METHOD FOR TREATMENT OF TUMORS USING NORDIHYDROGUAIARETIC ACID DERIVATIVES

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BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to the use of nordihydroguaiaretic acid derivatives, in particular derivatives containing substituents of naturally occuring amino acids, for the treatment of tumors and viral infections.

2. Background Information

Carcinogenesis is a multistage event affected by a variety of genetic and epigenetic factors and is typified by the outbreak of uncontrolled cell growth originated from different tissues. A universal goal for anticancer research lies in the development of a clinical treatment that is highly effective in curtailment of tumor growth, non-toxic to the host, and is affordable for most patients. Drugs that focus on the inhibition of targets that are unique to dividing cells should be effective chemotherapeutic agents without the risk of substantial side effects.

Cells pass through many checkpoints as they proceed through the cell cycle. Certain criteria must be met in order to pass each of these checkpoints. In the G2/M transition, the most essential regulator is the cyclin-dependent kinase CDC2. This kinase binds tightly to the regulatory protein cyclin B, and this complex, also called the maturation promoting factor (MPF), is responsible for stimulating a myriad of events that lead to the cell's entry into early prophase (1). Not surprisingly, the loss or deactivation of either component of the MPF will block cellular progression out of G2.

The expression and activity of the MPF is regulated at different levels. Cyclin B protein levels slowly rise through the G1 and S phases of the cell cycle, peak during the G2 to M phase transition, and drop sharply during mitosis (2). The CDC2 protein, on the other hand, is always present during the cell cycle, although levels rise slightly in the last stages of the G2 phase (3). The activity of the protein is dependent on the association with the appropriate cyclin, as well as on the dephosphorylation of its inhibitory sites by the phosphatase CDC25C (4,5). It has been shown that the failure of this dephosphorylation initiates G2 arrest in response to DNA damage by radiation or chemical action. Recent evidence also suggests that any remaining active CDC2 may be transported outside the nucleus following DNA damage (6).

A number of naturally occurring derivatives of the plant lignan nordihydroguaiaretic acid (NDGA) have been shown to block viral replication through the inhibition of viral transcription. This earlier work has shown that NDGA derivates, originally isolated from *Larrea Tridentata* and subsequently synthesized chemically, can inhibit the production of HIV (7,8), HSV (9), and HPV transcripts (10) by the deactivation of their Sp1-dependent promoters. Unexpectedly, one of these derivatives, tetra-O-methyl NDGA, appears to also induce cell cycle arrest in mammalian cell lines. The evidence presented hereinbelow demonstrates that M_4N is capable of inducing G2 arrest in mammalian cells without detected toxicity, and supports the view that this arrest is due to the inhibition of the cyclin-dependent kinase CDC2.

Human papillomavirus (HPV) infection causes unregulated cell growth in many types of squamous epithelial cells, resulting in afflictions ranging from benign pallilomae (warts) to cervical, penile and mouth cancer. The strong association of these cancers with HPV and the widespread occurrence of infection denotes the importance of developing an anti HPV therapy.

Most, if not all, viruses, including those replicatively active mutants, are host dependent. They require the participation of certain cellular factors for supporting viral growth. Host cellular factors, unlike viral proteins, are not under mutational pressure and are in general, structurally invariable. Thus, compounds that block the usage of these cellular factors at different stages of

the viral life cycle are likely to be good candidates as mutation insensitive antiviral drugs. Several studies using cellular factors as alternative targets for the inhibition of HIV-1 have been reviewed (11).

Applicants reported earlier that 3'-0 -methylated NDGA (i.e. Mal.4), isolated from Creosote bush (*Larrea tridentata*) can specifically block basal HIV transcription, Tat-regulated transactivation, and HIV replication in human cell culture(8, 12, 13). Mal.4 exerts its effects by interfering with the binding of transcription factor Sp1 to the promoter of the HIV proviral template. The target of Mal.4 is mapped to nucleotides -87 to -40, the Sp1 binding sites of the HIV long terminal repeat (LTR). The unmodified NDGA, *in vitro*, does not inhibit HIV transcription and has no effect on Sp1 binding (8).

Isolation and purification of plant lignans, however, is labor intensive and costly. In anticipation of the possible clinical use of plant lignans in controlling Sp1-regulated viral and tumor growth in humans, nine different methylated NDGA activities were synthesized chemically using unmethylated NDGA as the parent substrate in large quantities with low cost (7). At drug concentrations below 30 μM, tetra-O-methyl NDGA was found to be most effective in the control of replication HIV via inhibition of Sp1 regulated proviral transcription and transactivation (7). This study has since been extended to the control of the growth of Herpes simplex virus (HSV-1 and HSV-2) (9). Herpes simplex immediate early (IE) ICP4 gene is essential for HSV replication (14). Its promoter region possesses eight Sp1 consensus binding sites (15), five of which are required for ICP4 gene expression. It thus makes the ICP4 gene a good candidate for such testing. Applicants have found that both 3-O-methyl NDGA (Mal. 4) and tetra-O-methyl NDGA (M_4N) are effective transcriptional inhibitors for HSV ICP4 gene expression in Vero cells via the blocking of Sp1 protein binding to the ICP4 promoter as shown by the electrophoretic mobility shift assay (9).

When the anti-HSV activities of M4N and Mal. 4 were tested and compared to that of acycloguanosine (acyclovir, ACV) in infected Vero cells, Applicants observed that the IC_{50} for M_4N varied between 11.7 μM to 4 μM for 10 passages of HSV-1 and 4 passages of HSV-2 without obvious uprising

trend for requirement of higher drug concentration. However, the IC_{50} for ACV increased from 7 μM for the first viral passage to 444 μM for the tenth passage of HSV-1 and to >88 μM for the fourth passage of HSV-2 indicating their rapid build-up of drug resistance against ACV in Vero cells. Consequently, while the selective index, S.I. (TC_{50}/IC_{50}) remained relatively stable for M_4N, the S.I. for ACV dropped 60 fold following the viral passages in Vero cells (9). Thus M_4N is a mutation insensitive drug. It can inhibit ACV resistant HSV effectively (9).

Due to the fact that Sp1 is an important cellular transcription factor (16), the possible inhibitory effect of this class of compounds on the expression of Sp1-regulated cellular genes should be addressed. Ma1.4 cannot displace Sp1 once it is stably bound to its binding sites (8). It therefore seemed likely that NDGA derivatives would have a greater effect on Sp1-regulated genes in proliferating cells than on the expression of Sp1-regulated housekeeping genes in stationary cells. In the former case, the drug will be able to compete with Sp1 protein for the Sp1 sites in gene promoters during DNA synthesis, while in the latter case, the drug may have little effect on the transcribing chromatin of housekeeping genes with Sp1 protein already stably bound at their promoters. This, in fact, has been shown to be the case. As will be demonstrated below, by using gene array studies with 9600 expressed genes, Applicants found products of most Sp1 regulated genes remained at similar levels, and not affected by the drug treatment of cervical cancer cells C3 in culture (Figure 5). Even so, the relatively low selective index of M_4N certainly limits its use to the lowest effective concentration if the drug must be used systemically. On the other hand, human papilloma virus induces solid cervical and oral tumors initially through the Sp1 regulated expression of HPV E_6E_7 genes (17). Applicants reasoned that if drug can be delivered *in situ*, and be kept only in the tumor area, the drugs of high concentration may be used to effectively destroy the tumor with little damage to the patients.

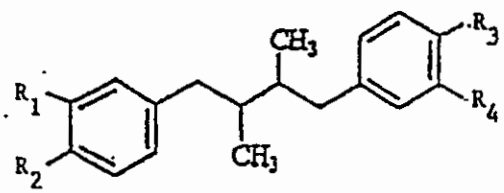
Survivin is an inhibitor of apoptosis that is abundantly expressed in many human cancers (35), but not in normal adult human tissue, and is considered a

possible modulator of the terminal effector phase of cell death/survival. (36). Survivin is expressed in G_2-M in a cell cycle-dependent manner, binding directly to mitotic spindle microtubules. It appears that survivin phosphorylation on Thr34 may be required to maintain cell viability at cell division (37), and expression of a phosphorylation-defective survivin mutant has been shown to trigger apoptosis in several human melanoma cell lines (38). Phosphorylated survivin acts on the caspase pathway to suppress the formation of caspase-3 and caspase-9, thereby inhibiting apoptosis. (Ref. 39, page 10 presents an outline of apoptosis signalling pathways.) Thus, compounds that reduce the expression of survivin will be expected to increase the rate of apoptosis and cell death. CDC-2 has been shown to be necessary for survivin phosphorylation (37).

SUMMARY OF THE INVENTION

Accordingly, it is one object of the invention to provide compounds and compositions for use in the treatment of cancerous and noncancerous tumors in animals, particularly in mammals, and most particularly in humans. According to this aspect of the invention, novel nordihydroguaiaretic acid derivatives are provided that inhibit tumor growth.

