty procedure) to the site of the

restriction or closure to be treated where it can then be expanded into contact with the body lumen by inflating the balloon. The catheter can then be withdrawn, leaving the stent of the present invention in place at the treatment site. The stent may therefore provide both a supporting structure for the lumen at the site of treatment and also a site for instillation of DNA at the lumen wall. The site of instillation can be either an arterial or venous wall.

Site specific instillation of a solution of DNA at an arterial wall using a balloon catheter has previously been described by the present inventors in U.S.S.N. 08/376,522, now allowed. Thus, the viability of incorporation of "naked DNA" into arterial cells and subsequent expression of that DNA has previously been demonstrated.

The stent can be placed in any peripheral or coronary artery or vein. The stent is preferably placed at the site of injury either immediately or soon after mechanical vessel injury.

Methods for expressing recombinant genes *in vivo* using the DNA coated stents

Recombinant genes can be expressed *in vivo* by implanting the DNA coated stents of the present invention in an artery or vein of a patient. Gene expression is continuous and can optionally be controlled with viral promoters or cell specific promoters such as smc, in particular sm 22 α .

SM 22 α is a putative calcium-binding protein that is expressed in cardiac, smooth and skeletal muscle lineages during mouse embryogenesis and in adult smcs (Lees-Miller et al., 1987, J. Biol. Chem. 262:2988; Duband et al., 1993, Differentiation, 55:1; Shanahan et al., 1993, Circ. Res. 73:193). Promoters of smcs are of particular interest because they direct transgene expression specifically in vascular and not visceral smooth muscle cells.

Method of treating coronary and peripheral vascular diseases with the DNA coated stents

Coronary and peripheral diseases, including restenosis, atherosclerosis, coronary artery bypass graft stenosis, vein bypass graft stenosis or restenosis, arterio-venous fistula stenosis or restenosis, 5 peripheral artery stenosis or restenosis, can be treated by implanting the DNA coated stent of the present invention, into a coronary or peripheral artery or vein of a patient. Suitable patients include mammals such as dogs, horses, cattle, humans, etc. Humans are preferred patients.

In an alternate embodiment, the DNA coated stent is implanted into the patient and an antiplatelet agent, anticoagulant agent, antimicrobial agent, anti-inflammatory agent, antimetabolic 10 agent, antimitotic agent or other drug is administered to reduce the incidence of restenosis.

Suitable anticoagulant agents can include drugs such as heparin, coumadin, protamine, hirudin and tick anticoagulant protein. Suitable antimitotic agents and antimetabolite agents can include drugs such as colchicine, methotrexate, azathioprine, vincristine, vinblastine, fluorouracil, adriamycin and mutamycin. Ganciclovir or acyclovir is preferably administered.

15 Having generally described this invention, a further understanding can be obtained by reference to certain specific examples which are provided herein for purposes of illustration only and are not intended to be limiting unless otherwise specified.

EXAMPLES**20 Procedure for coating the stents using thrombin polymerized fibrinogen (fibrin)**

Human fibrinogen was dissolved in water at concentrations of 30 mg/ml. 100 μ l of different concentrations of fibrinogen were used in the preparation. Fibrinogen was diluted in water when necessary and transferred to an Eppendorf tube.

25 Plasmid CAT (pCMV-CAT) was dissolved in water at concentrations of 10 mg/ml. The DNA was diluted in water in an Eppendorf tube to a final volume of 100 μ g/ml. 1 U of human

thrombin was added in the DNA solution and mixed gently.

The mixture of DNA and thrombin was added to the fibrinogen solution. After brief mixing, the mixture was loaded into Tygon tubing (1/8" ID; 1" to 1 1/4" long, Formulation S-50-HL) which was sealed at one end. A Johnson & Johnson metallic stent, 5.0 mm, was immediately 5 inserted into the DNA / fibrinogen / thrombin mixture in the tubing, and incubated until the mixture solidified. The fibrin-coated stent was removed and air dried.

The coated stent was installed into the left and right pig iliac femoral arteries using routine surgical procedures.

Three days after installment of the stents, the arteries were excised, and homogenized 10 using glass dowels. The protein extract was freeze-thawed 3x, heat-inactivated for 15 minutes at 65°C and the supernatant was collected. 300 µg of the soluble protein was used for CAT assays. The results were read using a Betagen machine which measures the acetylation of CAT.

Implantation of the DNA coated stents in the vasculature

15 Juvenile domestic pigs (3 months, 15-20 kg) of either sex are given aspirin (10 mg/kg) orally two days prior to surgery and three times weekly for the duration of the study.

Pigs were anesthetized using Telazol (6.0 mg/kg IM) and xylazine (2.2 mg/kg IM) and intubated with an endotracheal tube. 1% isofluane is administered throughout the surgical procedure. 150 units/kg of heparin were administered via IV prior to surgery.

