DEHYDROPHENYLAHISTINS AND ANALOGS THEREOF AND THE SYNTHESIS OF DEHYDROPHENYLAHISTINS AND ANALOGS THEREOF

Background of the Invention

Field of the Invention

The present invention relates to compounds and methods of synthetic preparation in the fields of chemistry and medicine. More specifically, the present invention relates to compounds and procedures for making compounds useful in the treatment of cancer and the treatment of fungal infections.

Brief Description of the Related Art

It is thought that a single, universal cellular mechanism controls the regulation of the eukaryotic cell cycle process. *See, e.g.*, Hartwell, L.H. *et al.*, Science (1989), 246: 629-34. It is also known that when an abnormality arises in the control mechanism of the cell cycle, cancer or an immune disorder may occur. Accordingly, as is also known, antitumor agents and immune suppressors may be among the substances that regulate the cell cycle. Thus, new methods for producing eukaryotic cell cycle inhibitors are needed as antitumor and immune-enhancing compounds, and should be useful in the treatment of human cancer as chemotherapeutic, anti-tumor agents. *See, e.g.*, Roberge, M. *et al.*, Cancer Res. (1994), 54, 6115-21.

Fungi, especially pathogenic fungi and related infections, represent an increasing clinical challenge. Existing antifungal agents are of limited efficacy and toxicity, and the development and/or discovery of strains of pathogenic fungi that are resistant to drugs currently available or under development. By way of example, fungi that are pathogenic in humans include among others *Candida* spp. including *C. albicans*, *C. tropicalis*, *C. kefyr*, *C. krusei* and *C. galbrata*; *Aspergillus* spp. including *A. fumigatus* and *A. flavus*; *Cryptococcus neoformans*; *Blastomyces spp.* including *Blastomyces dermatitidis*; *Pneumocystis carinii*; *Coccidioides immitis*; *Basidiobolus ranarum*; *Conidiobolus* spp.; *Histoplasma capsulatum*; *Rhizopus* spp. including *R. oryzae* and *R. microsporus*; *Cunninghamella* spp.; *Rhizomucor* spp.; *Paracoccidioides brasiliensis*; *Pseudallescheria boydii*; *Rhinosporidium seeberi*; and *Sporothrix schenckii* (Kwon-Chung, K.J. & Bennett, J.E. 1992 Medical Mycology, Lea and Febiger, Malvern, PA).

Recently, it has been reported that tryprostatins A and B (which are diketopiperazines consisting of proline and isoprenylated tryptophan residues), and five other structurally-related diketopiperazines, inhibited cell cycle progression in the M phase, *see* Cui, C. *et al.*, 1996 *J Antibiotics* **49**:527-33; Cui, C. *et al.* 1996 *J Antibiotics* **49**:534-40, and that these compounds also affect the microtubule assembly, *see* Usui, T. *et al.* 1998 *Biochem J* **333**:543-48; Kondon, M. *et al.* 1998 *J Antibiotics* **51**:801-04. Furthermore, natural and synthetic compounds have been reported to inhibit mitosis, thus inhibit the eukaryotic cell cycle, by binding to

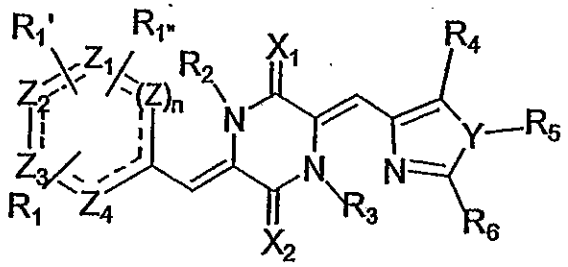
the colchicine binding-site (CLC-site) on tubulin, which is a macromolecule that consists of two 50 kDa subunits (□and □tubulin) and is the major constituent of microtubules. *See, e.g.*, Iwasaki, S., 1993 *Med Res Rev* **13**:183-198; Hamel, E. 1996 *Med Res Rev* **16**:207-31; Weisenberg, R.C. *et al.*, 1969 *Biochemistry* **7**:4466-79. Microtubules are thought to be involved in several essential cell functions, such as axonal transport, cell motility and determination of cell morphology. Therefore, inhibitors of microtubule function may have broad biological activity, and be applicable to medicinal and agrochemical purposes. It is also possible that colchicine (CLC)-site ligands such as CLC, steganacin, *see* Kupchan, S.M. *et al.*, 1973 *J Am Chem Soc* **95**:1335-36, podophyllotoxin, *see* Sackett, D.L., 1993 *Pharmacol Ther* **59**:163-228, and combretastatins, *see* Pettit, G.R. *et al.*, 1995 *J Med Chem* **38**:166-67, may prove to be valuable as eukaryotic cell cycle inhibitors and, thus, may be useful as chemotherapeutic agents.

Although diketopiperazine-type metabolites have been isolated from various fungi as mycotoxins, *see* Horak R.M. *et al.*, 1981 *JCS Chem Comm* 1265-67; Ali M. *et al.*, 1898 Toxicology Letters **48**:235-41, or as secondary metabolites, *see* Smedsgaard J. *et al.*, 1996 *J Microbiol Meth* **25**:5-17, little is known about the specific structure of the diketopiperazine-type metabolites or their derivatives and their antitumor activity, particularly *in vivo*. Not only have these compounds been isolated as mycotoxins, the chemical synthesis of one type of diketopiperazine-type metabolite, phenylahistin, has been described by Hayashi *et al.* in *J. Org. Chem.* (2000) 65, page 8402. In the art, one such diketopiperazine-type metabolite derivative, dehydrophenylahistin, has been prepared by enzymatic dehydrogenation of its parent phenylahistin. With the incidences of cancer on the rise, there exists a particular need for chemically producing a class of substantially purified diketopiperazine-type metabolite-derivatives having animal cell-specific proliferation-inhibiting activity and high antitumor activity and selectivity. There is therefore a particular need for an efficient method of synthetically producing substantially purified, and structurally and biologically characterized diketopiperazine-type metabolite-derivatives.

Also, PCT Publication WO/0153290 (July 26, 2001) describes a non-synthetic method of producing dehydrophenylahistin by exposing phenylahistin or a particular phenylahistin analog to a dehydrogenase obtained from *Streptomyces albulus*.

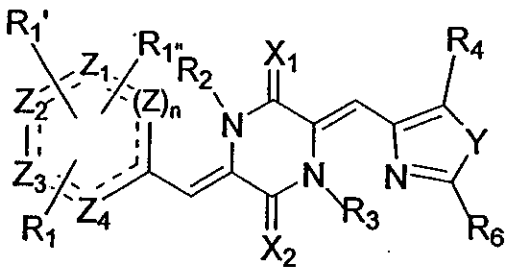
Summary of the Invention

Compounds, and methods for the synthetic manufacture of compounds, are disclosed for a class of compounds having the structure of Formula (I):



(I)

Accordingly, in a first aspect of the present invention, there is provided a method for the synthetic preparation of a compound having the structure of Formula (I):



(I)

wherein

R_1, R_4, and R_6, are each separately selected from the group consisting of a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups, hydroxy, carboxy, -CO-O-R_7, cyano, alkylthio, halogenated alkyl including polyhalogenated alkyl, halogenated carbonyl, and carbonyl -CCO-R_7, wherein R_7 is selected from a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups;

R_1' and R_1" are each independently selected from the group consisting of a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl,

and substituted phenyl groups, hydroxy, carboxy, -CO-O-R_7, cyano, alkylthio, halogenated alkyl including polyhalogenated alkyl, halogenated carbonyl, and carbonyl - CCO-R_7, wherein R_7 is selected from a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups;

R_1' and R_1" are either covalently bound to one another to form a ring or are not covalently bound to one another;

R_2, R_3, and R_5 are each separately selected from the group consisting of a hydrogen atom, a halogen atom, and saturated C_1-C_{12} alkyl, unsaturated C_1-C_{12} alkenyl, acyl, cycloalkyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, and substituted nitro groups, sulfonyl and substituted sulfonyl groups;

X_1 and X_2 are separately selected from the group consisting of an oxygen atom, a nitrogen atom, and a sulfur atom, each either unsubstituted or substituted with a R_5 group, as defined above;

Y is selected from the group consisting of a nitrogen atom substituted with R_5, an oxygen atom, a sulfur atom, a oxidized sulfur atom, and a methylene group substituted with one or more R_5;

n is an integer equal to zero, one or two;

Z, for each separate n, if non-zero, and Z_1, Z_2, Z_3 and Z_4 are each separately selected from a carbon atom, a sulfur atom, a nitrogen atom or an oxygen atom; and

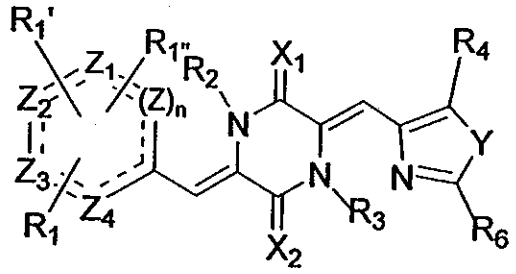
the dashed bonds may be either single or double bonds;

said method comprising:

reacting a diacyldiketopiperazine with a first aldehyde to produce an intermediate; and

reacting said intermediate with a second aldehyde to produce said compound, wherein said first aldehyde and said second aldehydes are selected from the group consisting of an oxazolecarboxaldeyhyde, imidazolecarboxaldehyde, a benzaldehyde, imidazolecarboxaldehyde derivatives, and benzaldehyde derivatives, thereby forming the compound.

Accordingly, in a second aspect of the present invention, there is provided a compound having the structure of Formula (I):



(I)

wherein

R_1 and R_6, are each separately selected from the group consisting of a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups, hydroxy, carboxy, -CO-O-R_7, cyano, alkylthio, halogenated alkyl including polyhalogenated alkyl, halogenated carbonyl, and carbonyl -CCO-R_7,

wherein R_7 is selected from a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups;

R_4 is a tertiary butyl group;

R_1' and R_1'' are each independently selected from the group consisting of a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups, hydroxy, carboxy, -CO-O-R_7, cyano, alkylthio, halogenated alkyl including polyhalogenated alkyl, halogenated carbonyl, and carbonyl - CCO-R_7, wherein R_7 is selected from a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups;

R, R_1' and R_1'' are either covalently bound to one another or are not covalently bound to one another;

R_2, R_3, and R_5 are each separately selected from the group consisting of a hydrogen atom, a halogen atom, and saturated C_1-C_{12} alkyl, unsaturated C_1-C_{12} alkenyl, acyl, cycloalkyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, and substituted nitro groups, sulfonyl and substituted sulfonyl groups;

X_1 and X_2 are separately selected from the group consisting of an oxygen atom, a nitrogen atom, and a sulfur atom, each either unsubstituted or substituted with a R_5 group, as defined above;

Y is selected from the group consisting of a nitrogen atom substituted with R_5, an oxygen atom, a sulfur atom, a oxidized sulfur atom, and a methylene group substituted with one or more R_5;

n is an integer equal to zero, one or two;

Z, for each separate n, if non-zero, and Z_1, Z_2, Z_3 and Z_4 are each separately selected from a carbon atom, a sulfur atom, a nitrogen atom or an oxygen atom; and

the dashed bonds may be either single or double bonds.

Accordingly, in a third aspect of the present invention, there is provided a pharmaceutical composition, comprising the compound as defined in the second aspect and a pharmaceutically acceptable carrier.

Accordingly, in a fourth aspect of the present invention, there is provided a pharmaceutical composition for treating or preventing fungal infection comprising an antifungally effective amount of a compound as defined in the second aspect together with a pharmaceutically acceptable carrier therefore.

Accordingly, in a fifth aspect of the present invention, there is provided a pharmaceutical composition for treating or preventing a tumor comprising a pharmaceutically effective amount of a compound as defined in the second aspect together with a pharmaceutically acceptable carrier therefore.

Accordingly, in a sixth aspect of the present invention, there is provided a use of a compound as defined in the second aspect in the manufacture of a medicament for the treatment of a disease state in a mammal.

Accordingly, in a seventh aspect of the present invention, there is provided a use of a compound as defined in the second aspect in the manufacture of a medicament for treating and/or preventing cancer in a mammal afflicted with cancer.

The disclosed compounds have the structure of Formula (I) wherein:

R_1, R_4, and R_6, are each separately selected from the group consisting of a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups, hydroxy, carboxy, -CO-O-R_7, cyano, alkylthio, halogenated alkyl including polyhalogenated alkyl, halogenated carbonyl, and carbonyl -CCO-R_7, wherein R_7 is selected from a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups;

R_1' and R_1'' are independently selected from the group consisting of a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups, hydroxy, carboxy, -CO-O-R_7, cyano, alkylthio, halogenated alkyl including polyhalogenated alkyl, halogenated carbonyl, and carbonyl -CCO-R_7, wherein R_7 is selected from a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups;

R_2, R_3, and R_5 are each separately selected from the group consisting of a hydrogen atom, a halogen atom, and saturated C_1-C_{12} alkyl, unsaturated C_1-C_{12} alkenyl, acyl, cycloalkyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, and substituted nitro groups, sulfonyl and substituted sulfonyl groups;

X_1 and X_2 are separately selected from the group consisting of an oxygen atom, a nitrogen atom, and a sulfur atom, each either unsubstituted or substituted with a R_5 group, as defined above;

Y is selected from the group consisting of a nitrogen atom, a substituted nitrogen atom with a R_5 group from above, an oxygen atom, a sulfur atom, a oxidized sulfur atom, a methylene group and a substituted methylene group;

n is an integer equal to zero, one or two;

Z, for each separate n, if non-zero, and Z_1, Z_2, Z_3 and Z_4 are each separately selected from a carbon atom, a sulfur atom, a nitrogen atom or an oxygen atom; and

the dashed bonds may be either single or double bonds;

with the proviso that, in a particular compound, if R_1, R_1', R_2, R_3, R_5 and R_6 are each a hydrogen atom, then it is not true that X_1 and X_2 are each an oxygen atom and R_4 is either 3,3-dimethylbutyl-1-ene or a hydrogen atom.

The methods can comprise the steps of:

reacting a diacyldiketopiperazine with a first aldehyde to produce an intermediate compound ; and

reacting said intermediate compound with a second aldehyde to produce said class of compounds with said generic structure, wherein

said first aldehyde and said second aldehydes are selected from the group consisting of an oxazolecarboxaldeyhyde, imidazolecarboxaldehyde, a benzaldehyde, imidazolecarboxaldehyde derivatives, and benzaldehyde derivatives, thereby forming a compound wherein

The disclosed compounds have the structure of Formula (I) wherein:

R_1, R_4, and R_6, are each separately selected from the group consisting of a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups, hydroxy, carboxy, -CO-O-R_7, cyano, alkylthio, halogenated alkyl including polyhalogenated alkyl, halogenated carbonyl, and carbonyl -CCO-R_7, wherein R_7 is selected from a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups;

R_1' and R_1'' are independently selected from the group consisting of a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups, hydroxy, carboxy, -CO-O-R_7, cyano, alkylthio, halogenated alkyl including polyhalogenated alkyl, halogenated carbonyl, and carbonyl -CCO-R_7, wherein R_7 is selected from a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl,

cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups;

R_2, R_3, and R_5 are each separately selected from the group consisting of a hydrogen atom, a halogen atom, and saturated C_1-C_{12} alkyl, unsaturated C_1-C_{12} alkenyl, acyl, cycloalkyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, and substituted nitro groups, sulfonyl and substituted sulfonyl groups;

X_1 and X_2 are separately selected from the group consisting of an oxygen atom, a nitrogen atom, and a sulfur atom, each either unsubstituted or substituted with a R_5 group, as defined above;

Y is selected from the group consisting of a nitrogen atom, a substituted nitrogen atom with a R_5 group from above, an oxygen atom, a sulfur atom, a oxidized sulfur atom, a methylene group and a substituted methylene group;

n is an integer equal to zero, one or two;

Z, for each separate n, if non-zero, and Z_1, Z_2, Z_3 and Z_4 are each separately selected from a carbon atom, a sulfur atom, a nitrogen atom or an oxygen atom; and

the dashed bonds may be either single or double bonds.

In preferred embodiments of the compound and method, the imidazolecarboxaldehyde is 5-(1,1-dimethyl-2-ethyl)imidazole-4-carboxaldehyde and the benzaldehyde comprises a single methoxy group. Additional preferred embodiments of the compounds described herein include compounds having a t-butyl group, a dimethoxy group, a chloro- group, and a methylthiophen group, and methods of making such compounds, as well as the compounds described in Tables 2, 3 and 4, as well as methods of making such compounds.

Also disclosed are methods and materials for treating neoplastic tissue or preventing cancers or infection by a pathogenic fungus. These methods and material can be particularly well suited for treatment of mammalian subjects, more particularly humans, and can involve administering to the subject a dehydrophenylahistin or its analog. The method can comprise administering to the subject a composition comprising an effective antitumor or antifungal amount of a dehydrophenylahistin or its analog.

Brief Description of the Drawings

The accompanying drawings, which are incorporated in and form part of the specification, merely illustrate certain preferred embodiments of the present invention. Together with the remainder of the specification, they are meant to serve to explain preferred modes of making certain compounds of the invention to those of skilled in the art. In the drawings:

Figure 1 illustrates a reaction scheme for producing dehydrophenylahistins by reacting a diacyldiketopiperazine 1 with an imidazolecarboxaldeheyde 2 to yield an intermediate compound 3 which is reacted with a benzaldehyde 4 to produce a dehydrophenylahistin.

Figure 2 depicts the HPLC profile of the synthetic crude dehydrophenylahistin.

Figure 3 illustrates a reaction scheme for producing dehydrophenylahistins by reacting a diacyldiketopiperazine 1 with a benzaldehyde 4 to yield an intermediate compound 17 which is reacted with an imidazolecarboxaldeheyde 15 to produce a dehydrophenylahistin.

Figure 4 depicts the HPLC profiles of the crude synthetic tBu-dehyrophenylahistin produced from Route A and from Route B.

Figure 5 illustrates two modification strategies for dehydroPLH for potent cytotoxic activity.

Figure 6 depicts the putative active conformation of dehydroPLH at the phenyl moiety.

Figure 7 depicts Cytochrome P450 metabolism of phenylahistin.

Figure 8 illustrates the *Z-E* migration of tBu-dehydroPLH.

Figure 9 depicts the synthesis and prodrug image of acyl-E-tBu-dehydroPLH.

Figure 10 depicts the temperature gradient of 3-Z-Benzylidene-6-[5"-(1,1-dimethylallyl)-1H-imidazol-4"-Z-ylmethylene]-piperazine-2,5-dione.

Figure 11 depicts the temperature gradient of 3-Z-benzylidene-6-(5"-tert-butyl-1*H*-imidazol-4"-Z-ylmethylene)-piperazine-2,5-dione.

Figure 12 depicts the effect of KPU-2, KPU-35 and t-butyl-phenylahistin in comparison to colchicine and taxol on HuVEC monolayer permeability to FITC-Dextran.

Figure 13 depicts the effect of KPU-2 alone and in combination with CPT-11 on estimated tumor growth in the HT-29 Human Colon Tumor Xenograft model.

Figure 14 depicts the effect of KPU-2 alone and in combination with CPT-11 on the weight of tumors excised at autopsy in individual mice in the HT-29 Human Colon Tumor Xenograft model.

Figure 15 depicts the effect of KPU-2 alone and in combination with CPT-11 on estimated tumor growth in the HT-29 Human Colon Tumor Xenograft model.

Figure 16 depicts the effect of KPU-2 alone and in combination with CPT-11 on the weight of tumors excised at autopsy in individual mice in the HT-29 Human Colon Tumor Xenograft model.

Figure 17 depicts the effects of: A. KPU-2, B. KPU-35 and C. t-butyl-phenylahistin alone and in combination with CPT-11 on estimated tumor growth in the HT-29 human colon tumor xenograft model.

Figure 18 depicts the effects of A. KPU-2, B. KPU-35 and C. t-butyl-phenylahistin alone and in combination with CPT-11 on the weight of tumors excised at autopsy in individual mice in the HT-29 Human Colon Tumor Xenograft model.

Figure 19 depicts the effects of KPU-2 alone and in combination with CPT-11 on tumor growth in the HT-29 human colon tumor xenograft model: comparison of three studies.

Figure 20 depicts the effects of KPU-2 alone and in combination with CPT-11 on final tumor weights in the HT-29 human colon tumor xenograft model: comparison of three studies.

Figure 21 depicts the effects of KPU-2 alone or in combination with Taxotere on estimated tumor growth in the DU-145 Human Prostate Tumor Xenograft Model.

Figure 22 depicts the effects of A. KPU-2, B. KPU-35 and C. t-butyl-phenylahistin alone and in combination with Taxotere on the estimated tumor growth based on observations made during the in-life portion of the DU-145 Human Prostate Tumor Xenograft Model.

Figure 23 depicts the effects of KPU-2 alone and in combination with Taxotere on the individual excised tumor weights at autopsy in the DU-145 Human Prostate Tumor Xenograft Model.

Figure 24 depicts the effects of KPU-35 alone and in combination with Taxotere on the individual excised tumor weights at autopsy in the DU-145 Human Prostate Tumor Xenograft Model.

Figure 25 depicts the effects of A. KPU-2, B. KPU-35 and C. t-butyl-phenylahistin alone and in combination with Taxotere in MCF-7 Human Breast Tumor Xenograft model.

Figure 26 depicts the effects of KPU-2 alone and in combination with Taxotere on estimated tumor growth in the A549 Human Lung Tumor Xenograft model.

Figure 27 depicts the effects of KPU-2 alone and in combination with Taxotere on the excised tumor weights at autopsy in the A549 Human Lung Tumor Xenograft model.

Figure 28 depicts the effects of KPU-2 alone and in combination with Paclitaxel on estimated tumor weight in the murine mammary fat pad implanted MDA-231 Human Breast Tumor model.

Figure 29 depicts effects of A. KPU-2, B. KPU-35 and C. t-butyl-phenylahistin alone and in combination with Paclitaxel in the Murine Melanoma B16 F10 Metastatic Tumor Model. In certain Figures, compounds are identified using an alternative designation. A complete chart to convert these alternative designations is as follows:

Alternative designation	Designation used herein
NPI-2350	(-)-phenylahistin
NPI-2352	KPU-01
NPI-2353	KPU-03
NPI-2354	KPU-04
NPI-2355	KPU-05
NPI-2356	KPU-06
NPI-2357	KPU-07
NPI-2358	KPU-02
NPI-2359	KPU-08

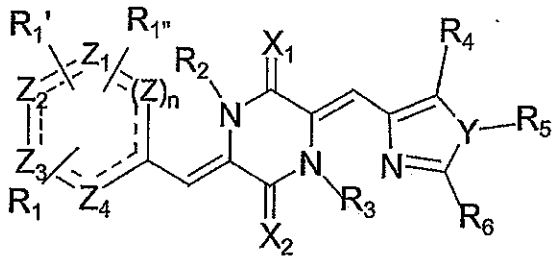
NPI-2360	KPU-09
NPI-2361	KPU-10
NPI-2362	KPU-11
NPI-2363	KPU-12
NPI-2364	KPU-13
NPI-2365	KPU-14
NPI-2366	KPU-15
NPI-2367	KPU-16
NPI-2368	KPU-17
NPI-2369	KPU-18
NPI-2370	KPU-19
NPI-2371	KPU-21
NPI-2372	KPU-22
NPI-2373	KPU-23
NPI-2374	KPU-24
NPI-2375	KPU-25
NPI-2376	KPU-28
NPI-2377	KPU-26
NPI-2378	KPU-27
NPI-2379	KPU-29
NPI-2380	KPU-20
NPI-2381	KPU-30
NPI-2382	KPU-31
NPI-2383	KPU-32
NPI-2384	KPU-33
NPI-2385	KPU-34
NPI-2386	KPU-35
NPI-2387	KPU-36
NPI-2388	KPU-37
NPI-2389	KPU-38
NPI-2390	KPU-39
NPI-2391	KPU-40
NPI-2392	KPU-41
NPI-2393	KPU-42
NPI-2394	KPU-43
NPI-2395	KPU-44
NPI-2396	KPU-45
NPI-2397	KPU-46
NPI-2398	KPU-47
NPI-2399	KPU-48
NPI-2400	KPU-49
NPI-2401	KPU-50
NPI-2402	KPU-51
NPI-2403	KPU-52
NPI-2404	KPU-53
NPI-2405	KPU-54
NPI-2406	KPU-55

NPI-2407	KPU-56
NPI-2408	KPU-57
NPI-2409	KPU-58
NPI-2410	KPU-59
NPI-2411	KPU-60
NPI-2412	KPU-61
NPI-2413	KPU-62
NPI-2414	KPU-63
NPI-2415	KPU-64
NPI-2416	KPU-65
NPI-2417	KPU-66
NPI-2418	KPU-67
NPI-2419	KPU-68
NPI-2420	KPU-69
NPI-2421	KPU-70
NPI-2422	KPU-71
NPI-2423	KPU-72
NPI-2424	KPU-73
NPI-2425	KPU-74
NPI-2426	KPU-75
NPI-2427	KPU-76
NPI-2428	KPU-77
NPI-2429	KPU-79
NPI-2430	KPU-80
NPI-2431	KPU-81
NPI-2432	KPU-82
NPI-2433	KPU-83
NPI-2434	KPU-84
NPI-2435	KPU-86
NPI-2436	KPU-87
NPI-2437	KPU-88
NPI-2438	KPU-89
NPI-2439	KPU-90
NPI-2440	KPU-91
NPI-2441	KPU-92
NPI-2442	KPU-80
NPI-2455	KPU-94
NPI-2456	KPU-95
NPI-2457	KPU-96
NPI-2458	KPU-97
NPI-2459	KPU-98
NPI-2460	t-butyl phenylahistin

Detailed Description of the Preferred Embodiment

The disclosure provides methods for the synthetic preparation of compounds, including novel compounds, including dehydrophenyalahistin and dehydrophenyalahistin analogs, and provides methods for producing pharmaceutically acceptable cell cycle inhibitors, antitumor agents and antifungal agents in relatively high yield, wherein said compounds and/or their derivatives are among the active ingredients in these cell cycle inhibitors, antitumor agents and antifungal agents. Other objects include providing novel compounds not obtainable by currently available, non-synthetic methods. It is also an object to provide a method of treating cancer, particularly human cancer, comprising the step of administering an effective tumor-growth inhibiting amount of a member of a class of new anti-tumor compounds. This invention also provides a method for preventing or treating a pathogenic fungus in a subject which involves administering to the subject an effective anti-fungal amount of a member of a class of new anti-fungal compounds, e.g., administering a dehydrophenylahistin or its analog in an amount and manner which provides the intended antifungal effect. In the preferred embodiment of the compounds and methods of making and using such compounds disclosed herein, but not necessarily in all embodiments of the present invention, these objectives are met.

Disclosed herein, also, are compounds, and methods of producing a class of compounds, wherein the compounds are represented by Formula (I):



(I)

wherein:

R_1, R_4, and R_6, are each separately selected from the group consisting of a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups, hydroxy, carboxy, -CO-O-R_7, cyano, alkylthio, halogenated alkyl including polyhalogenated alkyl, halogenated carbonyl, and carbonyl -CCO-R_7, wherein R_7 is selected from a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups;

R_1' and R_1" are independently selected from the group consisting of a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups, hydroxy, carboxy, -CO-O-R_7, cyano, alkylthio, halogenated alkyl including polyhalogenated alkyl, halogenated carbonyl, and carbonyl -CCO-R_7, wherein R_7 is selected from a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups;

R, R_1' and R_1" are either covalently bound to one another or are not covalently bound to one another;

R_2, R_3, and R_6 are each separately selected from the group consisting of a hydrogen atom, a halogen atom, and saturated C_1-C_{12} alkyl, unsaturated C_1-C_{12} alkenyl, acyl, cycloalkyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, and substituted nitro groups, sulfonyl and substituted sulfonyl groups;

X_1 and X_2 are separately selected from the group consisting of an oxygen atom, a nitrogen atom, and a sulfur atom, each either unsubstituted or substituted with a R_5 group, as defined above;

Y is selected from the group consisting of a nitrogen atom, a substituted nitrogen atom with a R_5 group from above, an oxygen atom, a sulfur atom, a oxidized sulfur atom, a methylene group and a substituted methylene group;

n is an integer equal to zero, one or two;

Z, for each separate n, if non-zero, and Z_1, Z_2, Z_3 and Z_4 are each separately selected from a carbon atom, a sulfur atom, a nitrogen atom or an oxygen atom; and

the dashed bonds may be either single or double bonds.

The method comprises a method of producing compounds of Formula (I) by the steps of:

reacting a diacyldiketopiperazine with a first aldehyde to produce an intermediate compound; and

reacting said intermediate compound with a second aldehyde to produce said class of compounds with said generic structure, wherein

said first aldehyde and said second aldehydes are selected from the group consisting of an oxazolecarboxaldeyhyde, imidazolecarboxaldehyde, a benzaldehyde, imidazolecarboxaldehyde derivatives, and benzaldehyde derivatives, thereby forming a compound of Formula (I) wherein

R_1, R_4, and R_6, are each separately selected from the group consisting of a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups, hydroxy, carboxy, -CO-O-R_7, cyano, alkylthio, halogenated alkyl

including polyhalogenated alkyl, halogenated carbonyl, and carbonyl -CCO-R_7, wherein R_7 is selected from a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups;

R_1' and R_1" are independently is selected from the group consisting of a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups, hydroxy, carboxy, -CO-O-R_7, cyano, alkylthio, halogenated alkyl including polyhalogenated alkyl, halogenated carbonyl, and carbonyl -CCO-R_7, wherein R_7 is selected from a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups;

R_2, R_3, and R_5 are each separately selected from the group consisting of a hydrogen atom, a halogen atom, and saturated C_1-C_{12} alkyl, unsaturated C_1-C_{12} alkenyl, acyl, cycloalkyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, and substituted nitro groups, sulfonyl and substituted sulfonyl groups;

X_1 and X_2 are separately selected from the group consisting of an oxygen atom, a nitrogen atom and a sulfur atom, and

Y is selected from the group consisting of a nitrogen atom, a substituted nitrogen atom with a R_5 group from above, an oxygen atom, a sulfur atom, a oxidized sulfur atom, a methylene group and a substituted methylene group;

Z, for each separate n, if non-zero, and Z_1, Z_2, Z_3 and Z_4 are each separately selected from a carbon atom, a sulfur atom, a nitrogen atom or an oxygen atom; and

the dashed bonds may be either single or double bonds.

Also provided are pharmaceutically acceptable salts and pro-drug esters of the compound of Formulae (I) and (II) and provides methods of synthesizing such compounds by the methods disclosed herein.

The term "pro-drug ester," especially when referring to a pro-drug ester of the compound of Formula (I) synthesized by the methods disclosed herein, refers to a chemical derivative of the compound that is rapidly transformed *in vivo* to yield the compound, for example, by hydrolysis in blood or inside tissues. The term "pro-drug ester" refers to derivatives of the compounds disclosed herein formed by the addition of any of several ester-forming groups that are hydrolyzed under physiological conditions. Examples of pro-drug ester groups include pivoyloxymethyl, acetoxymethyl, phthalidyl, indanyl and methoxymethyl, as well as other such groups known in the art, including a (5-R-2-oxo-1,3-dioxolen-4-yl)methyl group. Other examples of pro-drug

ester groups can be found in, for example, T. Higuchi and V. Stella, in "Pro-drugs as Novel Delivery Systems", Vol. 14, A.C.S. Symposium Series, American Chemical Society (1975); and "Bioreversible Carriers in Drug Design: Theory and Application", edited by E. B. Roche, Pergamon Press: New York, 14-21 (1987) (providing examples of esters useful as prodrugs for compounds containing carboxyl groups).

The term "pro-drug ester," as used herein, also refers to a chemical derivative of the compound that is rapidly transformed *in vivo* to yield the compound, for example, by hydrolysis in blood. The term "pro-drug ester" refers to derivatives of the compounds disclosed herein formed by the addition of any of several ester-forming groups that are hydrolyzed under physiological conditions. Examples of pro-drug ester groups include pivoyloxymethyl, acetoxymethyl, phthalidyl, indanyl and methoxymethyl, as well as other such groups known in the art, including a (5-R-2-oxo-1,3-dioxolen-4-yl)methyl group. Other examples of pro-drug ester groups can be found in, for example, T. Higuchi and V. Stella, in "Pro-drugs as Novel Delivery Systems", Vol. 14, A.C.S. Symposium Series, American Chemical Society (1975); and "Bioreversible Carriers in Drug Design: Theory and Application", edited by E. B. Roche, Pergamon Press: New York, 14-21 (1987) (providing examples of esters useful as prodrugs for compounds containing carboxyl groups).

The term "pharmaceutically acceptable salt," especially when referring to a pharmaceutically acceptable salt of the compound of Formula (I) synthesized by the methods disclosed herein, refers to any pharmaceutically acceptable salts of a compound, and preferably refers to an acid addition salt of a compound. Preferred examples of pharmaceutically acceptable salt are the alkali metal salts (sodium or potassium), the alkaline earth metal salts (calcium or magnesium), or ammonium salts derived from ammonia or from pharmaceutically acceptable organic amines, for example C_1-C_7 alkylamine, cyclohexylamine, triethanolamine, ethylenediamine or tris-(hydroxymethyl)-aminomethane. With respect to compounds synthesized by the method that are basic amines, the preferred examples of pharmaceutically acceptable salts are acid addition salts of pharmaceutically acceptable inorganic or organic acids, for example, hydrohalic, sulfuric, phosphoric acid or aliphatic or aromatic carboxylic or sulfonic acid, for example acetic, succinic, lactic, malic, tartaric, citric, ascorbic, nicotinic, methanesulfonic, p-toluensulfonic or naphthalenesulfonic acid.

The term "pharmaceutically acceptable salt," as used herein, also refers to any pharmaceutically acceptable salts of a compound, and preferably refers to an acid addition salt of a compound. Preferred examples of pharmaceutically acceptable salt are the alkali metal salts (sodium or potassium), the alkaline earth metal salts (calcium or magnesium), or ammonium salts derived from ammonia or from pharmaceutically acceptable organic amines, for example C_1-C_7 alkylamine, cyclohexylamine, triethanolamine, ethylenediamine or tris-(hydroxymethyl)-aminomethane. With respect to compounds that are basic amines, the preferred examples of pharmaceutically acceptable salts are acid addition salts of pharmaceutically acceptable inorganic or organic acids, for example, hydrohalic, sulfuric, phosphoric acid or aliphatic or aromatic carboxylic

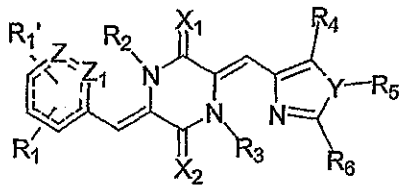
or sulfonic acid, for example acetic, succinic, lactic, malic, tartaric, citric, ascorbic, nicotinic, methanesulfonic, p-toluensulfonic or naphthalenesulfonic acid.

Preferred pharmaceutical compositions disclosed herein include pharmaceutically acceptable salts and pro-drug esters of the compound of Formula (I) synthesized by the method disclosed herein. Accordingly, if the manufacture of pharmaceutical formulations involves intimate mixing of the pharmaceutical excipients and the active ingredient in its salt form, then it is preferred to use pharmaceutical excipients which are non-basic, that is, either acidic or neutral excipients.

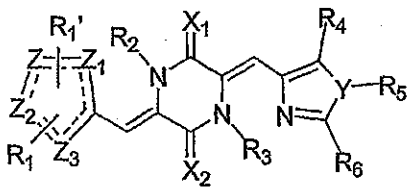
In preferred embodiments of the methods of the compounds disclosed herein, a relatively rigid, planar pseudo three-ring structure may be formed. To stabilize such a relatively rigid, planar pseudo three-ring structure, R_3 may preferably chosen to be hydrogen.

In other preferable embodiments of the compounds and methods described herein, n is equal to zero or one, more preferable one, and Z_2, Z_3, and Z_4, and each separately selected from an oxygen atom, a nitrogen atom, and a carbon atom, more preferable at one least one of Z_2, Z_3, and Z_4 being a carbon atom, and most preferable at least two of Z_2, Z_3, and Z_4 being a carbon atom. All Z's may simultaneous be carbon atoms.

Still other preferred embodiments of the methods and compositions disclosed herein involve compounds having the structures of Formulae (Ia) and (Ib), below:



(Ia)



(Ib)

wherein the variable groups are as defined herein.

The term "halogen atom," as used herein, means any one of the radio-stable atoms of column 7 of the Periodic Table of the Elements, *i.e.*, fluorine, chlorine, bromine, or iodine, with fluorine and chlorine being preferred.

The term "alkyl," as used herein, means any unbranched or branched, substituted or unsubstituted, saturated hydrocarbon, with C_1-C_6 unbranched, saturated, unsubstituted hydrocarbons being preferred, with

methyl, ethyl, iosbutyl, and tert-butyl being most preferred. Among the substituted, saturated hydrocarbons, C_1-C_6 mono- and di- and per-halogen substituted saturated hydrocarbons and amino-substituted hydrocarbons are preferred, with perfluromethyl, perchloromethyl, perfluoro-tert-butyl, and perchloro-tert-butyl being the most preferred. The term "substituted" has its ordinary meaning, as found in numerous contemporary patents from the related art. See, for example, U.S. Patent Nos. 6,583,143, 6,509,331; 6,506,787; 6,500,825; 5,922,683; 5,886,210; 5,874,443; and 6,350,759. Specifically, the definition of substituted is as broad as that provided in U.S. Patent No. 6,583,143, which defines the term substituted as any groups such as alkyl, aryl, arylalkyl, heteroaryl, heteroarylalkyl, heterocycle and heterocyclealkyl, wherein at least one hydrogen atom is replaced with a substituent. The term "substituted" is also as broad as the definition provided in U.S. Patent No. 6,509,331, which defines the term "substituted alkyl" such that it refers to an alkyl group, preferably of from 1 to 10 carbon atoms, having from 1 to 5 substituents, and preferably 1 to 3 substituents, selected from the group consisting of alkoxy, substituted alkoxy, cycloalkyl, substituted cycloalkyl, cycloalkenyl, substituted cycloalkenyl, acyl, acylamino, acyloxy, amino, substituted amino, aminoacyl, aminoacyloxy, oxyacylamino, cyano, halogen, hydroxyl, carboxyl, carboxylalkyl, keto, thioketo, thiol, thioalkoxy, substituted thioalkoxy, aryl, aryloxy, heteroaryl, heteroaryloxy, heterocyclic, heterocyclooxy, hydroxyamino, alkoxyamino, nitro, --SO-alkyl, --SO-substituted alkyl, --SO-aryl, --SO-heteroaryl, --SO_2-alkyl, --SO_2-substituted alkyl, --SO_2-aryl and --SO_2-heteroaryl. The other above-listed patents also provide standard definitions for the term "substituted" that are well-understood by those of skill in the art. The term "cycloalkyl" refers to any non-aromatic hydrocarbon ring, preferably having five to twelve atoms comprising the ring. The term "acyl" refers to alkyl or aryl groups derived from an oxoacid, with an acetyl group being preferred.

