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(54) Title: DPAGT1 INHIBITORS OF CAPURAMYCIN ANALOGUES AND THEIR ANTIMIGRATORY ACTIVITIES OF SOLID TUMORS

(57) Abstract: Provided herein are compounds and methods of using these compounds to treat disorders related to DPAGT1 function, including cancer and bacterial infections.



**DPAGT1 INHIBITORS OF CAPURAMYCIN ANALOGUES
AND THEIR ANTIMIGRATORY ACTIVITIES OF SOLID TUMORS**

RELATED APPLICATIONS

5 This application claims priority to U.S. Provisional Application No. 63/046,103 filed June 30, 2020, the content of which is hereby incorporated by reference in its entirety.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

10 This invention was made with government support under Grant No. GM114611 awarded by the National Institutes of Health. The government has certain rights in the invention.

BACKGROUND

15 *N*-acetylglucosamine-phosphotransferase1 (DPAGT1) is an enzyme that catalyzes the first step in the dolichol-linked oligosaccharide pathway for glycoprotein biosynthesis. This protein is an integral membrane protein of the endoplasmic reticulum. Several solid cancers, including pancreatic cancers, require high DPAGT1 expression in order for cancer progression. Whereas tunicamycin, a nucleoside antibiotic, has been shown to inhibit DPAGT1, its non-selective activity is toxic to healthy cells. Capuramycin, another
20 nucleoside antibiotic, displays narrow spectrum of antibacterial activity by targeting bacterial translocase I (MraY), but not DPAGT1. Capuramycin is less toxic than tunicamycin.

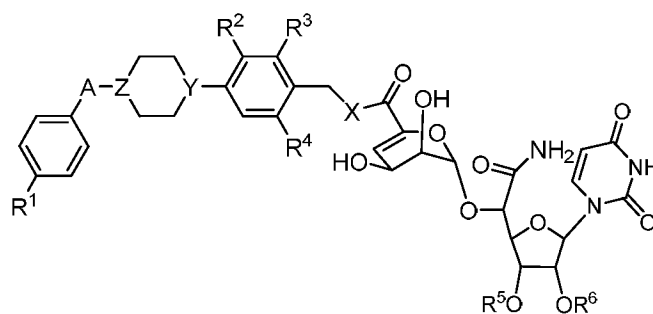
 Therefore, there remains a need for DPAGT1-selective inhibitors to prevent cancer progression.

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SUMMARY

 Provided herein are compounds and methods of using these compounds to treat disorders related to DPAGT1 function, including cancer and bacterial infections.

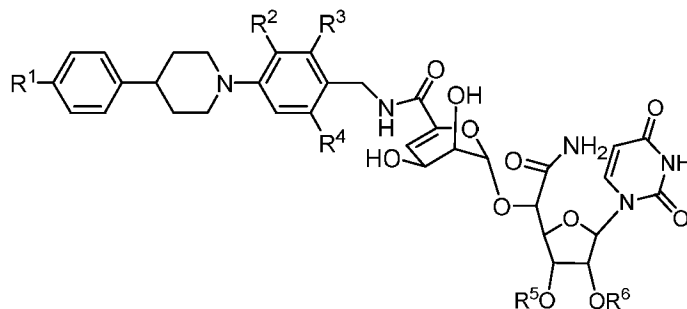
 In an aspect, provided herein is a compound of Formula I:



(I)

or a pharmaceutically acceptable salt thereof, wherein the variables are defined herein.

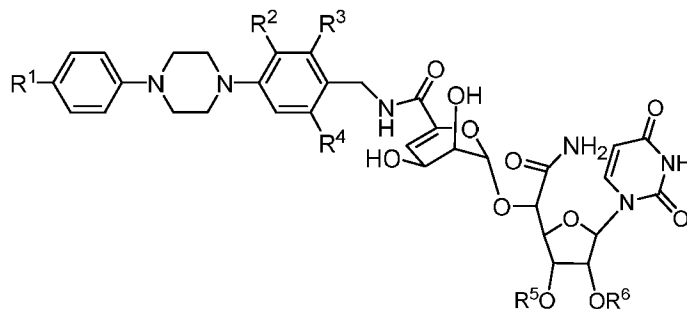
In an embodiment, the compound of Formula I is a compound of Formula II:



(II)

or a pharmaceutically acceptable salt thereof.

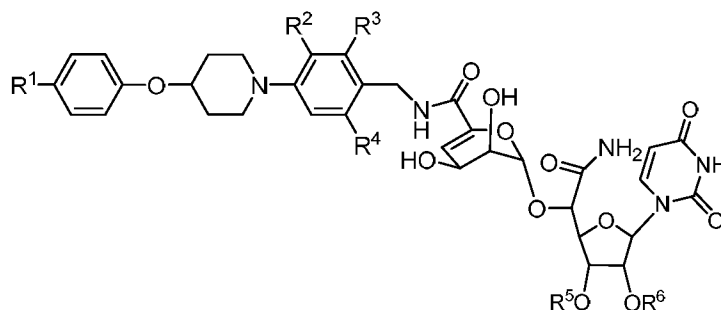
In another embodiment, the compound of Formula I is a compound of Formula III:



(III)

or a pharmaceutically acceptable salt thereof.