20 Following prepping and draping, a midline abdominal incision was made, extending caudally to the pubis through the skin and fascia, and the abdominal musculature was divided in the midline. The peritoneal cavity was opened and the intestines retracted cranially using a Balfour retractor. Using a combination of blunt and sharp dissection, each iliac and femoral artery was isolated from their cranial extent, caudally to beyond the bifurcation of the femoral artery.

The internal iliac artery was ligated at its most caudal point with 2-0 silk. Ties were looped around the proximal iliac and femoral arteries, then temporarily secured. An arteriotomy of the internal iliac artery was made just proximal to the ligature. The balloon-expandable stent was advanced to the iliac artery and the balloon inflated using an inflation device at pressure of 6 atmospheres. The balloon was deflated and the balloon catheter removed, then the internal iliac artery was ligated followed by release of the loops. Restoration of arterial blood flow was confirmed. The peritoneum and the muscle were closed with 1-0 vicryl continuous sutures, and the fascial layer closed with 1-0 vicryl interrupted sutures. The skin was closed with staples.

Results

The following data demonstrate the expression of the reporter gene, CAT, in porcine arteries in vivo following implantation of the DNA coated stent.

	Fibrinogen (mg)	Reporter DNA (μg)	% CAT activity	days after stent placement
1	15	100	8.4, 23.1, 6.2	3
	15	500	7.5, 3.9	3
	15	1000	2.0	3
2	15	100	3.4	7
3	15	100	2.54	10
4	10	100	2.8	3
5	10	100	0.9	10

The above data was used to determine the optimal dose of DNA and fibrinogen. This data supports the principle that DNA coated stents can be implanted in a patient, the gene is expressed as a protein, and sufficient quantities of protein are produced to allow measurement thereof.

Having now fully described the invention, it will be apparent to one of ordinary skill in the art that many changes and modifications can be made thereto without departing from the spirit or scope of the invention as set forth herein.

WHAT IS CLAIMED IS:

1. A device comprising an intravascular stent coated with a polymerizable matrix and DNA encoding a therapeutically useful protein.
2. The device of claim 1, wherein the stent is a polymeric or metallic stent.
3. The device of claim 2, wherein the stent is stainless steel.
4. The device of claim 1, wherein the therapeutically useful protein is a gene encoding an antiplatelet agent, anticoagulant agent, antimitotic agent, antioxidant, antimetabolite agent, or anti-inflammatory agent.
5. The device of claim 4, wherein the therapeutically useful protein inhibits the proliferation of cells.
6. The device of claim 5, wherein the therapeutically useful protein is thymidine kinase, p16, p21, p27, p57, retinoblastoma or cytosine deaminase.
7. The device of claim 6, wherein the therapeutically useful protein is thymidine kinase or cytosine deaminase.
8. The device of claim 1, wherein the stent is coated with about 50 µg to about 5 mg of DNA.
9. The device of claim 1, wherein the polymerizable matrix is fibrinogen.
10. A method for expressing therapeutically useful amounts of recombinant genes in vivo, comprising the step of instilling a device into the vasculature of a patient, wherein the device comprises a stent coated with a polymerizable matrix and DNA encoding a therapeutically useful protein.
11. The method of claim 10, wherein the therapeutically useful protein is an antiplatelet agent, anticoagulant agent, antimitotic agent, antioxidant, antimetabolite agent, or anti-inflammatory agent.

12. The method of claim 11, wherein the therapeutically useful protein inhibits the proliferation of cells.
13. The method of claim 12, wherein the therapeutically useful protein is thymidine kinase, p16, p21, p27, p57, retinoblastoma or cytosine deaminase.
14. The method of claim 13, wherein the therapeutically useful protein is thymidine kinase or cytosine deaminase.
15. A method for treating or preventing a vascular disease, comprising the step of implanting a device into the vascular of a patient, wherein the device comprises a stent coated with a polymerizable matrix and DNA encoding a protein therapeutically useful for treating the vascular disease.
16. The method of claim 15, wherein the therapeutically useful protein is an antiplatelet agent, anticoagulant agent, antimitotic agent, antioxidant, antimetabolite agent, or anti-inflammatory agent.
17. The method of claim 16, wherein the therapeutically useful protein inhibits the proliferation of cells.
18. The method of claim 17, wherein the therapeutically useful protein is thymidine kinase, p16, p21, p27, p57, retinoblastoma or cytosine deaminase.
19. The method of claim 18, wherein the therapeutically useful protein is thymidine kinase or cytosine deaminase.
20. The method of claim 19 wherein the disease is restenosis, atherosclerosis, coronary artery bypass graft stenosis or restenosis, arterio-venous fistula stenosis or restenosis, or peripheral artery stenosis or restenosis.