The term "alkenyl," as used herein, means any unbranched or branched, substituted or unsubstituted, unsaturated hydrocarbon including polyunsaturated hydrocarbons, with C_1-C_6 unbranched, mono-unsaturated and di-unsaturated, unsubstituted hydrocarbons being preferred, and mono-unsaturated, di-halogen substituted hydrocarbons being most preferred. In the R_1 and R_4 positions, of the compound of structure (I) a z-isoprenyl moiety is particularly preferred. The term "cycloalkenyl" refers to any non-aromatic hydrocarbon ring, preferably having five to twelve atoms comprising the ring.

The terms "aryl," "substituted aryl," "heteroaryl," and "substituted heteroaryl," as used herein, refer to aromatic hydrocarbon rings, preferably having five, six, or seven atoms, and most preferably having six atoms comprising the ring. "Heteroaryl" and "substituted heteroaryl," refer to aromatic hydrocarbon rings in which at least one heteroatom, *e.g.*, oxygen, sulfur, or nitrogen atom, is in the ring along with at least one carbon atom.

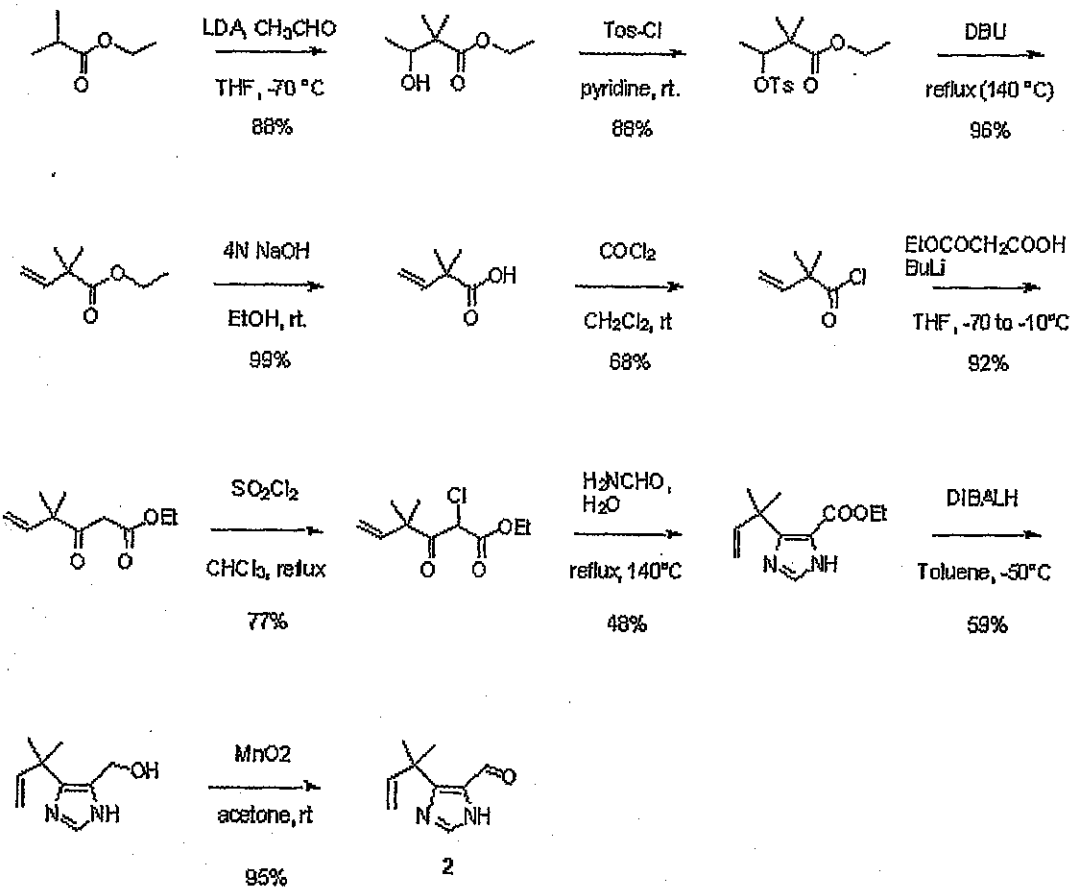
The term "alkoxy" refers to any unbranched, or branched, substituted or unsubstituted, saturated or unsaturated ether, with C_1-C_6 unbranched, saturated, unsubstituted ethers being preferred, with methoxy being preferred, and also with dimethyl, diethyl, methyl-isobutyl, and methyl-tert-butyl ethers also being preferred.

The term "cycloalkoxy" refers to any non-aromatic hydrocarbon ring, preferably having five to twelve atoms comprising the ring.

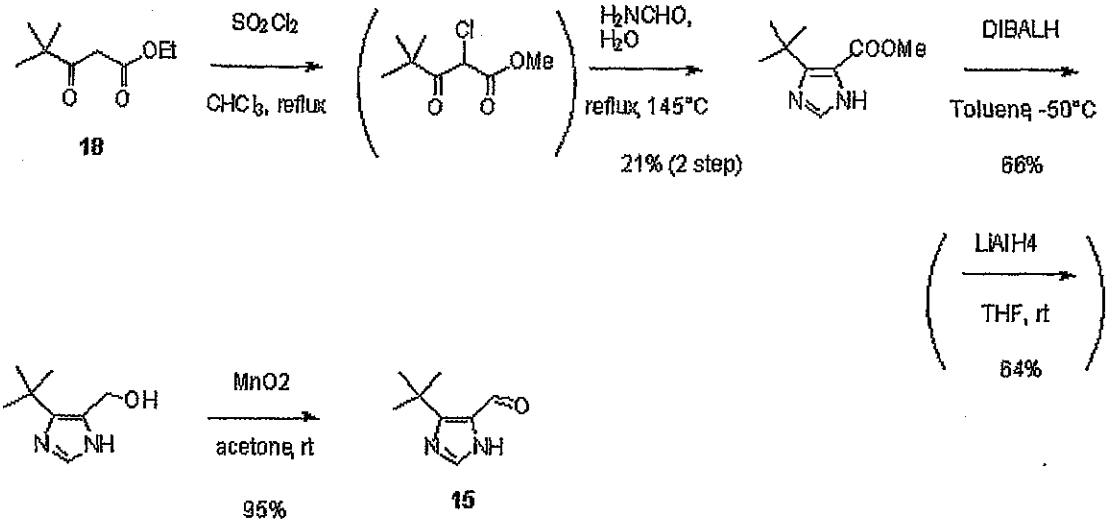
The terms "purified," "substantially purified," and "isolated" as used herein refer to the compound being free of other, dissimilar compounds with which the compound is normally associated in its natural state, so that the compound of the invention comprises at least 0.5%, 1%, 5%, 10%, or 20%, and most preferably at least 50% or 75% of the mass, by weight, of a given sample.

The compound of Formula (I) may be chemically synthesized or produced from reagents known and available in the art. For example, modifications of diacyldiketopiperazine (diacetyldiketopiperazine) have been described, for example, by Loughlin *et al.*, 2000 *Bioorg Med Chem Lett* **10**:91 or by Brocchini *et al.* in WO 95/21832. The diacyldiketopiperazine (diacetyldiketopiperazine) may be prepared, for example, by diacetylation of inexpensive 2,5-piperazinedione (TCI Cat. No. G0100, 25 g) with sodium acetate and sodium anhydride. The diacetyl structure of the activated deketopiperazine can be replaced with other acyl groups, to include carbamates such as Boc (t-butoxycarbonyl), Z (benzoyloxycarbonyl).

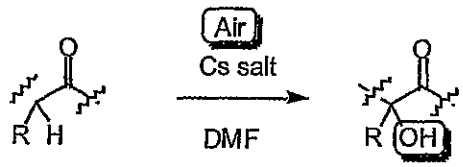
The imidazolecarboxaldehyde may be prepared, for example, according the procedure disclosed in Hayashi *et al.*, 2000 *J Organic Chem* **65**: 8402 as depicted below:



Another example of an imidazolecarboxaldehyde derivative is an imidazole-4-carboxaldehyde **15** derivative which can be produced from, for example, a commercially available beta-ketoester **18** (TCI Cat, No. P1031, 25mL) by the following route:



The synthetic method disclosed herein may be preferably performed in the presence of cesium carbonate as a base in DMF and in a deoxygenated atmosphere. The inert atmosphere circumvents the probable oxidation of activated α-carbon atoms of the diketopiperazine ring during the treatment with cesium carbonate (see below) as reported, for example, by Watanabe *et al.*, *18th International Congress of Heterocyclic Chemistry in Yokohama, Japan* (30 July 2001), Abstract, page 225.



Air-oxidation of Activated Carbonyl Compounds with Cesium Salts

Other embodiments of the synthetic method involve modifications to the compounds used in or otherwise involved in the synthesis of compounds represented by Formula (I). Such derivatives may include modifications to the phenyl ring, introduction of other aromatic ring systems, position of the aromatic ring, alterations to the imidazole ring system and/or further modifications to the 5-position on the imidazole ring. Examples of such modifications are discussed, for example, in Example 4. The result of such modifications include increased nitrogen content of the phenyl ring and/or the compound which may increase compound solubility. Other modifications may incorporate derivatives of known tubulin inhibitors, thereby mimicking the

activity of the tubulin inhibitors. Other modifications may simplify the synthesis of the β-ketoester involved in the production of the imidazolecarboxaldehyde used in the methods disclosed herein.

Pharmaceutical Compositions

The present invention also encompasses the compounds disclosed herein, optionally and preferably produced by the methods disclosed herein, in pharmaceutical compositions comprising a pharmaceutically acceptable carrier prepared for storage and subsequent administration, which have a pharmaceutically effective amount of the products disclosed above in a pharmaceutically acceptable carrier or diluent. Acceptable carriers or diluents for therapeutic use are well known in the pharmaceutical art, and are described, for example, in Remington's Pharmaceutical Sciences, Mack Publishing Co. (A.R. Gennaro edit. 1985). Preservatives, stabilizers, dyes and even flavoring agents may be provided in the pharmaceutical composition. For example, sodium benzoate, ascorbic acid and esters of p-hydroxybenzoic acid may be added as preservatives. In addition, antioxidants and suspending agents may be used.

The dehydrophenylahistin or dehydrophenylahistin analog compositions may be formulated and used as tablets, capsules, or elixirs for oral administration; suppositories for rectal administration; sterile solutions, suspensions for injectable administration; patches for transdermal administration, and sub-dermal deposits and the like. Injectables can be prepared in conventional forms, either as liquid solutions or suspensions, solid forms suitable for solution or suspension in liquid prior to injection or infusion, or as emulsions. Suitable excipients are, for example, water, saline, dextrose, mannitol, lactose, lecithin, albumin, sodium glutamate, cysteine hydrochloride, human serum albumin and the like. In addition, if desired, the injectable pharmaceutical compositions may contain minor amounts of nontoxic auxiliary substances, such as wetting agents, pH buffering agents, and the like. If desired, absorption enhancing preparations (for example, liposomes), may be utilized.

Pharmaceutical formulations for parenteral administration include aqueous solutions of the active compounds in water-soluble form. Additionally, suspensions of the active compounds may be prepared as appropriate oily injection suspensions. Suitable lipophilic solvents or vehicles include fatty oils such as sesame oil, or other organic oils such as soybean, grapefruit or almond oils, or synthetic fatty acid esters, such as ethyl oleate or triglycerides, or liposomes. Aqueous injection suspensions may contain substances which increase the viscosity of the suspension, such as sodium carboxymethyl cellulose, sorbitol, or dextran. Optionally, the suspension may also contain suitable stabilizers or agents that increase the solubility of the compounds to allow for the preparation of highly concentrated solutions.

Pharmaceutical preparations for oral use may be obtained by combining the active compounds with solid excipient, optionally grinding a resulting mixture, and processing the mixture of granules, after adding suitable auxiliaries, if desired, to obtain tablets or dragee cores. Suitable excipients are, in particular, fillers

such as sugars, including lactose, sucrose, mannitol, or sorbitol; cellulose preparations such as, for example, maize starch, wheat starch, rice starch, potato starch, gelatin, gum tragacanth, methyl cellulose, hydroxypropylmethyl-cellulose, sodium carboxymethylcellulose, and/or polyvinylpyrrolidone (PVP). If desired, disintegrating agents may be added, such as the cross-linked polyvinyl pyrrolidone, agar, or alginic acid or a salt thereof such as sodium alginate. Dragee cores are provided with suitable coatings. For this purpose, concentrated sugar solutions may be used, which may optionally contain gum arabic, talc, polyvinyl pyrrolidone, carbopol gel, polyethylene glycol, and/or titanium dioxide, lacquer solutions, and suitable organic solvents or solvent mixtures. Dyestuffs or pigments may be added to the tablets or dragee coatings for identification or to characterize different combinations of active compound doses. For this purpose, concentrated sugar solutions may be used, which may optionally contain gum arabic, talc, polyvinyl pyrrolidone, carbopol gel, polyethylene glycol, and/or titanium dioxide, lacquer solutions, and suitable organic solvents or solvent mixtures. Dyestuffs or pigments may be added to the tablets or dragee coatings for identification or to characterize different combinations of active compound doses. Such formulations can be made using methods known in the art (see, for example, U.S. Patent Nos. 5,733,888 (injectable compositions); 5,726,181 (poorly water soluble compounds); 5,707,641 (therapeutically active proteins or peptides); 5,667,809 (lipophilic agents); 5,576,012 (solubilizing polymeric agents); 5,707,615 (anti-viral formulations); 5,683,676 (particulate medicaments); 5,654,286 (topical formulations); 5,688,529 (oral suspensions); 5,445,829 (extended release formulations); 5,653,987 (liquid formulations); 5,641,515 (controlled release formulations) and 5,601,845 (spheroid formulations).

Further disclosed herein are various pharmaceutical compositions well known in the pharmaceutical art for uses that include intraocular, intranasal, and intraauricular delivery. Pharmaceutical formulations include aqueous ophthalmic solutions of the active compounds in water-soluble form, such as eyedrops, or in gellan gum (Shedden et al., 2001 *Clin Ther* **23**(3):440-50) or hydrogels (Mayer et al., 1996 *Ophthalmologica* **210**:101-3); ophthalmic ointments; ophthalmic suspensions, such as microparticulates, drug-containing small polymeric particles that are suspended in a liquid carrier medium (Joshi, A., 1994 *J Ocul Pharmacol* **10**:29-45), lipid-soluble formulations (Alm et al., 1989 *Prog Clin Biol Res* **312**:447-58), and microspheres (Mordenti, 1999 *Toxicol Sci* **52**:101-6); and ocular inserts. Such suitable pharmaceutical formulations are most often and preferably formulated to be sterile, isotonic and buffered for stability and comfort. Pharmaceutical compositions may also include drops and sprays often prepared to simulate in many respects nasal secretions to ensure maintenance of normal ciliary action. As disclosed in Remington's Pharmaceutical Sciences (Mack Publishing, 18th Edition), and well-known to those skilled in the art, suitable formulations are most often and preferably isotonic, slightly buffered to maintain a pH of 5.5 to 6.5, and most often and preferably include antimicrobial preservatives and appropriate drug stabilizers. Pharmaceutical formulations for intraauricular

delivery include suspensions and ointments for topical application in the ear. Common solvents for such aural formulations include glycerin and water.

When used as a cell cycle inhibitor, a tumor-growth-inhibiting, or a fungus-growth-inhibiting compound, the compound of Formula (I) can be administered by either oral or a non-oral pathways. When administered orally, it can be administered in capsule, tablet, granule, spray, syrup, or other such form. When administered non-orally, it can be administered as an aqueous suspension, an oily preparation or the like or as a drip, suppository, salve, ointment or the like, when administered via injection or infusion, subcutaneously, intreperitoneally, intravenously, intramuscularly, or the like. Similarly, it may be administered topically, rectally, or vaginally, as deemed appropriate by those of skill in the art for bringing the compound into optimal contact with a tumor, thus inhibiting the growth of the tumor. Local administration at the site of the tumor is also contemplated, either before or after tumor resection, as are controlled release formulations, depot formulations, and infusion pump delivery.

Methods of Administration

The present invention also encompasses methods for making and for administering the disclosed chemical compounds and the disclosed pharmaceutical compositions. Such disclosed methods include, among others, (a) administration though oral pathways, which administration includes administration in capsule, tablet, granule, spray, syrup, or other such forms; (b) administration through non-oral pathways, which administration includes administration as an aqueous suspension, an oily preparation or the like or as a drip, suppository, salve, ointment or the like; administration via injection or infusion, subcutaneously, intraperitoneally, intravenously, intramuscularly, intradermally, or the like; as well as (c) administration topically, (d) administration rectally, or (e) administration vaginally, as deemed appropriate by those of skill in the art for bringing the compound into contact with living tissue; and (f) administration via controlled released formulations, depot formulations, and infusion pump delivery. As further examples of such modes of administration and as further disclosure of modes of administration, disclosed herein are various methods for administration of the disclosed chemical compounds and pharmaceutical compositions including modes of administration through intraocular, intranasal, and intraauricular pathways.

The pharmaceutically effective amount of the dehydrophenylahistin or dehydrophenylahistin analog composition required as a dose will depend on the route of administration, the type of animal, including human, being treated, and the physical characteristics of the specific animal under consideration. The dose can be tailored to achieve a desired effect, but will depend on such factors as weight, diet, concurrent medication and other factors which those skilled in the medical arts will recognize.

In practicing the methods, the products or compositions can be used alone or in combination with one another, or in combination with other therapeutic or diagnostic agents. For example, as disclosed herein, the

compounds disclosed herein are effective in the treatment of cancer when used in combination with other actives, specifically other chemotherapeutics, for example biologics and the specific chemotherapeutics CPT-11, Taxotene (docataxel) and pacitaxel. The compounds disclosed herein are also effective in the treatment of cancer when used in combination with other actives, including anti-vascular agents, anti-angiogenenic agents, such as Erbuitux (Imclone/bristol-Myers) and Iressa (AstraZeneca), other VEGF inhibitors and biologics, more specifically, at least one anti-VEGF antibodies, especially monoclonal antibodies to the VEGF receptor, including DC101, a rat monoclonal antibody, which blocks the mouse VEGF receptor 2 (flk-1). Such conmbinations may be utilized *in vivo*, ordinarily in a mammal, preferably in a human, or *in vitro*. In employing them *in vivo*, the disclosed cmpounds, alone or in combination with other chemotherapeutics or other biologic products, may be administered to the mammal in a variety of ways, including parenterally, intravenously, via infusion or injection, subcutaneously, intramuscularly, colonically, rectally, vaginally, nasally or intraperitoneally, employing a variety of dosage forms. Such methods may also be applied to testing chemical activity *in vivo*.

As will be readily apparent to one skilled in the art, the useful *in vivo* dosage to be administered and the particular mode of administration will vary depending upon the age, weight and mammalian species treated, the particular compounds employed, and the specific use for which these compounds are employed. The determination of effective dosage levels, that is the dosage levels necessary to achieve the desired result, can be accomplished by one skilled in the art using routine pharmacological methods. Typically, human clinical applications of products are commenced at lower dosage levels, with dosage level being increased until the desired effect is achieved. Alternatively, acceptable *in vitro* studies can be used to establish useful doses and routes of administration of the compositions identified by the present methods using established pharmacological methods.

In non-human animal studies, applications of potential products are commenced at higher dosage levels, with dosage being decreased until the desired effect is no longer achieved or adverse side effects disappear. The dosage may range broadly, depending upon the desired affects and the therapeutic indication. Typically, dosages may be between about 10 microgram/kg and 100 mg/kg body weight, preferably between about 100 microgram/kg and 10 mg/kg body weight. Alternatively dosages may be based and calculated upon the surface area of the patient, as understood by those of skill in the art. Administration may be oral on an every third da6y, aevery other day, daily, twice daily, or thirce daily basis.

The exact formulation, route of administration and dosage can be chosen by the individual physician in view of the patient's condition. *See* for example, Fingl *et al.*, in The Pharmacological Basis of Therapeutics, 1975. It should be noted that the attending physician would know how to and when to terminate, interrupt, or adjust administration due to toxicity, or to organ dysfunctions. Conversely, the attending physician would also

know to adjust treatment to higher levels if the clinical response were not adequate (precluding toxicity). The magnitude of an administrated dose in the management of the disorder of interest will vary with the severity of the condition to be treated and to the route of administration. The severity of the condition may, for example, be evaluated, in part, by standard prognostic evaluation methods. Further, the dose and perhaps dose frequency, will also vary according to the age, body weight, and response of the individual patient. A program comparable to that discussed above may be used in veterinary medicine.

Depending on the specific conditions being treated, such agents may be formulated and administered systemically or locally. A variety of techniques for formulation and administration may be found in Remington's Pharmaceutical Sciences, 18th Ed., Mack Publishing Co., Easton, PA (1990). Suitable administration routes may include oral, rectal, transdermal, vaginal, transmucosal, or intestinal administration; parenteral delivery, including intramuscular, subcutaneous, intramedullary injections, as well as intrathecal, direct intraventricular, intravenous, via infusion, intraperitoneal, intranasal, or intraocular injections.

For injection or infusion, the agents may be formulated in aqueous solutions, for example, in physiologically compatible buffers such as Hanks' solution, Ringer's solution, or physiological saline buffer. For such transmucosal administration, penetrants appropriate to the barrier to be permeated are used in the formulation. Such penetrants are generally known in the art. Use of pharmaceutically acceptable carriers to formulate the compounds herein disclosed for the practice of the invention into dosages suitable for systemic administration is within the scope of the invention. With proper choice of carrier and suitable manufacturing practice, the compositions disclosed herein, in particular, those formulated as solutions, may be administered parenterally, such as by intravenous injection or infusion. The compounds can be formulated readily using pharmaceutically acceptable carriers well known in the art into dosages suitable for oral administration. Such carriers enable the compounds to be formulated as tablets, pills, capsules, liquids, gels, syrups, slurries, suspensions and the like, for oral ingestion by a patient to be treated.

Agents intended to be administered intracellularly may be administered using techniques well known to those of ordinary skill in the art. For example, such agents may be encapsulated into liposomes, then administered as described above. All molecules present in an aqueous solution at the time of liposome formation are incorporated into the aqueous interior. The liposomal contents are both protected from the external micro-environment and, because liposomes fuse with cell membranes, are efficiently delivered into the cell cytoplasm. Additionally, due to their hydrophobicity, small organic molecules may be directly administered intracellularly.

Determination of the effective amounts is well within the capability of those skilled in the art, especially in light of the detailed disclosure provided herein. In addition to the active ingredients, these pharmaceutical compositions may contain suitable pharmaceutically acceptable carriers comprising excipients

and auxiliaries which facilitate processing of the active compounds into preparations which can be used pharmaceutically. The preparations formulated for oral administration may be in the form of tablets, dragees, capsules, or solutions. The pharmaceutical compositions may be manufactured in a manner that is itself known, for example, by means of conventional mixing, dissolving, granulating, dragee-making, levitating, emulsifying, encapsulating, entrapping, or lyophilizing processes.

Compounds disclosed herein can be evaluated for efficacy and toxicity using known methods. For example, the toxicology of a particular compound, or of a subset of the compounds, sharing certain chemical moieties, may be established by determining *in vitro* toxicity towards a cell line, such as a mammalian, and preferably human, cell line. The results of such studies are often predictive of toxicity in animals, such as mammals, or more specifically, humans. Alternatively, the toxicity of particular compounds in an animal model, such as mice, rats, rabbits, or monkeys, may be determined using known methods. The efficacy of a particular compound may be established using several art recognized methods, such as *in vitro* methods, animal models, or human clinical trials. Art-recognized *in vitro* models exist for nearly every class of condition, including the conditions abated by the compounds disclosed herein, including cancer, cardiovascular diseasae and various fungal infections. Similarly, acceptable animal models may be used to establish efficacy of chemicals to treat such conditions. When selecting a model to determine efficacy, the skilled artisan can be guided by the state of the art to choose an appropriate model, dose, and route of administration, and regime. Of course, human clinical trials can also be used to determine the efficacy of a compound in humans.

When used as an anti-cancer agent, or a tumor-growth-inhibiting compound, the compounds disclosed herein may be administered by either oral or a non-oral pathways. When administered orally, it can be administered in capsule, tablet, granule, spray, syrup, or other such form. When administered non-orally, it can be administered as an aqueous suspension, an oily preparation or the like or as a drip, suppository, salve, ointment or the like, when administered via injection or infusion, subcutaneously, intreperitoneally, intravenously, intramuscularly, intradermally, or the like. Similarly, it may be administered topically, rectally, or vaginally, as deemed appropriate by those of skill in the art for bringing the compound into optimal contact with a tumor, thus inhibiting the growth of the tumor. Local administration at the site of the tumor or other disease condition is also contemplated, either before or after tumor resection, or as part of an art-recognized treatment of the disease condition. Controlled release formulations, depot formulations, and infusion pump delivery are similarly contemplated.

When used as an anti-cancer agent or an anti-tumor agent, may be orally or non-orally administered to a human patient in the amount of about .0007 mg/day to about 7,000 mg/day of the active ingredient, and more preferably about 0.07 mg/day to about 70 mg/day of the active ingredient at, preferably, one time per day or, less preferably, over two to about ten times per day. Alternatively and also preferably, the compound may

preferably be administered in the stated amounts continuously by, for example, an intravenous drip. Thus, for a patient weighing 70 kilograms, the preferred daily dose of the active anti-tumor ingredient would be about 0.0007 mg/kg/day to about 35 mg/kg/day including 1.0 mg/kg/day and 0.5 mg/kg/day, and more preferable, from 0.007 mg/kg/day to about 0.050 mg/kg/day, including 0.035 mg/kg/day. Nonetheless, as will be understood by those of skill in the art, in certain situations it may be necessary to administer the anti-tumor compound in amounts that excess, or even far exceed, the above-stated, preferred dosage range to effectively and aggressively treat particularly advanced or lethal tumors.

When used as an antifungal agent the preferrable amount of the dehydrophenylahistin or its analog effective in the treatment or prevention of a particular fungal pathogen will depend in part on the characteristics of the fungus and the extent of infection, and can be determined by standard clinical techniques. *In vitro* or *in vivo* assays may optionally be employed to help identify optimal dosage ranges. Effective doses may be extrapolated from dose-response curves derived from *in vitro* analysis or preferably from animal models. The precise dosage level should be determined by the attending physician or other health care provider and will depend upon well known factors, including route of administration, and the age, body weight, sex and general health of the individual; the nature, severity and clinical stage of the infection; the use (or not) of concomitant therapies.

The effective dose of the dehydrophenylahistin or its analog will typically be in the range of about 0.01 to about 50 mg/kgs, preferably about 0.1 to about 10 mg/kg of mammalian body weight per day, administered in single or multiple doses. Generally, the compound may be administered to patients in need of such treatment in a daily dose range of about 1 to about 2000 mg per patient.

To formulate the dosage including the compounds disclosed herein as a tumor-growth-inhibiting compound, known surface active agents, excipients, smoothing agents, suspension agents and pharmaceutically acceptable film-forming substances and coating assistants, and the like may be used. Preferably alcohols, esters, sulfated aliphatic alcohols, and the like may be used as surface active agents; sucrose, glucose, lactose, starch, crystallized cellulose, mannitol, light anhydrous silicate, magnesium aluminate, magnesium methasilicate aluminate, synthetic aluminum silicate, calcium carbonate, sodium acid carbonate, calcium hydrogen phosphate, calcium carboxymethyl cellulose, and the like may be used as excipients; magnesium stearate, talc, hardened oil and the like may be used as smoothing agents; coconut oil, olive oil, sesame oil, peanut oil, soya may be used as suspension agents or lubricants; cellulose acetate phthalate as a derivative of a carbohydrate such as cellulose or sugar, or methylacetate-methacrylate copolymer as a derivative of polyvinyl may be used as suspension agents; and plasticizers such as ester phthalates and the like may be used as suspension agents. In addition to the foregoing preferred ingredients,

sweeteners, fragrances, colorants, preservatives and the like may be added to the administered formulation of the compound, particularly when the compound is to be administered orally.

The compositions disclosed herein in a pharmaceutical compositions may also comprise a pharmaceutically acceptable carrier. Such compositions may be prepared for storage and for subsequent administration. Acceptable carriers or diluents for therapeutic use are well known in the pharmaceutical art, and are described, for example, in Remington's Pharmaceutical Sciences, Mack Publishing Co. (A.R. Gennaro edit. 1985). For example, such compositions may be formulated and used as tablets, capsules or solutions for oral administration; suppositories for rectal or vaginal administration; sterile solutions or suspensions for injectable administration. Injectables can be prepared in conventional forms, either as liquid solutions or suspensions, solid forms suitable for solution or suspension in liquid prior to injection or infusion, or as emulsions. Suitable excipients include, but are not limited to, saline, dextrose, mannitol, lactose, lecithin, albumin, sodium glutamate, cysteine hydrochloride, and the like. In addition, if desired, the injectable pharmaceutical compositions may contain minor amounts of nontoxic auxiliary substances, such as wetting agents, pH buffering agents, and the like. If desired, absorption enhancing preparations (for example, liposomes), may be utilized.

The pharmaceutically effective amount of the composition required as a dose will depend on the route of administration, the type of animal being treated, and the physical characteristics of the specific animal under consideration. The dose can be tailored to achieve a desired effect, but will depend on such factors as weight, diet, concurrent medication and other factors which those skilled in the medical arts will recognize.

The products or compositions, as described above, may be used alone or in combination with one another, or in combination with other therapeutic or diagnostic agents. Specifically, the disclosed compounds products may be used alone or in combination with other chemothepeutics or bioloigics, includinbg antibodies, for the treatment of cancer, or in combination with other antiinfective for the treatment of fungal infection. These products or combposition can be utilized *in vivo* or *in vitro*. The useful dosages and the most useful modes of administration will vary depending upon the age, weight and animal treated, the particular compounds employed, and the specific use for which these composition or compositions are employed. The magnitude of a dose in the management or treatment for a particular disorder will vary with the severity of the condition to be treated and to the route of administration, and depending on the disease conditions and their severity, the compositions may be formulated and administered either systemically or locally. A variety of techniques for formulation and administration may be found in Remington's Pharmaceutical Sciences, 18th ed., Mack Publishing Co., Easton, PA (1990).

To formulate the compounds of Formula (I), preferably synthetically produced according to the methods disclosed herein, as a cell cycle inhibitor, a tumor-growth-inhibiting, or an antifungal compound,

known surface active agents, excipients, smoothing agents, suspension agents and pharmaceutically acceptable film-forming substances and coating assistants, and the like may be used. Preferably alcohols, esters, sulfated aliphatic alcohols, and the like may be used as surface active agents; sucrose, glucose, lactose, starch, crystallized cellulose, mannitol, light anhydrous silicate, magnesium aluminate, magnesium methasilicate aluminate, synthetic aluminum silicate, calcium carbonate, sodium acid carbonate, calcium hydrogen phosphate, calcium carboxymethyl cellulose, and the like may be used as excipients; magnesium stearate, talc, hardened oil and the like may be used as smoothing agents; coconut oil, olive oil, sesame oil, peanut oil, soya may be used as suspension agents or lubricants; cellulose acetate phthalate as a derivative of a carbohydrate such as cellulose or sugar, or methyiacetate-methacrylate copolymer as a derivative of polyvinyl may be used as suspension agents; and plasticizers such as ester phthalates and the like may be used as suspension agents. In addition to the foregoing preferred ingredients, sweeteners, fragrances, colorants, preservatives and the like may be added to the administered formulation of the compound produced by the method, particularly when the compound is to be administered orally.

The cell cycle inhibitors, the antitumor agents, and the antifungal agents that may be produced by the method may be orally or non-orally administered to a human patient in the amount of about 0.001 mg/kg/day to about 10,000 mg/kg/day of the active ingredient, and more preferably about 0.1 mg/kg/day to about 100 mg/kg/day of the active ingredient at, preferably, once every three days on a cyclic basis, once oevery other day, one time per day, twice per day, or less preferably, over two to about ten times per day. Alternatively and also preferably, the compound produced by the method may preferably be administered in the stated amounts continuously by, for example, an intravenous drip. Thus, for the example of a patient weighing 70 kilograms, the preferred daily dose of the active anti-tumor ingredient would be about 0.07 mg/day to about 700 grams/day, and more preferable, 7 mg/day to about 7 grams/day. Nonetheless, as will be understood by those of skill in the art, in certain situations it may be necessary to administer the anti-tumor compound produced by the method in amounts that excess, or even far exceed, the above-stated, preferred dosage range to effectively and aggressively treat particularly advanced or lethal tumors.

In the case of using the cell cycle inhibitor produced by methods as a biochemical test reagent, the compound produced by methods of the invention inhibits the progression of the cell cycle when it is dissolved in an organic solvent or hydrous organic solvent and it is directly applied to any of various cultured cell systems. Usable organic solvents include, for example, methanol, methylsulfoxide, and the like. The formulation can, for example, be a powder, granular or other solid inhibitor, or a liquid inhibitor prepared using an organic solvent or a hydrous organic solvent. While a preferred concentration of the compound produced by the method of the invention for use as a cell cycle inhibitor is generally in the range of about 1 to about 100 µg/ml, the most appropriate use amount varies depending on the type of cultured cell system and the purpose

of use, as will be appreciated by persons of ordinary skill in the art. Also, in certain applications it may be necessary or preferred to persons of ordinary skill in the art to use an amount outside the foregoing range.

From a pharmaceutical perspective, certain embodiments provide methods for preventing or treating fungal infections and/or a pathogenic fungus in a subject, involve administering to the subject a composition including a dehydrophenylahistin or its analog, for example, administering the dehydrophenylahistin or its analog in an amount and manner which provides the intended antifungal effect.

Other embodiments include the treatment or prevention of infection in a patient by a pathogenic fungus such as those listed above or referred to below.

Another embodiment relates to the treatment or prevention of infection in a patient by a pathogenic fungus which is resistant to one or more other antifungal agents, especially an agent other than dehydrophenylahistin or its analog, including e.g. amphotericin B or analogs or derivatives thereof (including 14(s)-hydroxyamphotericin B methyl ester, the hydrazide of amphotericin B with 1-amino-4-methylpiperazine, and other derivatives) or other polyene macrolide antibiotics, including, e.g., nystatin, candicidin, pimaricin and natamycin; flucytosine; griseofulvin; echinocandins or aureobasidins, including naturally occurring and semi-synthetic analogs; dihydrobenzo[a]napthacenequinones; nucleoside peptide antifungals including the polyoxins and nikkomycins; allylamines such as naftifine and other squalene epoxidease inhibitors; and azoles, imidazoles and triazoles such as, e.g., clotrimazole, miconazole, ketoconazole, econazole, butoconazole, oxiconazole, terconazole, itraconazole or fluconazole and the like. For additional conventional antifungal agents and new agents under deveopment, see e.g. Turner and Rodriguez, 1996 *Current Pharmaceutical Design*, 2:209-224. Another embodiment involves the treatment or prevention of infection in a patient by a pathogenic fungus in cases in which the patient is allergic to, otherwise intolerant of, or nonresponsive to one or more other antifungal agents or in whom the use of other antifungal agents is otherwise contra-indicated. Those other antifungal agents include, among others, those antifungal agents disclosed above and elsewhere herein.

In the foregoing methods for treatment or prevention, a dehydrophenylahistin or its analog, is administered to the subject in an effective antifungal amount.

Other embodiments relate to the treatment or prevention of infection by a pathogenic fungus in a patient by administration of a dehydrophenylahistin or its analog, in conjunction with the administration of one or more other antifungal agents, including for example, any of the previously mentioned agents or types of agents (e.g. in combination with treatment with amphotericin B, preferably in a lipid or liposome formulation; an azole or triazole such as fluconazole, for example; an aureobasidin; dihydrobenzo[a]napthacenequinone; or an echinocardin) as well as with a different dehydrophenylahistin or its analog.

The dehydrophenylahistin or its analog may be administered before, after or at the same time the other antifungal agent is administered. In certain embodiments, the combination therapy will permit the use of reduced amounts of one or both antifungal components, relative to the amount used if used alone.

Still other embodiments relate to administration of a dehydrophenylahistin or its analog to a subject for the treatment or prevention of infection by a pathogenic fungus, where the subject is immunosuppressed or immunocompromised, e.g. as the result of genetic disorder, disease such as diabetes or HIV or other infection, chemotherapy or radiation treatment for cancer or other disease, or drug- or otherwise induced immunosuppression in connection with tissue or organ transplantation or the treatment of an autoimmune disorder. Where the patient is being or will be treated with an immunosuppressive agent, e.g., in connection with a tissue or organ transplantation, a dehydrophenylahistin or its analog may be co-administered with the immunosuppressive agent(s) to treat or prevent a pathogenic fungal infection.