By nordihydroguaiaretic acid derivatives is meant compounds of the structure



(I)

wherein R_1, R_2, R_3 and R_4 independently represent -OH, -OCH_3, -O(C=O)CH_3, or an amino acid residue, but are not each -OH simultaneously. Amino acid substituents are intended to include, *inter alia*, alanine, arginine, asparagine, aspartate, cysteine, glutamate, gluamine, glycine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine,

proline, serine, threonine, tryptophan, tyrosine, valine, 5-hydroxylysine, 4-hydroxyproline, thyroxine, 3-methylhistidine, ε-N-methyllysine, ε-N,N,N-trimethyllysine, aminoadipic acid, γ-carboxyglutamic acid, phosphoserine, phosphothreonine, phosphotyrosine, N-methylarginine, and N-acetyllysine.

Particularly preferred compounds for use according to the invention are M_4N and G_4N, which are shown in Figure 1.

It is a further object of the invention to provide a method for treating cancerous and noncancerous tumors by the use of these novel derivatives, and by similar derivatives that are known in the art, but have not heretofore been used for the treatment of tumors. The method should be especially effective against rapidly proliferating cell types containing the cyclin dependent kinase CDC2. It is a further object of the invention to provide a method of inhibiting CDC2 in a eukaryotic cell cycle, particularly in an animal cell, more particularly in a mammalian cell, and most particularly in a human cell.

Tumors to be treated include any tumor that is sensitive to the above-mentioned compounds used according to the methods of the invention. In particular, this includes rapidly dividing cancerous and benign tumors that are sensitive to inhibition of the cyclin-dependent kinase CDC2 cycle.

The term "cancerous tumor" is intended to include any malignant tumor that may or may not have undergone metastasis. The term "noncancerous tumor" is intended to include any benign tumor. These terms are used as customarily understood by persons of skill in the art.

Examples of benign and malignant tumors which may be treated by the compositions and methods of the invention can be found in Table 1-1 of Cancer Biology (Raymond W. Ruddon, Cancer Biology, 3rd Ed., Oxford Univ. Press, 1995, incorporated herein by reference). Tumors to be treated include those that are known to be of viral origin, as well as those that are not of viral origin. The compositions and methods of the invention are expected to be particularly useful in the treatment of solid tumors.

It is yet another object of the invention to provide a method of inhibiting the cyclin-dependent kinase CDC2 cycle. This method will be useful in

inhibiting cell proliferation, particularly in rapidly dividing cell types.

In a preferred embodiment, the compounds and compositions described herein are used in the treatment of HPV-induced tumors. HPV-induced tumors include in particular, but are not limited to, cervical, oral, penile and head and neck cancers that are associated with HPV infection. The method comprises local application of nordihydroguaiaretic acid derivatives, in particular tetra-O-methyinordihydroguaiaretic acid (M_4N) and tetraglycinal nordihydroguaiaretic acid (G_4N), to cancerous and non-cancerous HPV-induced tumors.

It is yet another object of the invention to provide a method of inhibiting viral replication and growth by the administration of the compounds of formula I containing amino acid substituents. Preferred for use in this method are compounds in which the amino acid substituents R_1, R_2 R_3 and R_4 are identical.

It is a further object of the invention to provide a method of inhibiting survivin production in a eukaryotic cell cycle in a cell that expresses survivin, particularly in a cancer cell. The inventors have found that the nordihydroguaiaretic acid derivatives of the invention downregulate survivin mRNA and protein levels and activate both CDC-2 and the caspase pathway, thereby increasing the level of apoptosis in cell populations where survivin is expressed. This method should provide a treatment for cancers where survivin is expressed by suppressing or eliminating survivin expression, thereby increasing the rate of apoptosis.

It is contemplated that M_4N, G_4N and other derivatives will be administered by local injection into the tumors, generally along with pharmaceutically acceptable diluents, excipients and carriers. In preferred embodiments, M_4N is injected into tumors in the form of a DMSO solution, and G_4N is administered in PBS solution. The use of G_4N will complement the use of M_4N, particularly in larger tumors (> 2 cm^3), due to its water solubility, which allows it to spread to a larger region of the tumor. Other water-soluble and water-insoluble nordihydroguaiaretic acid derivatives can be similarly employed, according to the invention. These may also be employed in lipid based formulations for systemic delivery, as known and

used in the art.

By pharmaceutically acceptable diluents, excipients and carriers is meant such compounds as will be known to persons of skill in the art as being compatible with M_4N, G_4N and other similar derivatives and suitable for local administration to a human or other mammal according to the invention. Although the examples hereinbelow describe administration by means of local injection, other means of local administration, such as topical application or targeted delivery to the tumor site, may also be used.

The amount of compound administered to obtain the desired treatment effect will vary but can be readily determined by persons of skill in the art. The amount of dosage, frequency of administration, and length of treatment are dependent on the circumstances, primarily on the size and type of tumor. However, dosages of from 10 mg to 20 mg of either M_4N alone or with similar amounts of G_4N per gram tumor weight at intervals from daily to weekly or less frequently may be mentioned for purposes of illustration. Administration of 50 μl to 100 μl of M_4N dissolved in DMSO at a concentration of 200 mg/ml, either alone or in combination with G_4N, is expected to be effective in many cases for tumors of 1-1.5 cm^3.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1. Structures of M_4N and G_4N

Figure 2A. HPV-16 LCR showing region of E_6/E_7 promoter (pPV16P97) and the binding site for Sp1 protein.

Figure 2B. The effect of M_4N on the E_6/E_7 promoter activity in C-33A cells. (Inhibition of E_6/E_7 promoter driven luciferase gene transcription by different concentration of M_4N)

Figures 3A-3C. Inhibition of Viral E_6 and E_7 RNA Transcripts by 40 μM M_4N. Total RNA isolated from C_3 cells treated with either 40 μM M_4N or

DMSO alone in growth media for 71 hours was subjected to relative RTPCR. The RTPCR samples were removed after increasing cycles of amplification and resolved on an agarose gel. The gel photographs (3A and 3B) indicate these cycles, the presence of (+) or absence (-) of M_4N in the growth media, and two digests of a pGMT vector used as size markers. The amplification map (2C) indicates the two expected size products of the amplification, resulting from the alternate splicing of the early viral RNA transcript.

Figure 4A. Inhibition of C3 Cell Growth by M_4N.

Figure 4B. Inhibition of C3 Cell Growth Following the Removal of M_4N.

Figures 5A-5B. Effect of M_4N on gene expression in C3 cells as examined by the GENE Assay analysis. 5A. GENE expressed in C3 cells after > 2 hours of DMSO treatment (C3 DMSO). 5B. GENE expressed in C3 cells after > 2 hours of M_4N treatment using DMSO as solvent (C3 M_4N).

Figures 6A-6B. Visual observations of tumor-bearing mice following M_4N treatment. 6A. Mice bearing single tumors were treated with in situ injection of DMSO (#3) or M_4N (#7). *In situ* injection of M_4N was also made to one of the two tumors grown in mouse #9. 6B. M_4N treated tumor (white scar) with untreated tumor from the same mouse, #9 as described in Table 2.

Figure 7. Histopathology Effect of M_4N and M_4N/G_4N on Tumor Growth in Mice. First column from the panel presents the large size of tumors from mouse #4, 10, 12, following DMSO treatment (CON) as compared to the relatively small drug treated (M_4N or M_4N/G_4N) lesions from mouse #12, 10, 27 and 20 (M_4N). The subsequent photographs are examples of these tumors examined at 100X magnification (A, B, C, DMSO treated, D untreated, E, F, G, H, M_4N or M_4N/G_4N treated) mice (Table 1 and Table 2).

Figure 8. HSV-1 replication in the absence of drugs (HSV-C, HSV-SC), in the

presence of ineffective drugs ($ABDS_1$ ["HSV-$ABDS_1$"], $ABDS_2$ ["HSV-$ABDS_2$"])and in the presence of effective drugs (M_4N ["HSV-4N"] and ACV ["HSV-ACV"]).

Figure 9. M_4N Causes Growth Arrest in Mammalian Cells. (a-d) C3, CEM-T4, C33a, and TC-1 cells were treated with different concentrations of M_4N. The number of cells present at the initiation of the experiment is indicated as Day 0. After three days the number of viable cells were counted and plotted versus the M_4N concentration. (e) C3 cells were split into T-25 flasks with 5 X 10^3 cells per flask and given either M_4N in 1% DMSO in media or 1% DMSO in media alone (first media change). After 3 days, one-half of the M_4N treated cells were given fresh media containing only 1% DMSO (M-D), while the rest of the cells were given fresh media with the same conditions (second media change). The cells were counted daily and plotted versus the time of treatment.