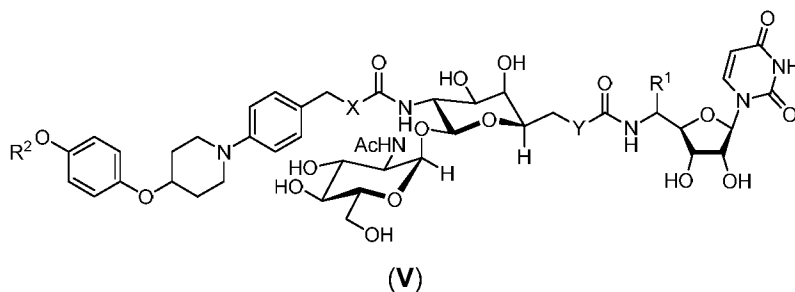
In yet another embodiment, the compound of Formula I is a compound of Formula IV:



(IV)

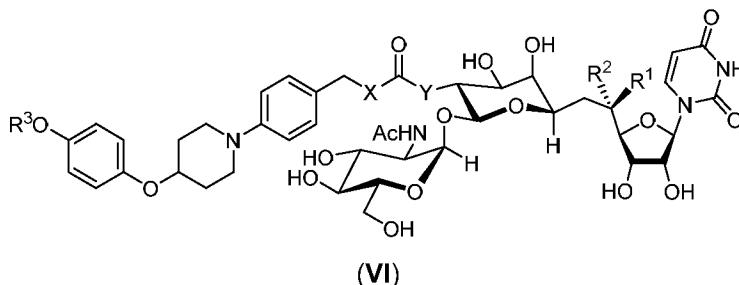
5 or a pharmaceutically acceptable salt thereof.

In another aspect, provided herein is a compound of Formula V:



or a pharmaceutically acceptable salt thereof.

In yet another aspect, provided herein is a compound of Formula VI:



or a pharmaceutically acceptable salt thereof.

In another aspect, provided herein is a method of inhibiting dolichyl-phosphate *N*-acetylglucosaminophosphotransferase (DPAGT1) in a subject in need thereof, comprising administering to the subject a therapeutically effective amount of any of the compounds disclosed herein, or a pharmaceutically acceptable salt thereof.

In still another aspect, provided herein is a method of treating cancer in a subject in need thereof, comprising administering to the subject a therapeutically effective amount of any of the compounds disclosed herein, or a pharmaceutically acceptable salt thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows DPAGT1 in *N*-glycan biosynthesis.

Figures 2A, 2B and 2C show phase area confluence of PD002 treated with CPPB in kinetic proliferation assays.

Figures 3A and 3B show analyses of migration inhibition of pancreatic cancers, a cervical carcinoma, and a colorectal adenocarcinoma by treatment of CPPB in wound healing (scratch) assays.

Figure 4 shows cells migration of PD002 by gemcitabine, tunicamycin, and CPPB via transwell chamber.

Figure 5 shows immunofluorescent staining to observe the effect of CPPB on snail in pancreatic cancer cells and a colorectal adenocarcinoma.

Figure 6 shows a western blot for CPPB in cervical cancer.

Figure 7 shows immunofluorescent staining to observe the effect of CPPB on E-cadherin in pancreatic cancer cells and a colorectal adenomcarcinoma.

Figure 8 shows immunofluorescent staining to observe the effect of CPPB on DPAGT1 expression levels in pancreatic cancer cells and a colorectal adenomcarcinoma.

5 **Figure 9** shows RT-qPCR analyses of DPAGT1 expression level in PD002 treated with CPPB.