Another aspect of this invention is the treatment or prevention of infection by a pathogenic fungus in a patient infected, or suspected of being infected, with HIV, by administration of an antifungal dehydrophenylahistin or its analog, in conjunction with the administration of one or more anti-HIV therapeutics (including e.g. HIV protease inhibitors, reverse transcriptase inhibitors or anti-viral agents). The dehydrophenylahistin or its analog may be administered before, after or at the same time as administration of the anti-HIV agent(s).

Another aspect of this invention is the treatment or prevention of infection by a pathogenic fungus in a patient by administration of an antifungal dehydrophenylahistin or its analog, in conjunction with the administration of one or more other antibiotic compounds, especially one or more antibacterial agents, preferably in an effective amount and regiment to treat or prevent bacterial infection. Again, the dehydrophenylahistin or its analog may be administered before, after or at the same time as administration of the other agent(s).

Pathogenic fungal infections which may be treated or prevented by the disclosed methods include, among others, Aspergillosis, including invasive pulmonary aspergillosis; Blastomycosis, including profound or rapidly progressive infections and blastomycosis in the central nervous system; Candidiasis, including retrograde candidiasis of the urinary tract, e.g. in patients with kidney stones, urinary tract obstruction, renal transplantation or poorly controlled diabetes mellitus; Coccidioidomycosis, including chronic disease which does not respond well to other chemotherapy; Cryptococcosis; Histopolasmosis; Mucormycosis, including e.g. craniofacial mucormycosis and pulmonary mucormycosis; Paracoccidioidomycosis; and Sporotrichosis. It should be noted that administration of a composition comprising an antifungal amount of one or more dehydrophenylahistin or its analogs may be particularly useful for treating or preventing a pathogenic fungal

infection in a mammalian subject where the fungus is resistant to one or more other antifungal therapies, or where the use of one or more other antifungal therapies is contraindicated, e.g., as mentioned above.

Antifungal pharmaceutical compositions containing at least one antifungal dehydrophenylahistin or its analog, are also provided for use in practicing the disclosed methods. Those pharmaceutical compositions may be packaged together with an appropriate package insert containing, *inter alia*, directions and information relating to their antifungal use. Pharmaceutical compositions are also provided which contain one or more dehydrophenylahistin or its analog together with a second antifungal agent.

Methods of Treating Fungal Infections

Certain embodiments disclosed herein relate to methods for treating or preventing a pathogenic fungal infection, including for example Aspergillosis, including invasive pulmonary aspergillosis; Blastomycosis, including profound or rapidly progressive infections and blastomycosis in the central nervous system; Candidiasis, including retrograde candidiasis of the urinary tract, e.g. in patients with kidney stones, urinary tract obstruction, renal transplantaion or poorly controlled diabetes mellitus; Coccidioidomycosis, including chronic disease which does not respond well to other chemotherapy; Cryptococcosis; Histopolasmosis; Mucormycosis, including e.g. craniofacial mucormycosis and pulmonary mucormycosis; Paracoccidioidomycosis; and Sporotrichosis. The methods may involve administering at least one antifungal dehydrophenylahistin or its analog, as described above, to a human subject such that the fungal infection is treated or prevented. In certain embodiments the dehydrophenylahistin or its analog may be administered in conjunction with administration of one or more non-dehydrophenylahistin or its analog antifungal agents such as amphotericin B, or an imidazole or triazole agent such as those mentioned previously.

The pathogenic fungal infection may be topical, e.g., caused by, among other organisms, species of *Candida*, *Trichophyton*, *Microsporum* or *Epiderinophyton* or mucosal, e.g., caused by *Candida albicans* (e.g. thrush and vaginal candidiasis). The infection may be systemic, e.g., caused by *Candida albicans*, *Cryptococcus neoformans*, *Aspergillus fumigatus*, *Coccidiodes*, *Paracocciciodes*, *Histoplasma* or *Blastomyces* spp. The infection may also involve eumycotic mycetoma, chromoblastomycosis, cryptococcal meningitits or phycomycosis.

Further embodiments relate to methods for treating or preventing a pathogenic fungal infection selected from the group consisting of *Candida* spp. including *C. albicans*, *C. tropicalis*, *C. kefyr*, *C. krusei* and *C. galbrata*; *Aspergillus* spp. including *A. fumigatus* and *A. flavus*; *Cryptococcus neoibrmans*; *Blastomyces* spp. including *Blastomyces dermatitidis*; *Pneumocvstis carinii*; *Coccidioides immitis*; *Basidiobolus ranarum*; *Conidiobolus* spp.; Histoplasma capsulatum; Rhizopus spp. including R. oryzae and R. microsporus; Cunninghamella spp.; Rhizoniucor spp.; Paracoccidioides brasiliensis; Pseudallescheria boydii; Rhinosporidium seeberi; and Sporothrix schenckii. Again, the method may involve administering a non-

immunosuppressive antifungal dehydrophenylahistin or its analog to a patient in need thereof such that the fungal infection is treated or prevented without inducing an untoward immunosuppressive effect.

Further embodiments relate to methods for treating or preventing a pathogenic fungal infection which is resistant to other antifungal therapy, including pathogenic fungal infections which are resistant to one or more antifungal agents mentioned elsewhere herein such as amphotericin B, flucytosine, one of the imidazoles or triazoles (including e.g. fluconazole, ketoconazole, itraconazole and the other previously mentioned examples). The methods may involve administering to the patient one or more antifungal dehydrophenylahistin or its analog, in an amount and dosing regimen such that a fungal infection resistant to another antifungal therapy in the subject is treated or prevented.

Further embodiments relate to methods for treating or preventing a pathogenic fungal infection in a patient who is allergic to, intollerant of or not responsive to another antiftingal therapy or in whom the use of other antifungal agents is otherwise contra-indicated, including one or more other antifungal agents mentioned elsewhere herein such as amphotericin B, flucytosine, one of the imidazoles or triazoles (including e.g. fluconazole, ketoconazole, itraconazole and the other previously mentioned examples). The methods may involve administering to such patient one or more antifungal dehydrophenylahistin or its analog, in an amount such that a fungal infection is treated or prevented.

Packaged Dehydrophenylahistin or its analogs

Certain embodiments relate to packaged dehydrophenylahistin or its analogs, preferably packaged nonimmunosuppressive antifungal dehydrophenylahistin or its analogs, which term is intended to include at least one dehydrophenylahistin or its analog, as described above, packaged with instructions for administering the dehydrophenylahistin or its analog(s) as an antifungal agent without causing a untoward immunosuppressive effects within a human subject. In some embodiments, the non-immunosuppressive antifungal dehydrophenylahistin or its analog is a member of one of the preferred subsets of compounds described above. The dehydrophenylahistin or its analog can be packaged alone with the instructions or can be packaged with another dehydrophenylahistin or its analog, raparnycin or another ingredient or additive, e.g., one or more of the ingredients of the pharmaceutical compositions. The package can contain one or more containers filled with one or more of the ingredients of the phan-naceutical compositions. Optionally associated with such container(s) can be a notice in the form prescribed by a governmental agency regulating the manufacture, use or sale of pharmaceutical or biological products, which notice reflects approval by the agency of manufacture, use or sale for human administration.

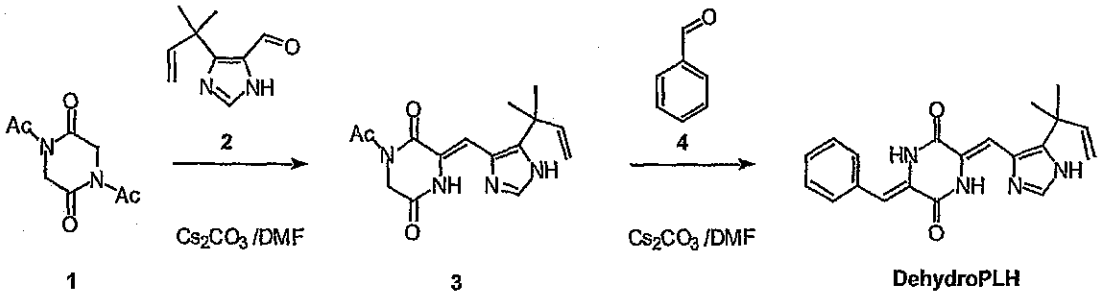
The following non-limiting examples are meant to describe the preferred methods using certain preferred embodiments. Variations in the details of the particular methods

employed and in the precise chemical compositions obtained will undoubtedly be appreciated by those of skill in the art.

EXAMPLE 1

A. Synthesis of Dehydrophenylahistin

Dehydrophenylahistin was synthesized by condensation according to the following basic reaction scheme, as shown in Figure 1:



N,N'-diacetyl-2,5-piperazinedione

25.0 g of global 2,5-piperazinedione 1 [2,5-piperazinedione (Aldrich G640-6), 25.0 g, 0.218 mol] in 100 mL of acetic anhydride (Ac_2O) was mixed with sodium acetate (NaOAc) (17.96 g, .0218 mol). The mixture was heated at 110°C for 8 h using a double coiled condenser under an Ar atmosphere. After Ac_2O was removed by evaporation, the residue was dissolved in AcOEt, washed with 10% citric acid, 10% $NaHCO_3$ and saturated NaCl (three times each), dried over Na_2SO_4, and concentrated in vacuo. The residue was triturated with ether to form a solid. This solid was recrystallized from EtOAc with ether-hexane to afford 26.4 g (61%) of N,N'-diacetyl-2,5-piperazinedione **1**.

1-Acetyl-3-{(Z)-1-[5-(1,1-dimethyl-2-propenyl)-1*H*-4-imidazolyl]methylidene}-2,5-piperazinedione **2**

To a solution of 5-(1,1-dimethyl-2-propenyl)imidazole-4-carboxaldehyde (100 mg, 0.609 mmol) in DMF (2 mL) was added compound **1** (241 mg, 1.22 mmol) and the solution was repeatedly evacuated in a short time to remove oxygen and flushed with Ar, followed by the addition of Cs_2CO_3 (198 mg, 0.609 mmol) and the evacuation-flushing process was repeated again. The resultant mixture was stirred for 5 h at room temperature. After the solvent was removed by evaporation, the residue was dissolved in the mixture of EtOAc and 10% Na_2CO_3, and the organic phase was washed with 10% Na_2CO_3 again and saturated NaCl for three times, dried over Na_2SO_4 and concentrated in vacuo. The residual oil was purified by column chromatography on silica using $CHCl_3$-MeOH (100:0 to 50:1) as an eluant to give 60 mg (33 %) of a pale yellow solid **2**.

Dehydrophenylahistin

To a solution of **2** (30 mg, 0.099 mmol) in DMF (0.8 mL) was added benzaldehyde (51 μL, 0.496 mmol, 5 eq) and the solution was repeatedly evacuated in a short time to remove oxygen and flushed with Ar, followed by the addition of Cs_2CO_3 (53 mg, 0.149 mmol, 1.5 eq) and the evacuation-flushing process was repeated again. The resultant mixture was heated for 2.5 h at 80°C. (The temperature must be increased

slowly. Rapid heating increases the production of E-isomer at the benzylidene moiety.) After the solvent was removed by evaporation, the residue was dissolved in EtOAc, washed with water for two times and saturated NaCl for three times, dried over Na_2SO_4 and concentrated *in vacuo*. On TLC using $CHCl_3$-MeOH (10:1), you can observe a spot with bright green-yellow luminescence at 365 nm UV. The purity of this crude product was more than 75% from HPLC analysis. The resulting residue was dissolved in 90% MeOH aq and applied to reverse-phase HPLC column (YMC-Pack, ODS-AM, 20 x 250 mm) and eluted using a linear gradient from 70 to 74% MeOH in water over 16 min at a flow rate of 12 mL/min, and the desired fraction was collected and concentrated by evaporation to give a 19.7 mg (60%) of yellow colored dehydrophenylahistin. The HPLC profile of the synthetic crude dehydrophenylahistin is depicted in Figure 2.

In the purification of dehydrophenylahistin, as shown in Figure 4, a major peak was the desired Z-form compound of dehydrophenylahistin. The formation of an *E*-isomer was observed as a minor component (about 10%), which was eluted as a more polar peak than Z-isomer. As other minor peaks, the reduced *Z*- and *E*-compounds, in which the dimethylallyl part of dehydrophenylahistin was reduced, was also observed. The formation of these reduced compounds was due to the aldehyde **2** with a reduced impurity, which was generated during the reduction of with DIBAL-H and was not separated in the subsequent process.

These minor compounds could be removed by preparative HPLC purification, afforded dehydrophenylahistin with the Z-configuration at the benzylidene part in a 60% yield (20% yield in two steps) with more than 95% purity. The compounds with *E*-configuration at the imidazole side of the diketopiperazine ring was not observed in this HPLC chart, suggesting that the first reaction from compound **1** to **3** in Figure 1 is Z-selective.

B. Chemical Characteristics:

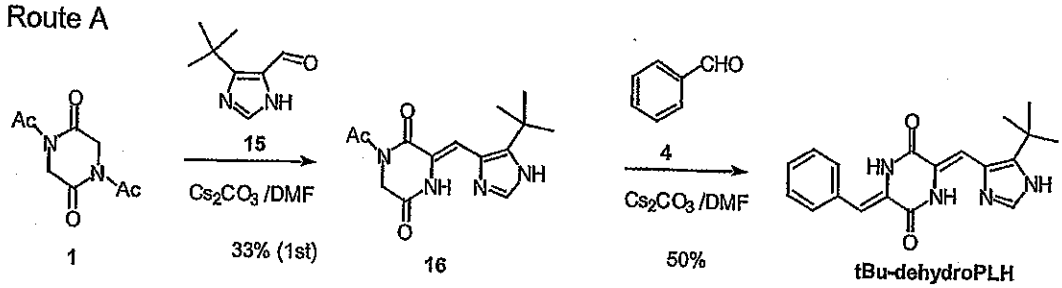
The above dehydrophenylahistin compound is a pale yellow solid. Its structure is confirmed by standard NMR analyses.

EXAMPLE 2

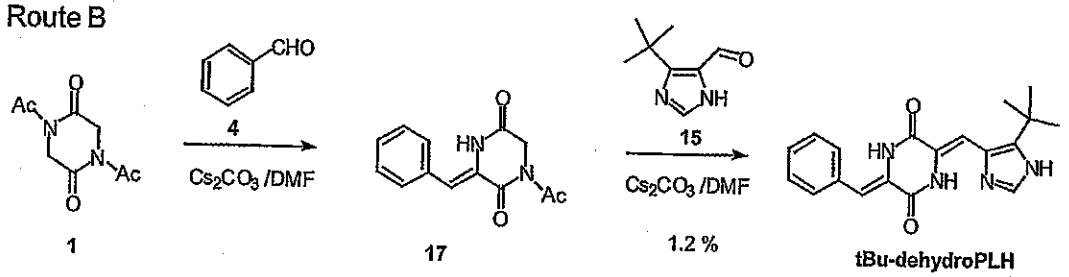
Synthesis and Physical Characterization of tBu-dehydrophenylahistin Derivatives

Structural derivatives of dehydrophenylahistin were synthesized according to the following reaction schemes to produce tBu-dehydrophenylahistin. Synthesis by Route A (see Figure 1) is similar in certain respects to the synthesis of the dehydrophenylahistin synthesized as in Example 1.

Route A



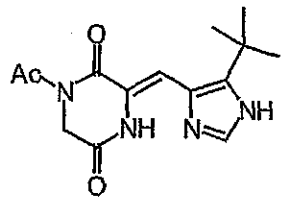
Route B



Route A:

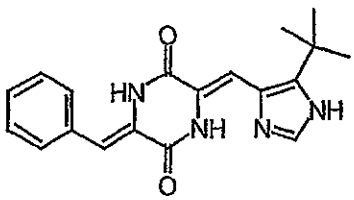
N,N'-diacethyl-2,5-piperazinedione 1 was prepared as in Example 1.

1) 1-Acetyl-3-{(Z)-1-[5-tert-butyl-1*H*-4-imidazolyl]methylidene}]-2,5-piperazinedione (16)



To a solution of 5-tert-butylimidazole-4-carboxaldehyde **15** (3.02 g, 19.8. mmol) in DMF (30 mL) was added compound **1** (5.89 g, 29.72 mmol) and the solution was repeatedly evacuated in a short time to remove oxygen and flushed with Ar, followed by the addition of Cs_2CO_3 (9.7 g, 29.72 mmol) and the evacuation-flushing process was repeated again. The resultant mixture was stirred for 5 h at room temperature. After the solvent was removed by evaporation, the residue was dissolved in the mixture of EtOAc and 10% Na_2CO_3, and the organic phase was washed with 10% Na_2CO_3 again and saturated NaCl for three times, dried over Na_2SO_4 and concentrated in vacuo. The residual oil was purified by column chromatography on silica using $CHCl_3$-MeOH (100:0 to 50:1) as an eluant to give 1.90 g (33 %) of a pale yellow solid 16. ^1H NMR (270 MHz, $CDCl_3$) 12.14 (d, br-s, 1H), 9.22 (br-s, 1H), 7.57 (s, 1H), 7.18, (s, 1H), 4.47 (s, 2H), 2.65 (s, 3H), 1.47 (s, 9H).

2) t-Bu-dehydrophenylahistin



To a solution of 1-Acetyl-3-{(Z)-1-[5-tert-butyl-1*H*-4-imidazolyl]methylidene}]-2,5-piperazinedione **(16)** (11 mg, 0.038 mmol) in DMF (1.0 mL) was added benzaldehyde (19 L, 0.19 mmol, 5 eq) and the solution was repeatedly evacuated in a short time to remove oxygen and flushed with Ar, followed by the addition of Cs_2CO_3 (43 mg, 0.132 mmol, 3.5 eq) and the evacuation-flushing process was repeated again. The resultant mixture was heated for 2.5 h at 80°C. After the solvent was removed by evaporation, the residue was dissolved in EtOAc, washed with water for two times and saturated NaCl for three times, dried over Na_2SO_4 and concentrated in vacuo. The resulting residue was dissolved in 90% MeOH aq and applied to reverse-phase HPLC column (YMC-Pack, ODS-AM, 20 x 250 mm) and eluted using a linear gradient from 70 to 74% MeOH in water over 16 min at a flow rate of 12 mL/min, and the desired fraction was collected and concentrated by evaporation to give a 6.4 mg (50%) of yellow colored tert-butyl-dehydrophenylahistin. ^1H

NMR (270 MHz, $CDCl_3$) δ12.34 br-s, 1H), 9.18 (br-s, 1H), 8.09 (s, 1H), 7.59 (s, 1H), 7.31 - 7.49 (m, 5H), 7.01 s, 2H), 1.46 (s, 9H).

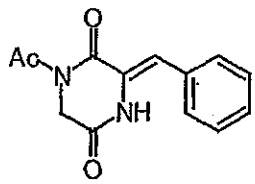
The dehydrophenylahistin reaction to produce tBu-dehydrophenylahistin is identical to Example 1.

The total yield of the tBu-dehydrophenylahistin recovered was 16.5%.

Route B:

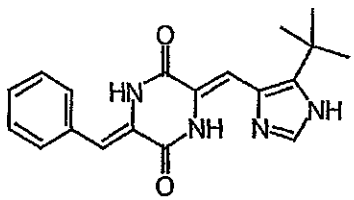
N,N'-diacethyl-2,5-piperazinedione 1 was prepared as in Example 1.

1) 1-Acetyl-3-[(Z)-benzylidene1]-2,5-piperazinedione (17)



To a solution of benzaldehyde **4** (0.54 g, 5.05. mmol) in DMF (5 mL) was added compound 1 (2.0 g, 10.1 mmol) and the solution was repeatedly evacuated in a short time to remove oxygen and flushed with Ar, followed by the addition of Cs_2CO_3 (1.65 g, 5.05 mmol) and the evacuation-flushing process was repeated again. The resultant mixture was stirred for 3.5 h at room temperature. After the solvent was removed by evaporation, the residue was dissolved in the mixture of EtOAc and 10% Na_2CO_3, and the organic phase was washed with 10% Na_2CO_3 again and saturated NaCl for three times, dried over Na_2SO_4 and concentrated in vacuo. The residual solid was recrystalized from MeOH-ether to obtain a off-white solid of **17**; yield 1.95 g (79%).

2) t-Bu-dehydrophenylahistin



To a solution of 1-Acetyl-3-[(Z)-benzylidene1]-2,5-piperazinedione **(17)** (48 mg, 0.197 mmol) in DMF (1.0 mL) was added 5-tert-butylimidazole-4-carboxaldehyde **15** (30 mg, 0.197 mmol) and the solution was repeatedly evacuated in a short time to remove oxygen and flushed with Ar, followed by the addition of Cs_2CO_3 (96 mg, 0.296 mmol) and the evacuation-flushing process was repeated again. The resultant mixture was heated for 14 h at 80°C. After the solvent was removed by evaporation, the residue was dissolved in EtOAc, washed with water for two times and saturated NaCl for three times, dried over Na_2SO_4 and concentrated in vacuo. The resulting residue was dissolved in 90% MeOH aq and applied to reverse-phase HPLC column (YMC-Pack, ODS-AM, 20 x 250 mm) and eluted using a linear gradient from 70 to 74% MeOH

in water over 16 min at a flow rate of 12 mL/min, and the desired fraction was collected and concentrated by evaporation to give a 0.8 mg (1.2%) of yellow colored tert-butyl-dehydrophenylahistin.

The total yield of the tBu-dehydrophenylahistin recovered was 0.9%.

The HPLC profile of the crude synthetic tBu-dehyrophenylahistin from Route A and from Route B is depicted in Figure 4.

Two other tBu-dehydrophenylahistin derivatives were synthesized according to the method of Route A. In the synthesis of the additional tBu-dehydrophenylahistin derivatives, modifications to the benzaldehyde compound **4** were made.

Figure 4 illustrates the similarities of the HPLC profiles (Column: YMC-Pack ODS-AM (20 x 250mm); Gradient: 65% to 75% in a methanol-water system for 20 min, then 10 min in a 100% methanol system; Flow rate: 12mL/min; O.D. 230 nm) from the synthesized dehydrophenylahistin of Example 1 (Fig 2) and the above exemplified tBu-dehydrophenylahistin compound produced by Route A.

The sequence of introduction of the aldehydes is a relevant to the yield and is therefore aspect of the synthesis. An analogue of dehydrophenylahistin was sythesized, as a control or model, wherein the dimethylallyl group was changed to the tert-butyl group with a similar steric hindrance at the 5-position of the imidazole ring.

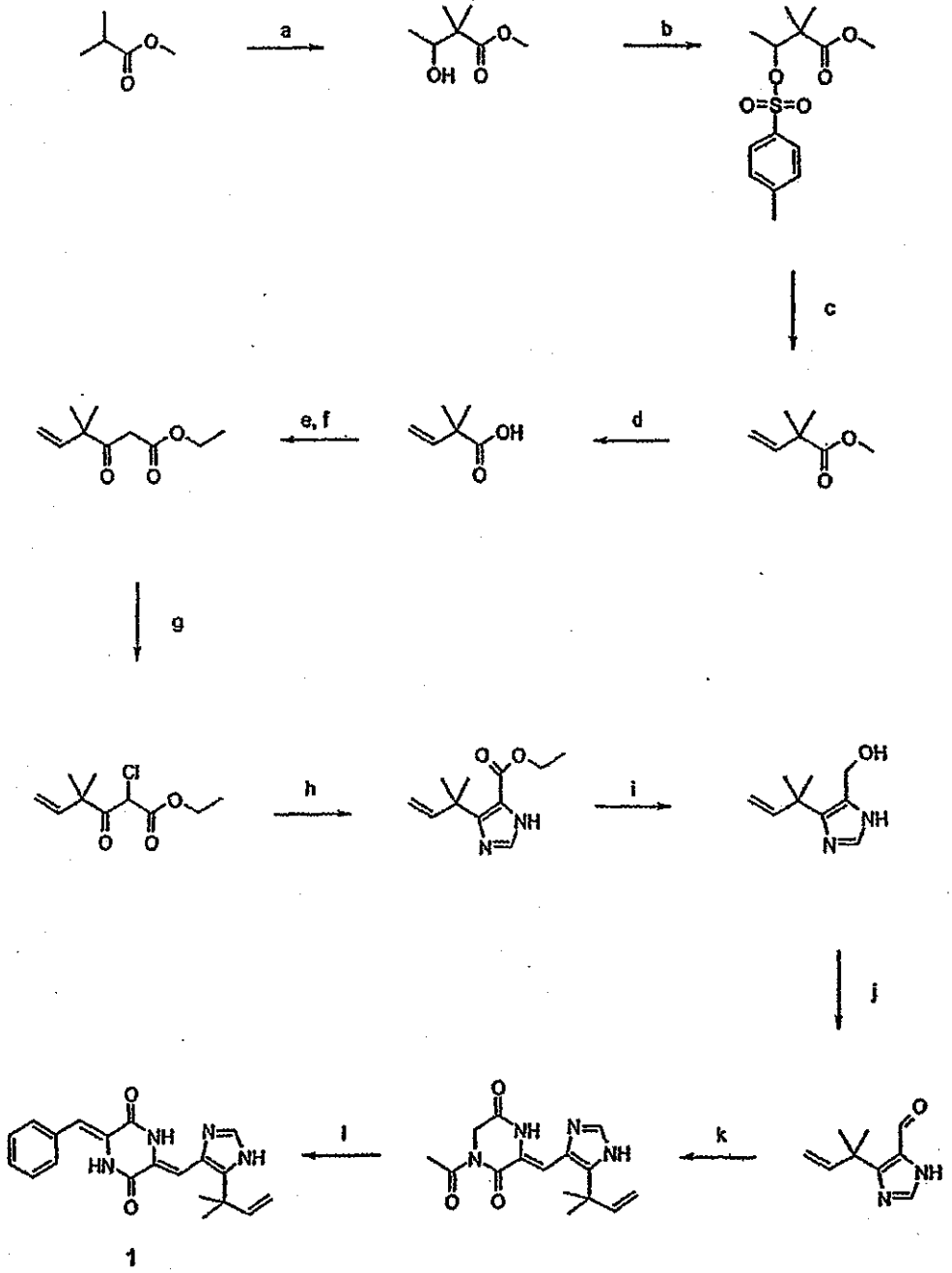
The synthesis of this "tert-butyl (tBu)-dehydrophenylahistin" using "Route A" was as shown above: Particularly, the sequence of introduction of the aldehyde exactly follows the dehydrophenylahistin synthesis, and exhibited a total yield of 16.5% tBu-dehydrophenylahistin. This yield was similar to that of dehydrophenylahistin (20%). Using "Route B", where the sequence of introduction of the aldehydes is opposite that of Route "A" for the dehydrophenylahistin synthesis, only a trace amount of the desired tBu-dehydroPLH was obtained with a total yield of 0.9%, although in the introduction of first benzaldehyde **4** gave a 76% yield of the intermediate compound **17**. This result indicated that it may be difficult to introduce the highly bulky imidazole-4-carboxaldehydes **15** with a substituting group having a quaternary-carbon on the adjacent 5-position at the imidazole ring into the intermediate compound **17**, suggesting that the sequence for introduction of aldehydes is an important aspect for obtaining a high yield of dehydrophenylahistin or an analog of dehydrophenylahistin employing the synthesis disclosed herein.

From the HPLC analysis of the final crude products, as shown in Figure 4, a very high content of tBu-dehydrophenylahistin and small amount of by-product formations were observed in the crude sample of Route A (left). However, a relatively smaller amount of the desired tBu-dehydrophenylahistin and several other by-products were observed in the sample obtained using Route B (right).

EXAMPLE 3

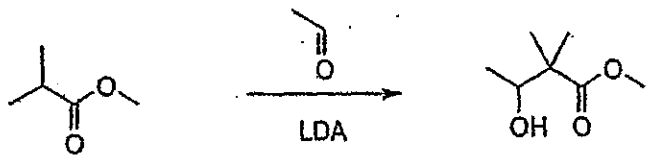
Alternative, Larger-Scale Synthesis of Dehydrophenylahistin and Analogs

Synthesis of 3-Z-Benzylidene-6-[5"-(1,1-dimethylallyl)-1H-imidazol-4"-Z-ylmethylene]-piperazine-2,5-dione [Dehydrophenylahistin] (1)



Reagents: a) LDA, CH_3CHO; b) Tos-Cl, pyridine; c) DBU; d) NaOH; e) $C_2Cl_2O_2$; f) $KOOCCH_2COOEt$, BuLi; g) SO_2Cl_2; h) H_2NCHO, H_2O; i) $LiAlH_4$; j) MnO_2; k) 1,4-diacetyl-piperazine-2,5-dione, Cs_2CO_3; l) benzaldehyde, Cs_2CO_3

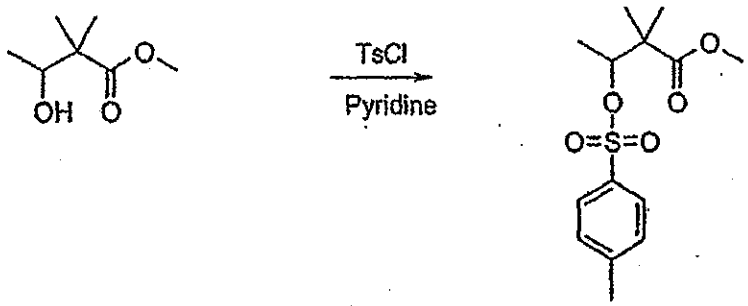
3-Hydroxy-2,2-dimethyl-butyric acid methyl ester



A solution of LDA in heptane/THF/ethylbenzene (2 M, 196 ml, 0.39 mol) was added under argon to a solution of methyl isobutyrate (45 ml, 0.39 mol) in THF (270 ml) at -60° and the resultant mixture was stirred for 30 min. A solution of acetaldehyde (27 ml, 0.48 mol) in THF (45 ml), precooled to -60°, was added slowly and the resulting solution stirred for a further 30 min. Saturated ammonium chloride (50 ml) was added and the solution was allowed to warm to room temperature. The reaction mixture was extracted with ethyl acetate, and the extracts were washed with HCl (2 M), sodium bicarbonate, then brine. The organic layer was dried over magnesium sulfate, filtered, then evaporated to give a clear oil (52.6 g). Distillation 76-82°/30 mmHg gave pure 3-hydroxy-2,2-dimethyl-butyric acid methyl ester (42.3 g, 74%). (Burk et al., *J. Am. Chem. Soc.*, 117:4423-4424 (1995)).

^1H NMR (400 MHz, $CDCl_3$) δ 1.15 (d, *J* = 6.2 Hz, 3H); 1.17 (s, 6H); 2.66 (d, *J* = 6.2 Hz, 1H, *-OH*); 3.71 (s, 3H, *-OMe*); 3.87 (app quintet, *J* = 6.4 Hz, 1H, *H3*).

2,2-Dimethyl-3-(toluene-4-sulfonyloxy)-butyric acid methyl ester



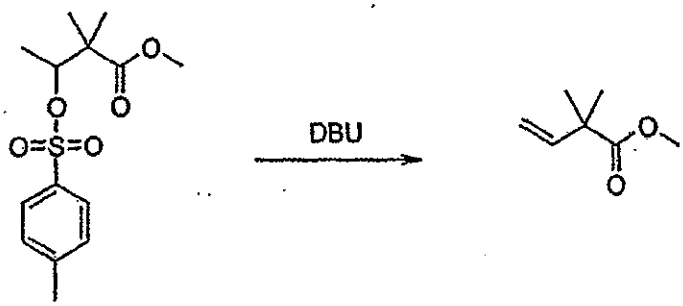
To a cooled (0°) solution of 3-hydroxy-2,2-dimethyl-butyric acid methyl ester (52.0 g, 0.36 mol) in pyridine (100 ml) was added gradually, *p*-toluene sulfonyl chloride (69.0 g, 0.36 mol). The mixture was

allowed to warm to room temperature and was stirred for 60 h. The reaction was again cooled in ice and was acidified by addition of HCl (2 M). The resultant solution was extracted with ethyl acetate, the extracts were washed with HCl, then brine, dried and evaporated to give an oil which formed a white precipitate upon standing. This mixture was dissolved in the minimum amount of ethyl acetate and then light petroleum was added to afford a white precipitate which was collected and washed with more light petroleum. The filtrate was partially evaporated and a second crop of crystals was collected and added to the first to afford *2,2-dimethyl-3-(toluene-4-sulfonyloxy)-butyric acid methyl ester* (81.2 g, 76%).

^{1}H NMR (400 NMz, $CDCl_3$) δ 1.12 (s, 3H); 1.13 (s, 3H); 1.24 (d, *J* = 6.4 Hz, 3H); 2.45 (s, 3H, *-PhMe*) 3.58 (s, 3H, *-OMe*); 4.94 (quartet, *J* = 6.4 Hz, 1H, *H3*), 7.33 (d, *J* = 8.0 Hz, 2H), 7.78 (d, *J* = 8.0 Hz, 2H).

Evaporation of the final filtrate afforded additional crude 2,2-dimethyl-3-(toluene-4-sulfonyloxy)-butyric acid methyl ester (19.0 g, 18%).

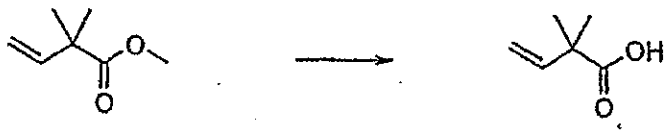
2,2-Dimethyl-but-3-enoic acid methyl ester



A solution of 2,2-dimethyl-3-(toluene-4-sulfonyloxy)-butyric acid methyl ester (18.06 g, 0.06 mol) in DBU (15 ml) was heated at 140-160° for 3.5 h. The mixture was allowed to cool to room temperature and was then diluted with ether. The mixture was washed with HCl (1 M), sodium bicarbonate, then brine. The ethereal layer was dried and partially evaporated to give a concentrated solution of 2,2-dimethyl-but-3-enoic acid methyl ester (10 g). (Savu and Katzenellenbogen, *J. Org. Chem*, 46:239-250 (1981)). Further evaporation was avoided due to the volatility of the product (bp 102°). (Tsaconas et al., *Aust. J. Chem.*, 53:435-437 (2000)).

^{1}H NMR (400 NMz, $CDCl_3$) δ 1.31 (s, 6H); 3.68 (s, 3H); 5.06 (d, *J* = 17.1 Hz, 1H, *-CH=CH$_2$*); 5.11 (d, *J* = 10.7 Hz, 1H, *-CH=CH$_2$*); 6.03 (dd, *J* = 17.1, 10.7 Hz, 1H, *-CH=CH$_2$*).

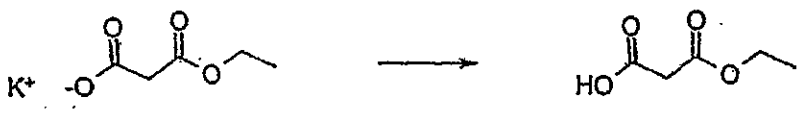
2,2-Dimethyl-but-3-enoic acid



The above ethereal solution of 2,2-dimethyl-but-3-enoic acid methyl ester (10 g) was diluted with ethanol (25 ml), sodium hydroxide (4 M, 22 ml) was added and the mixture was stirred overnight. The solution was partially evaporated to remove the ethanol and the resultant mixture was added to HCl (1M, 100 ml). The product was extracted with ethyl acetate and the extracts were dried and evaporated to give 2,2-dimethyl-but-3-enoic acid (6.01 g, 88% 2 steps). (Hayashi et al., *J. Org. Chem.*, 65:8402-8405 (2000).

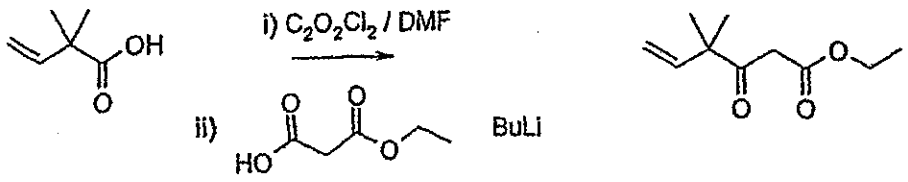
^{1}H NMR (400 MHz, $CDCl_3$) δ 1.33 (s, 6H); 5.11 (d, *J* = 10.8 Hz, 1H, -*CH*=*CH*$_2$); 5.15 (d, *J* = 17.2 Hz, 1H, -*CH*=*CH*$_2$); 6.05 (dd, *J* = 17.2, 10.8 Hz, 1H, -*CH*=*CH*$_2$).

Monoethyl hydrogen malonate (Wierenga and Skulnick, "Aliphatic and Aromatic β-keto Esters from Monoethyl Malonate: Ethyl 2-Butyrylacetate," *Organic Syntheses* Collective Volume 7, 213).



Ethyl potassium malonate (25.0 g, 0.15 mol) was suspended in water (15.6 ml) and cooled in an ice bath. Concentrated HCl (12.5 ml) was added dropwise over 30 min, then the mixture was stirred for a further 10 min. The precipitate was filtered, then washed twice with ether. The filtrate was separated and the aqueous phase was extracted with ether. The combined ethereal solutions were dried ($MgSO_4$) and evaporated to afford, as an oil, monoethyl hydrogen malonate (19.2 g, 99%) which was dried under vacuum overnight (or 50°/1 mm for 1 h) prior to use.

4,4-Dimethyl-3-oxo-hex-5-enoic acid ethyl ester

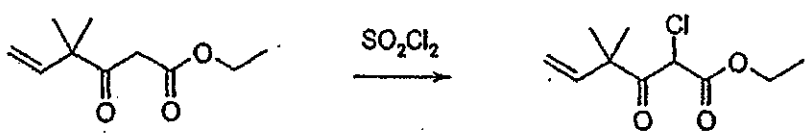


Oxalyl chloride (3.83 ml, 43.9 mmol) was added dropwise to a cooled (0°) solution of 2,2-dimethyl-but-3-enoic acid (5.0 g, 43.9 mmol) and DMF (1 drop) in anhydrous dichloromethane (25 ml). The mixture was stirred for 1 h at 0°, then for 16 h at room temperature. Fractional distillation (121°/760 mmHg) afforded 2,2-dimethyl-but-3-enoyl chloride (4.1 g, 71%).