Figure 10. Cells Treated With M_4N Arrest in G2/M. C3 cells (a), C33a cells (b), CEM-T4 cells (c), and TC1 cells (d) were grown for three days in media containing either 1% DMSO or 1% DMSO with M_4N (M_4N). The cells were trypsinized, fixed with ethanol, stained with propidium iodide, and were subsequently analyzed by flow cytommetry. The data is displayed as number of cells (3-5 X 10^4 total cells) versus propidium iodide stain intensity. The indicated stages of the cell cycle are labeled and correspond to the relative cellular DNA compliment as determined by staining intensity.

Figure 11. C3 Cells Treated With 40μM M_4N Demonstrate G2 Cell Structures. C3 cells were grown on coverslips for three days in media containing either 1% DMSO (Control) or 1% DMSO with 40μM M_4N (M_4N). Samples were fixed with ethanol and incubated with antibodies against α (green) and γ (orange) tubulin (a) or with the DAPI DNA stain (b). Cells were examined by fluorescence microscopy.

Figure 12. CDC2 and Viral Oncogenes are Reduced by M_4N. C3 cells were grown for different amounts of time (numbers are in hours) in media containing either 1% DMSO (D) or 1% DMSO with 40 μM M_4N (M). After the specified times, total protein or total RNA was isolated from the cells. Western blots (a - top two panels) were performed using antibodies against CDC2 or cyclin B with the same nitrocellulose filter. Kinase assays (a - bottom two panels) were performed, following immunoprecipitation with antibodies to cyclin B, by incubation with γ-^{32}P ATP and histone H1. The coomassie stain of the PAGE gel is included as control for loading. Kinase assays for 24 and 72 hour drug treatments were performed separately. Northern blots (b) were performed on total RNA extracts. Filters were incubated overnight with random-primed ^{32}P-labeled DNA for CDC2 or GAPDH, washed, and exposed to film for three days. The same filter was used to test CDC2 and GAPDH RNA. rtPCR analysis (c) was performed on total RNA extracts with primers hybridizing to regions within either HPV-16 E7 or GAPDH. Both primer pairs were used in the same reactions, and the products were analyzed by agarose gel electrophoresis.

Figure 13. Electrophoretic mobility shift assay (EMSA) of G_4N interaction with the HIV Sp1-binding sites (-87 to -49). (A) G_4N inhibition of Sp1-167D binding to ^{32}P labeled HIV Sp1 DNA template. Lane 1, template alone; lane 2, template plus 0.1 μg Sp1-167D; lanes 3-9, template incubated with increasing concentrations of G_4N (0.25 to 1.75 mM prior to the addition of 0.1 μg Sp1-167D. (B) G_4N displacement of Sp1-167D bound to HIV template. Lane 1, template alone; lane 2, template plus 0.1 μg Spl-167D plus 100-fold excess of unlabeled template; lane 3, template plus 0.1 μg Spl-167D; lanes 4-10, Spl/DNA complex challenged with increasing concentrations of G_4N (0.25 to 1.75 mM); lane 11, template incubated in reaction buffer containing 1.75 mM G_4N. (C) Sp1-167D displacement of G_4N bound to template. Lane 1, template alone; lanes 2-4, template plus increasing amounts of Sp1-167D (0.075, 0.150, 0.300 μg); lanes 5-8, template incubated in reaction buffer containing

1.2 mM G_4N followed by challenge with increasing amounts of Sp1-167D (0.075, 0.150, 0.300 μg), lane 8 received no Spl-167D. (D) Plot of diminishing Spl-167D/DNA complex band intensities in response to increasing concentrations of G_4N used in (A) ---•--- and (B) —•—. The gels used were 5% non-denaturing polyacrylamide with each lane receiving 5 μl of each reaction volume as described in experimental section and Ref. [1].

Figure 14. Inhibition of HIV Tat-regulated transactivation in Cos cells by G_4N.

Figure 15. SIV production with presence of G_4N. 10^7 174 x cells, a human T-cell lymphoma cell line, were mixed with a 24 hrs. harvest stock of SIV mac 239 (4 ng of p27) for two hours at 37. Cells were resuspended and 1 x 10^5 cells in 100 μl medium were added to each well of three 96-well plates. Various concentrations of G_4N from a freshly made stock were prepared and added to each of the six designed well. Culture supernatants were collected after four and eight days for viral production analysis. Viral production was assayed by a modified p27 capsid protein antigen capture ELISA as described in experimental section.

Figure 16. Inhibition of HIV p24 antigen production in H9 cells by G_4N. Inhibition in percentage was calculated by comparing p24 level from an average of two duplicate cultures of G_4N treated and not treated H9 cells 9 days following viral infection with a AZT resistant HIV strain, HIV-1RTMF.

Figure 17. RT-PCR Analysis of Survivin Gene Expression. (a) Top: Survivin gene expression in C3 cells treated with 40 μM M_4N for 24 hours and 72 hours, respectively (lanes 3 and 4) and in the untreated controls (lanes 1 and 2). Bottom: the corresponding GAPDH controls. Band intensities were quantitated with Scion Image. (b) Survivin RT-PCR product signals were normalized to those of the GAPDH controls and plotted.

Figure 18. Drug concentration-dependent down-regulation of survivin protein. (a) C3 cells were incubated with various concentrations of M_4N for 72 hours and the

total cell lysate was immunoblotted against survivin. (b) Relative band intensities were quantitated by Scion Image and plotted against M_4N concentration.

Figure 19. Immunoblot analysis of caspase-3 cleavage in C3 cells treated with M_4N for 72 hours. (a) Western blot of caspase-3 showed cleavage of the 32 KD procaspase-3 and the formation of the active 20 KD cleaved product. (b) Band intensities were quantitated and plotted against M_4N concentration.

DETAILED DESCRIPTION OF THE INVENTION

Experimental Methods

NDGA derivatives were synthesized chemically (7). Cell line C3 is a HPV16E + L plus activated Ras transformed cell line of C57 BL/6kh origin provided by W. Martin Kast of Loyola University Medical Center, Chicago, Illinois, U.S.A. It is maintained and cultivated as described by Greenstone et Al. (18) and Feltkamp et al. (19, 20).

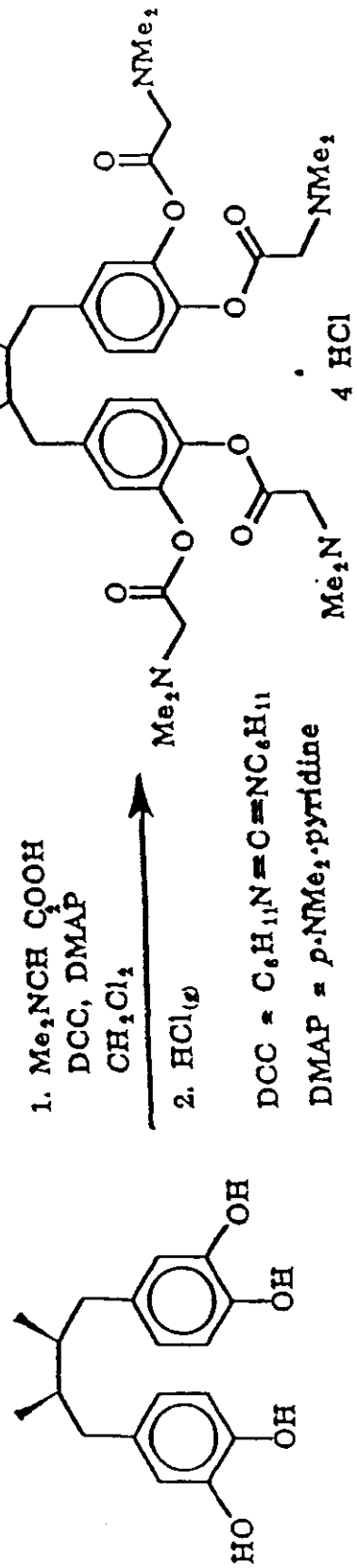
Synthesis of G_4N:

Standard Procedure for the Preparation of *meso*-1,4-Bis [3,4 - (dimethylaminoacetoxy) phenyl]- (2R,3S)- dimethylbutane Hydrochloride Salt

Tetraglycinyl NDGA, G_4N. To a dichloromethane (250 ml) solution containing NDGA (12.8 g, 42.3 mmol, 1.0 equiv) and N,N, -dimethylglycine (26.2 g, 254 mmol, 6.0 equiv) were added DCC (52.4 g, 254 mmol, 6.0 equiv) and DMAP (2.32 g, 18.9 mmol, 1.0 equiv). The reaction mixture was stirred for 24 h under nitrogen at room temperature. After the reaction mixture was filtered, the solution was concentrated under reduced pressure. Acetone (250 ml) was then added into the reaction flask and the solution was bubbled with excess HCl(g). The water-soluble precipitate was dissolved in H_2O and re-precipitated twice at room temperature from acetone to give (1) (29, 2 g, 36.8 mmol) as a white solid in 87% yield. Proton NMR spectra were obtained on a Varian Unity-400 (400 MHz) spectrometer by use of D_2O solvent and TSP as Internal standard. Carbon-13 NMR spectra were obtained on a Varian Unity-

400 (400 Mhz) spectometer by use of D_2O as solvent. Carbon-13 chemical shifts are referenced to the TSP singlet (δ0.0 ppm).