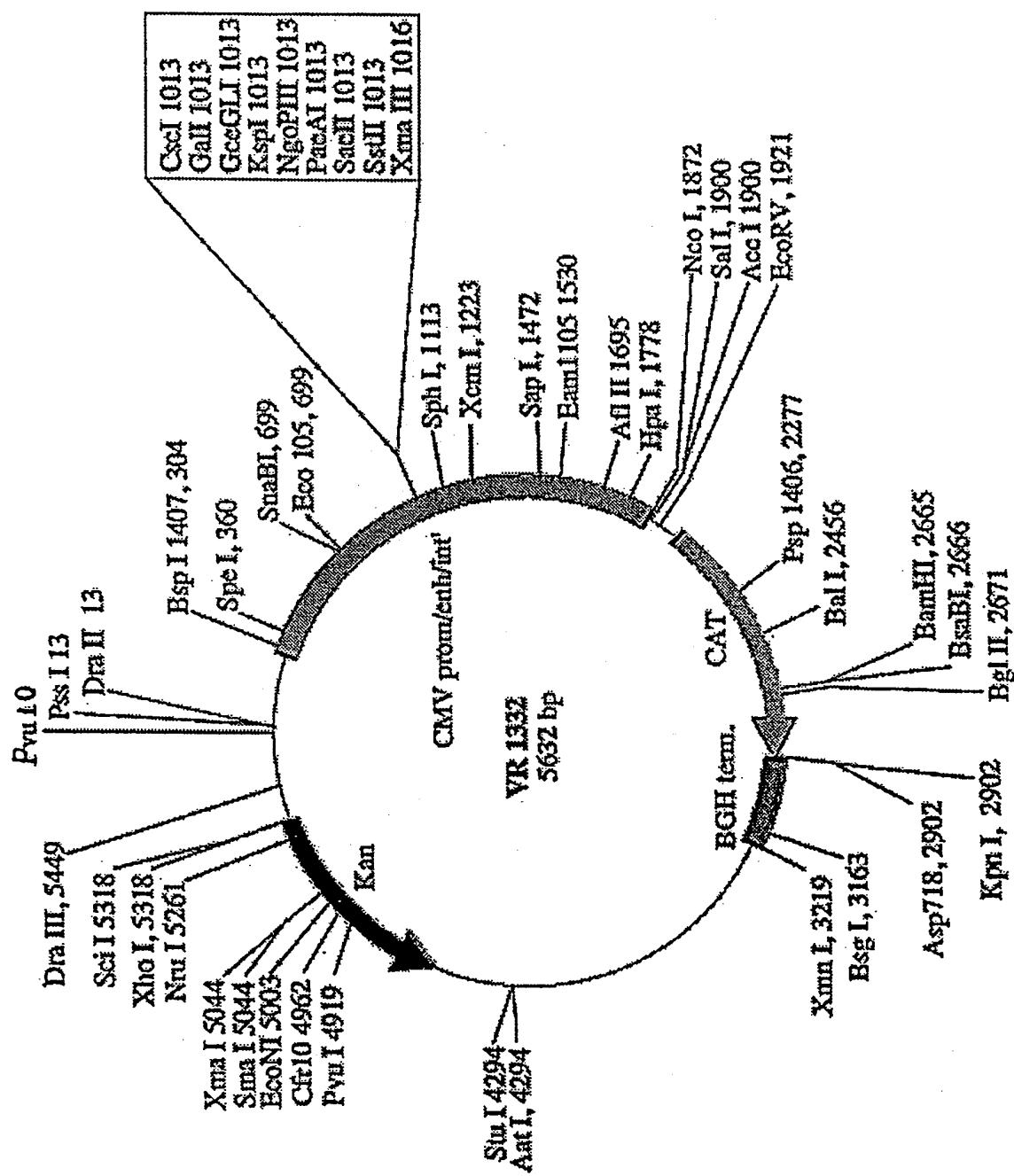


FIG. 1
SUBSTITUTE SHEET (RULE 26)

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US98/13301

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : A61F 2/04; A61N 1/30
 US CL : 604/52; 623/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 604/52; 623/12

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
 604/19, 53, 104, 195; 623/1, 11, 900

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,628,785 A (SCHWARTZ et al) 13 May 1997, entire document.	1-20
Y,P	US 5,698,531 A (NABEL et al) 16 December 1997, entire document.	1-20
A,P	US 5,686,409 A (MCFADDEN et al) 11 November 1997, col. 3 line 45 to col. 4 line 29; col. 5 lines 56-67; col. 6 lines 7-15, col. 78 lines 44-55; col. 10 lines 20-54; col. 11 lines 13-42; col. 12 lines 13-45.	1-20

Further documents are listed in the continuation of Box C.

See patent family annex.

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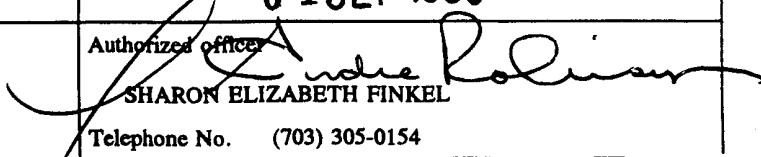
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