Monoethyl hydrogen malonate (7.2 g, 0.05 mol) and bipyridyl (few milligrams) were dissolved in THF (90 ml) and the system was flushed with nitrogen. The solution was cooled to -70°, then BuLi (2.5 M in hexanes, 37 ml, 0.09 mol) was added. After the addition of only ~10 ml of BuLi the solution turned pink and additional THF (15 ml) was required to enable magnetic stirring. The cooling bath was removed and the remaining BuLi was added, the temperature was allowed to reach -10°, upon which the solution turned colorless. The mixture was again cooled to -60° and a solution of 2,2-dimethyl-but-3-enoyl chloride (4.1 g, 0.03 mol) in THF (12 ml) was added dropwise. After addition was complete the mixture was allowed to warm to 0° and stir for 3 h, then it was added to a 1:1 mixture of ether/1M HCl (260 ml) at 0° and stirred for a further 1.5 h. The organic layer was removed, washed with HCl (1 M), sodium bicarbonate solution, brine then dried and evaporated to give 4,4-dimethyl-3-oxo-hex-5-enoic acid ethyl ester (5.6 g, 98%). (Hayashi et al., *J. Org. Chem.*, 65:8402-8405 (2000). Distillation with a Kugelrohr oven (160°/1 mmHg) afforded pure material.

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.26 (s, 6H); 1.27 (t, *J* = 6.9 Hz, 3H, -CH_2CH_3); 3.51 (s, 2H); 4.18 (q, *J* = 6.9 Hz, 2H, -CH_2CH_3); 5.20 (d, *J* = 17.7 Hz, 1H, -CH=CH_2); 5.21 (d, *J* = 9.6 Hz, 1H, -CH=CH_2); 5.89 (dd, *J* = 17.7, 9.6 Hz, 1H, -CH=CH_2).

2-Chloro-4,4-dimethyl-3-oxo-hex-5-enoic acid ethyl ester



Sulfuryl chloride (0.84 ml, 10.4 mmol) was added to a cooled (0°) solution of 4,4-dimethyl-3-oxo-hex-5-enoic acid ethyl ester (1.83 g, 9.93 mmol) in chloroform (7 ml). The resulting mixture was allowed to warm to room temperature and stir for 30 min, after which it was heated under reflux for 2 h. After cooling to room

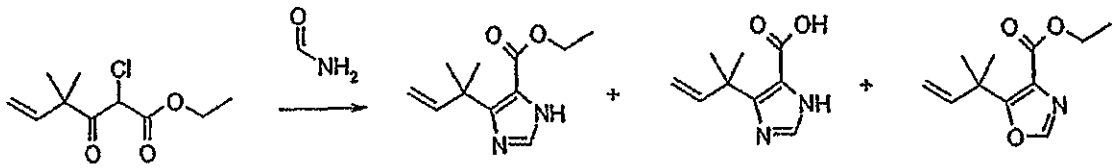
temperature the reaction mixture was diluted with chloroform, then was washed with sodium bicarbonate, water then brine. The organic phase was dried and evaporated to afford, as a brown oil, 2-chloro-4,4-dimethyl-3-oxo-hex-5-enoic acid ethyl ester (2.01 g, 93%). (Hayashi et al., *J. Org. Chem.*, 65:8402-8405 (2000).

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.28 (t, *J* = 7.0 Hz, 3H, -CH_2CH_3); 1.33 (s, 3H); 1.34 (s, 3H); 4.24 (q, *J* = 7.0 Hz, 2H, -CH_2CH_3); 5.19 (s, 1H; 5.28 (d, *J* = 16.9 Hz, 1H, -CH=CH_2); 5.29 (d, *J* = 10.9 Hz, 1H, -CH=CH_2); 5.96 (dd, *J* = 16.9, 10.9 Hz, 1H, -CH=CH_2).

LC/MS t_R = 8.45 (219.3 [M(Cl^{37})+H]$^+$ min.

This material was reacted without further purification.

5-(1,1-Dimethyl-allyl)-3H-imidazole-4-carboxylic acid ethyl ester



A suspension of 2-chloro-4,4-dimethyl-3-oxo-hex-5-enoic acid ethyl ester (19.4 g, 0.09 mol) and water (1.94 ml, 0.11 mol) in formamide (36.8 ml) was shaken briefly, then dispensed into 15 x 18 ml vials. The vials were sealed and heated at 150° for 5 h. After cooling to room temperature, the vials' contents were combined and extracted exhaustively with chloroform. The extracts were dried and evaporated to afford a concentrated formamide solution (14.7 g). This was added to a silica column (7 cm diameter, 11 cm height) packed in 1% MeOH/1% Et_3N in chloroform. Elution of the column with 2 L of this mixture followed by 2 L of 2% MeOH/1% Et_3N in chloroform afforded, in the early fractions, a compound suspected of being *5-(1,1-dimethyl-allyl)-oxazole-4-carboxylic acid ethyl ester* (1.23 g. 7%).

HPLC (214nm) t_R = 8.68 (50.4%) min.

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.40 (t, *J* = 7.2 Hz, 3H, -CH_2CH_3); 1.54 (s, 6H); 4.38 (t, *J* = 7.2 Hz, 2H, -CH_2CH_3); 5.03 (d, *J* = 17.4 Hz, 1H, -CH=CH_2); 5.02 (d, *J* = 10.4 Hz, 1H, -CH=CH_2); 6.26 (dd, *J* = 17.4, 10.4 Hz, 1H, -CH=CH_2); 7.83 (s, 1H).

LCMS t_R = 8.00 (210.1 [M+H]$^+$, 361.1 [2M+H]$^+$) min.

Recovered from later fractions was the desired 5-(1,1-dimethyl-allyl)-3H-imidazole-4-carboxylic acid ethyl ester (3.13 g, 17%). (Hayashi et al., *J. Org. Chem.*, 65:8402-8405 (2000)).

HPLC (214nm) t_R = 5.52 (96.0%) min.

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.38 (t, *J* = 7.0 Hz, 3H); 1.57 (s, 6H); 4.35 (q, *J* = 7.0 Hz, 2H); 5.04-5.14 (m, 2H, -CH=CH_2); 6.28 (dd, *J* = 18.0, 10.4 Hz, 1H, -CH=CH_2); 7.52 (s, 1H).

LC/MS t_R = 5.30 (209.1 $[M+H]^+$, 417.2 $[2M+H]^+$) min.

Additional 5-(1,1-dimethyl-allyl)-3H-imidazole-4-carboxylic acid ethyl ester was also recovered from the column (3.59 g, 19%) which was of lower purity but still sufficient for further reaction.

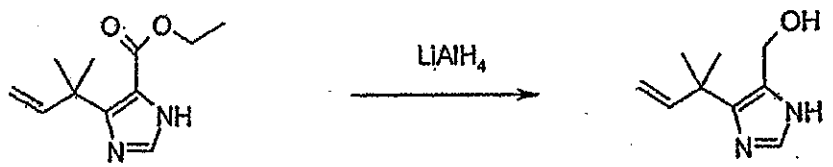
Another byproduct isolated from a similar reaction (smaller scale) by further elution of the column with 5% MeOH/1% Et_3N in chloroform was a compound suspected of being *5-(1,1-dimethyl-allyl)-3H-imidazole-4-carboxylic acid* (0.27 g, 9%).

HPLC (245nm) t_R = 5.14 (68.9%) min.

^1H NMR (400 MHz, CD_3OD) δ 1.45 (s, 6H); 4.97 (d, J = 10.6 Hz, 1H, -*CH*=*CH*$_2$); 5.01 (d, J = 17.7 Hz, 1H, -*CH*=*CH*$_2$); 6.28 (dd, J = 17.7, 10.6 Hz, 1H, -*CH*=*CH*$_2$); 7.68 (s, 1H).

LCMS t_R = 4.72 (181.0 $[M+H]^+$, 361.1 $[2M+H]^+$) min.

[5-(1,1-Dimethyl-allyl)-3H-imidazol-4-yl]-methanol



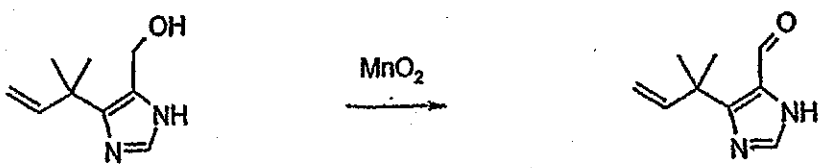
A solution of 5-(1,1-dimethyl-allyl)-3H-imidazole-4-carboxylic acid ethyl ester (3.13 g, 15.0 mmol) in THF (60 ml) was added dropwise to a suspension of lithium aluminium hydride (95% suspension, 1.00 g, 25.0 mmol) in THF (40 ml) and the mixture was stirred at room temperature for 4 h. Water was added until the evolution of gas ceased, the mixture was stirred for 10 min, then was filtered through a sintered funnel. The precipitate was washed with THF, then with methanol, the filtrate and washings were combined, evaporated, then freeze-dried to afford [5-(1,1-dimethyl-allyl)-3H-imidazol-4-yl]-methanol (2.56 g, 102%). Residual water was removed by azeotroping with chloroform prior to further reaction. (See Hayashi et al., *J. Org. Chem.*, 65:8402-8405 (2000)).

HPLC (240nm) t_R = 3.94 (56.8%) min.

^1H NMR (400 MHz, CD_3OD) δ 1.43 (s, 6H); 4.57 (s, 2H); 5.01 (d, J = 10.5 Hz, 1H, -*CH*=*CH*$_2$); 5.03 (d, J = 17.7 Hz, 1H, -*CH*=*CH*$_2$); 6.10 (dd, J = 17.7, 10.5 Hz, 1H, -*CH*=*CH*$_2$); 7.46 (s, 1H).

LC/MS t_R = 3.77 (167.3 $[M+H]^+$) min.

5-(1,1-Dimethyl-allyl)-3H-imidazole-4-carbaldehyde



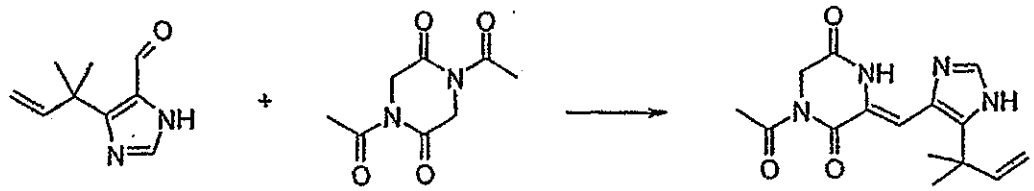
Manganese dioxide (20 g, 0.23 mol) was added to a solution of [5-(1,1-dimethyl-allyl)-3H-imidazol-4-yl]-methanol (2.56 g, 0.02 mol) in acetone (300 ml) and the resulting mixture was stirred at room temperature for 5 h. The mixture was filtered through filter paper and the residue was washed with acetone. The filtrate and washings were combined and evaporated to afford 5-(1,1-dimethyl-allyl)-3H-imidazole-4-carbaldehyde (1.82 g, 51%). (Hayashi et al., *J. Org. Chem.*, 65:8402-8405 (2000)).

HPLC (240nm) t_R = 4.08 (91.5%) min.

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.56 (s, 6H); 5.16 (d, *J* = 10.6 Hz, 1H, *-CH=CH$_2$*); 5.19 (d, *J* = 17.3 Hz, 1H, *CH=CH$_2$*); 6.22 (dd, *J* = 17.3, 10.6 Hz, 1H, *-CH=CH$_2$*); 7.75 (s, 1H), 10.02 (s, 1H, *HCO*).

LC/MS t_R = 3.75 (165.2 $[M+H]^+$) min.

1-Acetyl-3-[5'-(1,1-dimethyl-allyl)-1H-imidazol-4'-Z-ylmethylene]-piperazine-2,5-dione



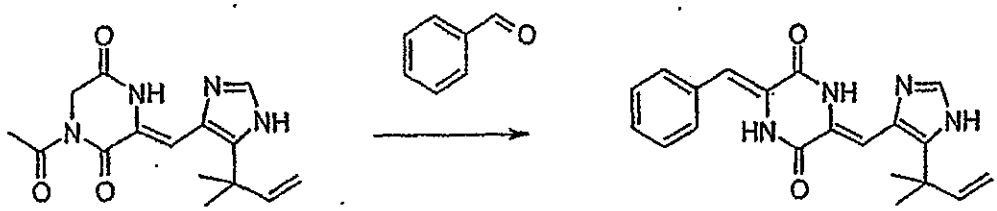
To a solution of 5-(1,1-dimethyl-allyl)-3H-imidazole-4-carbaldehyde (1.78 g, 0.01 mol) in DMF (35 ml) was added 1,4-diacetyl-piperazine-2,5-dione (8.59 g, 0.04 mol) and the mixture was evacuated, then flushed with argon. The evacuation-flushing process was repeated a further two times, then cesium carbonate (3.53 g, 0.01 mol) was added. The evacuation-flushing process was repeated a further three times, then the resultant mixture was heated at 45° for 5 h. The reaction mixture was partially evaporated (heating under high vacuum) until a small volume remained and the resultant solution was added dropwise to ice-water (50 ml). The yellow precipitate was collected, washed with water, then freeze-dried to afford 1-acetyl-3-[5'-(1,1-dimethyl-allyl)-1H-imidazol-4'-ylmethylene]-piperazine-2,5-dione (1.18 g, 36%). (Hayashi, Personal Communication (2001)).

HPLC (214nm) t_R = 6.01 (72.6%) min.

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.53 (s, 6H); 2.64 (s, 3H); 4.47 (s, 2H); 5.19 (d, *J* = 17.3 Hz, 1H, *-CH=CH$_2$*); 5.23 (d, *J* = 10.7 Hz, 1H, *-CH=CH$_2$*); 6.06 (dd, *J* = 17.3, 10.7 Hz, 1H, *-CH=CH$_2$*); 7.16 (s, 1H), 7.59 (s, 1H), 9.47 (bs, 1H); 12.11 (bs, 1H) [observed ~2% 1,4-diacetyl-piperazine-2,5-dione contamination δ 2.59 (s, 6H); 4.60 (s, 4H).]

LC/MS t_R = 6.65 (303.3 $[M+H]^+$, 605.5 $[2M+H]^+$) min. (n.b. different system used).

3-Z-Benzylidene-6-[5"-(1,1-dimethylallyl)-1H-imidazol-4"-Z-ylmethylene]-piperazine-2,5-dione



To a solution of 1-acetyl-3-[5'-(1,1-dimethyl-allyl)-1H-imidazol-4'-ylmethylene]-piperazine-2,5-dione (2.91 g, 9.62 mmol) in DMF (70 ml) was added benzaldehyde (4.89 ml, 48.1 mmol) and the solution was evacuated, then flushed with Argon. The evacuation-flushing process was repeated a further two times, then cesium carbonate (4.70 g, 14.4 mmol) was added. The evacuation-flushing process was repeated a further three times, then the resultant mixture was heated under the temperature gradient ad shown below.

After a total time of 5 h the reaction was allowed to cool to room temperature and the mixture was added to ice-cold water (500 ml). The precipitate was collected, washed with water (300 ml), then freeze-dried to afford a yellow solid (2.80 g). This material was dissolved in chloroform (250 ml) filtered through filter paper and evaporated to azeotrope remaining water. The residual yellow precipitate (2.70 g, HPLC (214nm) t_R = 7.26 (93.6%) min.) was partially dissolved in chloroform (20 ml), the suspension was sonicated for 5 min, then the solid was collected and air dried to afford 3-Z-benzylidene-6-[5"-(1,1-dimethylallyl)-1*H*-imidazol-4"-Z-ylmethylene]-piperazine-2,5-dione (1.82 g, 54%) (Hayashi, Personal Communication (2001)), m.p. 239-240° (dec.).

HPLC (214nm) t_R = 6.80 (1.92) min, 7.33 (95.01%).

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.53 (s, 6H); 5.18 (d, *J* = 17.6 Hz, 1H, -*CH*=*CH*$_2$); 5.21 (d, *J* = 11.0 Hz, 1H, -*CH*=*CH*$_2$); 6.06 (dd, *J* = 17.6, 11.0 Hz, 1H, -*CH*=*CH*$_2$); 6.99 (s, 1H, -*C*-*C*=*CH*); 7.00 (s, 1H, -*C*-*C*=*CH*); 7.30-7.50 (m, 5 x ArH); 7.60 (s, H2"); 8.07 (bs, NH); 9.31 (bs, NH); 12.30 (bs, NH).

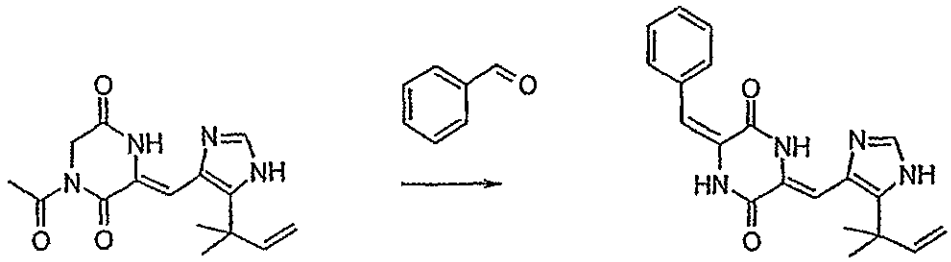
LC/MS t_R = 6.22 (349.3 $[M+H]^+$, E isomer), 6.73 (349.5 $[M+H]^+$, 697.4 $[2M+H]^+$, Z isomer) min.

ESMS *m/z* 349.5 $[M+H]^+$, 390.3 $[M+CH_4CN]^+$.

Evaporation of the chloroform solution gave additional 3-Z-benzylidene-6-[5"-(1,1-dimethylallyl)-1*H*-imidazol-4"-Z-ylmethylene]-piperazine-2,5-dione (0.76 g, 29%).

HPLC (214nm) t_R = 7.29 (84.5%) min.

3-E-Benzylidene-6-[5"-(1,1-dimethylallyl)-1H-imidazol-4"-Z-ylmethylene]-piperazine-2,5-dione



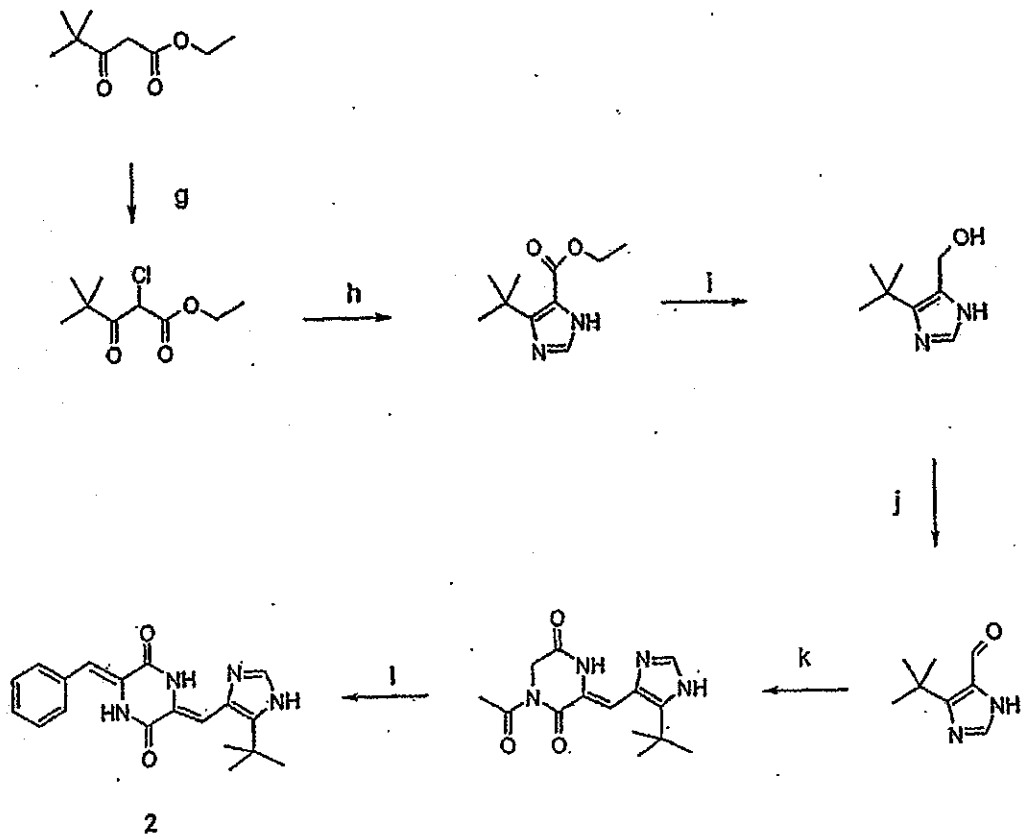
Preparative HPLC purification of a crude sample of material synthesized as above afforded the geometric isomer 3-E-Benzylidene-6-[5"-(1,1-dimethylallyl)-1H-imidazol-4"-Z-ylmethylene]-piperazine-2,5-dione (1.7 mg).

HPLC (214nm) t_R = 6.75 (87.79) min.

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.52 (s, 6H); 5.19 (d, J = 20.8 Hz, 1H, $CH=CH_2$); 5.22 (d, J = 14.0 Hz, 1H, $CH=CH_2$); 6.05 (dd, J = 18.0, 10.4 Hz, 1H, $CH=CH_2$); 6.33 (s, 1H, C-C=CH); 6.90-7.65 (m, 7H).

ESMS m/z 349.5 $[M+H]^+$, 390.4 $[M+CH_4CN]^+$.

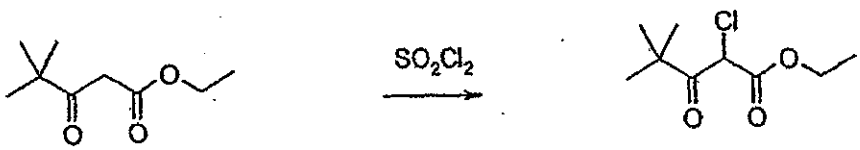
Synthesis of 3-Z-Benzylidene-6-(5"-tert-butyl-1H-imidazol-4"-Z-ylmethylene)-piperazine-2,5-dione (2)



2

Reagents: g) SO_2Cl_2; h) H_2NCHO, H_2O; I)$LiAlH_4$; j) MnO_2; k) 1,4-diacetyl-piperazine-2,5-dione, Cs_2CO_3; 1) benzaldehyde, Cs_2CO_3

2-Chloro-4,4-dimethyl-3-oxo-pentanoic acid ethyl ester



Sulfuryl chloride (14.0 ml, 0.17 mol) was added to a cooled (0°) solution of ethyl pivaloylacetate (27.17 g, 0.16 mol) in chloroform (100 ml). The resulting mixture was allowed to warm to room temperature and was stirred for 30 min, after which it was heated under reflux for 2.5 h. After cooling to room temperature, the reaction mixture was diluted with chloroform, then washed with sodium bicarbonate, water then brine.

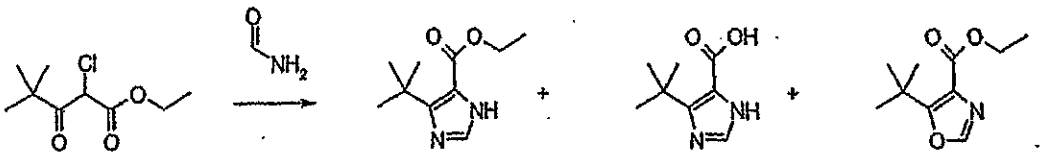
The organic phase was dried and evaporated to afford, as a clear oil, 2-chloro-4,4-dimethyl-3-oxo-pentanoic acid ethyl ester (33.1 g, 102%). (Durant et al., "Aminoalkylimidazoles and Process for their Production." Patent No. GB1341375 (Great Britain, 1973)).

HPLC (214nm) t_R = 8.80 (92.9%) min.

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.27 (s, 9H); 1.29 (t, J = 7.2 Hz, 3H); 4.27 (q, J = 7.2 Hz, 2H); 5.22 (s, 1H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 13.8, 26.3, 45.1, 54.5, 62.9, 165.1, 203.6.

5-tert-Butyl-3H-imidazole-4-carboxylic acid ethyl ester



A solution of 2-chloro-4,4-dimethyl-3-oxo-pentanoic acid ethyl ester (25.0 g, 0.12 mol) in formamide (47.5 ml) and water (2.5 ml) was shaken, then dispensed into 15 x 8 ml vials. All vials were sealed and then heated at 150° for 3.5 h. The vials were allowed to cool to room temperature, then water (20 ml) was added and the mixture was exhaustively extracted with chloroform. The chloroform was removed to give a concentrated formamide solution (22.2 g) which was added to a flash silica column (6 cm diameter, 12 cm height) packed in 1% MeOH/1% Et_3N in chloroform. Elution of the column with 2.5 L of this mixture followed by 1 L of 2% MeOH/1% Et_3N in chloroform gave, in the early fractions, a product suspected of being *5-tert-butyl-oxazole-4-carboxylic acid ethyl ester* (6.3 g, 26%).

HPLC (214nm) t_R = 8.77 min.

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.41 (t, J = 7.2 Hz, 3H); 1.43 (s, 9H); 4.40 (q, J = 7.2 Hz, 2H); 7.81 (s, 1H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 14.1, 28.8, 32.5, 61.3, 136.9, 149.9, 156.4, 158.3.

ESMS *m/z* 198.3 $[M+H]^+$, 239.3 $[M+CH_4CN]^+$.

LC/MS t_R = 7.97 (198.1 $[M+H]^+$) min.

Recovered from later fractions was 5-tert-butyl-3H-imidazole-4-carboxylic acid ethyl ester (6.20 g, 26%). (Durant et al., "Aminoalkylimidazoles and Process for their Production." Patent No. GB1341375 (Great Britain, 1973)).

HPLC (214nm) t_R = 5.41 (93.7%) min.

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.38 (t, *J* = 7.0 Hz, 3H); 1.47 (s, 9H); 4.36 (q, *J* = 7.2 Hz, 2H); 7.54 (s, 1H).

^{13}C NMR (100 MHz, $CDCl_3$) δ 13.7, 28.8, 32.0, 59.8, 124.2, 133.3, 149.2, 162.6.

ESMS *m/z* 197.3 $[M+H]^+$, 238.3 $[M+CH_4CN]^+$.

Further elution of the column with 1L of 5% MeOh/1% Et_3N gave a compound suspected of being *5-tert-butyl-3H-imidazole-4-carboxylic acid* (0.50 g, 2%).

HPLC (245nm) t_R = 4.68 (83.1%) min.

^{1}H NMR (400 MHz, CD_3OD) δ 1.36 (s, 9H); 7.69 (s, 1H).

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.37 (s, 9H); 7.74 (s, 1H).

^{1}H NMR (400 MHz, CD_3SO) δ 1.28 (s, 9H); 7.68 (s, 1H).

ESMS *m/z* 169.2 $[M+H]^+$, 210.4 $[M+CH_4CN]^+$.

(5-tert-Butyl-3H-imidazol-4-yl)-methanol



A solution of 5-tert-butyl-3-imidazole-4-carboxylic acid ethyl ester (3.30 g, 16.8 mmol) in THF (60 ml) was added dropwise to a suspension of lithium aluminium hydride (95% suspension, 0.89 g, 22.2 mmol) in THF (40 ml) and the mixture was stirred at room temperature for 3 h. Water was added until the evolution of gas ceased, the mixture was stirred for 10 min, then was filtered through a sintered funnel. The precipitate was washed with THF, then with methanol, the filtrate and washings were combined and evaporated. The residue was freeze-dried overnight to afford, as a white solid (5-tert-butyl-3H-imidazol-4-yl)-methanol (2.71 g, 105%). (Durant et al., "Aminoalkylimidazoles and Process for their Production." Patent No. GB1341375 (Great Britain, 1973)).

HPLC (240nm) t_R = 3.70 (67.4%) min.

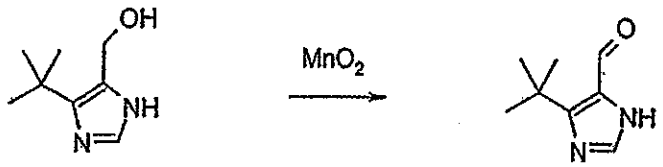
^{1}H NMR (400 MHz, CD_3OD) δ 1.36 (s, 9H); 4.62 (s, 2H); 7.43 (s, 1H).

^{13}C NMR (100 MHz, CD_3OD) δ 31.1, 33.0, 57.9, 131.4, 133.9, 140.8.

LC/MS t_R = 3.41 (155.2 $[M+H]^+$) min.

This material was used without further purification.

5-tert-Butyl-3H-imidazole-4-carbaldehyde



Manganese dioxide (30 g, 0.35 mol) was added to a heterogeneous solution of (5-tert-butyl-3H-imidazol-4-yl)-methanol (4.97 g, 0.03 mol) in acetone (700 ml) and the resulting mixture was stirred at room temperature for 4 h. The mixture was filtered through a pad of Celite and the pad was washed with acetone. The filtrate and washings were combined and evaporated. The residue was triturated with ether to afford, as a colorless solid, 5-tert-butyl-3H-imidazole-4-carbaldehyde (2.50 g, 51%). (Hayashi, Personal Communication (2000)).

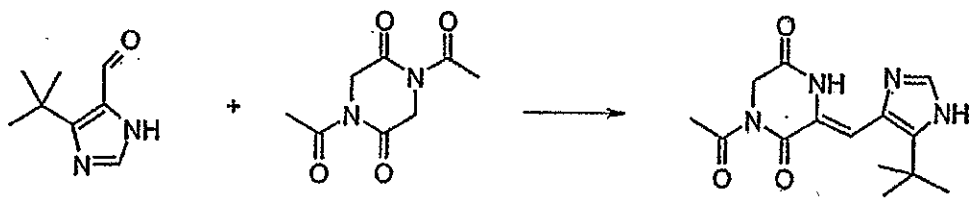
HPLC (240nm) t_R = 3.71 (89.3%) min.

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.48 (s, 9H); 7.67 (s, 1H); 10.06 (s, 1H).

LC/MS t_R = 3.38 (153.2 $[M+H]^+$) min.

Evaporation of the filtrate from the trituration gave additional 5-tert-butyl-3H-imidazole-4-carbaldehyde (1.88 g, 38%).

1-Acetyl-3-(5'-tert-butyl-1H-imdazol-4'-Z-ylmethylene)-piperazine-2,5-dione



To a solution of 5-tert-butyl-3*H*-imidazole-4-carbaldehyde (2.50 g, 164.4 mmol) in DMF (50 ml) was added 1,4-diacetyl-piperazine-2,5-dione (6.50 g, 32.8 mmol) and the solution was evacuated, then flushed with argon. The evacuation-flushing process was repeated a further two times, then cesium carbonate (5.35 g, 16.4 mmol) was added. The evacuation-flushing process was repeated a further three times, then the resultant mixture was stirred at room temperature for 5 h. The reaction mixture was partially evaporated (heat and high vacuum) until a small volume remained and the resultant solution was added dropwise to water (100 ml). The yellow precipitate was collected, then freeze-dried to afford 1-acetyl-3-(5'-tert-butyl-1H-imidazol-4'-Z-ylmethylene)-piperazine-2,5-dione (2.24 g, 47%). (Hayashi, Personal Communication (2000)).

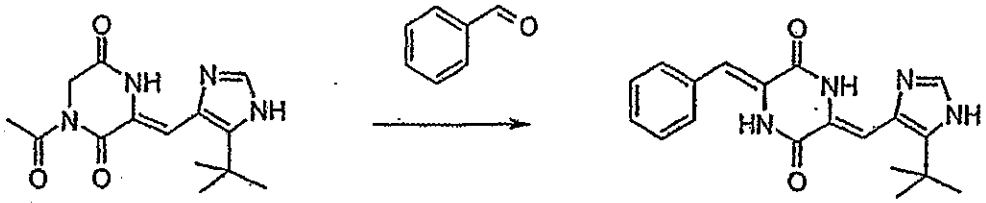
HPLC (214nm) t_R = 5.54 (94.4%) min.

^{1}H NMR (400 MHz, $CDCl_3$) δ 1.47 (s, 9H); 2.65 (s, 3H), 4.47 (s, 2H); 7.19 (s, 1H); 7.57 (s, 1H), 9.26 (s, 1H), 12.14 (s, 1H).

^{13}C NMR (100 MHz, $CDCl_3$+CD_3OD) δ 27.3, 30.8, 32.1, 46.5, 110.0, 123.2, 131.4, 133.2, 141.7, 160.7, 162.8, 173.0

LC/MS t_R = 5.16 (291.2 $[M+H]^+$, 581.6 $[2M+H]^+$) min.

3-Z-Benzylidene-6-(5"-tert-butyl-1H-imidazol-4"-Z-ylmethylene)-piperazine-2,5-dione



To a solution of 1-acetyl-3-(5'-tert-butyl-1H-imidazol-4'-Z-ylmethylene)-piperazine-2,5-dione (2.43 g, 8.37 mmol) in DMF (55 ml) was added benzaldehyde (4.26 ml, 41.9 mmol) and the solution was evacuated, then flushed with nitrogen. The evacuation-flushing process was repeated a further two times, then cesium carbonate (4.09 g, 12.6 mmol) was added. The evacuation-flushing process was repeated a further three times, then the resultant mixture was heated under the temperature gradient as shown below. After a total time of 5 h the reaction was allowed to cool to room temperature and the mixture was added to ice-cold water (400 ml). The precipitate was collected, washed with water, then freeze-dried to afford a yellow solid (2.57 g, HPLC (214nm) t_R = 6.83 (83.1%) min.). This material was dissolved in chloroform (100 ml) and evaporated to azeotrope remaining water, resulting in a brown oil. This was dissolved in chloroform (20 ml) and cooled in ice. After 90 min the yellow precipitate was collected and air-dried to afford 3-Z-benzylidene-6-(5"-tert-butyl-1*H*-imidazol-4"-Z-ylmethylene)-piperazine-2,5-dione (1.59 g, 56%). (Hayashi, Personal Communication (2000)).

HPLC (214nm) t_R = 6.38 (2.1%), 6.80 (95.2) min.

^1H NMR (400 MHz, $CDCl_3$) δ 1.46 (s, 9H); 7.01 (s, 1H, -C-C=*CH*); 7.03 (s, 1H, -*C*-C=CH); 7.30-7.50 (m, 5H, *Ar*); 7.60 (s, 1H); 8.09 (bs, NH); 9.51 (bs, NH); 12.40 (bs, NH).

LC/MS t_R = 5.84 (337.4 $[M+H]^+$, E isomer), 6.25 (337.4 $[M+H]^+$, 673.4 $[2M+H]^+$, Z isomer) min.

ESMS *m/z* 337.3 $[M+H]^+$, 378.1 $[M+CH_4CN]^+$.

Evaporation of the chloroform solution gave additional 3-Z-benzylidene-6-(5"-tert-butyl-1*H*-imidazol-4"-Z-ylmethylene)-piperazine-2,5-dione (0.82 g, 29%). HPLC (214nm) t_R = 6.82 (70.6%) min.

General Experimental

Sodium bicarbonate refers to a 5% solution.

Organic solvents were dried over sodium sulfate unless otherwise stated.

Analytical Conditions

NMR Conditions

^{1}H NMR (400 MHz) analysis was performed on a Varian Inova Unity 400 MHz NMR machine. Samples were run in deuterated chloroform containing 0.1% TMS (unless otherwise specified). Chemical shifts (ppm) are referenced relative to TMS (0.00 ppm) or CH_3OH at 3.30 ppm for samples run CD_3OD. Coupling constants are expressed in hertz (Hz).

Analytical HPLC Conditions

System 6 conditions:

RP-HPLC was done on a Rainin Microsorb-MV C18 (5 μm, 100Å) 50 x 4.6 mm column.

Buffer A: 0.1% aqueous TFA

Buffer B: 0.1% TFA in 90% aqueous MeCN

Gradient: 0 - 100% Buffer B over 11 min

Flow rate: 1.5 mL/min

LCMS Conditions

LCMS were run on a Perkin-Elmer Sciex API-100 instrument.

LC conditions:

Reverse Phase HPLC analysis

Column: Monitor 5 μm C18 50x4.6 mm

Solvent A: 0.1% TFA in water

Solvent B: 0.085% TFA in 90% aqueous MeCN

Gradient: 0-100% B over 11.0 min

Flow rate: 1.5 mL/min

Wavelength: 214 nm

MS conditions:

Ion Source: Ionspray

Detection: Ion counting

Flow rate to the mass spectrometer: 300 μL/min after split from column (1.5 mL/min).

ESMS Conditions

ESMS was done on a Perkin Elmer/Sciex-API III LC/MS/MS using an electrospray inlet.