The synthesis is depicted in Scheme 1.


1. Me2NCH2COOH
DCC, DMAP
CH2Cl2
2. HCl(g)
DCC = C6H11N=C=NC6H11
DMAP = p-NMe2-pyridine
4 HCl

General Procedure. All reactions were carried out in oven-dried glassware (120°C) under an atmosphere of nitrogen, unless as indicated otherwise. Acetone, dichloromethane, 1,4-dioxane, ethyl acetate, hexanes, and tetrahydrofuran were purchased from Mallinckrodt Chemical Co. Acetone was dried with 4A molecular sieves and distilled. Dichloromethane, ethyl acetate, and hexanes were dried and distilled from CaH_2. 1,4 -Dioxane and tetrahydrofuran were dried by distillation from sodium and benzophenone under an atmosphere of nitrogen. Nordihydroguaiaretic acid was purchased from Fluka Chemical Co. N,N' -Dicyclohexylcarbodiimide (DCC), 4-dimethylaminopyridine (DMAP), morpholine, triethylamine, and potassium carbonate were purchased from Merck Inc. 1 -Bromo-3-chloropropane, N,N -dimethylglycine, and methylphosphorodichloridate were purchased from Aldrich Chemical Co.

Analytical thin layer chromatography (TLC) was performed on precoated plates (silica gel 60 F-254), purchased from Merck Inc. Gas chromatographic analyses were performed on a Hewlett-Packard 5890 Series II instrument equipped with a 25-m cross-linked methyl silicone gum capillary column (0.32 mm i.d.). Nitrogen gas was used as a carrier gas and the flow rate was kept constant at 14.0 ml/min. The retention time (t_R) was measured under the following conditions: injector temperature 260°C, isothermal column temperature 280°C. Gas chromatography and low resolution mass spectral analyses were performed on a Hewlett-Packard 5890 Series II instrument equipped with a Hewlett-Packard 5971A Mass Selective Detector and a capillary HP-1 column. Separations by medium-pressure liquid chromatography (MPLC) were performed at a flow rate of 120 ml/h by use of a Jasco Model 880-PU intelligent HPLC pump. The MPLC packing material, Reversed Phase Silica Gel C18 (particle size 0.035-0.070 mm), was purchased from Knauer Co. Purification by gravity column chromatography was carried out by use of Merek Reagents Silica Gel 60 (particle size 0.063-0.200 mm, 70-230 mesh ASTM).

Infrared (JR) spectra were measured on a Bomem Michelson Series

FT-IR spectrometer. The wave numbers reported are referenced to the polystyrene 1601 cm^{-1} absorption. Absorption intensities are recorded by the following abbreviations: s, strong; m, medium; w, weak. Proton NMR spectra were obtained on a Varian Unity-400 (400 MHz) spectrometer by use of D20 as solvent and 3-(trimethylsilyl)propionic acid, sodium salt as internal standard. Carbon-13 NMR spectra were obtained on a Varian Unity-400 (100 MHz) spectrometer by use of D_20 as solvent. Carbon-13 chemical shifts are referenced to the center of the 3-(trimethylsilyl)propionic acid, sodium salt singlet (6 0.0 ppm). Multiplicities are recorded by the following abbreviations: s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet; J. coupling constant (hertz). High-resolution mass spectra were obtained by means of a JEOL JMS-HX110 mass spectrometer.

meso-1,4Bis[3,4(dimethyleminoacetoxy)phe 3S-dimethylbutane Hydrochloride Salt (2). To a solution of NDGA (1, 12.81 g, 42.37 mmol, 1.0 equiv) and N,N-dimethylglycine (26.21 g, 254.2 mmol, 6.0 equiv) in dichloromethane (250 ml) was added DCC (52.45 g, 254.2 mmol, 6.0 equiv) and DMAP (5.176 g, 42.37 mmol, 1.0 equiv). The reaction mixture was stirred for 24 h under nitrogen at room temperature. After dicyclohexylurea in the reaction mixture was filtered off, the resultant solution was concentrated under reduced pressure. Acetone (250 ml) was then added into the residue and the resultant solution was bubbled with excess HCl (g). The precipitate was dissolved in water and re-precipitated twice by use of acetone at room temperature to give 2 (28.97 g, 36.86 mmol) as a white solid in 87% yield: ^1H NMR (D_20, 400 MHz)δ 0.78 (d, J = 6.0 Hz, 6 H. 2 x CH_3), 1.73 (m, 2 H. 2 x CH), 2.38 (dd, J=13.2, 9.6 Hz, 2 H. 2 x ArCH), 2.78 (dd, J = 13.2, 4.4 Hz, 2 H. 2 x ArCH), 3.03 (s, 24 H. 8 x CH_3N), 4.53 (s, 8 H, 4 x CH_2N), 7.22 (m, 4 H. 4 x ArH), 7.29 (d, J= 8.4 Hz, 2 H. 2 x ArH); ^{13}C NMR(D_20, 100 MHz) δ 18.11, 40.82, 41.73, 46.75, 59.59, 125.79, 126.58, 131.63, 140.66, 142.47, 146. 11, 167.84; IR (KBr) 3461 (br), 2963 (m), 1777 (s, C=O), 1620 (m), 1478 (m), 1377 (m), 1210(m), 1106 (m), 961 (w), 852 (w) cm^{-1}; MS (FAB) of (2-4 HCl) m/z (relative intensity) 643 (M+, 30), 600 (20), 558 (43), 515 (20), 473 (42), 430 (13), 388 (26), 185 (18), 93 (38),58 (100), 44 (22); HRMS (FAB) of

(2 - 4 HCl) calcd for $C_{34}H_{50}N_4O_8$ 642.3628, found 642.3614; Anal. Calcd for $C_{34}H_{54}N_4O_8Cl_4$: C, 51.78; H. 6.90; N. 7.10; O. 16.23. Found: C, 51.70; H. 6.85; N. 7.05; O. 16.21.

It will be appreciated that by suitable substitution of other N,N-dimethyl-substituted amino acids, additional amino acid substituted compounds of the invention can be synthesized.

Example 1

Effect of M_4N and several other NDGA derivatives of SP1-regulated HPV E_6/E_7 promoter activity.

The effect of M_4N and several other NDGA derivatives of SP1-regulated HPV E_6E_7 promoter activity was examined using luciferase as a reporter. The assay depends upon DNA transfection of the HPV16 LCR (P_{97} promoter) fused to the luciferase reporter gene into C33A cells by calcium phosphate methods. C33A is a cervical tumor cell line (ATCC accession no. HTB-31) that does not contain any integrated HPV DNA, but has transcription factors necessary for a robust expression of the HPV early gene promoter. One day following DNA transfection various drug concentrations dissolved with the help of dimethyl sulfoxide (DMSO) were added to the cells. Thirty hours after drug treatment (so that the assay is complete within the standard forty-eight hours for transient transfection experiments), the cells were lysed and specific luciferase activity was determined (Luciferase Assay Systems, Promega, U.S. Pat. No. 5,283,179). As the M_4N drug concentration was increased the specific luciferase activity decreased.

The results (shown in Figure 2) demonstrate that M_4N dramatically reduces Sp1 regulated transcription initiation at the HPV E_6/E_7 promoter in luciferase assay.

Example 2

Inhibition of E_6/E_7 mRNA synthesis following M_4N treatment

Inhibition of E_6/E_7 mRNA synthesis following M_4N treatment was

measured by RT-PCR in cervical cell line C_3. Relative RT-PCR was performed with quantities of total cellular RNA standardized to the cell numbers counted. The RT-PCR product was analyzed on a 2% agarose gel. The results are shown in Fig. 3. The RT-PCR results indicated that the amplified cDNAs of the expected size for E7 (321 bp) and E6 (204 bp) were detected in the DMSO treated cells as early as cycle 22 of amplification. These same products were barely detectable in the drug treated RNA extracts following 30 cycles of amplification. No amplified products were detected for the no template PCR control or from total RNA extracts of the HPV16-negative C33a cell line.

Example 3

Inhibition of cervical C3 cell growth by M_4N treatment

HPV-16 transformed immortal mouse epithelial cells (C3 cells) were plated at a density of 10^5 cells per vial. After 24 hours, ½ of the vials were given growth media containing 40 μM M_4N dissolved in 1% DMSO while the other half were given growth media containing only 1% DMSO. The results are shown in Figure 4A. Within 24 hrs a difference in cell morphology between drug treated and control C3 cells was observed. The growth and division of the drug treated cells was markedly reduced in comparison to the untreated control, while the fraction of viable cells compared to the total cell count remained constant for both drug treated and DMSO only control cells. This indicates that M_4N dramatically reduces cell division.