Solvent: 0.1% AcOH in 60% aqueous MeCN

Flow rate: 25 μL/min

Ionspray: 5000 V

Orifice plate: 55 V

Acquisition time: 2.30 min

Scan range: 100-1000 amu/z

Scan step size: 0.2 amu/z

Preparative RP-HPLC Purification Conditions

Reverse phase HPLC purification was carried out using Nebula with the Waters XterraMS column (19x50 mm, 5 μm, C18) using the following conditions:

Solvent A: 0.1% aqueous TFA

Solvent B: 0.1% TFA in 90% aqueous MeCN

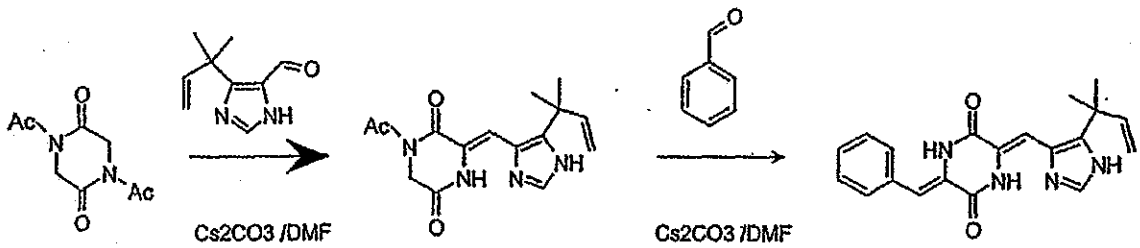
Gradient: 5-95% B over 4 min

Flow rate: 20 mL/min

Wavelength: 214 nm

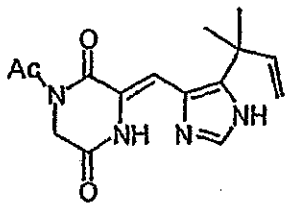
Abbreviations are as follows: br s: broad singlet; BuLi : n-butyl lithium; d: doublet; DBU: 1,8-diazabicyclo[5.4.0]undec-7-ene; ESMS: electrospray mass spectrometry; HCl: hydrochloric acid; HPLC: high performance liquid chromatography; LCMS: liquid chromatography mass spectrometry; LD: lithium diisopropylamide; *M+*: molecular ion; m: multiplet; MeCN: acetonitrile; M: mass spectrometry; MW: molecular weight; NMR: nuclear magnetic resonance; q: quartet; s: singlet; : triplet; t_R: retention time; TFA: trifluoroacetic acid; THF: tetrahydrofuran

Detailed Procedure for the Synthesis of Dehydrophenylahistin



1 2

1-Acetyl-3-{(Z)-1-[5-(1,1-dimethyl-2-propenyl)-1*H*-4-imidazolyl]methylidene}]-2,5-piperazinedione (2)



To a solution of 5-(1,1-dimethyl-2-propenyl)imidazole-4-carboxaldehyde (100 mg, 0.609 mmol) in DMF (2 mL) was added compound 1 (241 mg, 1.22 mmol) and the solution was repeatedly evacuated in a short time to remove oxygen and flushed with Ar, followed by the addition of Cs_2CO_3 (198 mg. 0.609 mmol) and the evacuation-flushing process was repeated again. The removal of oxygen is prefered because such removal is believed to decrease oxidation of alpha-carbon at the position 6 of the diketopiperazine ring. The resultant mixture was stirred for 5 h at room temperature. After the solvent was removed by evaporation, the residue was dissolved in the mixture of EtOAc and 10% Na_2CO_3, and the organic phase was washed with 10% Na_2CO_3 again and saturated NaCl for three times, dried over Na_2CO_3 and concentrated in vacuo. The residual oil was purified by column chromatography on silica using $CHCl_3$-MeOH (100:0 to 50:1) as an eluant to give 60 mg (33%) of a pale yellow solid 2.

Dehydrophenylahistin

To a solution of 2 (30 mg, 0.099 mmol) in DMF (0.8 mL) was added benzaldehyde (51 μL, 0.496 mmol, 5 eq) and the solution was repeatedly evacuated in a short time to remove oxygen and flushed with Ar, followed by the addition of Cs_2CO_3 (53 mg, 0.149 mmol, 1.5 eq) and the evacuation-flushing process was repeated again. The resultant mixture was heated for 2.5 h at 80°C. (The temperature must be increased slowly. Rapid heating increases the production of E-isomer at the benzylidene moiety.) After the solvent was removed by evaporation, the residue was dissolved in EtOAc, washed with water for two times and saturated NaCl for three times, dried over Na_2SO_4 and concentrated in vacuo. On TLC using $CHCl_3$-MeOH (10:1), you can observe a spot with bright green-yellow luminescence at 365 nm UV. The purity of this crude product was more than 75% from HPLC analysis. The resulting residue was dissolved in 90% MeOH aq and applied to reverse-phase HPLC column (YMC-Pack, ODS-AM, 20 x 250 mm) and eluted using a linear gradient from 70 to 74% MeOH in water over 16 min at a flow rate of 12 mL/min, and the desired fraction was collected and concentrated by evaporation to give a 19.7 mg (60%), although the yields are not optimized for each step,. of yellow colored dehydrophenylahistin.

***

EXAMPLE 4

Biological Characteristics of Dehydrophenylahistin and Dehydrophenylahistin Analogs

A. Biological Evaluation

The biological characteristics of synthesized tBu-dehydrophenylahistin and dehydrophenylahistin were evaluated in both HT29 human colon cells, and PC-3 prostatic adenocarcinoma cells.

HT-29 (ATCC HTB-38) a human colorectal adenocarcinoma was maintained in McCoy's complete medium (McCoy's 5A medium with L-glutamine and 25mM HEPES supplemented with 10% FBS, 1mM Na

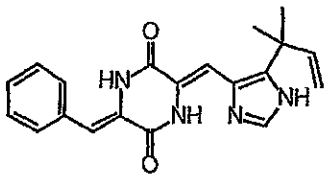
pyruvate, 1X NEAA, 2mM L-glutamine, and Pen/Strep at 100IU/ml and 100µg/ml, respectively). PC-3 (ATCC CRL-1435), a human prostate adenocarcinoma, was maintained in F12K complete medium (F12K medium supplemented with 10% FBS; 2mM Glutamine; 1% HEPES; and Pen/Strep at 100IU/ml and 100µg/ml, respectively). Cell lines were cultured at 37 °C, 5% CO_2 in a 95% humidified incubator.

For tumor cytotoxicity assays HT-29 or PC-3 cells were seeded at 5,000 cells/well in 90 µl complete media into a Corning 3904 black-walled, clear-bottom tissue culture plate and the plate were incubated overnight to allow cells to establish and enter log phase growth. 20 mM stock solutions of dehydrophenylahistin and tBu-dehydrophenylahistin were prepared in 100% DMSO and stored at -20 °C. 10X concentrated serial dilutions of the two compounds were prepared in appropriate culture medium for final concentrations ranging from 20×10^{-5} M to 20×10^{-10} M. Ten µl volumes of the 10X serial dilutions were added to the test wells in triplicate and the plates returned to the incubator for 48 hours. The final concentration of DMSO was 0.25% in all samples.

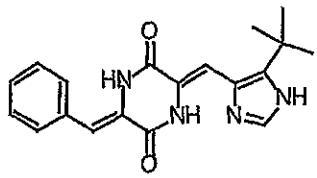
Following 48 hours of drug exposure 10 µl of 0.2 mg/ml resazurin (obtained from Sigma-Aldrich Chemical Co.) in Mg^{2+}, Ca^{2+} free PBS was added to each well and the plates were returned to the incubator for 3-4 hours. The plates were removed and resazurin fluorescence was measured using 530 nm excitation and 590 nm emission filters in a Fusion fluorimeter (Packard Instruments). Resazurin dye without cells was used to determine the background, which was subtracted from the data for all experimental wells. The data were analyzed using Prism software (GraphPad Software). The data were normalized to the average of the cells treated with media only (100% cell growth) and EC_{50} values were determined using a standard sigmoidal dose response curve fitting algorithm.

As indicated in Table 1 below, tBu-dehydrophenylahistin demonstrates about a 4-times greater cytotoxic activity in comparison with dehydrophenylahistin.

Table 1. Cytotoxic Effect of dehydrophenylahistin and derivative.



Dehydrophenylahistin



tBu-dehydrophenylahistin

	EC_{50} (nM)	
cell	ΔPLH	tBu-ΔPLH
HT29	48	13
PC-3	5.4	1.0

B. Structure and Activity Study of Dehydrophenylahistin Derivatives

The cytotoxic effects of phenylahistin, dehydrophenylahistin and various derivatives of dehydrophenylahistin were examined in P388 murine leukemia cells, HT-29 human colon cells, and PC-3 prostatic adenocarcinoma cells.

As explained above, HT-29 a human colorectal adenocarcinoma was maintained in McCoy's complete medium (McCoy's 5A medium with L-glutamine and 25mM HEPES supplemented with 10% FBS, 1mM Na pyruvate, 1X NEAA, 2mM L-glutamine, and Pen/Strep at 100IU/ml and 100µg/ml, respectively). PC-3, a human prostate adenocarcinoma, was maintained in F12K complete medium (F12K medium supplemented with 10% FBS; 2mM Glutamine; 1% HEPES; and Pen/Strep at 100IU/ml and 100µg/ml, respectively). Cell lines were cultured at 37 °C, 5% CO_2 in a 95% humidified incubator.

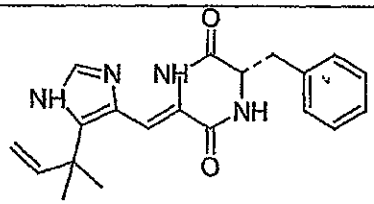
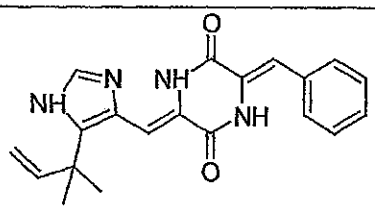
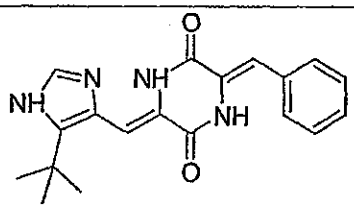
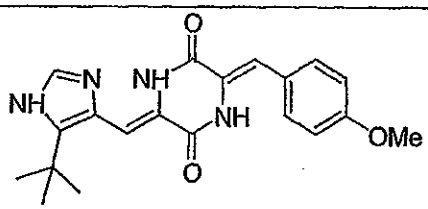
For tumor cytotoxicity assays HT-29 or PC-3 cells were seeded at 5,000 cells/well in 90 µl complete media into a Corning 3904 black-walled, clear-bottom tissue culture plates and the plates were incubated overnight to allow cells to establish and enter log phase growth. 20 mM stock solutions of dehydrophenylahistin and tBu-dehydrophenylahistin were prepared in 100% DMSO and stored at -20 °C. 10X concentrated serial dilutions of the two compounds were prepared in appropriate culture medium for final concentrations ranging from 20×10^{-5} M to 20×10^{-10} M. Ten µl volumes of the 10X serial dilutions were added to the test wells in triplicate and the plates returned to the incubator for 48 hours. The final concentration of DMSO was 0.25% in all samples.

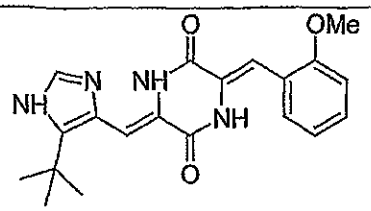
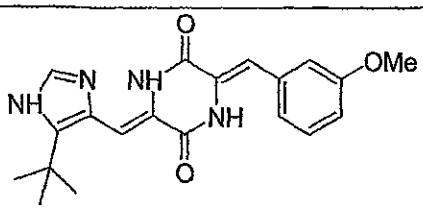
Following 48 hours of drug exposure 10µl of 0.2 mg/ml resazurin (obtained from Sigma-Aldrich Chemical Co.) in Mg^{2+}, Ca^{2+} free PBS was added to each well and the plates were returned to the incubator for

3-4 hours. The plates were removed and resazurin fluorescence was measured using 530 nm excitation and 590 nm emission filters in a Fusion fluorimeter (Packard Instruments). Resazurin dye without cells was used to determine the background, which was subtracted from the data for all experimental wells. The data were analyzed using Prism software (GraphPad Software). The data were normalized to the average of the cells treated with media only (100% cell growth) and EC_{50} values were determined using a standard sigmoidal dose response curve fitting algorithm.

EC_{50} and IC_{50} values of phenylahistin, dehydrophenylahistin and dehydrophenylahistin derivatives are summarized in Table 2 below.

Table 2. SAR study of phenylahistin or dehydrophenylahistin and of dehydrophenylahistin derivatives

COMPOUNDS	STRUCTURE	EC_{50} (nM)		IC_{50} (nM)
		HT-29	PC-3	P-388
(-)-Phenylahistin		1600	n.t.	833 ± 153 (n=5)
KPU-1 ΔPLH		48	4.7	36 ± 12.8 (n=5)
KPU-2 tBu-ΔPLH		13	1	31.8 ± 5.0 (n=5)
KPU-6 tBu-ΔPLH-p-OMe		>2000	n.t.	9333 ± 5457 (n=3)

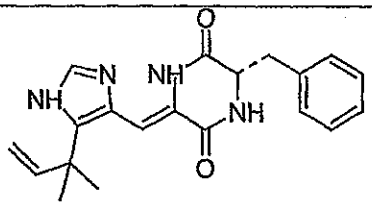
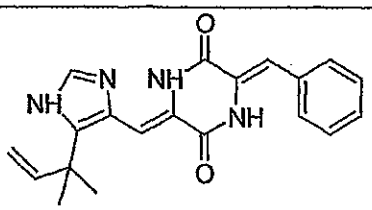
KPU-8 tBu-ΔPLH-o-OMe		89		315 ± 137 (n=4)
KPU-9 tBu-ΔPLH-M-OMe		31		20.8 ± 68 (n=4)
Colchicine	—			208±68 (n=4)

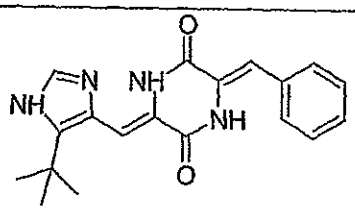
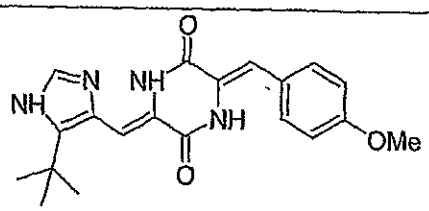
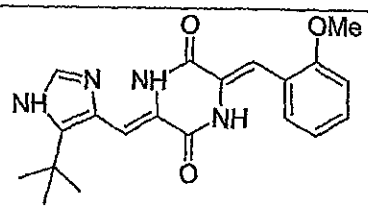
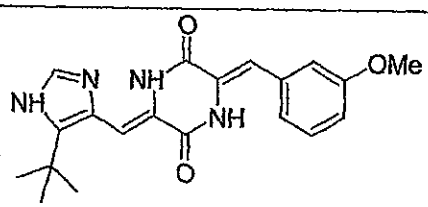
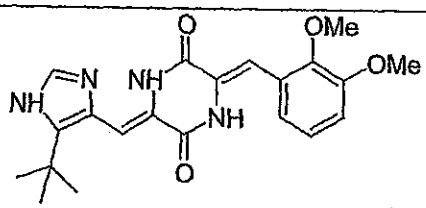
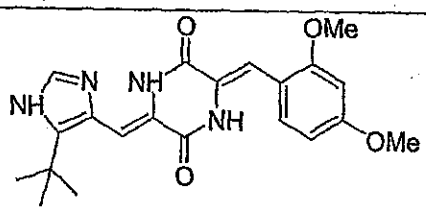
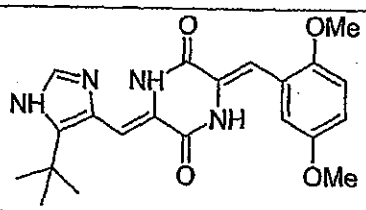
Modifications to the phenyl ring have a significant effect of the cytotoxic activities. In comparison with the activity of tBu-dehydrophenylahistin (#6), the activity of the methoxy group at the meta-position (KPU-9) exhibited the highest activity than the other derivatives with an IC_{50} of 20.8±3.3 nM in P388 cells. The KPU-9 derivative also exhibited cytotoxicity in HT-29 cells (EC_{50} 31 nM). Dehydrophenylahistin, tBu-dehydrophenylahistin (KPU-2) and the KPU-9 derivative all exhibited cytotoxicity in P388 cells.

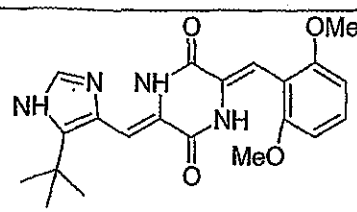
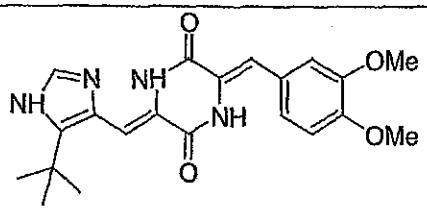
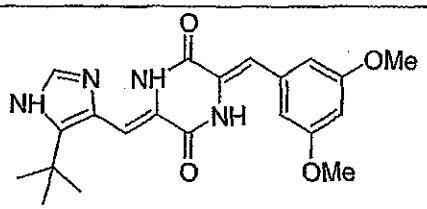
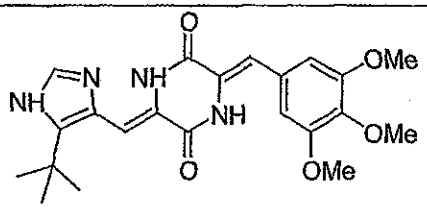
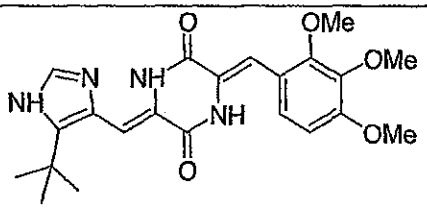
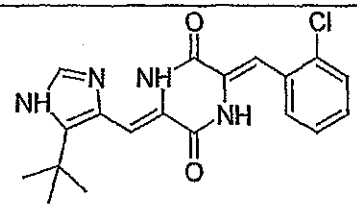
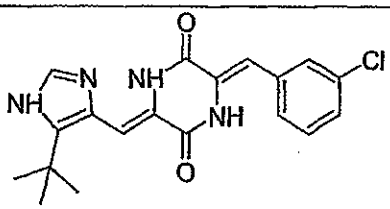
C. Structure and Activity Study of Additional Dehydrophenylahistin Derivatives

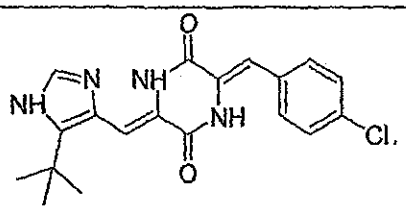
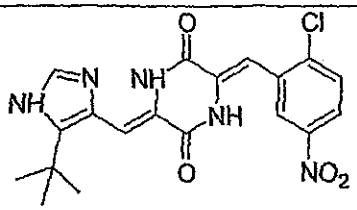
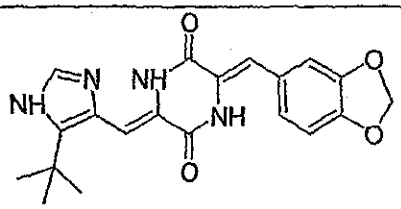
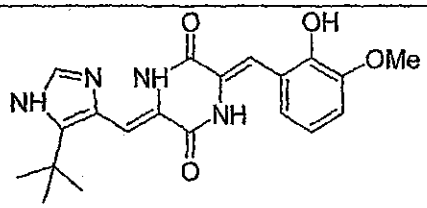
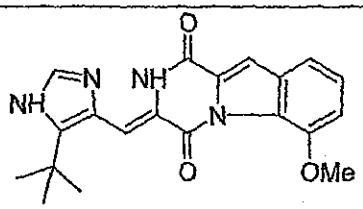
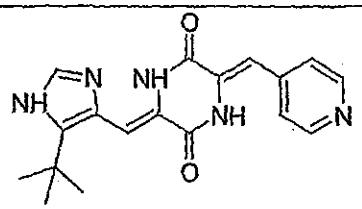
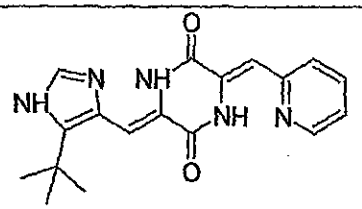
The cytotoxic effects of phenylahistin, dehydrophenylahistin and various additional derivatives of dehydrophenylahistin were examined in HT-29 human colon cells and PC-3 prostatic adenocarcinoma cells using the methodology described above.

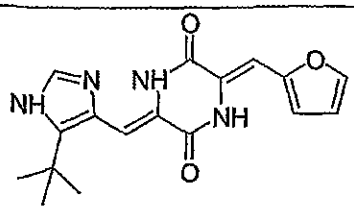
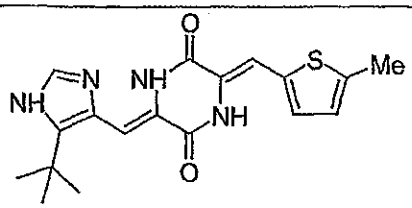
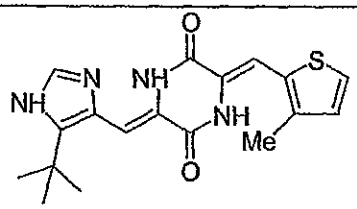
Table 3. SAR study of phenylahistin, dehydrophenylahistin and of additional dehydrophenylahistin derivatives

COMPOUNDS	STRUCTURE	SALT FORM	M.W.	EC_{50} (nM)	
				HT-29	PC-3
(-)-Phenylahistin		-	350.41	1600	n.t.
KPU-1 ΔPLH		-	348.40	48	4.7

COMPOUNDS	STRUCTURE	SALT FORM	M.W.	EC_{50} (nM)	
				HT-29	PC-3
KPU-2 tBu-ΦPLH		-	336.39	13	1
KPU-6 tBu-ΦPLH-p-OMe		-	366.41	>2000	n.t.
KPU-8 tBu-ΦPLH-o-OMe		-	366.41	89	
KPU-9 tBu-ΦPLH-m-OMe		-	366.41	31	
KPU-14 tBu-ΦPLH-2,3-diOMe		TFA	396.44 510.46 (+TFA)	610	96%
KPU-12 tBu-ΦPLH-2,4-diOMe		-	396.44	4980	
KPU-10 tBu-ΦPLH-2,5-diOMe		-	396.44	1350	

COMPOUNDS	STRUCTURE	SALT FORM	M.W.	EC_{50} (nM)	
				HT-29	PC-3
KPU-15 tBu-iPLH-2,6-diOMe		TFA	396.44 510.46 (+TFA)	4430	96%
KPU-13 tBu-iPLH-3,4-diOMe		-	396.44	2130	
KPU-16 tBu-iPLH-3,5-diOMe		-	396.44	42	82%
KPU-11 tBu-iPLH-3,4,5-triOMe		-	426.47	> 20 μM	
KPU-17 tBu-iPLH-2,3,4-triOMe		TFA	426.47 540.49 (+TFA)	4060	94%
KPU-18 tBu-iPLH-o-Cl		TFA	370.83 484.86 (+TFA)	42	100%
KPU-19 tBu-iPLH-m-Cl		TFA	370.83 484.86 (+TFA)	20	98%

COMPOUNDS	STRUCTURE	SALT FORM	M.W.	EC_{50} (nM)	
				HT-29	PC-3
KPU-20 tBu-PLH-p-Cl		TFA	370.83 484.86 (+TFA)	545	
KPU-21 tBu-PLH-2Cl-5-NO_2		TFA	415.83 529.85 (+TFA)	51	100%
KPU-22 tBu-PLH-3,4-methylene-dioxy		TFA	380.40 494.42 (+TFA)	82	95%
KPU-23 tBu-PLH-2-OH-3-OMe (o-vanillin)		TFA	382.41 496.44 (+TFA)	5870	86%
KPU-24 tBu-PLH-cyclized-3-MeO		TFA	364.40 487.42 (+TFA)	7040	100%
KPU-25 tBu-PLH-4-pyridyl		TFA	337.38 565.42 (+2TFA)	544	98%
KPU-28 tBu-PLH-2-pyridyl		TFA	337.38 565.42 (+2TFA)	> 20 μM	99%

COMPOUNDS	STRUCTURE	SALT FORM	M.W.	EC_{50} (nM)	
				HT-29	PC-3
KPU-26 tBu-dPLH-2-furyl		TFA	326.35 440.37 (+TFA)	600	88%
KPU-27 tBu-dPLH-5-Me-2-thienyl		TFA	356.44 470.47 (+TFA)	80	97%
KPU-29 tBu-dPLH-3-Me-2-thienyl		TFA	356.44 470.47 (+TFA)	44	81%

EXAMPLE 5

Other Dehydrophenylahistin Analogs

A. Modifications for the synthesis of dehydrophenylahistin derivatives

Other derivatives of dehydrophenylahistin are synthesized using the foregoing techniques alone or in conjunction with other well known organic synthesis techniques.

Modifications to the diacyldiketopiperazine and the first and second aldehydes involved in the synthesis method vary according to the desired derivative to produce. Derivatives are synthesized that:

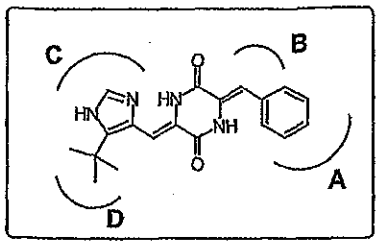
A) modify the phenyl ring and/or introduce other aromatic ring systems,

B) alter the position of the aromatic ring,

C) alter the imidazole aromatic ring system, and/or

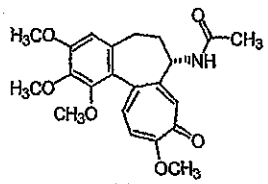
D) modify the 5-position on the imidazole ring.

The figure below depicts regions of the dehydrophenylahistin compound modified to produce derivatives of dehydrophenylahistin. Non-limiting examples of modifications are disclosed, and based on this disclosure would be understood by those of skill in the art.

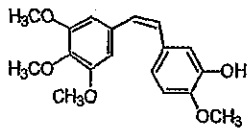


A 1) Modification of the phenyl ring besed on the structure of known anti-tubulin compounds

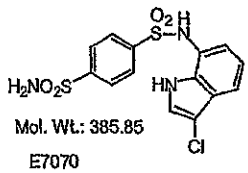
Alkyl, Halogen, Alkoxy, Acetyl, Sulfonamide, Amino, Hydroxyl, Nitro, etc.



Colchicine



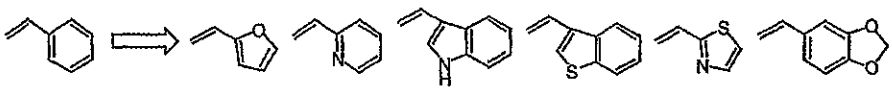
Combretastatin A-4



Mol. Wt.: 385.85

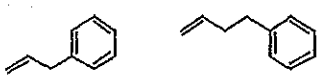
E7070
0.15 ug/mL
P-388 Phase II

2) Introduction of other aromatic ring systems

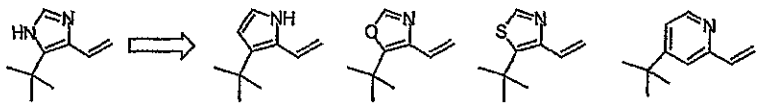


etc

B Position of the aromatic ring

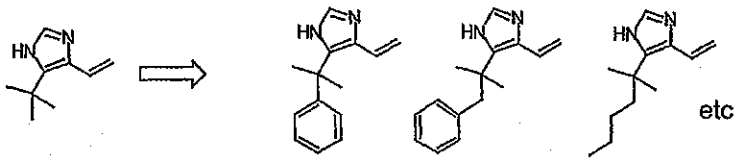


C Change to the other ring systems



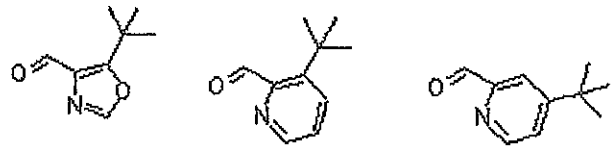
etc

D Further modification of the 5-positin on the imidazole ring



etc

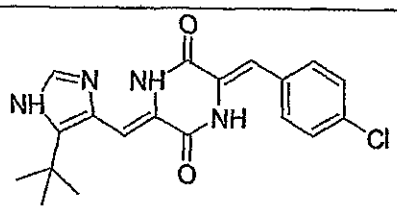
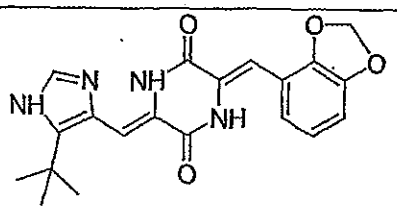
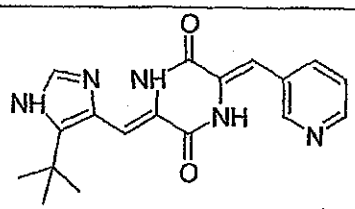
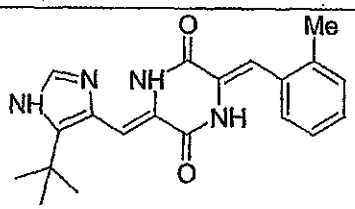
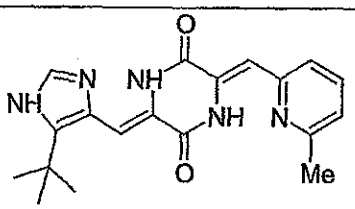
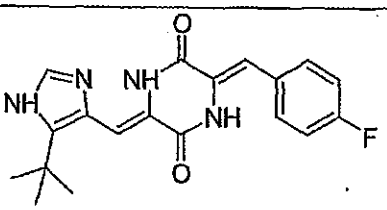
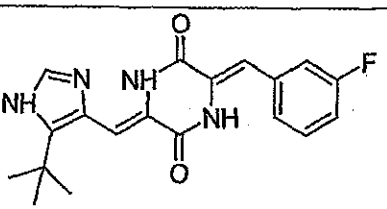
Expanding on the above modifications to the dehydrophenylahistin compound, derivatives of the compound may include the following substitutions at the phenyl ring (**A**): $-CF_3$, $-SO_2NH_2$ ($-SO_2NR_1R_2$), $-SO_3H$, $-CONH_2$ ($-CONR_1R_2$), $-COOH$, etc. Other ring systems (**C**) may also include the following:

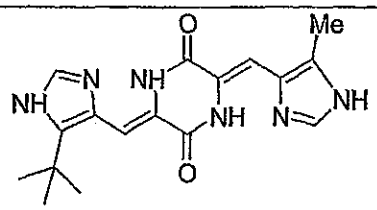
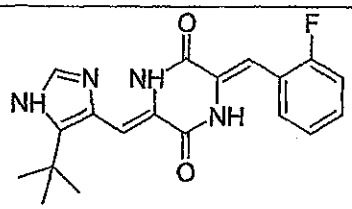
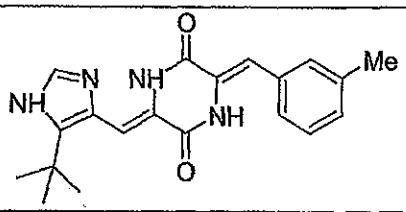
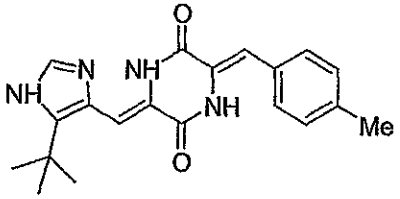
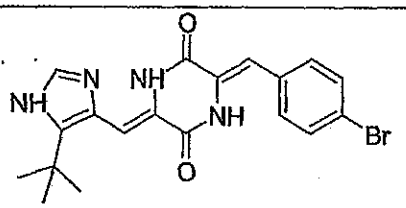
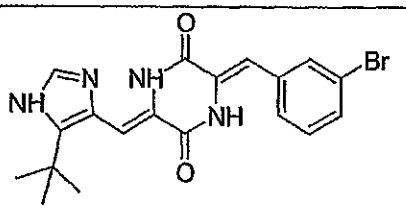
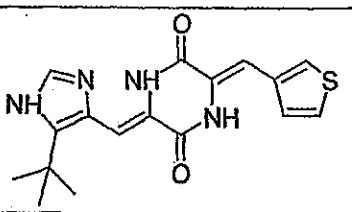


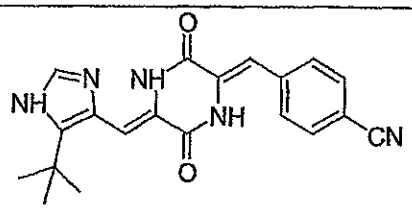
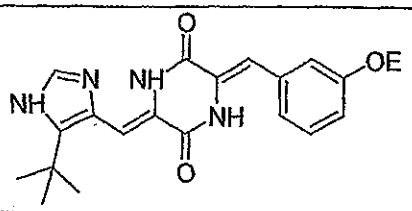
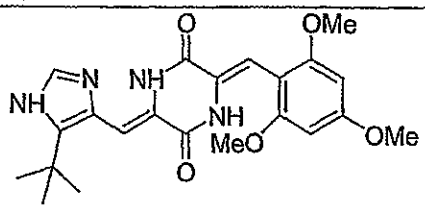
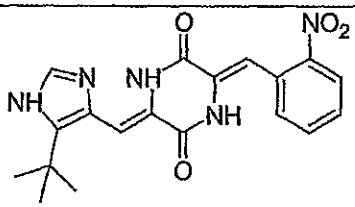
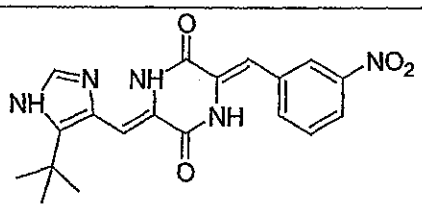
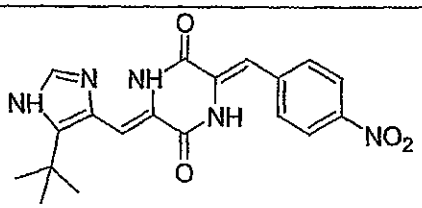
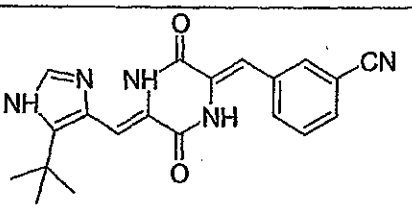
B. Examples of synthesized dehydrophenylahistin derivatives

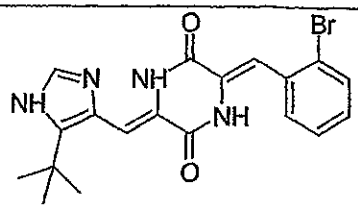
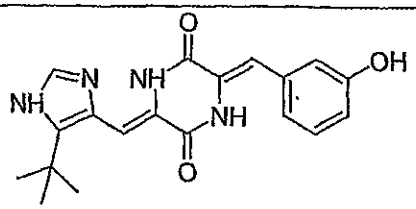
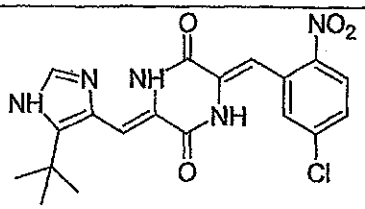
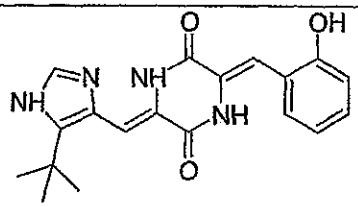
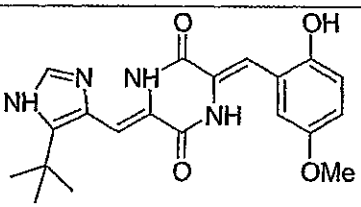
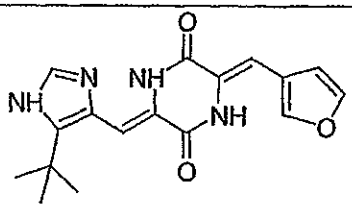
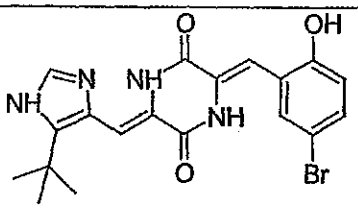
Additional examples of synthesized dehydrophenylahistin derivatives are disclosed in the Table 4.