The effect on C3 growth following removal of M_4N from the medium was also examined. C3 cells were plated at a density of 10^4 cells per vial. At time=0, 2/3 of the vials were given growth media supplemented with 40 μM M_4N in 1% DMSO. The remaining vials were given growth media containing only 1% DMSO. After 73 hours, ½ of the vials that had received M_4N in their growth media were washed and media containing only 1% DMSO was added. The other 2/3 of the cell vials were washed and replaced with the same media administered before. The results, shown in Figure 4B, indicate that the rate of cell growth was not notably increased in M_4N treated sample following the

change to drug-free media, indicating that M_4N continues to significantly reduce cell division even after its removal from the extracellular environment.

Example 4

Analysis of cellular gene expression in C3 cells before and after 72 hrs of drug treatment.

Gene expression with 9600 gene arrays was studied (Fig. 5). Five micrograms each of poly A^+ RNA from 72 hrs. M_4N (40 μm) treated (C_3 M_4N) and non-treated (C_3 DMSO) was used in a pair of human 9600 gene array hybridization study according to the procedure described in Genomics 51, 313-324 1998. The hybridization image was captured by a color video camera with a Nikon 55 mm AF micro Niko lens and digitized by a Macintosh LC630 computer. Such detection via enzyme substrate reaction of color-forming enzymes in either single or dual-color mode is reproducible and extremely sensitive (can detect <5 copies of transcript per cell with RNAs from 10^7 cells).

The computer print outs showing differentially expressed genes (C_3 M_4N/C_3 DMSO >10 and C_3 DMSO/C_3 M_4N >10) were listed for examination. Image files in TIFF format and data files in MS excel format are kept on ZIP diskette. Gene names and clone ID numbers are available for obtaining Image clones for future northern blot confirmation.

Among a group of genes that are either up-regulated or down-regulated 72 hrs after M_4N treatment, the following are those specifically related to cell division and apoptosis. Several other cell cycle related genes are also greatly upregulated in response to M_4N. In addition to cyclin-dependent kinase CDC2 (Example 11), for example:

	Increase
Cyclin-dependent kinase inhibitor	(100X)
Apoptosis (APO-1) antigen	(100X)
Death Domain Three DR_3	(100X)

Ras-related protein RAP-1	(60X)
Human Map Kinase	(40X)

The following cell cycle related genes are greatly downregulated in response to M_4N:

	Treated	Untreated
Cyclin-dependent kinase 7	(5%)	100%
Human cytokine receptor	(2%)	100%
Proliferating cell nuclear antigen, PCNA	(1%)	100%
Human TNF-related Apoptosis APO_2	(3%)	100%
Cysteine protease	(7%)	100%

At earlier time points, such as after one hour drug treatment, E_6/E_7 level was found to be similar with those in control cells while after 4.5 hrs, **E_6/E_7 were no longer detectable by RT-PCR (10). Gene expressions with 9600 gene arrays can be repeated with RNA isolated from these short-time treated cells (1 hour and 5 hours) in order to further pin down the initial cellular effects of the drug.**

Example 5

Targeting C3 tumor growth in mice by <u>local</u> injection of M_4N

Thirty six C57bl-16 NCR mice were injected with 5×10^5 C3 cells between the shoulders on the backs of the mice. Twenty four of the mice developed tumors within 20 days. Daily injection (50 μl-100 μl of M_4N or M_4N/G_4N) (200 mg/ml M_4N in DMSO, 200mg/ml G_4N in PBS) showed profound effect in tumor growth in animals, as shown in Tables 1 and 2, Fig. 6 and 7.

Table 1. M_4N and G_4N Effect on Growth of Single Tumors Developed in Mice

Mouse #	Treatment Period Days 1-16	Lesion Size (mm)			Wt. Of Excised Lesion (g)		Body wt. (g)		
		Day 1	Day 7	Day 21	Day 16	Day 24	Day 1	Day 16	Day 24
1	DMSO*	3x8x3.3	—	5x7x4	—	0.3	18.8	—	20.2
2	DMSO	4.4x6x3.5	10x12x8	—	1.56	—	19.6	20.5	—
3	DMSO	0.8x0.8x1	—	10.5x11x9	—	1.14	18.2	—	16.1
4	DMSO	2.8x3.8x2.5	—	18x11x9	—	2.9	17.6	—	20.2
	Days 1-16								
6	M_4N	—	9x8x5	—	0.2	—	19	19.2	—
7	M_4N	—	6x7x7	—	—	0.1	18.2	—	20.4
11	M_4N	1x1.3x1	9.5x10x9	—	—	0	19.5	—	20.2
14	M_4N	3.8x3.8x3.5	8x9x6	—	0.4	—	17	17.6	—
15	M_4N	—	5x4x4	—	0.1	—	18.9	20.0	—
16	M_4N	2.8x2.8x2.8	9x6x4	—	0	—	17.2	17.6	—
17	M_4N	2.3x2.3x2.3	6x6x4	—	0.2**	—	17.3	—	—

	Days 1-10	Days 9-17								
18	M_4N	G_4N	3x2.8x3	8x7x5	—	—	1.0***	18.8	—	21.1
19	M_4N	G_4N	—	5x5x5	—	0.2	—	18.2	19.9	—
21	M_4N	G_4N	1.8x1.8x1.8	9x10x5	—	0.2	—	17.3	19.2	—
22	M_4N	G_4N	—	7x7x5	—	—	0	17.9	—	19.5
27	M_4N	G_4N	2.5x5x2.5	9x6x6	—	—	1.8***	20	—	20.7
28	M_4N	G_4N	2.8x2.3x2.8	5x5x4	—	0.17	—	18.1	19.8	—
29	M_4N	G_4N	2.8x2.5x2.8	5x6x4	—	—	0.2	18.8	—	19.6

***DMSO = Vehicle for Drug**

**** Taken on Day 15**

***** Lesion contained mostly necrotic cells as also found in lesions from mouse 6, 7, 11, 14, 15, 17, 19, 21, 28, 19 (Fig. 6,7). There were no lesions** left in mouse #11 and #22 following drug treatments. Tumors found in control mouse #1, 2, 3, 4 contained growing cells (Fig. 2).

Experimental Procedures:

36 C57bl-16NCR mice were injected with 5 X 10^5 C3 cells/mouse. Injections were 100 μL made subcutaneously between the shoulders on the backs of the mice. Cells were suspended in low-salt HBSS and suspension uniformity was maintained by gentle vortexing.

24 mice developed tumors. Their lesion sizes were measured by dial caliper. These mice were shaved, weight and treatment begun (Day 1). Four mice were sequestered as controls. Control mice received 50 μl DMSO injected intratumorally daily. Experimental mice (10) received 50 μl M_4N dissolved in DMSO(200mg/mL). An additional 10 mice received M_4N treatments for 8 days followed by G_4N treatments (50 μl, 200mg/ml in PBS) daily for 8 days. Injections were made to several regions of tumor. Mice

anesthetized with ether or metaphane prior to injection.

Table 2. M_4N and G_4N Effect on Growth of Treated Lesions in Mice Carrying Multiple Tumors

Mouse #	Treatment Period		Lesion Size (mm)		Wt. Of Excised Lesion (g)		Body wt. (g)	
	Days 1-16		Day 1	Day 7	Treated*	Not Treated**	Day 1	Day 24
9	M_4N		1.3x5x0.75	7x9x8	0.25	0.6	20.2	17.9
10	M_4N		2.3x2.5x2.3	9.5x10x9	0.1	2.9	17.5	22.1
12	M_4N		2.5x2.5x2.5	8x9x6	0.11	1.82	17.8	20.0
	Days 1-9	Days 10-18						
20	M_4N	G_4N	1.8x1.8x1.8	9x10x5	0.1	0.2	17	20.2
24	M_4N	G_4N	—	7x9x6	0	1.7	17.2	20.8
26	M_4N	G_4N	5x3.3x2.5	7x7x7	0.2	1.9	19.3	20.6

*Drug in DMSO was injected directly to the tumor regions

** From adjacent tumors deprived of drug

Table 3. Toxicity Studies of G_4N in Mice

	Group	# of Mice	Route	Treatment per day	Days of Injection	Mortality
1	187.5mg/kg	3	Subcutaneous	2X	6	0/3
2	375mg/kg	3	Subcutaneous	1X	6	0/3
3	750mg/kg	4	Subcutaneous	1X	6	1/4
4	375mg/kg	2	IV	2X	6	0/2

C57BL-16NCR female mice from NCI were used in this experiment. Tetraglycinal NDGA (G_4N) was freshly made everyday in PBS in concentrations of 75mg/ml. Injections of 0.05 ml for group 1, 0.1 ml for groups

2 and 4, and 0.2 ml for group 3 per treatment were made for a period of 6 days. Experiments lasted seven days. Body weights were determined before and after six days of injection. No significant weight changes were observed during the experimental period.