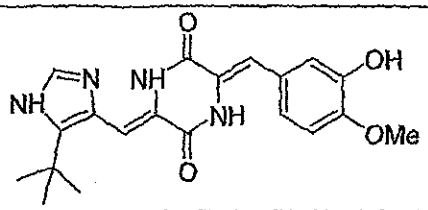
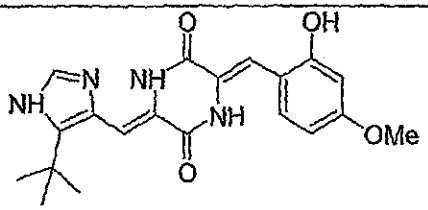
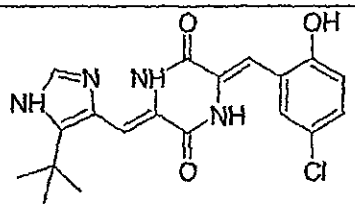
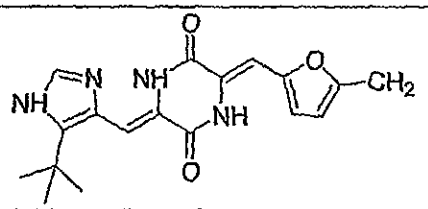
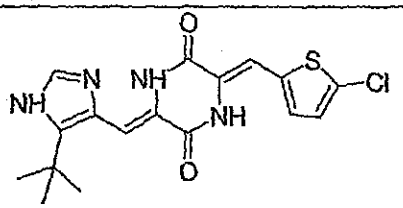
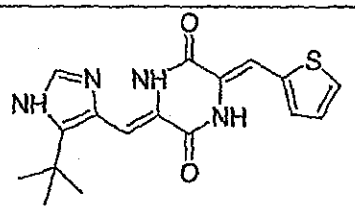
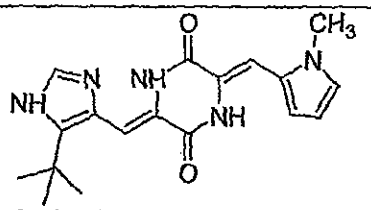
Table 4. Additional synthesized derivatives of dehydrophenylahistin

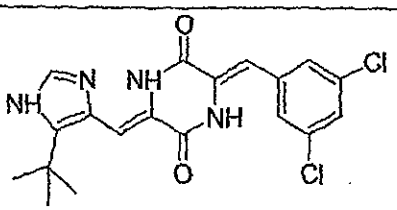
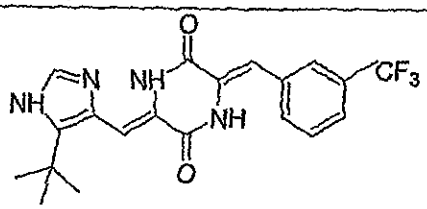
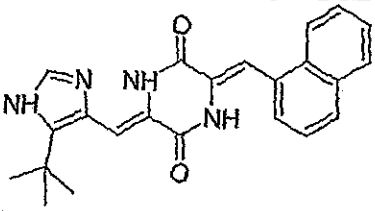
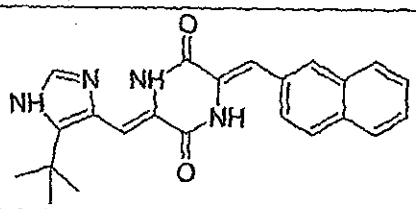
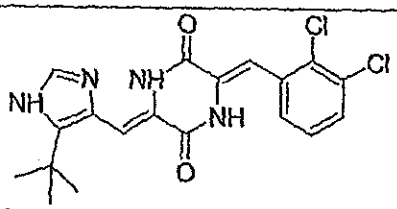
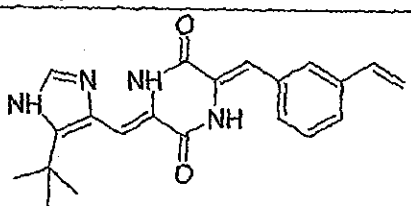
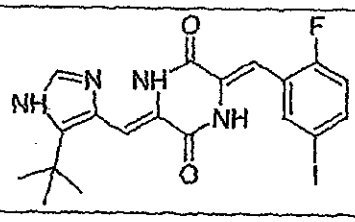
COMPOUNDS	STRUCTURE	SALT FORM	M.W.
KPU-20 tBu-DPLH-p-Cl		TFA	370.83 484.86 (+TFA)
KPU-30 tBu-DPLH-2,3-methylendioxy		TFA	380.40 494.42 (+TFA)
KPU-31 tBu-DPLH-3-pyridyl		2TFA	337.38 565.42 (+2TFA)
KPU-32 tBu-DPLH-o-Me		TFA	350.41 464.44 (+TFA)
KPU-33 Tbu-DPLH-3-Me-2-pyridyl		2TFA	351.40 579.45 (+2TFA)
KPU-34 tBu-DPLH-4-F		TFA	354.38 468.40 (+TFA)
KPU-35 tBu-DPLH-m-F		TFA	354.38 468.40 (+TFA)

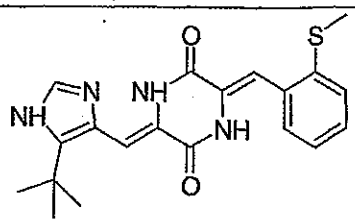
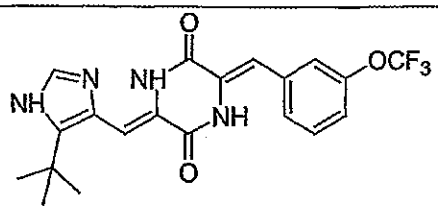
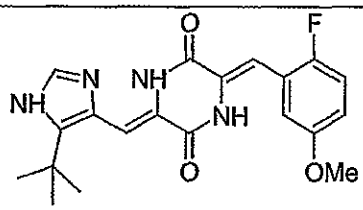
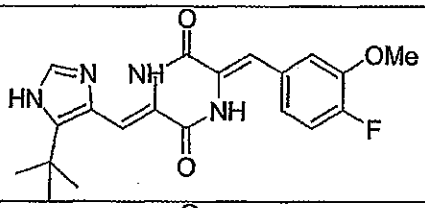
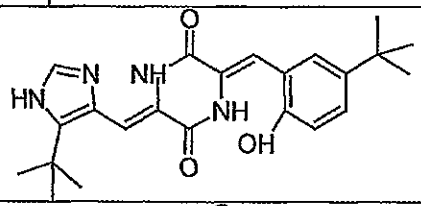
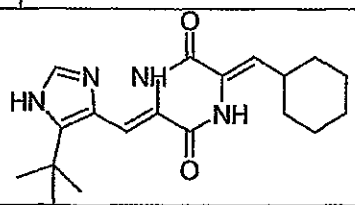
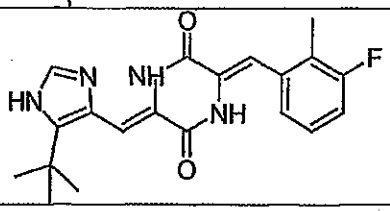
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KPU-37 tBu-dPLH-o-F		TFA	354.38 468.40 (+TFA)
KPU-38 tBu-dPLH-m-Me		TFA	350.41 464.44 (+TFA)
KPU-39 tBu-dPLH-p-Me		TFA	350.41 464.44 (+TFA)
KPU-40 tBu-dPLH-p-Br		TFA	415.28 529.31 (+TFA)
KPU-41 tBu-dPLH-m-Br		TFA	415.28 529.31 (+TFA)
KPU-42 tBu-dPLH-3-thienyl		TFA	342.42 456.44 (+TFA)

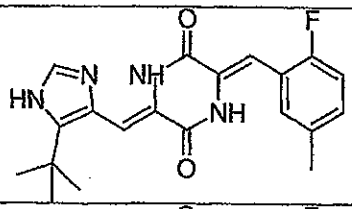
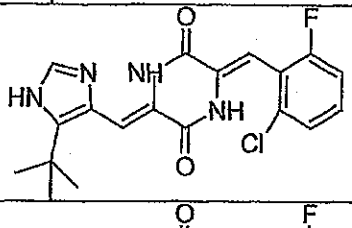
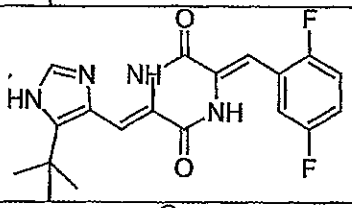
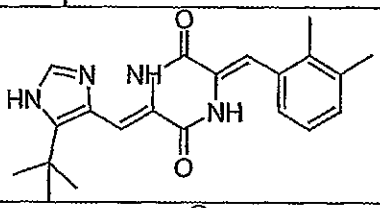
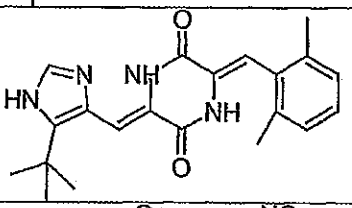
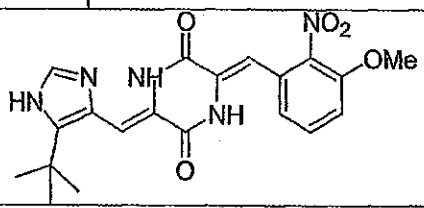
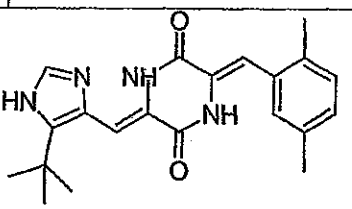
COMPOUNDS	STRUCTURE	SALT FORM	M.W.
KPU-43 tBu-PLH-p-CN		TFA	361.40 475.42 (+TFA)
KPU-44 tBu-PLH-m-EtO		TFA	380.44 494.46 (+TFA)
KPU-45 TBu-PLH-2,4,6-TriOMe		TFA	426.47 540.49 (+TFA)
KPU-46 tBu-PLH-o-NO_2		TFA	381.39 495.41 (+TFA)
KPU-47 tBu-PLH-m-NO_2		TFA	381.39 495.41 (+TFA)
KPU-48 tBu-PLH-p-NO_2		TFA	381.39 495.41 (+TFA)
KPU-49 tBu-PLH-m-CN		TFA	361.40 475.42 (+TFA)

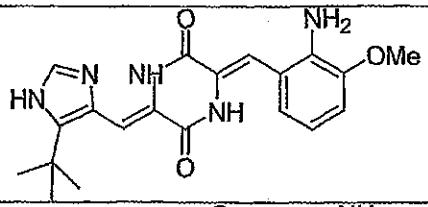
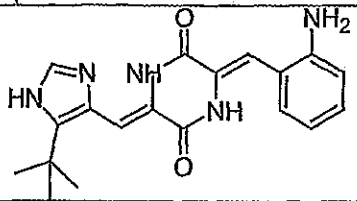
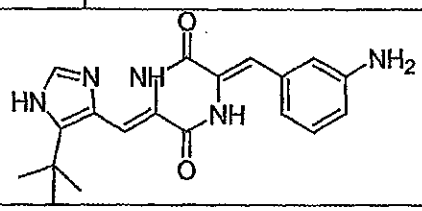
COMPOUNDS	STRUCTURE	SALT FORM	M.W.
LPU-50 tBu-ΦPLH-o-Br		TFA	415.28 529.31 (+TFA)
KPU-51 tBu-ΦPLH-m-OH		TFA	352.39 466.41 (+TFA)
KPU-52 TBu-ΦPLH-2-NO_2-5-Cl		TFA	415.83 529.85 (+TFA)
KPU-53 tBu-ΦPLH-o-OH		TFA	352.39 466.41 (+TFA)
KPU-54 TBu-ΦPLH-2-OH-5-OMe		TFA	382.41 496.44 (+TFA)
KPU-55 tBu-ΦPLH-3-furanyl		TFA	326.35 440.37 (+TFA)
KPU-56 tBu-ΦPLH-2-OH-5-Br		TFA	431.28 545.31 (+TFA)

COMPOUNDS	STRUCTURE	SALT FORM	M.W.
KPU-57 TBu-ΨPLH-2-OH-4-OMe		TFA	382.41 496.44 (+TFA)
KPU-58 TBu-ΨPLH-2-OH-4-OMe		TFA	382.41 496.44 (+TFA)
KPU-59 tBu-ΨPLH-2-OH-5-Cl		TFA	386.83 (+TFA) 500.86
KPU-60 TBu-ΨPLH-5-Me-2-furanyl		TFA	340.38 454.40 (+TFA)
KPU-61 TBu-ΨPLH-5-Cl-2-thionyl		TFA	376.86 490.88 (+TFA)
KPU-62 tBu-ΨPLH-2-thionyl		TFA	342.42 456.44 (+TFA)
KPU-63 TBu-ΨPLH-N-Me-2-pyrrole		TFA	339.39 453.42 (+TFA)

COMPOUNDS	STRUCTURE	SALT FORM	M.W.
KPU-64 tBu-ΦPLH-3,5-diCl		TFA	405.27
KPU-65 tBu-ΦPLH-m-CF_3		TFA	404.39
KPU-66 TBu-ΦPLH-1-Naphthalene		TFA	386.44
KPU-67 TBu-ΦPLH-2-Naphthalene		TFA	386.44
KPU-68 TBu-ΦPLH-2,3-diCl		TFA	405.27
KPU-69 TBu-ΦPLH-m-Vinyl		TFA	362.42
KPU-77 TBu-ΦPLH-2-F-5-I		TFA	480.28

COMPOUNDS	STRUCTURE	SALT FORM	M.W.
KPU-79 TBu-PLH-2-(Methylthio)		TFA	368.45
KPU-80 TBu-PLH-m-OCF_3		TFA	420.38
KPU-81 TBu-PLH-2-F-5-OMe		TFA	384.38
KPU-82 TBu-PLH-4-F-3-OMe		TFA	384.38
KPU-83 TBu-PLH-2-OH-5-tBu		TFA	408.39
KPU-84 TBu-PLH-cyclohexane		TFA	341.39
KPU-86 TBu-PLH-2-Me-3-F		TFA	368.39

COMPOUNDS	STRUCTURE	SALT FORM	M.W.
KPU-87 TBu-ΙPLH-2-F-5-Me		TFA	368.39
KPU-88 TBu-ΙPLH-2-Cl-6-F		TFA	388.83
KPU-89 TBu-ΙPLH-2,5-di-F		TFA	372.38
KPU-90 TBu-ΙPLH-2,3-di-Me		TFA	364.38
KPU-91 TBu-ΙPLH-2,6-di-Me		TFA	364.38
KPU-92 TBu-ΙPLH-2-NO_2-3-OMe		TFA	411.39
KPU-93 TBu-ΙPLH-2,5-diMe		TFA	364.38

COMPOUNDS	STRUCTURE	SALT FORM	M.W.
KPU-94 TBu-ΨPLH-2-NH_2-3-OMe		TFA	381.399
KPU-96 TBu-ΨPLH-2-NH_2		TFA	351.41
KPU-97 TBu-ΨPLH-m-NH_2		TFA	351.41

C. Evaluation of dehydrophenylahistin derivatives

Evaluation of derivatives described above are assessed according to the methods described in Example 3. Additional evaluation of the derivatives are extended to specific activities such as determining the inhibiting effect on cell proliferation, the effects on a specific cellular mechanism (i.e. microtuble function), effects on cell cycle progression, evaluating *in vitro* anti-tumor activity against cancer cell lines, etc. Some evaluation method protocols are given below.

1) Cell Proliferation Inhibiting Effect of Dehydrophenylahistin And Its Analogs

Into each well of a 96-well microtiter plate, 100μl of A-549 cells derived from human lung cancer prepared to 10^5 cells/ml in a culture medium obtained by adding 10% bovine fetus serum to EMEM culture medium (Nissui Seiyaku Co., Ltd.) having antitumor effect against A-549 cells derived from human lung cancer are placed. Methanol solution of the derivative obtained by the above-listed examples are added to the wells of the uppermost row, specimens are diluted by the half-log dilution method and added, and the plate is incubated in a carbon dioxide gas incubator at 37°C for 48 hours. The result is added in lots of 10μl with MTT reagent (3-(4,5-dimethyl-2-thiazole)-2,5-diphenyl-2H-tetra bromide)(1mg/ml • PBS), followed by incubation in a carbon dioxide gas incubator at 37 °C for 6 hours. The culture medium is discarded and the crystal of produced in the cells are dissolved in 100μl/well of dimethylsulfoxide. Absorption of 595 nm light is then measured with a microplate reader. By comparing the light absorptions of the untreated cells to that of cells treated with a specimen of a known concentration, the specimen concentration that inhibited cell proliferation 50% (IC_{50}) is calculated.

2) Cell Cycle Inhibiting Activity of Dehydrophenylahistin And Its Analogs

Cell strain A431 is derived from human lung cancer. EMEM culture medium containing 10% bovine fetal serum and 1% MEM nonessential amino acid solution (SIGMA M2025) is used to incubate A431 cells at 37 °C in an incubator saturated with 5% carbon dioxide gas and water vapor. The refined specimen of dehydrophenylahistin obtained in by the methods above are added to the cells in the log-growth phase and progression of the cell cycle is analyzed by flow cytometer and microscopic observation.

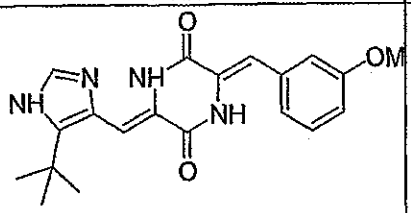
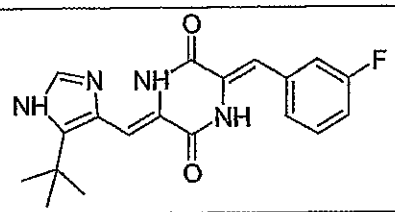
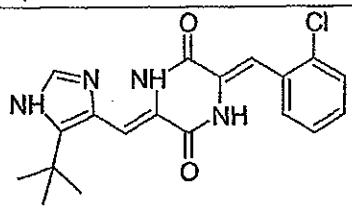
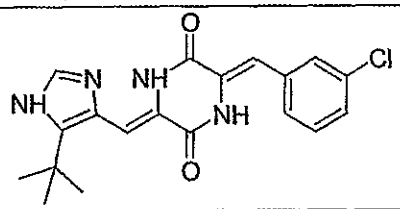
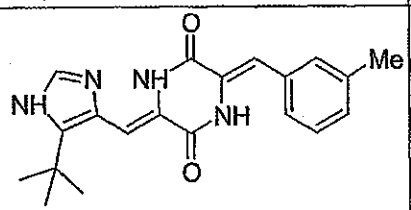
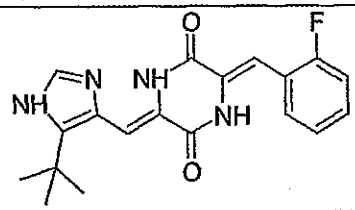
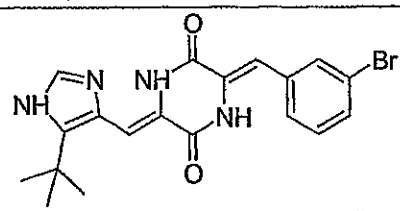
EXAMPLE 6

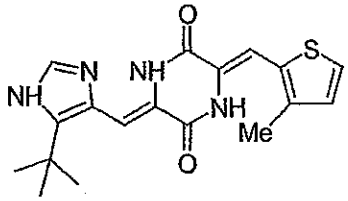
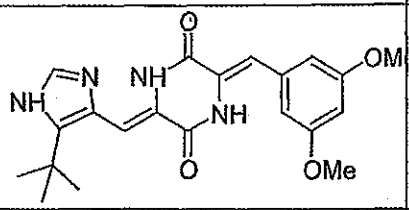
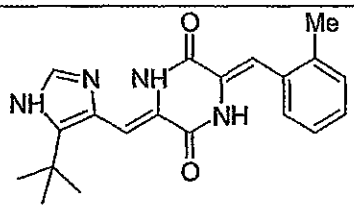
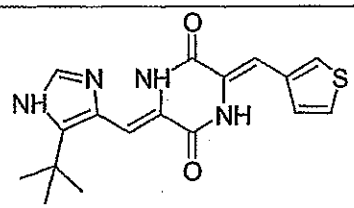
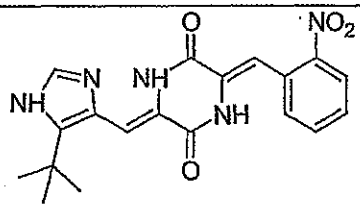
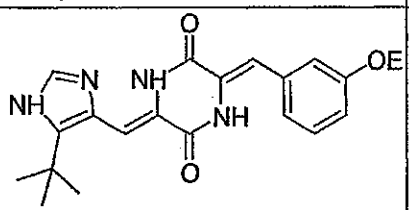
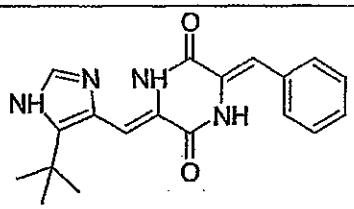
Structure-Activity Relationship Of Synthesized Dehydrophenylahistin (DehydroPLH) Derivatives

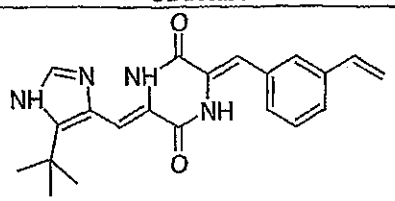
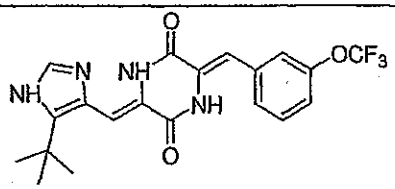
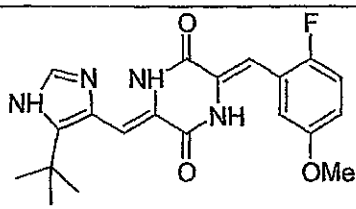
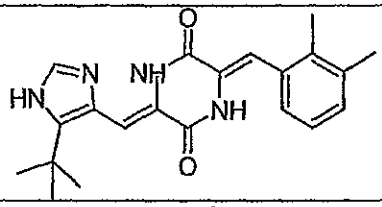
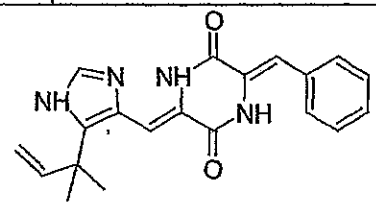
1) Overview in derivative syntheses

Many, but not all, of the derivatives of dehydroPLH disclosed herein include one, two, or three modifications at the phenyl ring (Figure 5 below). The derivatives were synthesized by the methods described above. As shown in Table 5, certain compounds showed more potent cytotoxic activity than dehydroPLH and tBu-dehydroPLH. The most potent compound exhibiting an EC50 value of 3 nM was **KPU-90**. This value was 16-times and 4-times higher than that of dehydroPLH and tBu-dehydroPLH, respectively. These derivatives have mono-substitution at the *o*- or *m*-position of the phenyl ring with the halogen atoms such as fluorine and chlorine atoms or the methyl, vinyl or methoxy group. Derivatives with substitutions to heteroaryl structures such as the npahthalene, thiophene and furan rings also elicited a potent activity.. **KPU-35, 42, 69, 80 and 81** also showed higher activity than tBu-dehydroPLH.

Table 5. Synthetic potent dehydroPLH derivatives

Compound	Structure	EC_{50} (nM)
KPU-9		31
KPU-35		10
KPU-18		42
KPU-19		20
KPU-38		45
KPU-37		21
KPU-41		31

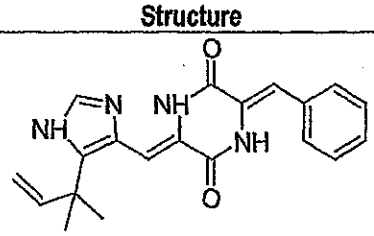
Compound	Structure	EC_{50} (nM)
KPU-29		44
KPU-16		42
KPU-32		42
KPU-42		54
KPU-46		44
KPU-44		43
tBu-iPLH (KPU-2)		13

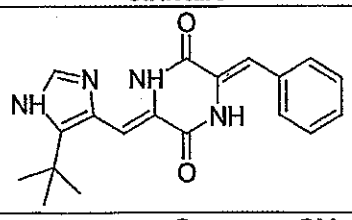
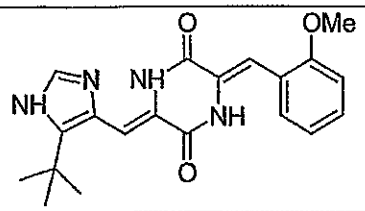
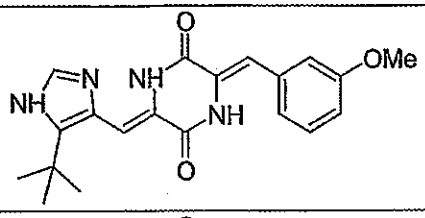
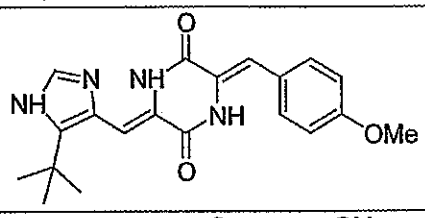
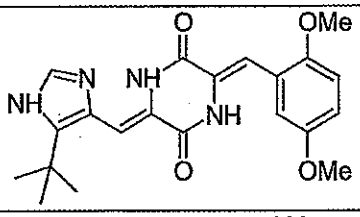
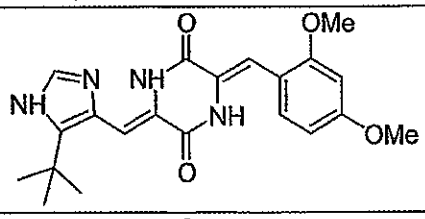
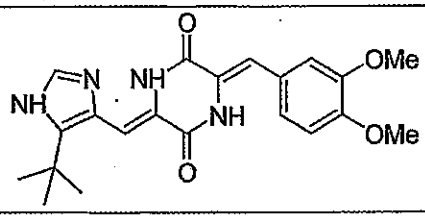
Compound	Structure	EC_{50} (nM)
KPU-69		16
KPU-80		13
KPU-81		19
KPU-90		3
DehydroPLH (KPU-1)		48

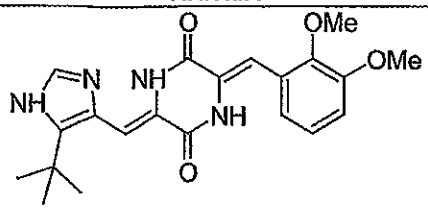
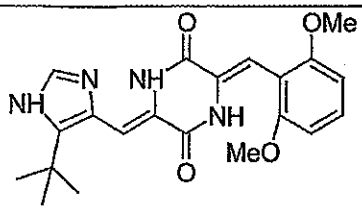
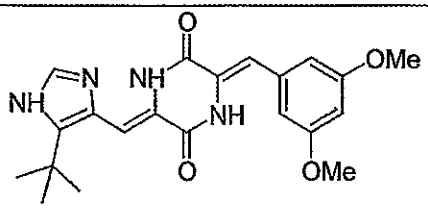
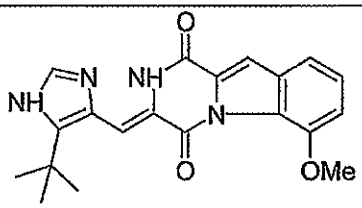
2) Introduction of the methoxy groups to the phenyl ring

Colchicine recognizes the same binding site on β-tubulin as PLH. Colchicine has four characteristic methoxy groups on its A and B rings. A series of substitutions with the single or multiple methoxy groups was performed and the results of cytotoxic activity is shown in Table 6.

Table 6. Effect of the methoxy group substitution on the proliferation of HT-29 cells

Compound	Structure	EC50 (nM)
DehydroPLH (KPU-1)		48

Compound	Structure	EC50 (nM)
tBuPLH (KPU-2)		13
KPU-8		89
KPU-9		31
KPU-6		6730
KPU-10		1350
KPU-12		4980
KPU-13		2130

Compound	Structure	EC50 (nM)
KPU-14		610
KPU-15		4430
KPU-16		42
KPU-24		7040

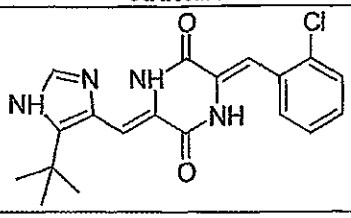
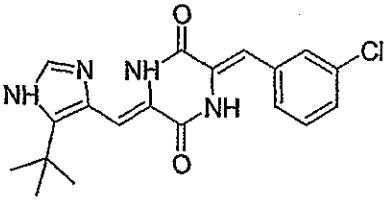
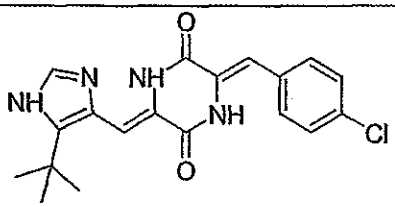
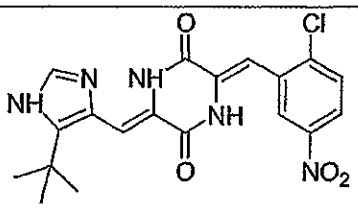
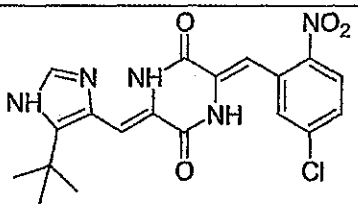
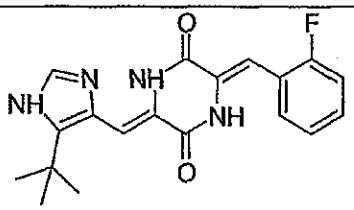
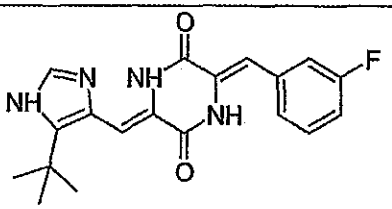
The result demonstrated that substitutions at the *m*- or *o*-position increased cytotoxic activity against HT-29 cells. **KPU-9 and 16** showed high activity. The methoxy-derivatives with triple substitution (**KPU-11, 17** and **45**) also showed activity. The structure of **KPU-24** was assigned by MASS analysis.

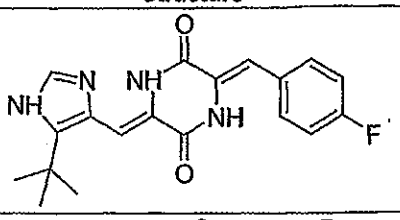
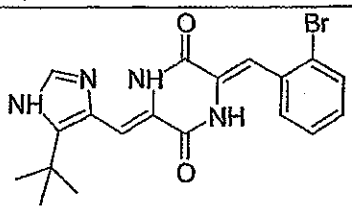
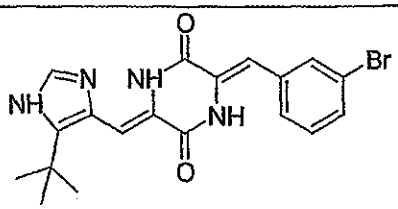
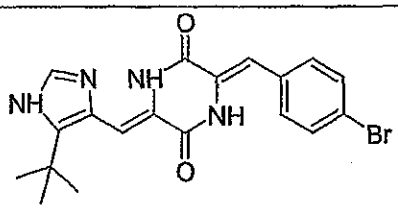
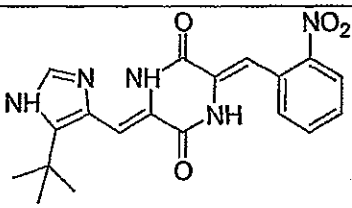
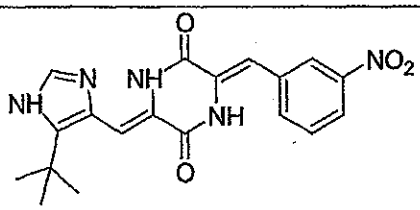
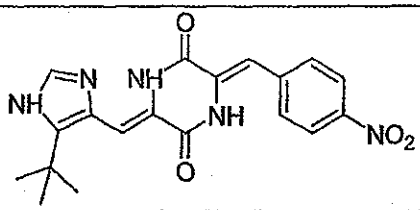
3) Modification with the electron-withdrawing groups

To study more expanded structure-activity relationship on the phenyl ring, a series of different functional groups were introduced, which include both electron-withdrawing and -donating groups. The result of cytotoxicity against HT-29 cells is shown in Tables 7 and 8, respectively.

Substitution at the *o*- or *m*-position effectively increased activity. These results were well consistent with the case of the methoxy group.

Table 7. Effect of the electron-withdrawing group on proliferation of HT-29 cells

Compound	Structure	EC_{50} (nM)
KPU-18		42
KPU-19		20
KPU-20		545
KPU-21		51
KPU-52		110
KPU-37		21
KPU-35		10

Compound	Structure	EC_{50} (nM)
KPU-34		466
KPU-50		38
KPU-41		31
KPU-40		623
KPU-46		44
KPU-47		40
KPU-48		> 20 μM

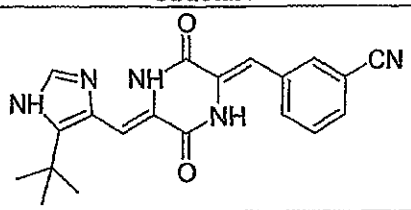
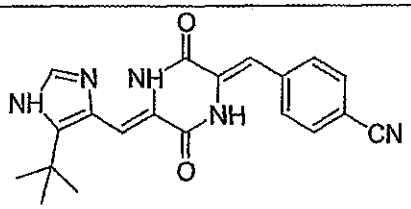
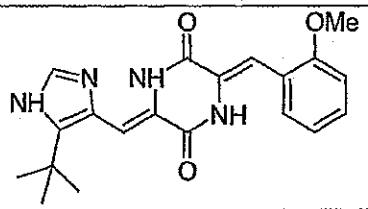
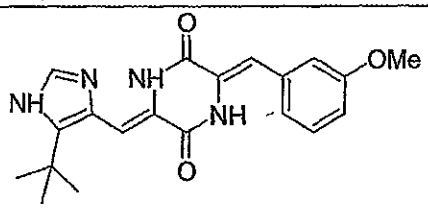
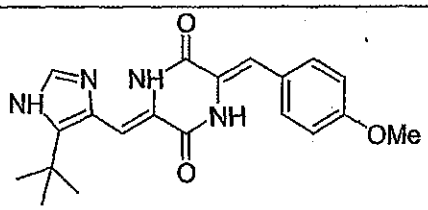
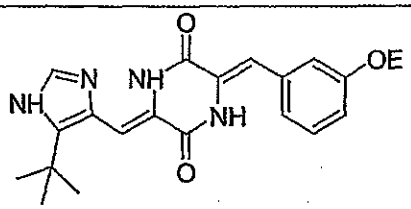
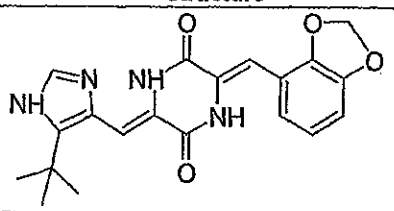
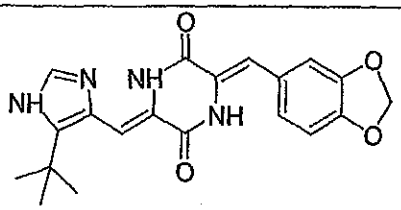
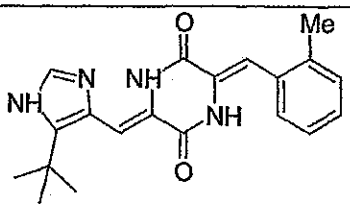
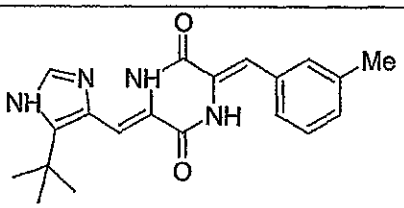
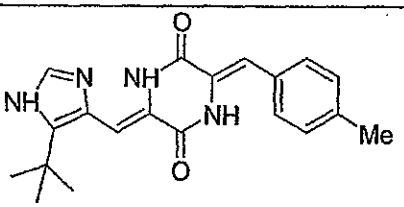
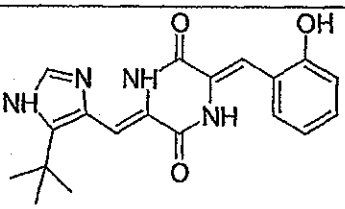
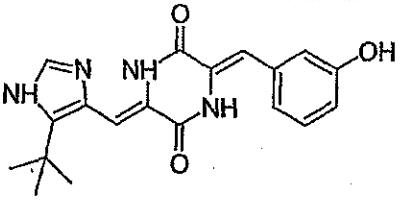
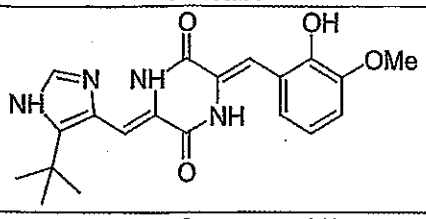
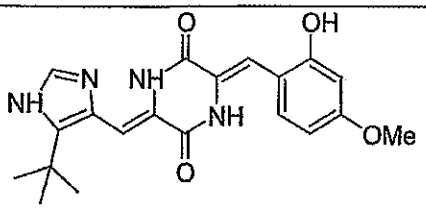
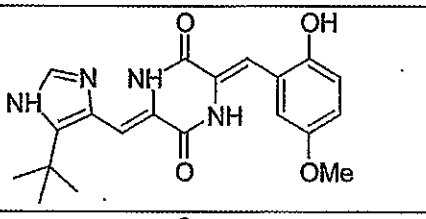
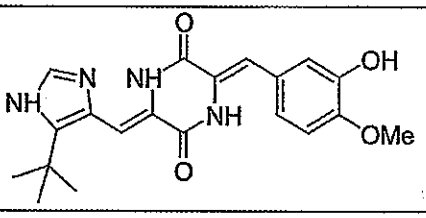
Compound	Structure	EC_{50} (nM)
KPU-49		28
KPU-43		> 20 μM

Table 8. Effect of the electron-donating group on proliferation of HT-29 cells

Compound	Structure	EC_{50} (nM)
KPU-8		89
KPU-9		31
KPU-6		6730
KPU-44		43

Compound	Structure	EC_{50} (nM)
KPU-30		477
KPU-22		82
KPU-32		42
KPU-38		45
KPU-39		460
KPU-53		> 20 μM
KPU-51		617

Compound	Structure	EC_{50} (nM)
KPU-23		5870
KPU-58		>20 ▯M
KPU-54		> 20 μM
KPU-57		> 20 μM

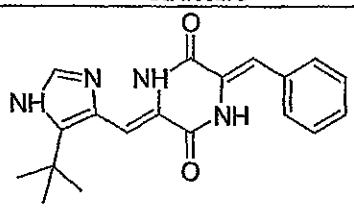
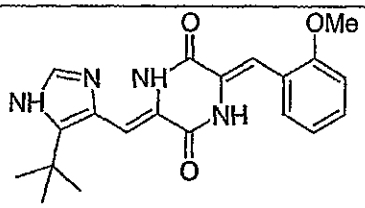
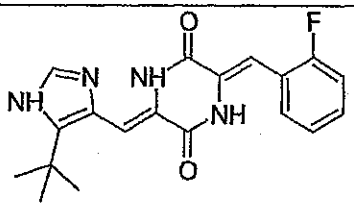
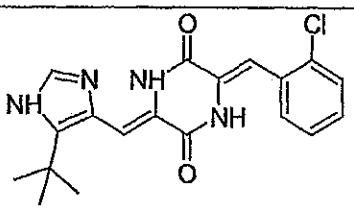
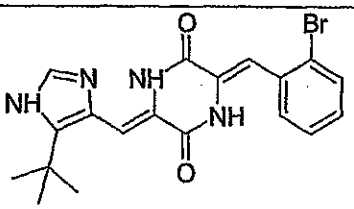
The present disclosure is not bound by or limited to any particular scientific theory. Nonethless, it is appreciated that persons of skill in the art may interpret the results presented herein to suggest that a relatively smaller functional group, affecting less steric hinderance, may be preferred to elicit more potent activity, and slightly large groups such as the ethoxy group (when compared to the methoxy group) or the Br atom (when compared to the Cl atom) may affect steric hindrance unfavorable to interaction with, for example, the tubulin binding site. Moreover, because the electrical property of these substituents did not affect the activity, it is suggested that these relatively small substituents do not directly interact with the binding site of β-tubulin, but restrict the conformation of dehydroPLH suitable for the binding. Or, as another possible hypothesis, the hydrophobic property may be a more important factor at the binding site for *o*- or *m*-position on β-tubulin, since introduction of the hydrophilic hydroxyl group, which can form the hydrogen bonding as a hydrogen-donor, drastically decreased the activity.

As shown in Table 9, the effect of the substituents in the cytotoxic activity at the *o*-position may be ordered, as in the case of *m*-position, as shown in Table 10. The compounds having effective functional groups, which showed higher activity than tBu-dehydroPLH, may also be further modified. And since the migration of the stereochemistry from *Z* to *E* under the visible light irradiation was observed, substituents that

decrease the electron density in the conjugated double bonds may contribute to the reduction of *Z* to *E* migration by the light, results in more physicochemically stable structures. Temperature can also effect this migration.

Modification at two parts of the ring can be prefered for the development of potent but also biologically stable compounds. The phenyl ring of phenylahistin is oxidized by cytochrome P-450. Double modification that reduce the electron density of the phenyl ring may therefore be effective to avoid P-450 oxidation. Thus, the combination of the small electron withdrawing group such as the fluorine atom to the element that can increase the activity such as -OMe, -Me, -Cl, -F and Br, may result in more potent and biologically stable drug compounds.

Table 9. Summary of modification at the o-position

Compound	Structure	EC_{50} (nM)
KPU-2		48
KPU-8		89
KPU-37		21
KPU-18		42
KPU-50		38

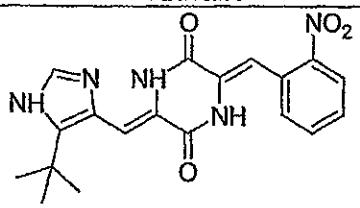
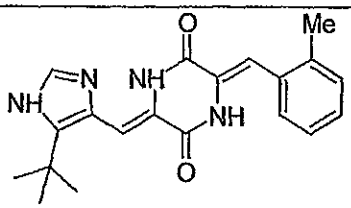
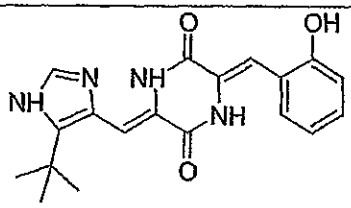
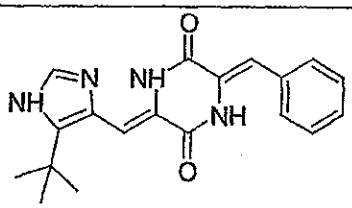
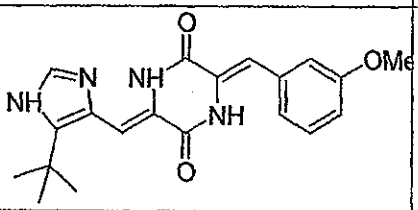
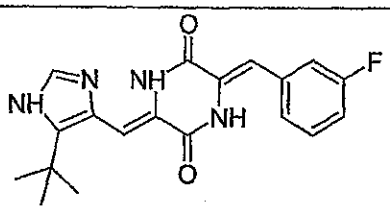
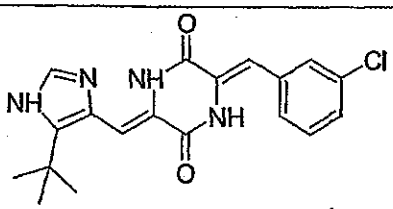
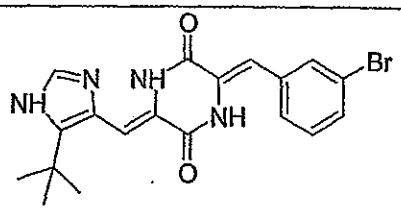
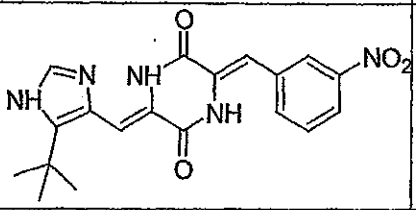
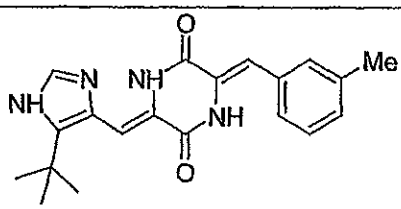
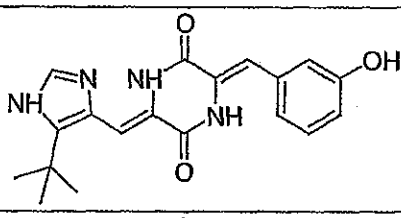
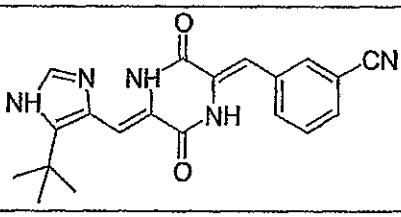
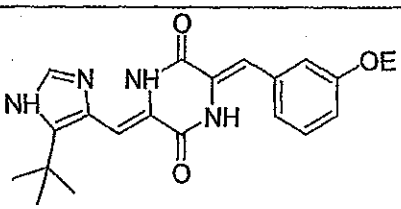
Compound	Structure	EC_{50} (nM)
KPU-46		44
KPU-32		42
KPU-53		> 20 μM

Table 10. Summary of modification at the *m*-position

Compound	Structure	EC_{50} (nM)
KPU-2		48
KPU-9		31
KPU-35		10
KPU-19		20

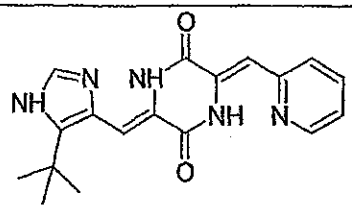
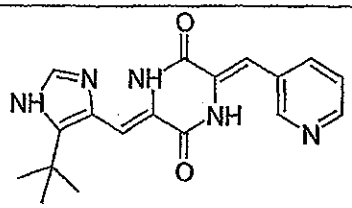
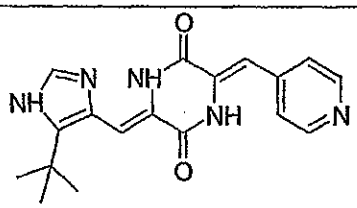
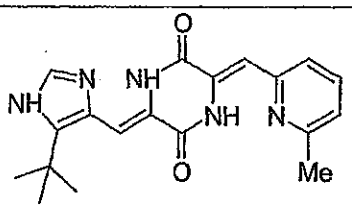
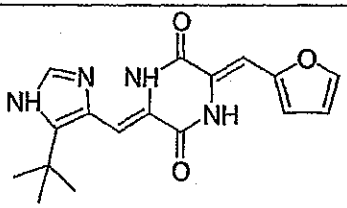
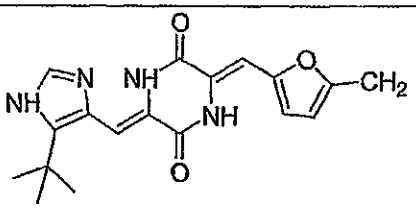
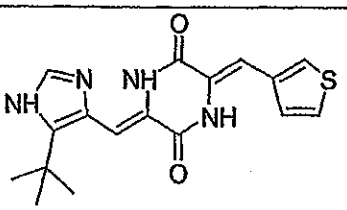
Compound	Structure	EC_{50} (nM)
KPU-41		31
KPU-47		40
KPU-38		45
KPU-51		617
KPU-49		28
KPU-44		43

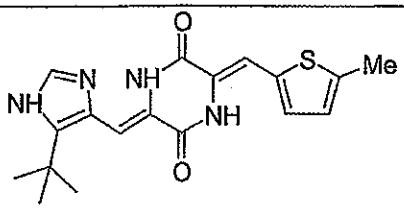
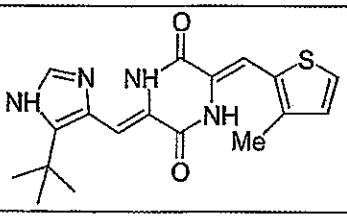
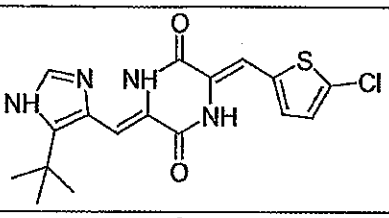
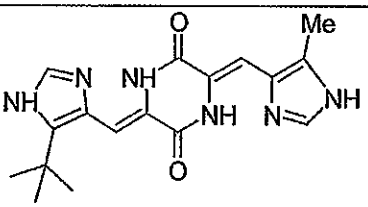
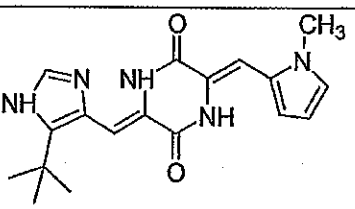
4) Substitution of the phenyl ring to aryl-heterocycles

The phenyl ring may also be replaced by heteroaryl groups. The result of such replacements in terms of the cytotoxic activity are shown in Table 11. Since the arylic nitrogen atoms can form a hydrogen bonding with a NH group of the diketopiperazine ring and restrict the conformation of the molecule between pyridine and diketopiperazine rings to an uniplanar structure, the active conformation of dehydroPLH would be

required a certain level of dihedral angle formed by the steric repulsion between an amide hydrogen atom of the diketopiperazine ring and an o-hydrogen atom of the phenyl ring (Figure 6).

Table 11. Effect of the replacement with the heteroaryl ring on proliferation of HT-29 cells

Compound	Structure	EC_{50} (nM)
KPU-28		>20 μM
KPU-31		96
KPU-25		544
KPU-33		>20 μM
KPU-26		600
KPU-60		71
KPU-42		54

Compound	Structure	EC_{50} (nM)
KPU-27		80
KPU-29		44
KPU-61		184
KPU-36		2790
KPU-63		105

Replacing the phenyl ring with a smaller furan or thiophene ring, for example, **KPU-29** or **-42**, exhibited activity. The phenyl ring can be changed to other aromatic structure while maintaining the potent activity.

5) Metabolism of phenylahistin

In the recent his study, (±)-phenylahisitn was treated with rat hepatic microsome or human hepatic P450s. In human case at least seven metabolites were detected, and two of them, i.e., P1 and P3, were major metabolites, represented more than 60% of the recovered metabolites.

Since there is no exo-olefin structure in tBu-dehydroPLH, present synthesized derivatives have no oxidization like P1 and P4. However, oxidizations such as P3 and P5 are formed during the hepatic

metabolism. Various derivatives, which prevent such metabolism, are effective to avoid P450 oxidization at the phenyl ring. The imidazole ring can also be modified to avoid the unfavorable oxidation.

6) Physicochemical stability of dehydroPLH

The physicochemical stability is one of the unfavorable problems of dehydroPLH. In phenylahistin, since there is no additional olefin structure at the benzyl part, there is no such problem. However, in dehydroPLH, the benzylidene moiety can be easily activated, probably with the visible light, and the *Z* to *E* migration frequently occurs due to the existence of longer conjugation of the double bond. This migration occurred even under normal room light. In the cytotoxic assay, some of the compounds migrate to *E*-form during the incubation, although this migration probably equilibrates at the 1 : 1 ratio in the case of dehydroPLH. This migration can be controled. The *Z* to *E* migration is also known in combretastatin A4, a same type of tubulin inhibitor, and a few studies for improving this problem were reported.

7) Prodrug Synthesis

The *E*-form may also be used as a prodrug of dehydroPLH or of one or more of its analogs, including those analogs described herein. One of the undesired properties of anti-tubulin drugs involves its low selectivity between tumor and intact tissues, although these drugs belong to one of the molecular target therapies. This causes undesired side effects. However, if the compounds functions selectively only in tumor tissues, negative side effects of anti-microtubule drugs can be reduced. Since the dehydroPLH (Z-form) can be produced from its *E*-isomer by visible light irradiation, the *E*-form is administered and photo irradiation is performed only at the tumor site, then only the tumor is damaged by photo-produced Z-form and the adverse effect to the intact tissues is reduced.

The *E*-form can be protected chemically by the addition of a bulky but biodegradable acyl group, which is introduced into the diketopiperazine ring as a prodrug. This acyl group can be cleaved by the protease in the body. Therefore, the acylated-*E*-compound is maintained before administration, then after administration it is changed to the real *E*-form, which can migrate to the bioactive Z-form by the local photo irradiation.

The synthetic scheme of this acyl-E-form of tBu-dehydroPLH is summarized in Figure 9.

EXAMPLE 7

Pharmaceutical Formulations of the Synthesized Dehydrophenylahistins

1) Formulations Administered Intravenously, by Drip, Injection, Infusion or The Like

Vials containing 5 g of powdered glucose are each added aseptically with 10 mg of a compound synthesized by the method and sealed. After being charged with nitrogen, helium or other inert gas, the vials are stored in a cool, dark place. Before use, the contents are dissolved in ethanol and added to 100 ml of a 0.85% physiological salt water solution. The resultant solution is administered as a method of inhibiting the

growth of a cancerous tumor in a human diagnosed as having such a tumor at between approximately 10 ml/day to approximately 1000 ml/day, intravenously, by drip, or via a subcutaneous or intraperitoneal injection, as deemed appropriate by those of ordinary skill in the art.

2) Formulation to be Administered Orally Or The Like

A mixture obtained by thoroughly blending 1 g of a compound synthesized by the method, 98 g of lactose and 1 g of hydroxypropyl cellulose is formed into granules by any conventional method. The granules are thoroughly dried and sifted to obtain a granule preparation suitable for packaging in bottles or by heat sealing. The resultant granule preparations are orally administered at between approximately 100ml/day to approximately 1000 ml/day, depending on the symptoms, as deemed appropriate by those of ordinary skill in the art of treating cancerous tumors in humans.

3) Formulation to be Administered Topically

Administration to an individual of an effective amount of the compound can also be accomplished topically by administering the compound(s) directly to the affected area of the skin of the individual. For this purpose, the compound administered or applied is in the form of a composition including a pharmacologically acceptable topical carrier, such as a gel, an ointment, a lotion, or a cream, which includes, without limitation, such carriers as water, glycerol, alcohol, propylene glycol, fatty alcohols, triglycerides, fatty acid esters, or mineral oils. Other topical carriers include liquid petroleum, isopropyl palmitate, polyethylene glycol, ethanol (95%), polyoxyethylene monolaurate (5%) in water, or sodium lauryl sulfate (5%) in water. Other materials such as anti-oxidants, humectants, viscosity stabilizers, and similar agents may be added as necessary. Percutaneous penetration enhancers such as Azone may also be included. In addition, in certain instances, it is expected that the compound may be disposed within devices placed upon, in, or under the skin. Such devices include patches, implants, and injections which release the compound into the skin, by either passive or active release mechanisms.

EXAMPLE 8

In vitro Pharmacology of KPU-2, KPU-35 and t-butyl phenylahistin

The *in vitro* efficacy studies performed with KPU-2, KPU-35 and t-butyl phenylahistin included: A) a panel of six tumor cell lines, B) studies in multidrug-resistant tumor cells, and C) studies to determine the mechanism of action.

A). Study of KPU-2, KPU-35 and t-butyl phenylahistin in a panel of six tumor cell lines

The following cell lines (source in parentheses) were used: HT29 (human colon tumor; ATCC; HTB-38), PC3 (human prostate tumor; ATCC; CRL-1435), MDA-MB-231 (human breast tumor; ATCC; HTB-26), NCI-H292 (human non-small cell lung tumor; ATCC; CRL-1848), OVCAR-3 (human ovarian tumor; ATCC;

HTB-161), B16-F10 (murine melanoma; ATCC; CRL-6475) and CCD-27sk (normal human fibroblast; ATCC; CRL-1475). Cells were maintained at subconfluent densities in their respective culture media.

Cytotoxicity assays were performed as described above in Example 4, using Resazurin fluorescence as an indicator of cell viability.

The disclosed compounds are effective agents against a variety of different and distinct tumor cell lines. Specifically, for example, KPU-2 and KPU-35 were most effective on the HT-29 tumor cell line, both in terms of potency (active in the low nanomolar range) and efficacy (most responsive in terms of the maximum cytotoxic effect); t-butyl-phenylahistin exhibited its greatest potency against the PC-3 tumor cell line, although the greatest efficacy was displayed against the HT-29 cell line; KPU-2 and KPU-35 were generally 10-40 fold more potent than t-butyl-phenylahistin whereas the efficacy was similar for all three compounds in the different tumor cell lines; the HT-29, PC-3, MDA-MB-231 and NCI-H292 tumor cell lines all responded similarly to the NPI compounds, whereas the B16-F10 appeared to be somewhat less sensitive. t-butyl-phenylahistin displayed a marked differential between normal fibroblasts and the tumor cell lines, with a ratio ranging from >20 - >100, except for the OVCAR-3 cell line.

Table 12 Activity of KPU-2, KPU-35 and t-butyl phenylahistin in the Tumor Panel Screen

Cell Line	KPU-2			KPU-35			t-butyl-phenylahistin		
	Mean	SD	n	Mean	SD	n	Mean	SD	n
HT-29 Colon									
IC50 nM	9.8	2.4	4	8.2	2.0	4	420	473	3
% Cytotoxicity	82.5	5.3	4	81.3	4.0	4	88	0.2	3
PC-3 Prostate									
IC50 nM	13.4	0.7	4	13.2	2.5	4	174	-	2
% Cytotoxicity	60.3	2.1	4	56.8	1.0	4	59.5	-	2
MDA-MB-231 Breast									
IC50 nM	13.8	1.9	3	9.7	4.2	4	387	-	2
% Cytotoxicity	56.7	7.2	3	59.3	5.6	4	65.5	-	2
NCI-H292 Lung									
IC50 nM	17.5	1.1	4	15.9	1.1	4	384	194	3
% Cytotoxicity	70.5	2.9	4	68.5	2.9	4	65	5	3
OVCAR-3 Ovary									
IC50 nM	>20,000	-	4	>20,000	-	4	>20,000	-	2
% Cytotoxicity	45.8	3.0	4	39	2.2	4	37	-	2
B16-F10 Melanoma									
IC50 nM	37.1	26.3	4	32.3	19.9	4	736	650	3
% Cytotoxicity	71.8	2.5	4	72.0	2.2	4	74	2	3
CCD-27sk Fibroblast									
IC50 nM	9.2	2.9	4	7.4	2.6	4	>20,000	-	2
% Cytotoxicity	64.3	2.4	4	60.8	1.9	4	45	-	2

B). Studies in Drug Resistant Cell Lines

One of the major challenges in the use of chemotherapeutic agents in clinical oncology is the development of resistance to the drug effect by the tumor cells. There are several mechanisms for the development of resistance, each of which will have differential effects on chemotherapeutic drugs. These mechanisms include increased expression of ATP-dependent efflux pumps such as the P-glycoprotein encoded by *MDR1* or the multidrug-resistance associated protein 1 encoded by *MRP1*. Reduced drug uptake, alteration of the drug's target, increasing repair of drug-induced DNA damage, alteration of the apoptotic pathway and the activation of cytochrome P450 enzymes are other examples of mechanisms by which cancer cells become resistant to anticancer drugs. The selected compounds were studied in three different cell lines that exhibit two different mechanisms of resistance; the overexpression of the P-glycoprotein and altered topoisomerase II activity.

1) Human Uterine Sarcoma Tumor Cell Line Pair: MES-SA (Taxol Sensitive) and MES-SA DX (Taxol Resistant).

This cell line expresses elevated mdr-1 mRNA and P-glycoprotein (an extrusion pump mechanism). Pretreatment with cyclosporin-A (CsA) blocks P-glycoprotein and reinstates activity in the resistant cell line for those compounds for which the resistance is due to elevated P-glycoprotein.

As can be seen from Table 13, KPU-2, and KPU-35 have the same potency in the resistant cell line as in the sensitive line and the potency of t-butyl-phenylahistin was only slightly reduced. Cyclosporin A (CsA) pretreatment did not alter the potency of the selected compounds. In contrast, taxol was virtually inactive in the MES-SA DX resistant cell line, whereas this compound was very potent in the sensitive cell line. CsA treatment restored the sensitivity to taxol of the MES-SA DX cell line. The MES-SA DX cell line also showed reduced susceptibility to etoposide (60 fold), doxorubicin (34 fold) and mitoxantrone (20 fold).

These data indicate that the effects of KPU-2, KPU-35 and t-butyl-phenylahistin are not susceptible to the taxol-related resistance mechanism (p-glycoprotein) in this cell line, and that cross-resistance from taxol does not occur to these selected compounds in this model.

Table 13 Activity of KPU-2, KPU-35, t-butyl-phenylahistin and Taxol in MES-SA Taxol Sensitive and MES-SA DX Taxol Resistant Human Uterine Sarcoma Tumor Cell Lines

Compound Study	MES-SA Sensitive			MES-SA DX Resistant			
	No CsA	CsA Pretreat		No CsA		CsA Pretreat	
	IC50 nM	IC50 nM	Ratio No CsA	IC50 nM	Ratio MES-SA	IC50 nM	Ratio No CsA
KPU-2							
Study I	8.5	-	-	10.5	1.2	-	-
Study II	19.4	27.4	1.4	21.7	1.1	37.8	1.74
KPU-35							
Study I	6.6	-		5.2	0.8	-	-
Study III	3.9	2.0	0.5	2.5	0.6	6.7	2.7
t-butyl-phenylahistin							
Study I	144	-	-	825	5.7	-	-
Study III	122	162	1.3	694	4.3	622	0.9
Taxol							
Study I	4.4	-	-	>20,000	>455	-	-
Study II	13.3	7.6	0.6	>>100	>>8	40	<<0.25
Study III	7.3	2.8	0.4	>24,000	>3000	2.0	<<0.001

2) Human Acute Promyelocytic Leukemia Cell Line Pair: HL-60 (Mitoxantrone-Sensitive) and HL-60/MX-2 (Mitoxantrone-Resistant)

This cell line is considered to have atypical drug resistance properties with altered topoisomerase II catalytic activity without overexpression of P-glycoprotein.

As can be seen in Table 14, these results indicate that the potencies of the selected novel compounds are very similar in the sensitive and resistant HL-60 cell lines. In contrast, Mitoxantrone loses efficacy by a factor of 24-fold in the resistant HL-60/MX-2 cell line.

Thus, KPU-2, KPU-35 and t-butyl-phenylahistin are not susceptible to the same resistance mechanisms as Mitoxantrone in this cell line, and there is no cross-resistance from Mitoxantrone to these selected novel compounds in this model.

Table 14. Activity of KPU-2, KPU-35, t-butyl-phenylahistin and Mitoxantrone in the HL-60 Human Acute Promyelocytic Leukemia Tumor Sensitive and Resistant Cell Line Pair

Compound	HL-60 Sensitive	HL-60 Resistant	
	IC50 nM	IC50 nM	Ratio to Sensitive
KPU-2	6.4	8.17	1.28
KPU-35	9.2	7.3	0.79
t-butyl-phenylahistin	255	175	0.69
Mitoxantrone	202	4870	24.1

3). Human Breast Carcinoma Cell Line Pair: MCF-7 (Taxol Sensitive) and MCF-7/ADR (Taxol Resistant)

This study involved KPU-2 in comparison to taxol. KPU-2 demonstrated similar potencies in both the sensitive and resistant members of this cell line pair. In contrast, taxol was virtually inactive in the resistant cell line whereas there was low nanomolar potency in the sensitive cell line (Table 15).

These studies confirm in a different human tumor cell line that taxol resistance does not transfer to KPU-2.

Table 15. Activity of KPU-2 and Taxol in the MCF-7 Human Breast Carcinoma Sensitive and Resistant Cell Line Pair

Compound	MCF-7 Sensitive	MCF-7/ADR Resistant	
	IC50 nM	IC 50 nM	Ratio to Sensitive
KPU-2	39.6	27.4	0.69
Taxol	2.6	>>100	>>38

C) Studies of the Mechanism of Action

1). Action on Microtubule Function

Human umbilical vein endothelial cells (HuVEC from Cambrex) were used in this study, for evaluating the effects of KPU-2 and t-butyl-phenylahistin in comparison to colchicine and taxol on tubulin by staining for α-tubulin.

Thirty minutes exposure to KPU-2, t-butyl-phenylahistin or colchicine (all at 2 μM) induced microtubule depolymerization as was indicated by the lack of intact microtubule structure in contrast to that observed in the DMSO Control and cell membrane blebbing (a clear indication of apoptosis) in the HuVEC cells, whereas taxol did not induce microtubule depolymerization under these conditions. Colchicine is a known microtubule depolymerizing agent whereas taxol is a tubulin stabilizing agent. Similar results were obtained when CCD-27sk cells were exposed to KPU-2 or colchicine.

2). Induction of Apoptosis

Apoptosis and its dysregulation play an important role in oncology; the selective induction of the programmed cell death cycle in tumor cells is the goal of many chemotherapeutic drug discovery programs. This induction of apoptosis can be demonstrated by different methods including the characteristic cell membrane blebbing, DNA fragmentation, hyperphosphorylation of the antiapoptotic factor Bcl-2, activation of the caspase cascade and cleavage of poly (ADP ribose) polymerase (PARP).

The characteristic signs of apoptotic cell death include cell membrane blebbing, disruption of nuclei, cell shrinkage and condensation and finally cell death, very distinctive from necrotic cell death. KPU-2

induced the typical morphological changes associated with early stages of apoptosis in human prostate tumor cells. A similar finding was also clear in the treatment of HuVEC cells with KPU-2.

3). DNA Fragmentation

A late stage characteristic of apoptosis is internucleosomal DNA cleavage that results in a distinctive ladder pattern that can be visualized by gel electrophoresis. This approach was used to study the effect of KPU-2 on DNA laddering in Jurkat cells (human T cell leukemia line) in comparison to halimide and dehydrophenylahistin (KPU-1). KPU-2 induced DNA laddering at the 1 nM concentration whereas halimide and KPU-1 were much less potent.

4). Activation of the Caspase Cascade

Several enzymes in the caspase cascade are activated during apoptosis, including Caspase-3, -8 and-9. The activity of Caspase-3 was monitored in Jurkat cells following treatment with KPU-2, KPU-35 and t-butyl-phenylahistin.

The results indicate that caspase-3 was activated in a dose-dependent manner by treatment with all three compounds in a manner similar to halimide. The caspase-3 activation occurred over a similar concentration range as for the IC50s for cytotoxicity in the Jurkat cell line (Table 16).

Table 16 Cytotoxicity of KPU-2, KPU-35 and t-butyl-phenylahistin in Jurkat Cells

NPI Compound	Cytotoxicity	
	Potency IC50 nM	Efficacy % Cell Death
KPU-2	11	94
KPU-35	5	93
t-butyl-phenylahistin	165	93
Mitoxantrone	41	99

5). Cleavage of Poly(ADP-ribose) Polymerase (PARP) in Jurkat Cells

In order to assess the ability of these compounds to induce apoptosis in Jurkat cells, cleavage of poly(ADP-ribose) polymerase (PARP) was monitored. PARP is a 116 kDa nuclear protein that is one of the main intracellular targets of Caspase-3. The cleavage of PARP generates a stable 89 kDa product, and this process can be easily monitored by western blotting. Cleavage of PARP by caspases is one of the hallmarks of apoptosis, and as such serves as an excellent marker for this process. KPU-2 at 100 nM induced cleavage of PARP in Jurkat cells 10 hours after exposure of the cells to the compound. KPU-2 appeared to be more active than either halimide or KPU-1.

6). Enhanced Vascular Permeability in HuVEC Cells

Compounds that depolymerize microtubules (e.g. combretastatin A-4-phosphate, ZD6126) have been shown to induce vascular collapse in tumors *in vivo*. This vascular collapse is preceded by a rapid induction of vascular cell permeability initially to electrolytes and soon after to large molecules. The enhanced permeability of HuVEC cells to a fluorescent-labeled dextran is used as a proxy assay for vascular collapse.

KPU-2, KPU-35 and t-butyl-phenylahistin all rapidly (within 1 hour) induced significant HuVEC monolayer permeability, to an extent similar to colchicine. The microtubule stabilizing agent taxol was inactive in this assay (Figure 12).

7). Profile in A Broad Kinase Screen

KPU-2 was initially screened at a concentration of 10 μM in a panel of 60 different kinases; the ATP concentration was 10 μM. Four kinases were inhibited by greater than 50% in the primary screen and the IC50's determined in secondary screening are presented in Table 17. All of the IC50 values are in the low micromolar range, which indicates that inhibition of these kinases is not related to the low nanomolar activities observed for tumor cell cytotoxicity.

Table 17. Activity of KPU-2 against Selected Kinases

Kinase	IC50 (μM)
CDK1/Cyclin B (human)	10.1
c-RAF (human)	8.9
JNK3 (rat)	6.8
Lyn (mouse)	11.1

EXAMPLE 9

In vivo Pharmacology

Preliminary studies with KPU-2 were performed using the MX-1 (breast) and HT-29 (colon) xenograft models and the P-388 murine leukemia tumor model, in the mouse. Other tumor models selected on the basis of activity in the *in vitro* tumor panel were the DU-145 (prostate), MCF-7 (breast), and the A549 (lung) cell lines. The human pancreatic tumor (MiaPaCa-2) was also included. The novel compounds were studied as monotherapy and in combination with a clinically-used chemotherapeutic agent. The doses of the selected novel compounds were determined from the acute tolerability testing (Maximally Tolerated Dose, MTD) and were adjusted if necessary during each study. The doses of the clinically-used chemotherapeutic agents were selected on the basis of historical studies.

KPU-2 was the first compound to be studied in these five tumor models. Following the initial results from this study, all three compounds were compared in the HT-29 human colon tumor, the DU-145 human prostate and the MCF-7 human breast tumor xenograft models.

The above models all use the subcutaneous xenograft implantation technique and are potentially subject to selective effects of a compound on the subcutaneous vasculature producing a magnified (or apparent) antitumor activity. In order to circumvent this possibility, two other tumor models have been incorporated in the research. One of these is the observation of lung metastases following the intravenous injection of B16-F10 mouse melanoma tumor cells. The other model is the implantation of MDA-231 human breast tumor cells in the mouse mammary fat pad. While this latter model is a xenograft model, the subcutaneous vasculature does not play a role.

Methods

1). Xenograft Models

Animals used were (exceptions are indicated for individual studies): female nude mice (*nu/nu*) between 5 and 6 weeks of age (~20g, Harlan); group size was 9-10 mice per group unless otherwise indicated.

Cell lines used for tumor implantation were: HT-29 human colon tumor; MCF-7 human breast tumor; A549 human non small cell lung tumor; MiaPaCa-2 human pancreas tumor; DU-145 human prostate tumor.

Selected novel compounds were administered as monotherapy via the intraperitoneal (i.p.) route at the doses indicated for the individual study; for the combination studies the selected reference chemotherapy agents were injected 15-30 min prior to the compound.

Vehicles used in these studies were: 12.5% DMSO, 5% Cremaphor and 82.5% peanut oil for the selected novel compounds; (1:3) Polysorbate 80:13% ethanol for taxotere; (1:1) Cremaphor:ethanol for paclitaxel; for CPT-11 each mL of solution contained 20 mg of irinotecan hydrochloride, 45 mg of sorbitol NF powder, and 0.9 mg of lactic acid, the pH being adjusted to 7.4 with NaOH or HCl. Saline dilutions are used to achieve the injection concentrations used for the reference compounds.

HT-29 Human Colon Tumor Model

Animals were implanted subcutaneously (s.c.) by trocar with fragments of HT-29 tumors harvested from s.c. growing tumors in nude mice hosts. When the tumor size reached 5 mm x 5 mm (about 10-17 days) the animals were matched into treatment and control groups. Mice were weighed twice weekly and tumor measurements were obtained using calipers twice weekly, starting on Day 1. The tumor measurements were converted to estimated mg tumor weight using the formula $(W^2xL)/2$. When the estimated tumor weight of the control group reached an average of 1000 mg the mice were weighed, sacrificed and the tumor removed. The tumors were weighed and the mean tumor weight per group was calculated and the tumor growth inhibition (TGI) was determined for each group (100% minus the change in the mean treated tumor weight/the change in the mean control tumor weight x 100.

In this model unless otherwise noted for the individual study, the selected novel compounds were injected intraperitoneally every third day for 15 days [1, 4, 8, 11 and 15 (q3dx5)]; CPT-11 was administered intraperitoneally on days 1, 8 and 15 (qwx3).

MCF-7 Human Breast Tumor Model

Female nude mice (~20 g) were implanted s.c. with 21-day release estrogen (0.25 mg) pellets 24 hours prior to the s.c. implantation with MCF-7 tumor fragments (harvested from s.c. tumors in nude mice hosts). The study then proceeded as described for the HT-29 model, using taxotere as the standard chemotherapy agent.

In this model unless otherwise noted for the individual study, the novel compounds were injected via the intraperitoneal route daily on Days 1-5, inclusive (qdx5); taxotere was administered intravenously on Days 1, 3 and 5 (qodx3).

A549 Human Lung Tumor Model

Animals were implanted s.c. by trocar with fragments of A549 tumors harvested from s.c. growing tumors in nude mice hosts. When the tumor size reached 5 mm x 5 mm (about 10-17 days) the animals were matched into treatment and control groups. The rest of the study proceeded as described for the HT-29 model, using taxotere and CPT-11 as the standard chemotherapy agents.

In this model unless otherwise noted for the individual study, the tested compounds were administered via the intraperitoneal route on a q3dx5 dose schedule for the CPT-11 combination or on a qdx5 dose regimen for the combination with taxotere; CPT-11 was administered via the intraperitoneal route on a qwx3 schedule; taxotere was administered intravenously on a qodx3 dose regimen.

MiaPaCa-2 Human Pancreas Tumor Model

Animals were implanted s.c. by trocar with fragments of MiaPaCa-2 tumors harvested from s.c. growing tumors in nude mice hosts. When the tumor size reached 5 mm x 5 mm (about 10 -17 days) the animals were matched into treatment and control groups. The rest of the study proceeded as described for the HT-29 model, using gemcitabine as the standard chemotherapy agent.

In this model unless otherwise noted for the individual study, test compounds were administered every third day via the intraperitoneal route on Days 1, 4, 7, 10 and 15 (q3dx5); gemcitabine was administered via the intraperitoneal route on Days 1, 4, 7 and 10 (q3dx4).

DU-145 Human Prostate Tumor Model

Male mice were implanted s.c. by trocar with fragments of DU-145 tumors harvested from s.c. growing tumors in nude male mice hosts. When the tumors reached ~ 5 mm x 5 mm (at about 13 -17 days) the animals were matched into treatment and control groups. The remainder of the study proceeded as for the HT-29 model, using taxotere as the standard chemotherapy agent.

In this model unless otherwise noted for the individual study, test compounds were administered via the intraperitoneal route on Days 1, 3, 5, 8 and 11 (q3dx5); taxotere was administered intravenously on Days 1, 3 and 5 (q2dx3).

2). Non Subcutaneous Implantation Tumor Models

The animals used were: female nude mice (*nu/nu*) (MDA-231 study) or B6D2F1 (B16-F10 studies) mice between 5 and 6 weeks of age (~20g, Harlan); group size was 10 mice per group unless otherwise indicated.

The cell lines used were: MDA-MB-231 human breast tumor and B16-F10 murine melanoma cells.

NPI compounds were administered as monotherapy via the intraperitoneal route at the doses indicated for the individual study; for the combination studies the selected reference chemotherapy agents were injected 15-30 min prior to the NPI compound.

MDA-231 Human Breast Tumor

Female nude mice were injected in the mammary fat pad with $2x10^6$ MDA-231 cells harvested from *in vitro* cell culture. When the tumor size reached 5 mm x 5 mm (about 14-28 days) the animals were matched into treatment and control groups. The study then proceeded as described for the HT-29 model, using paclitaxel as the standard chemotherapy agent.

In this model unless otherwise noted for the individual study, the test compounds were administered via the intraperitoneal route on Days 1, 4, 8, 11 and 15 (q3dx5); paclitaxel was administered via the intraperitoneal route on Days 1-5 (qdx5).

B16-F10 Metastatic Murine Melanoma Model

Mice received B16-F10 cells (prepared from an *in vitro* cell culture of B16-F10 cells) by the iv route on Day 0. On Day 1 mice were randomized into treatment and control groups and treatment commenced. Mice were weighed twice weekly, starting on Day 1. All mice are sacrificed on Day 16, the lungs removed, weighed and the surface colonies counted. Results are expressed as mean colonies of treated mice/mean colonies of control mice (T/C) x 100%). The metastasis growth inhibition (MGI) is this number subtracted from 100%. Paclitaxel was the standard chemotherapy agent used in this study.

In this model unless otherwise noted for the individual study, the test compounds were administered via the intraperitoneal route on Days 1-5 (qdx5); paclitaxel was administered intravenously on Days 1-5(qdx5).

When appropriate ($n \geq 3$), results are presented as means ± SEM. Statistical analysis of studies with several groups was performed using ANOVA with Neuman-Keuls post test, unless otherwise indicated. A one-tailed t-test was also used based on the hypothesis that the compound or drug, or the combination, would reduce tumor growth.

Results

Studies in the HT-29 Human Colon Tumor Xenograft Model

1. *In Vivo* Evaluation of KPU-2 +/- CPT-11 in the HT-29 Human Colon Tumor Xenograft Model

This study assessed changes in dosage strength and dosing regimen for KPU-2 alone and in combination with a relevant chemotherapeutic CPT-11 in the HT-29 model.