All treated mice, controls (mouse numbers 1-4) and experimental mice (mouse numbers 6, 7, 9, 10, 11, 12, 14, 15, 16, 17 M_4N numbers 18-22, 24, 26-29 M_4N/G_4N) exhibited swelling. Measurements of lesion sizes were made by dial caliper. Some mice experienced mild bleeding due to injection.

The treatment regimen and results were as follows:

Day 10: Mice weighed again. All mice exhibited growth up to two grams.

Day 12: No treatments made.

Day 13: All mice have raised skin but to very different degrees. The skin of one M_4N treated mouse (#7) has split open through which the "dried-out tumor" fell out.

Day 14: Injection volume raised to 100 µl.

Day 15: One M_4N treated mouse (#17) died due to overdose of anesthesia/handling. The skin at the lesion site of #17 cracked with the "dried-out tumor" showing. It was dissected, and lesion excised and weighed. Day 16: Four more M_4N treated mice (#6, 14, 15, 16), three M_4N/G_4N treated mice (#19,21,28) and one control mouse (#2) were euthanized, dissected and weighed. Remaining control mice (#1, 3, 4) were examined non-invasively and were carrying tumors.

Day 21: Tumor sizes from control mice were measured by dial caliper. Observation: The skin at the lesion sites of mouse #10 and #12 (M_4N treated regions) cracked with the "dried-out tumor" showing.

Day 24: Mouse #7 skin recovered completely. The experiment was terminated on this date. All remaining mice, M_4N treated (#7, 9, 10, 11, 12) and M_4N/G_4N treated (#18, 20, 24, 26, 29) were euthanized, dissected, examined and weighed.

The effects of M_4N and M_4N/G_4N on C3 tumor growth in mice are summarized in Tables 1 and 2 and Figures 5 and 6. Table 1 shows the drug

effect on C3 cell growth in mice carrying single tumors. The average weight of four excised tumors of the control group was 1.48 g while weights of lesions from M_4N treated and M_4N/G_4N treated were 0.142 and 0.51 g respectively. Drug treated lesions consisted mainly of dried out necrotic cells (Fig. 6). Tumors from the control group appeared homogenous and contained actively growing cells. Table 2 shows the drug effect on C3 tumor growth in mice carrying multiple tumors. In this study, drug was injected into one of the tumors. The average weight of untreated tumors was 1.77 g while that of M_4N treated lesions was 0.15 g. Similar results were obtained following M_4N/G_4N injection—the average weight of untreated tumors was 1.27 g, while that of the drug treated lesions was only 0.103 g.
The body weight changes of all mice during the entire experimental period appeared insignificant (Table 1 and 2).

Example 6

Drug treated (M_4N) and DMSO vehicle-treated or untreated tumors (CON) from two groups of mice were prepared for histopathology examination. The excised tumors were immediately fixed and then stored in 4% formaldehyde in phosphate buffered saline. The fixed tissue was then dehydrated through a series of graded alcohols and xylene and embedded in paraffin. The paraffin tissue blocks were thin sectioned and stained for microscopy with hematoxylin and eosin. Histopathology studies showed that the control tumors were unaffected by DMSO treatment and continued to grow. They show the high nuclear/cytoplasmic ratio, pleomorphic nuclear changes, high mitotic figures, spindle like sarcoma shape, and infiltration into the surrounding tissue characteristic of cancer cells. In contrast, those tumors receiving M_4N treatment discontinued growth shortly after treatment began. They demonstrate significant necrosis and areno longer viable. There is a small amount of drug precipitate visible at higher magnification, and focal areas show chronic inflammation and fibrosis. This healing effect leads to the shedding of these deceased tumor cells from the area. The same results are seen with M_4N/G_4N treatment as with the M_4N treatment alone. However, since G_4N is water-soluble, it

can spread to a larger area of the tumor than M_4N. It is expected that G_4N when used with M_4N synergistically may be more effective in treating tumors of large sizes (i.e. greater than 2 cm^3).

Example 7

Effect of M_4N on HSV-1 Skin Infection in Guinea pig

The drug M_4N was also tested in inhibition of HSV-1 replication in skin infections in guinea pigs. Guinea pig skin was pinched with needles and HSV-1 suppression was applied topically to infect each pricked area. M_4N was then applied to the pricked infected area following infection daily for 6 days.

Six areas of bared back skin of a guinea pig were punched sterilely with a 5=DIN needle. Two areas were infected with HSV-1 (HSV-C, culture supernatant, or isolated HSV in saline, HSV-SC). The other four areas were infected with HSV-SC. Fifteen minutes after infection, 30 μl of test compounds ($ABDS_1$, $ABDS_2$, ACV and M_4N (4N) in 60 mg/ml of DMSO were applied to each punched infected region of an area, five times per day for six days. $ABDS_1$ and $ABDS_2$ were included as negative controls. The photograph in Figure 8 was taken at day 6 and shows the extent of HSV-1 replication in the absence of drugs (HSV-C, HSV-SC), in the presence of ineffective drugs (HSV-$ABDS_1$, HSV-$ABDS_2$) and in the presence of effective drugs (HSV-M_4N and HSV-ACV). It can be seen that six large confluent blisters were developed in areas treated by HSV-C, HSV-SC, HSV-$ABDS_1$, HSV-$ABDS_2$, while no blisters were observed in infected areas following M_4N (4N) and ACV treatments. Clearcut results that M_4N can block HSV replication were obtained in this model system as shown by the disappearance of the skin lesions and by no shedding of the virus 4 days after the drug treatment. Initial animal studies also showed M_4N to be non-toxic to mice at concentrations as high as 300mg/kg when given intraperitoneally, and as high as 375 mg/kg when given either subcutaneously or by IV (Table 3) (6).

Example 8

M_4N for Clinical Treatment using *in situ* Injection

Administration of M_4N directly into tumors as a drug delivery route provides several distinctive advantages. 1) M_4N is a hydrophobic compound and is exceedingly soluble in DMSO (200 mg/ml). Therefore only a small volume of the drug solution is needed for injection in order to achieve effective dosage of the drug. In the mouse study described in Example 5, above, daily injection of 50 μl to 100 μl for several days was sufficient to completely stop tumor growth in mice. There have been several previous studies on the use of large dosages (30 ml IV per treatment) of DMSO for treating diseases (21). The results were not conclusive (22). However, since tens of millions of people have been safely tested with large amounts of DMSO worldwide in the past, it appears that DMSO should be safe as a vehicle for drug delivery when only small volume of it will be used (23). 2) By injection *in situ*, a majority of the drug residue remains insoluble and concentrated in the tumor areas, and does not enter the circulatory system, thus whole body toxicity is avoided. In addition, since enough drug remains within the tumor to suppress its growth, continued injection of drug is unnecessary after relatively few treatments. In the mouse study of Example 5, tumor cells continued to die even after discontinuation of M_4N injections. Thus when drug is directly targeted, tumor size becomes the determining factor for the required amount of drug to be administered. The difference between whole body weights of a human vs. a mouse becomes irrelevant. In the mouse tumor studies, 20 mg/day for 10 days were more than sufficient to eliminate tumors. There should be no reason to use a higher dosage than this for treating a human tumor of comparable size (1-1.5 cm^3). This should reduce the risk considerably in human trials.

Example 9

M_4N Treatment of Cells Blocks Cellular Proliferation

Our previous research on M_4N indicated that it could inhibit viral transcription by deactivation of Sp1-dependent promoters. Many mammalian

cell cycle genes also contain essential Sp1 promoters and M_4N may therefore block their transcription. This hypothesis was tested by examining the antiproliferative effect of M_4N on a number of different cell lines. Low concentrations (10 μM) of the parent compound, NDGA, have previously been shown to induce apoptosis in mammalian cells (24). This effect, however, can be circumvented by blocking one of the catechol oxygens or the addition of a hydrophilic group to NDGA (25). Increasing amounts of the NDGA derivative M_4N were tested on cultures of the HPV-16/ras transformed C3 cell line (26) to determine the optimal concentration required to inhibit proliferation (Figure 9a). The cells respond well to M_4N, ceasing division after 72 hours over the range of concentration from 40 to 60 μM. After three days at these concentrations the number of cells remained equal to the count at the initiation of treatment (day 0, Fig 9). A more modest reduction in cell growth was observed at lower concentrations of the drug and some cell death was seen at concentrations greater than 60 μM.