KPU-2 was administered at doses of 7.5 mg/kg ip daily for five days (qdx5), 3.75 mg/kg ip bid for five days, 7.5 mg/kg ip every second day for 10 days (qodx5) and 7.5 mg/kg ip every third day for 15 days (q3dx5). The combination of CTP-11 with NPI-2358 at a dose of 7.5 mg/kg ip q3dx5 resulted in a significantly greater effect than for either compound alone, which lasted for the duration of the study (Figure 13). These observations during the in-life portion of the study were confirmed by the mean group final tumor weights at autopsy for which only the combination group exhibited a statistically significant lower tumor weight than controls. In addition the difference between the mean tumor weights of the combination therapy and CPT-11 monotherapy groups was statistically significant (Figure 14). When the individual final tumor weights at autopsy are examined the greater effect of cotherapy is clear (Figure 14). The TGI of cotherapy was 78% as compared to 38.9% for CPT-11 alone. The TGI for the combined therapy group exceeds the NCI criterion of 58% for a positive result.

2. Study of KPU-2 +/- Standard Chemotherapy vs. Five Human Tumor Xenograft Models

This study consists of five different arms, each with its own protocol, timing, dosing regimen and reference compound. Each arm will be considered within the presentation of the particular tumor model.

The aim of the HT-29 arm of the study was to investigate a slightly higher dose of KPU-2 (10 mg/kg ip q3dx5) in the HT-29 human colon tumor xenograft model as compared to those used in the study described above, in which a marked synergy was observed between KPU-2 (7.5 mg/kg ip q3dx5) and CPT-11 (100 mg/kg ip qwx3).

As can be observed in Figure 15, the combination of KPU-2 and CPT-11 in this model resulted in a marked synergy in the inhibition of tumor growth, with the tumor growth being almost completely inhibited up to Treatment Day 29 in the combination therapy group. The combined therapy maintained efficacy and the estimated tumor growth for this group was significantly lower than for either monotherapy group. Accordingly, administration of KPU-2 and CPT-11 inhibited tumor growth and is an effective anti-tumor treatment.

The observations of the in-life portion of the study (estimated tumor growth, Figure 15) are supported by measurement of the weights of the tumors excised at autopsy (Figure 16). The tumor weights for the combination group was significantly less than the Controls ($p<0.01$), as were the tumor weights for CPT-11 alone ($p<0.05$).

When the individual final tumor weights are considered (Fig 16), the tumor size for the combination group was generally smaller than for the other treated or control groups. The TGI of the combination group was 65.8%, indicating a positive effect by the NCI criterion, while monotherapy did not reach the NCI criterion of TGI > 58%.

3. Study of activity of KPU-2, KPU-35 and t-butyl-phenylhistin in the HT-29 Human Colon Tumor Xenograft Study

The results of this study are presented in Figure 17 and Table 18. The combination therapy groups all indicated a marked synergy between the novel compounds and CPT-11. The individual tumor weights demonstrate the effectiveness of the cotherapy treatment (Figure 18). In each case the TGI for the combination group surpasses the NCI criterion for a positive effect, whereas the TGI for CPT-11 monotherapy did not reach this level.

Table 18. Summary of Studies Performed in the HT-29 Human Colon Tumor Model

Study Description		NPI-Compound		Chemotherapeutic Agent		Combination		Comments
Number Status	Endpoint	Number, mg/kg ip	Result TGI %	Name, Dose	Result TGI %	Results TGI %	Exceed NCI Criterion (TGI≥ 58 %)	
2164	TGI	KPU-2 7.5 qdx5 7.5 q3dx5	 No Effect No Effect	CPT-11 100 ip qwx3	39*	78 **,#	Combination	Synergy
2288	TGI	KPU-2 10→7.5 q3dx5	No Effect	CPT-11 100 ip qwx3	36.5*	65.8 **	Combination	Synergy See Text
2139	TGI	KPU-2 7.5 q3dx5	No Effect	CPT-11 100 ip qwx3	32.7	80.7 **, #	Combination	Synergy
2139	TGI	KPU-35 10→7.5 q3dx5	No Effect	CPT-11 100 ip qwx3	32.7	83.3 **,##	Combination	Synergy 1+ Day 13 1+ Day 27
2139	TGI	t-butyl- phenylahistin 30 q3dx5	No Effect	CPT-11 100 ip qwx3	32.7	77.7 *,#	Combination	Synergy

*p<0.05 vs Control; ** p<0.01 vs Control; # p<0.05 vs CPT-11 Alone; ## p<0.01 vs CPT-11 Alone;
+ = Number of Deaths

4. Summary of the Effects of KPU-2,KPU-35 and t-butyl-phenylahistin in Combination with CPT-11 in the HT-29 Human Colon Tumor Xenograft Model

When combined with CPT-11, KPU-2 enhanced the effect of CPT-11, the standard chemotherapeutic agent, to a level well in excess of the NCI criterion of a TGI ≥ 58% for a positive effect. The results generated in the three studies are very comparable for both the in-life observations (Figure 19) and for the weights of the tumors excised at autopsy (Figure 20).

Studies in the DU-145 Human Prostate Tumor Xenograft Model

Two studies have been completed with this model: the first study involved KPU-2 alone and in combination with taxotere; the second study compared KPU-2, KPU-35 and t-butyl-phenyalhistin alone and in combination with taxotere.

1. Effect of KPU-2 in Combination with Taxotere in the DU-145 Human Prostate Tumor Xenograft Model

As can be seen from the data obtained during the in-life portion of this study (Fig 21), the most effective treatment of the DU-145 human prostate tumor was the combined therapy of KPU-2 plus taxotere. The treatment effect was most pronounced at the beginning of the study and appeared to be reduced as the study progressed. From treatment Days 20 -27, the combination therapy did provide an apparent TGI that exceeded the NCI criterion (TGI ≥ 58%), and the estimated tumor weight of the combined therapy was significantly less than for either monotherapy.

2. Activity of KPU-2, KPU-35 and t-butyl-phenylahistin Alone or in Combination with Taxotere in the DU-145 Human Prostate Xenograft Model

Based on the data obtained with KPU-2 in combination with taxotere in the Study described above a second study comparing KPU-2 to KPU-35 and t-butyl-phenylahistin alone and in combination with taxotere was initiated.

The observations made during the in-life portion of this study indicate that the combination of either KPU-2 or KPU-35 with taxotere has a greater reduction on tumor growth than for taxotere alone (Figure 22). The tumor growth was almost completely blocked by KPU-35 in combination with taxotere.

The excised tumor weights at autopsy confirmed the observations made during the in-life segment of the study. The combination of either KPU-2 (Figure 23) or KPU-35 (Figure 24) with taxotere was significantly more effective than taxotere alone in blocking tumor growth. In the case of KPU-35, three of ten mice showed evidence for tumor shrinkage. The tumor growth inhibition indices indicated a marked inhibition of tumor growth for KPU-2 (group mean = 74.1 %) and an almost total block for KPU-35 (group mean = 92.5%). Taxotere alone did not reach the NCI established criterion for a positive effect (TGA ≥ 58%).

5. Studies in the MCF-7 Human Breast Tumor Xenograft Model

This study compared the effects of KPU-2, KPU-35 and t-butyl-phenylahistin in the MCF-7 human breast tumor xenograft model. The doses of the compounds were administered on Days 1, 2, 3, 4, and 7; Taxotere was administered on Days 1, 3 and 7.

The selected novel compounds have early onset, statistically significant effects when used in combination with taxotere in this model, apparently almost completely blocking estimated tumor growth (Figure 25). Of the three compounds, KPU-2 appeared to be the most effective, with t-butyl-phenylahistin also exhibiting a significant potentiation of taxotere.

6. Studies in the A549 Human Non Small Cell Lung Tumor Xenograft Model

The in-life observations during this study (Figure 26) indicated that the combination of KPU-2 (7.5 mg/kg ip, qdx5) with taxotere resulted in a marked inhibition of tumor growth as compared to the Control or either monotherapy group. This was confirmed by the autopsy tumor weights, as the mean of the cotherapy group was significantly less than that of taxotere alone or the Control group (Figure 27). The cotherapy group tumor weights form a cluster of low tumor weights, indicating the consistency of the effect.

When the tumor growth index is calculated, the cotherapy group had a TGI of 74.4% as compared to the control group well in excess of the NCI criterion for a positive effect (TGI ≥ 58%). Taxotere alone had a TGI of 26.1 %.

7. Studies in the MDA-231 Human Breast Tumor Orthotopic Xenograft Model

This model involves the placement of the human tumor tissue into the mouse mammary fat pad, a surrogate of the natural environment. In this manner the possibility of a positive effect due to a specific action on the subcutaneous vascular bed is avoided. This study compared the effect of KPU-2 (7.5 mg/kg ip, q3dx5) alone and in combination with paclitaxel (16 mg/kg ip, qdx5).

Three weeks into the study there was a significant inhibition of tumor growth in the combination therapy group, a highly significant effect. This effect appeared to be more marked than for taxotere alone (Figure 28).

8. Studies in the Murine Melanoma B16 F10 Metastatic Tumor Model

This study examined the effect of KPU-2, KPU-35 and t-butyl-phenylahistin alone and in combination with paclitaxel on the number of metastases appearing on the surface of the lung 16 days after the intravenous injection of B16 F10 melanoma cells to the mouse. This model is not a xenograft model; however, it does not involve a high degree of vascularization into the tumor mass.

In this model the most effective treatment was KPU-2 alone (Figure 29), having a mean metastases count about 10% less than that for paclitaxel (MGIs of 41.6% and 35.0 %, respectively). While this study does not itself establish that combination therapy is more effective than monotherapy, it does indicate that KPU-2, KPU-35 and t-butyl-phenylahistin are most effective in highly vascularized tumors.

EXAMPLE 10

Assays For Activity Against Pathogenic Fungi

Comparative activity of a dehydrophenylahistin or its analog against a pathogenic fungus, relative to known antifungal compounds recited above, for use in determining the dehydrophenylahistin or its analog's AF/IS value is measured directly against the fungal organism, e.g. by microtiter plate adaptation of the NCCLS broth macrodilution method described in *Diagn Micro and Infect Diseases* **21**:129-133 (1995). Antifungal activity can also be determined in whole-animal models of fungal infection. For instance, one may employ the steroid-treated mouse model of pulmonary mucormycosis (Goldaill, L.Z. & Sugar, A.M. 1994 *J Antimicrob Chemother* **33**:369-372). By way of illustration, in such studies, a number of animals are given no dehydrophenylahistin or its analog, various doses of dehydrophenylahistin or its analog (and/or combinations with one or more other antifungal agents), or a positive control (e.g. Amphotericin B), respectively, beginning before, at the time of, or subsequent to infection with the fungus. Animals may be treated once every 24 hours with the selected dose of dehydrophenylahistin or its analog, positive control, or vehicle only. Treatment is continued for a predetermined number of days, e.g. up to ten days. Animals are observed for some time after the treatment period, e.g. for a total of three weeks, with mortality being assessed daily. Models can involve systemic, pulmonary, vaginal and other models of infection with or without other treatments (e.g. treatment with steroids) designed to mimic a human subject susceptible to infection.

To further illustrate, one method for determining the *in vivo* therapeutic efficacies (ED_{50}, e.g. expressed in mg dehydrophenylahistin or its analog/kg subject), is a rodent model system. For example, a mouse is infected with the fungal pathogen such as by intravenous infection with approximately 10 times the 50% lethal dose of the pathogen (10^6 *C. albicans* cells /mouse). Immediately after the fungal infection, dehydrophenylahistin compounds are given to the mouse at a predetermined dosed volume. The ED_{50} is calculated by the method of Van der Waerden (*Arch Exp Pathol Pharmakol* **195**:389-412, 1940) from the survival rate recorded on 20th day post-infection. Generally, untreated control animals die 7 to 1 3 days post-infection.

In another illustrative embodimemt, *C. albicans* Wisconsin (C43) and *C. tropicalis* (C112), grown on Sabouraud dextrose agar (SDA) slants for 48 h at 28°C, are suspended in saline and adjusted to 46% transmission at 550 nm on a spectrophotometer. The inoculum is further adjusted by hemacytometer and confirmed by plate counts to be approximately 1 or 5 x 10^7 CFU/ml. CF-1 mice are infected by injection 1 or 5 x 10^6 CFU into the tail vein. Antiftingal agents are administered intravenously or subcutaneously in ethanol:water (10:90), 4 h post infection and once daily thereafter for 3 or 4 more days. Survival is monitored daily. The ED_{50} can be defined as that dose which allows for 50% survival of mice.

EXAMPLE 11

Evaluating Antimicotic Activity

Benzimidazoles and griseofulvin are anti-tubulin agents capable of binding to fungal microtubules. Once bound, these compounds interfere with cell division and intracellular transport in sensitive organisms, resulting in cell death. Commercially, benzimidazoles are used as fungicidal agents in veterinary medicine and plant disease control. A wide variety of fungal species, including *Botrytis cinerea*, *Beauveria bassiana*, *Helminthosporium solani*, *Saccharomyces cerevisiae* and *Aspergillus* are susceptible to these molecules. Toxicity concerns and increasing drug resistance, however, have negatively impacted their usage. Griseofulvin is used clinically to treat ringworm infections of the skin, hair and nails, caused by *Trichophyton* sp., *Microsporum* sp., and *Epidermophyton floccosum*. Its antifungal spectrum, however, is restricted to this class of fungal organisms. Genotoxicity is also a significant side effect. Terbinafine, while an alternative first-line treatment, is more costly. Further, clinical resistance recently has been observed in *Trichophyton rubrum* (the major causative agent for all dermatophyte infections).

In *Candida albicans*, microtubule/microfilament formation is affected where cells are exposed to the microtubule inhibitors nocodazole and chloropropham. These results further validate the exploration of cytoskeleton inhibitors as effective antimycotic agents. Accordingly, several of the compounds disclosed herein were evaluated for antimycotic activity.

Specifically, disclosed compounds were evaluated alongside commercially available microtubulin inhibitors as well as recognized antifungal agents. The test compounds and controls used in this study: (-)-Phenylahistin, KPU-1, KPU-2, KPU-11 and KPU-17, KPU-35, t-butyl phenylahistin, Colchicine (commercial microtubulin inhibitor tested versus 3 *Candida* isolates), Benomyl (commercial microtubulin inhibitor tested versus 3 *Candida* isolates), Griseofulvin (commercial microtubulin inhibitor and antibiotic control for testing versus 6 dermatophyte isolates), Amphotericin B (antibiotic control for testing versus 3 *Candida* isolates), Itraconazole (antibiotic control for testing versus 2 *Aspergillus* isolates).

Microorganisms against which these compounds were tested included: *Candida albicans, Candida glabrata, Aspergillus fumigatus, Trichophyton rubrum, Trichophyton mentagrophytes, Epidermophyton floccosum*. With the exception of *Candida glabrata* (one isolate), two isolates of each species were tested.

Antifungal susceptibility testing was accomplished according to the methods outlined in the National Committee for Clinical Laboratory Standards, M38-A "Reference Method for Broth Dilution Antifungal Susceptibility Testing of Conidium-Forming Filamentous Fungi; Approved Standard." This includes testing in RPMI-1640 with glutamine and without bicarbonate, an inoculum size of 0.4 - 5 × 10^4, and incubation at 30 or 35°C for 48 hours. The minimum inhibitory concentration (MIC) was defined as the lowest concentration that resulted in an 80% reduction in turbidity as compared to a drug-free control tube. Drug concentrations were 0.03-16 µg/ml for the investigational compounds, 0.015-8 µg/ml for itraconazole and griseofulvin.

The minimum inhibitory concentration (MIC) at which a compound prevented the growth of the target microorganism was assessed according to the modified version of the NCCLS protocol. Minimum inhibitory concentrations (MIC) were determined at the first 24-hour interval where growth could be determined in the drug-free control tube. The defined MIC was the lowest concentration that exhibited an 80% reduction in turbidity as compared to the growth control. The minimum lethal concentration (MLC) was determined by plating 0.1 µl from the MIC concentration and each concentration above the MIC. The MLC was called at the first concentration that exhibited five or fewer colonies of fungal growth representing a 99.95% kill. When a MIC was obtained, a minimum fungicidal concentration (MFC) was determined to assess the fungistatic/fungicidal nature of the compound. This procedure entails diluting drug-treated cell samples (removed from test wells containing compound at and above the MIC) to compound concentrations significantly below the inhibitory concentration and depositing them on agar plates. The compound is scored as fungistatic if the cells are able to resume growth and fungicidal if no regrowth is possible because the compound had killed the organisms.

Compounds disclosed herein were shown to be effective against two *Trichophyton* species. *T. rubrum* is the principal causative agent for human dermatophytic infections, and would be the key organism to target in the development of a clinical agent.

Compounds KPU-2, KPU-11 and KPU-17, KPU-35 & t-butylphenylahistin were equivalent in potency or in some cases more potent than griseofulvin, a current, standard pharmaceutical agent used for treating dermatophytic infections.

Compounds (-)-Phenylahistin and KPU-1 were significantly less potent than the other compounds when tested versus *T. rubrum* and weaker but more comparable to the others versus the sensitive *T. mentagrophytes* isolate.

In those instances when an MFC could be determined, the results indicate that these compounds are fungistatic in nature (see Tables 19 and 20).

Table 19. Antifungal Activity of Dehydrophenylahistins and Analogs Thereof

Compound	MICs and MFCs, μg/ml									
	C. albicans 90028		*C. albicans* 10231		*C. glabrata*		*A. fumigatus* isolate #1		*A. fumigatus* isolate #2	
	MIC	MFC	MIC	MFC	MIC	MFC	MIC	MFC	MIC	MFC
(-)-Phenylahistin	>70	ND**	>70*	ND	>70	ND	>16	ND	>16	ND
KPU-1	>68*	ND	>68	ND	>68	ND	>16	ND	>16	ND
KPU-2	>32	ND	>32	ND	>32	ND	>16	ND	>16	ND
KPU-11 and KPU-17	>32	ND	>32	ND	>32	ND	>16	ND	0.06	>16
KPU-35	>32	ND	>32	ND	>32	ND	>16	ND	<0.03	0.125
t-butyl phenylahistin	>32	ND	>32	ND	>32	ND	>16	ND	<0.03	0.125
amphotericin B	0.5	0.5	0.5	0.5	1	1	ND	ND	ND	ND
griseofulvin	ND	ND	ND	ND	ND	ND	ND	ND	0.5	ND
itraconazole	ND	ND	ND	ND	ND	ND	1	ND	ND	ND
colchicine	>128	ND	>128	ND	>128	ND	ND	ND	ND	ND
benomyl	64	>512	64	>512	64	>512	ND	ND	ND	ND

Table 20. Antifungal Activity of Dehydrophenylahistins and Analogs Thereof

Compound	MICs and MFCs, μg/ml											
	T. rubrum isolate #1		*T. rubrum* isolate #2		*T. mentagrophytes* isolate #1		*T. mentagrophytes* isolate #2		*E. floccosum* isolate #1		*E. floccosum* isolate #2	
	MIC	MFC	MIC	MFC	MIC	MFC	MIC	MFC	MIC	MFC		MFC
NPI2350	>16	ND	0.16	>16	16	>16	>16	ND	>16	ND	>16	ND
NPI2352	>16	ND	0.25	>16	4	>16	>16	ND	>16	ND	>16	ND
NPI2358	>16	ND	<0.03	0.125	2	>16	>16	ND	>16	ND	>16	ND
NPI2362	0.06	>16	<0.03	<0.03	1	>16	>16	ND	>16	ND	>16	ND
NPI2386	<0.03	0.125	<0.03	0.06	1	>16	>16	ND	>16	ND	>16	ND
NPI2460	<0.03	0.125	<0.03	<0.03	4	>16	>16	ND	>16	ND	>16	ND
amphotericin B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
griseofulvin	0.5	ND	<0.015	ND	1	ND	2	ND	2	ND	4	ND
itraconazole	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
colchicine	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
benomyl	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

The examples described above are set forth solely to assist in the understanding of the invention. Thus, those skilled in the art will appreciate that the disclosed methods and compounds encompass and may otherwise provide further derivatives of dehydrophenylahistins.

One skilled in the art would readily appreciate that the present invention is well adapted to obtain, for example, the ends and advantages mentioned, as well as others inherent. The methods and procedures described herein are presently representative of preferred embodiments and are exemplary. Changes therein and other uses will occur to those skilled in the art which are encompassed within the spirit of the invention.

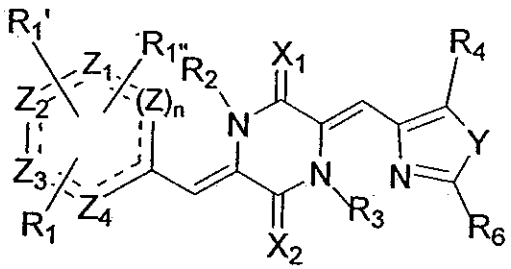
It will be readily apparent to one skilled in the art that varying substitutions and modifications may be made to the examples disclosed herein without departing from the scope and spirit of the invention.

As noted above, all patents and publications mentioned in the specification are indicative of the levels of those skilled in the art to which the invention pertains.

The invention illustratively described herein suitably may be practiced in the absence of any element or elements, limitation or limitations which is not specifically disclosed herein. The terms and expressions which have been employed are used as terms of description and not of limitation, and there is no intention that in the use of such terms and expressions indicates the exclusion of equivalents of the features shown and described or portions thereof. It is recognized that various modifications are possible within the scope of the invention. Thus, it should be understood that although the present invention has been specifically disclosed by preferred embodiments and optional features, modification and variation of the concepts herein disclosed may be resorted to by those skilled in the art, and that such modifications and variations are considered to be falling within the scope of the invention. The scope of the invention is solely defined by the following claims.

CLAIMS:

1. A method for the synthetic preparation of a compound having the structure of Formula (I):



(I)

wherein

R_1, R_4, and R_6, are each separately selected from the group consisting of a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups, hydroxy, carboxy, -CO-O-R_7, cyano, alkylthio, halogenated alkyl including polyhalogenated alkyl, halogenated carbonyl, and carbonyl -CCO-R_7, wherein R_7 is selected from a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups;

R_1' and R_1" are each independently selected from the group consisting of a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups, hydroxy, carboxy, -CO-O-R_7, cyano, alkylthio, halogenated alkyl including polyhalogenated alkyl, halogenated carbonyl, and carbonyl -CCO-R_7, wherein R_7 is selected from a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl,

substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups;

R_1' and R_1'' are either covalently bound to one another to form a ring or are not covalently bound to one another;

R_2, R_3, and R_5 are each separately selected from the group consisting of a hydrogen atom, a halogen atom, and saturated C_1-C_{12} alkyl, unsaturated C_1-C_{12} alkenyl, acyl, cycloalkyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, and substituted nitro groups, sulfonyl and substituted sulfonyl groups;

X_1 and X_2 are separately selected from the group consisting of an oxygen atom, a nitrogen atom, and a sulfur atom, each either unsubstituted or substituted with a R_5 group, as defined above;

Y is selected from the group consisting of a nitrogen atom substituted with R_5, an oxygen atom, a sulfur atom, a oxidized sulfur atom, and a methylene group substituted with one or more R_5;

n is an integer equal to zero, one or two;

Z, for each separate n, if non-zero, and Z_1, Z_2, Z_3 and Z_4 are each separately selected from a carbon atom, a sulfur atom, a nitrogen atom or an oxygen atom; and

the dashed bonds may be either single or double bonds;

said method comprising:

reacting a diacyldiketopiperazine with a first aldehyde to produce an intermediate; and

reacting said intermediate with a second aldehyde to produce said compound, wherein said first aldehyde and said second aldehydes are selected from the group consisting of an oxazolecarboxaldeyhyde, imidazolecarboxaldehyde, a benzaldehyde, imidazolecarboxaldehyde derivatives, and benzaldehyde derivatives, thereby forming the compound.

2. The method according to claim 1, wherein said first aldehyde is an imidazolecarboxaldehyde.

3. The method according to claim 1, wherein said second aldehyde is a benzaldehyde.

4. The method according to claim 1, wherein each of R_2, R_3, R_5 and R_6 is a hydrogen atom.

5. The method according to claim 1, wherein each of X_1 and X_2 is an oxygen atom.

6. The method according to claim 1, wherein R_4 is a saturated C_1-C_{12} alkyl.

7. The method according to claim 6, wherein said saturated C_1-C_{12} alkyl is a tertiary butyl group.

8. The method according to claim 1, wherein R_1 comprises a substituted phenyl.

9. The method according to claim 8, wherein said substituted phenyl group is methoxybenzene.

10. The method according to claim 1, wherein said first aldehyde is a benzaldehyde.

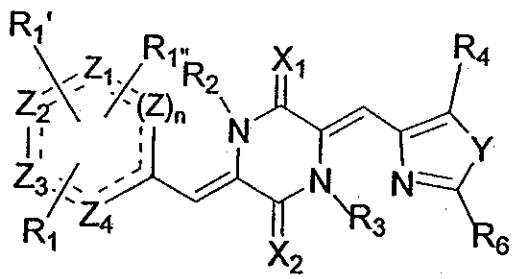
11. The method according to claim 1, wherein said second aldehyde is an imidazolecarboxaldehyde.

12. The method according to claim 1, wherein n is equal to zero or one.

13. The method according to claim 1, wherein n is equal to one.

14. The method according to claim 1, wherein n is equal to one and Z, Z_1, Z_2, Z_3 and Z_4 are each a carbon atom.

15. A compound having the structure of Formula (I):



(I)

wherein

R_1 and R_6, are each separately selected from the group consisting of a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups, hydroxy, carboxy, -CO-O-R_7, cyano, alkylthio, halogenated alkyl including polyhalogenated alkyl, halogenated carbonyl, and carbonyl -CCO-R_7,

wherein R_7 is selected from a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups;

R_4 is a tertiary butyl group;

R_1' and R_1'' are each independently selected from the group consisting of a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups, hydroxy, carboxy, -CO-O-R_7, cyano, alkylthio, halogenated alkyl including polyhalogenated alkyl, halogenated carbonyl, and carbonyl -CCO-R_7, wherein R_7 is selected from a hydrogen atom, a halogen atom, and saturated C_1-C_{24} alkyl, unsaturated C_1-C_{24} alkenyl, cycloalkyl, cycloalkenyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, azido, substituted nitro, phenyl, and substituted phenyl groups;

R, R_1' and R_1'' are either covalently bound to one another or are not covalently bound to one another;

R_2, R_3, and R_5 are each separately selected from the group consisting of a hydrogen atom, a halogen atom, and saturated C_1-C_{12} alkyl, unsaturated C_1-C_{12} alkenyl, acyl, cycloalkyl, alkoxy, cycloalkoxy, aryl, substituted aryl, heteroaryl, substituted heteroaryl, amino, substituted amino, nitro, and substituted nitro groups, sulfonyl and substituted sulfonyl groups;

X_1 and X_2 are separately selected from the group consisting of an oxygen atom, a nitrogen atom, and a sulfur atom, each either unsubstituted or substituted with a R_5 group, as defined above;

Y is selected from the group consisting of a nitrogen atom substituted with R_5, an oxygen atom, a sulfur atom, a oxidized sulfur atom, and a methylene group substituted with one or more R_5;

n is an integer equal to zero, one or two;

Z, for each separate n, if non-zero, and Z_1, Z_2, Z_3 and Z_4 are each separately selected from a carbon atom, a sulfur atom, a nitrogen atom or an oxygen atom; and

the dashed bonds may be either single or double bonds.

16. The compound of claim 15, wherein each of R_2, R_3, R_5 and R_6 is a hydrogen atom.

17. The compound of claim 15, wherein each of X_1 and X_2 is an oxygen atom.

18. The compound of to claim 15, wherein R_1 is a substituted phenyl group.

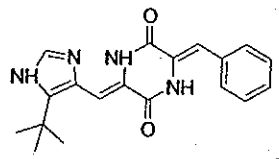
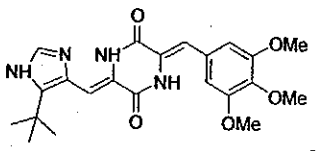
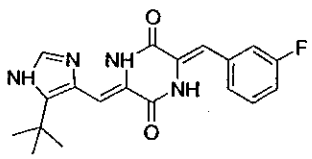
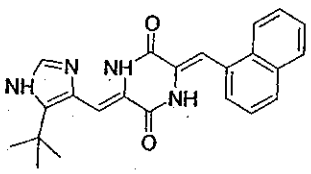
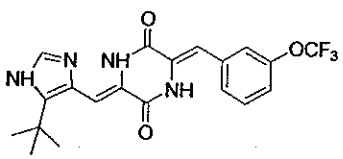
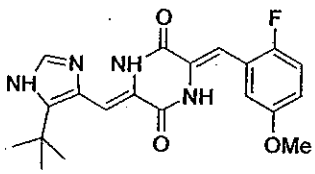
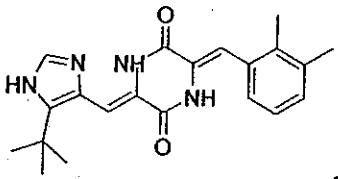
19. The compound of claim 18, wherein the substituted phenyl group is methoxybenzene.

20. The compound according to claim 15, wherein n is equal to zero or one.

21. The compound according to claim 15, wherein n is equal to one.

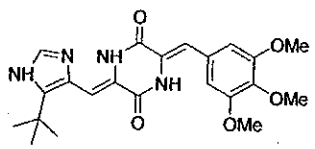
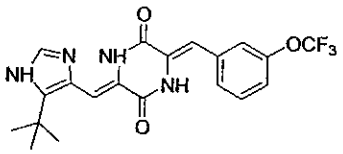
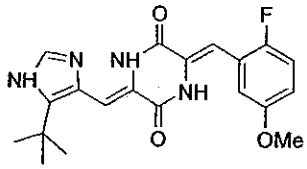
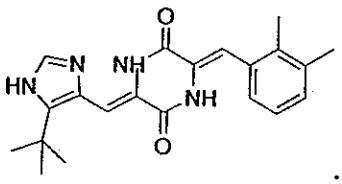
22. The compound according to claim 15, wherein n is equal to one and Z, Z_1, Z_2, Z_3 and Z_4 are each a carbon atom.

23. The compound of Claim 15, wherein said compound is selected from the group consisting of:


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, and

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24. A pharmaceutical composition, comprising the compound of Claim 15 and a pharmaceutically acceptable carrier.

25. The pharmaceutical composition of Claim 24, wherein said compound is selected from the group consisting of:




and


26. The pharmaceutical composition of Claim 24, wherein said compound has a cytotoxic activity.

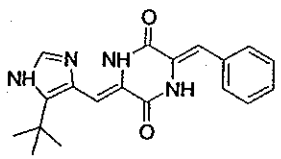
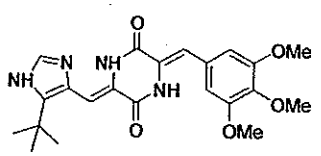
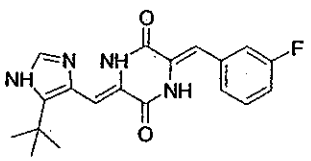
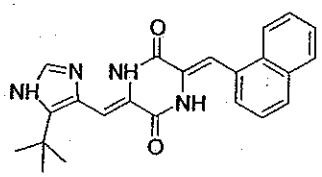
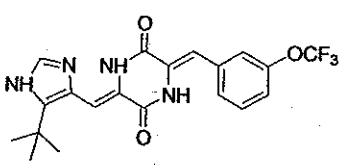
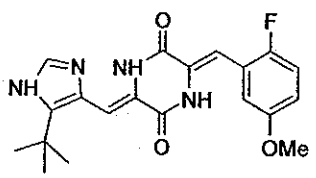
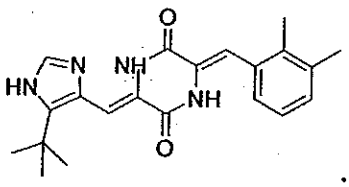
27. The pharmaceutical composition of Claim 24, wherein said compound is a cell-cycle inhibitor.

28. The pharmaceutical composition of Claim 24, wherein said compound has antifungal activity.

29. The pharmaceutical composition of Claim 24, wherein said compound has antitumor activity.

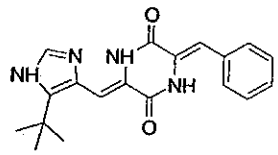
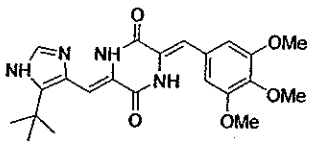
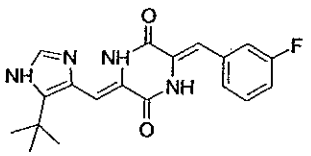
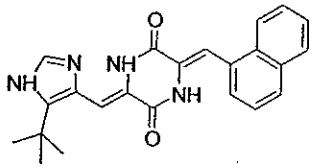
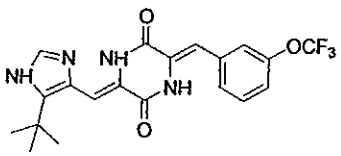
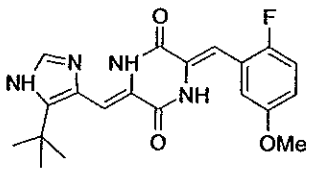
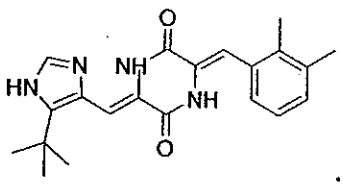
30. A pharmaceutical composition for treating or preventing fungal infection comprising an antifungally effective amount of a compound of claim 15 together with a pharmaceutically acceptable carrier therefore.

31. The composition of Claim 30, wherein said compound is selected from the group consisting of:







and


32. A pharmaceutical composition for treating or preventing a tumor comprising a pharmaceutically effective amount of a compound of claim 15 together with a pharmaceutically acceptable carrier therefore.

33. The pharmaceutical composition Claim 32, wherein said compound is selected from the group consisting of:

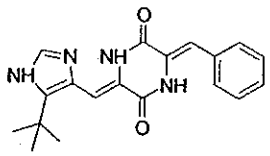
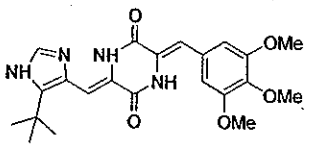
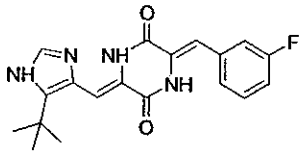
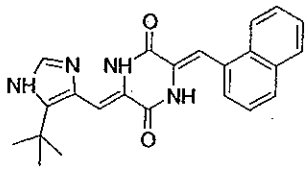
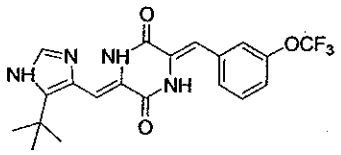
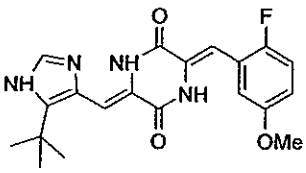
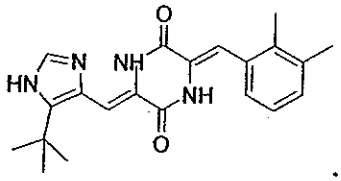

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34. Use of a compound of Claim 15 in the manufacture of a medicament for the treatment of a disease state in a mammal.

35. The use of Claim 34, wherein said disease state is neoplastic.

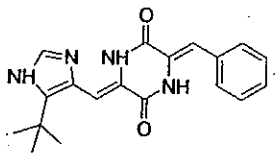
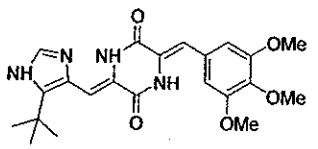
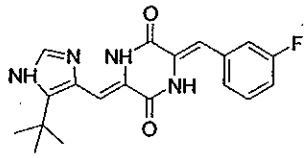
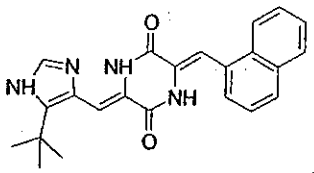
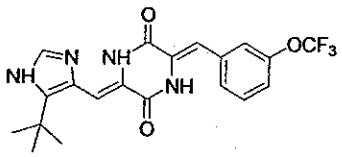
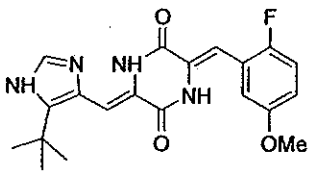
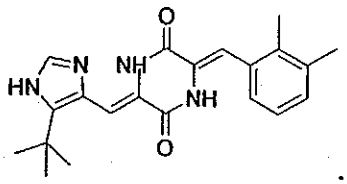
36. The use of Claim 34, wherein said disease state is a fungal infection.

37. The use of Claim 34, wherein said compound is selected from the group consisting of:


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38. Use of a compound of claim 15 in the manufacture of a medicament for treating and/or preventing cancer in a mammal afflicted with cancer.

39. The use of Claim 38, wherein said compound is selected from the group consisting of:


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, and

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40. The use of Claim 38, wherein the cancer comprises a tumor.

41. The use of Claim 38, wherein the cancer is a human colorectal adenocarcinoma.

42. The use of Claim 38, wherein the cancer is a prostate adenocarcinoma.

43. The use of Claim 38, wherein the cancer is a leukemia.

44. The use of Claim 38, wherein the cancer is a lung cancer.

45. The use of Claim 38, wherein the cancer is a breast cancer.

46. The use of Claim 38, wherein the cancer is an ovarian cancer.

47. The use of Claim 38, wherein the cancer is a melanoma.

48. The use of Claim 38, wherein the cancer is a uterine sarcoma.

49. The use of Claim 38, wherein the cancer is a prostate cancer.

50. The use of Claim 38, wherein the cancer is a pancreatic cancer.

51. The use of Claim 38, wherein the cancer is taxol resistant.

52. The use of Claim 38, wherein the cancer is a mitoxantrone resistant.