The antiproliferative effect of M_4N on the C3 cell line is not solely due to the drug's ability to deactivate the Sp1-dependent HPV-16 E6/E7 oncogene promoter, as similar growth inhibition was observed in the HPV-16 transformed TC-1 cell line whose E_6/E_7 oncogenes are under control of a non-Sp1 dependent retroviral promoter(27) (Figure 9d). In addition, growth of the C33a cell line (Figure 9c), an HPV-negative human cervical cancer cell line, and the CEM-T4 line (Figure 9b), a human leukemia cell line (28), was also blocked by treatment with M_4N. In the four cell lines that were treated with the drug, nearly all (>95%) of the arrested cells were viable until the concentration of M_4N exceeded a "threshold" value (60 μM for C3 cells, 40 μM for TC-1 cells, etc.). Above these concentrations the percentage of viable cells decreases precipitously. Interestingly, arrested cells maintained >95% viability even after prolonged exposure to the drug. The C3 cells exhibited no increase in cell death after eight days of treatment with 40 μM M_4N (Figure 9e).

Example 10

Cells Treated With M_4N Arrest in G2 Phase

Once it was established that cells treated with M_4N cease proliferation yet remain viable, analysis of cellular DNA content and fluorescence examination of cell structures were used to determine the point in the cell cycle where the cells arrest. Cells exposed to M_4N for 72 hours demonstrated increased G2/M DNA content relative to the controls (Figure 10a-d). The most extreme responses were seen from the C3 and CEMT4 cell lines, in which >90% of the cells show G2/M DNA content.

In order to distinguish between an arrest in G2 or a mitotic block, antibodies against α tubulin (green) and γ tubulin (red) were used to determine the status of the centrosomes in the C3 cell line following 72 hours M_4N treatment. As shown in Figure 11a, the centrosomes of M_4N treated cells are duplicated but still located next to each other in the nucleus of the cell. Since centrosomes separate during early prophase, it can be concluded that these cells have not begun mitosis. In contrast, the gamma tubulin staining of the control cells has the diffuse pattern characteristic of G1 or S phase (29). A lack of chromatin condensation in the M_4N treated cells was also observed with DAPI staining (Figure 12b), additional evidence that the cells have not moved forward out of G2 phase (30).

Example 11

Production of CDC2 is Inhibited by 40 μM M_4N

Since progression of cells out of G2 is dependent on the production of the MPF, the status of its protein components was examined in C3 cells treated with 40 μM M_4N. Asynchronous cells were grown for 24 or 72 hours in media containing either M_4N in 1% DMSO, or 1% DMSO alone. The cells were harvested, and equal amounts of total cellular protein were analyzed by western blotting. A marked reduction in the amount of CDC2 was observed after 72 hours treatment with M_4N (Figure 12a). However, levels of cyclin B, detected by stripping and reprobing the same membrane, were found to be unchanged. These results indicate that, under these conditions, the arrest is

not likely a response to p53 since it has been shown that overexpression of p53 leads to a decrease in cyclin B (31, 32). Consistent with the results of the western analysis, CDC2 kinase activity was eliminated by 72 hours of M_4N treatment (Figure 12a). These experiments support the view that the drug acts by inhibiting the production of the CDC2 protein, resulting in a loss of activity of the MPF.

Our previous studies demonstrating the ability of M_4N to block Sp1-dependent viral transcription suggest reduction of CDC2 mRNA levels as a possible mechanism for the decrease of CDC2 protein. This is consistent with the finding that the cyclin B protein, whose gene does not require Sp1 for its expression, is produced at normal levels while the CDC2 protein, whose gene has two essential Sp1 sites in its promoter, is substantially reduced in quantity. To test this hypothesis, northern blot analysis was performed on RNA harvested from C3 cells treated with 40 μM M_4N for 5 to 72 hours. As shown in Figure 12b, the amount of CDC2 mRNA is reduced after only 24 hours treatment with M_4N and nearly eliminated after 72 hours. Production of the non-Sp1 regulated housekeeping gene GAPDH was used as an RNA loading control, and its levels were not effected by 40 μM M_4N.

The use of the C3 cell line allows us an additional control for analysis of the mechanism of M_4N mediated cell cycle arrest since other Sp1-dependent gene promoters are also likely to be inhibited by M_4N treatment. This possibility was examined in C3 cells by analyzing the effect of M_4N on transcription from the Sp1 dependent HPV-16 E_6/E_7 promoter. rtPCR analysis of RNA isolated from C3 cells treated with 40 μM M_4N for 5 to 72 hours demonstrated a clear reduction in the levels of the E_7 transcript (Figure 12c). GAPDH was again used as an internal control in this experiment, and its levels were unaffected by drug treatment. These results provide additional evidence that M_4N reduces the transcripts of Sp1 regulated promoters.

Example 12

Inhibition of Sp1-Binding Activity by G_4N in a Gel Mobility-Shift Analysis.

Sp1 family proteins induce bends toward the major groove of DNA upon

binding (33). The zinc finger domain of the Sp1 protein is responsible for the binding of the GC Box sequence 5'-GGGGCGGGG-3'. From computational analysis, it was determined that G_4N, the aminoester derivative of NDGA, could form a stable complex with such a sequence in the major groove. To determine whether G_4N can serve as an Sp1 blocker as well as an Sp1 displacer, we performed Sp1/enhancer interaction studies in the presence or absence of G_4N by the gel mobility-shift analysis using only the DNB binding domain of Sp1 for testing. In the blocking experiment, different concentrations of G_4N were first incubated with ^{32}P-labelled DNA in the binding buffer for 30 min at 25°C. DNA binding domain of recombinant Sp1 protein (Sp1-167D) was next added and incubated for additional 30 min in the presence of a large excess of BSA protein. In the displacement study, the recombinant SP1-167D was first allowed to bind DNA, G_4N was then added at the second step of the incubation. The G_4N and Spl-167D concentrations and, the incubation and gel electrophoresis conditions were identical in both studies (experimental section). As shown in Figure 13, in either case, G_4N was found to be able keep DNA from interacting with Sp1-167D protein. When only the DNA binding domain of Sp1 alone was tested, G_4N appeared to be more efficient in displacement of the bound Sp1 than blocking Sp1 from binding to the enhancer, as shown by the gel mobility-shift analysis (Figure 13, A,B,D). We have also examined whether the bound G_4N can be replaced by Sp1-167D. In this study, the inhibition of Sp1-167D binding by G_4N was first established by the mobility-shift analysis (Fig 13C, lanes 2 and 5). When the G_4N bound template was challenged with additional Sp1-167D, we observed a dosage dependent increase of the band intensities of the Sp1-167D/DNA complex (Fig 6C, Lanes 6,7) indicating the displacement of G_4N by Sp1-167D from the template.

Example 13

Inhibition of Sp1 Regulated Tat-Transactivation of HIV Promoter Activity by G_4N.

As reported previously, methylated NDGA derivatives can block Sp1

binding to the enhancer sites of a variety of viral promoters including HIV, ICP4 of HSV, E_6/E_7 gene of HPV (8, 9, 10). We further tested the G_4N effect on the Tat-transactivation of HIV promoter activity in Cos cells by the SEAP assay as previously described. Basal level of the HIV LTR driven SEAP expression was previously found to be barely detectable in Cos cells. There were 60-fold or more increase in SEAP expression when Cos cells were cotransfected with the CMV promoter driven Tat gene (8). Such Tat-driven transactivation of the HIV LTR promoter activity was previously shown to be Sp1 regulated (7, 8). In the presence of G_4N, we observed inhibition of HIV transactivation in a dose-dependent fashion (Figure 14). An average value IC_{50} value of 36 μM for G_4N was comparable to that of 3-O-methyl NDGA, Ma1.4 (IC_{50} 25 μM) and somewhat higher than that of tetra-methyl NDGA, M_4N (IC_{50} 11 μM). The differences perhaps are due to the chemical nature of the test compounds affecting the drug uptake to the cells.

Example 14

Inhibition of SIV-1 and HIV-1 Production in Cell Cultures by G_4N.

Both HIV-1 and SIV are retroviruses that require integration into the host genome to complete their replication. Both rely on host transcription factors for their proviral transcriptions. Sp1 plays a central role for such expression in these two viruses sharing an almost identical mode of transcription regulation. In anticipation of using SIV infected rhesus monkeys as animal model for testing the antiviral effect of G_4N, we have studied and compared the G_4N effect in inhibition of SIV in 174 x CEM cells with that of HIV in H9 cells. Cellular toxicities of G_4N in these two cell lines were also examined. For SIV inhibition study, 10^7 174 x CEM cells were mixed with high titer stock of SIVmac 239 at 37°C for two hours and then washed twice with cold PBS buffer to remove the unabsorbed virus. Cell suspension was aliquoted into each well of three 96 well plates. Various concentrations of the G_4N solutions were made from freshly prepared stock and aliquoted separately and each to six wells in a column of one 96 well plate. Culture supernantants were collected every four days post infection. (P.I.) and fresh medium containing appropriate concentrations of the drug were added to the culture following supernatant collections. Viral production was assayed by a modified p27 core antigen capture ELISA as shown (Figure 15). There was no SIV production detected using G_4N in concentrations above 5 CIM. At G_4N concentrations below 2.5 CIM, SIV production was detected (Fig. 15) in culture supernatants from 4th and 8th days post infected cultures as compared to viral production in the absence of the drug. G_4N (250 μM or less) showed no toxic effect on uninfected 174 x CEM cells, as determined by the MTT assay (34).

A similar experiment was also carried out for the study of inhibition of HIV-1

by G_4N in H9 cells. The H9 cells were subcultured at 1 x 10^5/ml and were infected with an AZT resistant strain of HIV-1(HIV-1RTMF). G_4N in different concentrations was added two hours after infection. Fresh medium change was made every four days. Cell growth in the presence of G_4N was monitored carefully during the nine-day experimental period. Viral production was

assayed by a p24 core antigen capture ELISA. As shown (Figure 16), G_4N concentration of 80 CIM completely inhibited HIV replication in H9 cells. An IC_{50} of 12 μM CIM G_4N for the inhibition of HIV-1 RTMF was found. Again, there
was no detectable toxicity to uninfected H9 cells within the range of the assay (and below 250 μM).

Example 15

Effect of M_4N Treatment on Survivin Gene Expression in C3 Cells

Materials and methods

Cell Culture. C3 cells were grown as monolayers in Iscove's Modified Dulbecco's Medium (GIBCO BRL) supplemented with 5% fetal bovine serum (GIBCO BRL) and maintained in a humid incubator at 37°C in a 5% CO_2 environment.

M_4N Treatment. C3 cells ($5x10^6$) were seeded in 150-mm plates and allowed to attach to the plates. Twenty-four hours after seeding, cultures were washed twice with PBS and treated with M_4N dissolved in 1% DMSO mixed with the growth medium.

Cell extracts and immunoblotting. Cells were lysed in lysis buffer containing 50 mM HEPES pH 7,250 mM NaCl, 0.1% (v/v) Nonidet P-40, 10% glycerol, 1mM DTT, and 50 μl/ml protease inhibitor cocktail (Sigma). Protein concentration of the extract was determined by the Bradford assay (Bio-Rad Laboratories), and then 50 μg of protein was separated by SDS-PAGE and electrotransferred to nitrocellulose membrane (ECL). Membranes were incubated with primary antibodies against Survivin (Santa Cruz Biotechnology) and caspase-3 (Santa Cruz Biotechnology). Blots were then incubated with anti-rabbit biotin-conjugated secondary antibody and then with Avidx-AP™ streptavidin-alkaline phosphatase, and detected with CSPD® substrate (Tropix).

RT-PCR analysis. mRNA was isolated by the guanidinium thiocyanate and phenol method from the cultured cells as described in Molecular Cloning (40). A 343-base pair RT-PCR product was generated by using the survivin-sense

oligonucleotide primer 5'-GCATCGCCACCTTCAAGAACTGGCCC-3' and the survivin-antisense oligonucleotide primer 5'-CGGGTAGTCTTTGCAGTCTCTTCAAACTC-3'. GAPDH sense and anti-sense primers 5'-GAATCTACTGGCGTCTTCACC-3' and 5'-GTCATGAGCCCTTCCACGATGC-3' were used to generate a 238-base pair RT-PCR product as a control. mRNA aliquots were incubated in 20 µl reaction buffer containing 1 U or rRNAsin and DNAse at 75°C for 5 minutes followed by reverse transcription reaction with MMLV (Promega). The c-DNA products obtained were amplified under the PCR conditions: 55°C for 55 seconds, 60°C for 55 seconds, and 72°C for 1 minute for 30 cycles. The PCR products were separated by electrophoresis on a 1.8% agarose gel containing ethidium bromide and photographed under UV. The bands were quantitated by Scion Image and the signal intensities of the survivin PCR reaction products were normalized to those of the GAPDH PCR products to generate a survivin gene down-regulation graph.

To determine whether the Spl-regulated survivin gene expression in C3 cells is reduced by M4N treatment, we treated the cells with 40 µM M_4N for 24 hours and 72 hours. As shown in Figure 17, treatment of cells with M_4N resulted in a significant decrease in survivin gene expression in a time-dependent manner. Treatment with 40 p2d M_4N for 24 hours and 72 hours resulted in 65% and 80% reduction in survivin expression, respectively. Untreated cells did not show any reduction in survivin gene expression.

Survivin protein was also shown by immunoblotting to be downregulated by 72 hours of M4N treatment. This downregulation was dosage-dependent (Figure 18).

Example 16

Induction of Apoptosis with M4N treatment

Because our data showed that M4N resulted in survivin mRNA and protein reduction, we investigated whether this reduction induces apoptosis since survivin has anti-apoptosis function. As shown by immunoblotting of caspase-3 (Figure 19), treatment of M_4N for 72 hours resulted in caspase-3 activation. This activation

would be expected to result in an increase in an increase in apoptosis in cells treated with M_4N.

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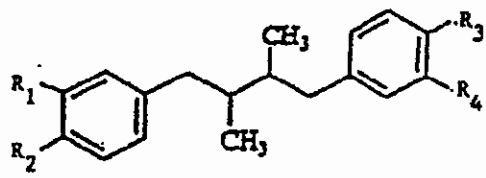
WHAT IS CLAIMED IS:

1. Use of a compound in the preparation of a medicament for the inhibition of survivin production or stimulation of apoptosis, wherein the compound has the following structural formula:



wherein R_1, R_2, R_3 and R_4 independently represent -OH, $-OCH_3$, $-O(C=O)CH_3$, or an unsubstituted or substituted amino acid residue or salt thereof, but are not each -OH, simultaneously.

2. The use of a compound according to claim 2, wherein R_I, R_2, R_3 and R_4 independently represent an unsubstituted or substituted amino acid residue or salt thereof.

3. The use of a compound according to claim 2, wherein the unsubstituted or substituted amino acid residue or salt thereof is selected from the group consisting of: alanine, arginine, asparagine, aspartate, cysteine, glutamate, glutamine, glycine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, proline, serine, threonine, tryptophan, tyrosine, valine, 5-hydroxylysine, 4-hydroxyproline, thyroxine, 3-methylhistidine, ε-N-methyllysine, ε-N,N,N-trimethyllysine, aminoadipic acid, γ-carboxyglutamic acid, phosphoserine, phosphothreonine, phosphotyrosine, N-methylarginine, N-acetyllysine, N,N-dimethyl-substituted amino acid residue and salts thereof.

4. The use of a compound according to claim 3, wherein the substituted amino acid residue or salt thereof is an N,N-dimethyl-substituted amino acid residue or a salt thereof.

5. The use of a compound according to claim 4, wherein the N,N-dimethyl-substituted amino acid residue is an NN-dimethylglycine residue.

6. The use of a compound according to claim 4, wherein the salt of the N,N-dimethyl-substituted amino acid residue is a chloride salt.

7. The use of a compound according to claim 1, wherein each of R_1, R_2, R_3 and R_4 is $-O(C=O)CN(CH_3)_2.Cl$.

8. The use of a compound according to claim 1, wherein each of R_1, R_2, R_3 and R_4 independently represent $-OCH_3$.

9. The use of a compound according to any one of claims 1-8, wherein the medicament further comprises at least one pharmaceutically acceptable excipient or carrier.

10. The use of a compound according to claim 9, wherein the pharmaceutically acceptable excipient or carrier is selected from the group consisting of dimethyl sulfoxide, phosphate buffered saline and a lipid based formulation.

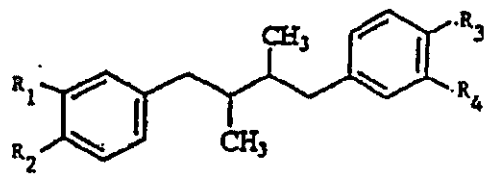
11. The use of a compound according to any one of claims 1-8, wherein the compound is a solid.

12. The use of a compound according to any one of claims 1-8, wherein the compound is in solution.

13. The use of a compound according to any one of claims 1-8, wherein the inhibition of surviving production or stimulation of apoptosis occurs in an animal cell.

14. The use of a compound according to any one of claims 1-8, wherein the inhibition of surviving production or stimulation of apoptosis occurs in a human cell.

15. Use of a compound in the preparation of a medicament for the treatment of a tumor, wherein the compound has the following structural formula:



wherein R_1, R_2, R_3 and R_4 independently represent -OH, $-OCH_3$, $-O(C=O)CH_3$, or an unsubstituted or substituted amino acid residue or salt thereof, but are not each -OH, simultaneously.

16. The use of claim 15 wherein said tumor is present in a mammal.

17. The use of claim 15 wherein said tumor is malignant.

18. The use of claim 15 wherein said tumor is benign.