DETAILED DESCRIPTION

Capuramycin is a nucleoside antibiotic that has a narrow-spectrum of activity against
 10 Gram-positive bacteria including *Mycobacterium tuberculosis* (Mtb) (Siricilla, S., et al., *J. Antibiot.* **2015**, 68, 271-278). To date, medicinal chemistry efforts on capuramycin have been focused on developing a new tuberculosis (TB) drug. New capuramycin analogues have been synthesized to improve bacterial phospho-MurNAc-pentapeptide translocase I (MraY and MurX for *Mycobacterium* spp.) enzyme as well as antimycobacterial activities (Kurosu, M. et al.,
 15 *Heterocycles* **2009**, 77, 217-225). Somewhat recently, the anti-*Clostridioides difficile* (formerly *Clostridium difficile*) activity of a capuramycin analogue has been reported (Moore, J. H., et al., *J. Antimicrob Chemother.* **2016**, 71, 1300-1306). Capuramycin is a specific inhibitor of MraY with the IC₅₀ value of 0.15 μM, however, some other nucleoside antibiotics (e.g., muraymycin A1 and tunicamycins) display activity against MraY, WecA (polyprenyl phosphate-GlcNAc-1-phosphate transferase), and its human homologue, DPAGT1 (N-acetylglucosaminephosphotransferase 1)-type phosphotransferases (Mitachi, K., et al. *J. Am. Chem. Soc.* **2016**, 138, 12975-12980). MraY is an essential enzyme for growth of the vast majority of bacteria that catalyzes the transformation from UDP-MurNAc-pentapeptide (Park's nucleotide) to prenyl-MurNAc-pentapeptide (lipid I) (van Heijenoort, J. *Microbiol. Mol. Biol. Rev.* **2007**, 71, 620-635). WecA catalyzes the transformation from UDP-GlcNAc to
 20 decaprenyl-P-P-GlcNAc, the first membrane-anchored glycopospholipid that is responsible for the biosynthesis of mycolylarabinogalactan in *Mycobacterium tuberculosis* (Mtb). WecA is an essential enzyme for the growth of Mtb and some other bacteria.

Biochemical studies of WecA enzyme are hampered by lack of selective inhibitor
 30 molecules. Tunicamycin shows inhibitory activity against these phosphotransferases with the IC₅₀ values of 3.38 μM (MraY/MurX), 0.15 μM (WecA), and 2.5 μM (DPAGT1). CPZEN-45, an antimycobacterial MraY inhibitor, was reported to exhibit WecA inhibitory activity (IC₅₀ ~0.058 μg/mL). It has been shown that 2'-O-methyl capuramycin does not exhibit MraY/MurX inhibitory activity, but displays a strong WecA inhibitory activity (IC₅₀ 0.060 μM). *In vitro* cytotoxicity of
 35 tunicamycin has been documented in a number of articles (Zhong, J-T., et al. *Tumor Biol.* **2017**, 39). Acute toxicity of tunicamycin due to its narrow therapeutic window (LD₅₀: 2.0 mg/kg,

LD100: 3.5 mg/kg mice, IP) discourages scientists from developing tunicamycin for new antibacterial, antifungal, and anti-cancer agents. A large number of scientists believe that cytotoxicity of tunicamycin is attributable to its interaction with DPAGT1, which catalyzes the first and rate limiting step in the dolichol-linked oligosaccharide pathway in N-linked glycoprotein biosynthesis (Figure 1).

Provided herein are novel DPAGT1 inhibitors that exhibit *in vitro* anti-invasion and anti-metastasis activity.

Definitions

As used herein, the articles “a” and “an” refer to one or to more than one (i.e., to at least one) of the grammatical object of the article. By way of example, “an element” means one element or more than one element. Furthermore, use of the term “including” as well as other forms, such as “include,” “includes,” and “included,” is not limiting.

As used herein, “pharmaceutical combination” or “combination” refers to formulations of the separate compounds with or without instructions for combined use or to combination products. The combination compounds may thus be entirely separate pharmaceutical dosage forms or in pharmaceutical compositions that are also sold independently of each other and where just instructions for their combined use are provided in the package equipment, e.g., leaflet or the like, or in other information, e.g., provided to physicians and medical staff (e.g. oral communications, communications in writing or the like), for simultaneous or sequential use for being jointly active.

As used herein, the terms “synergy” or “synergistic effect” refer to the effect achieved when the active ingredients, i.e., DPAGT1 inhibitor and additional therapeutic agent, used together is greater than the sum of the effects that results from using the compounds separately.

At various places in the present specification, certain features of the compounds are disclosed in groups or in ranges. It is specifically intended that such a disclosure include each and every individual subcombination of the members of such groups and ranges. For example, the term “C₁₋₆ alkyl” is specifically intended to individually disclose (without limitation) methyl, ethyl, C₃ alkyl, C₄ alkyl, C₅ alkyl and C₆ alkyl.

The term “n-membered,” where n is an integer, typically describes the number of ring-forming atoms in a moiety where the number of ring-forming atoms is n. For example, piperidinyl is an example of a 6-membered heterocycloalkyl ring, pyrazolyl is an example of a 5-membered heteroaryl ring, pyridyl is an example of a 6-membered heteroaryl ring and 1,2,3,4-tetrahydro-naphthalene is an example of a 10-membered cycloalkyl group.

At various places in the present specification, variables defining divalent linking groups may be described. It is specifically intended that each linking substituent include both

the forward and backward forms of the linking substituent. For example, $\text{-NR}(\text{CR}'\text{R}'')_n\text{-}$ includes both $\text{-NR}(\text{CR}'\text{R}'')_n\text{-}$ and $\text{-(CR}'\text{R}'')_n\text{NR-}$ and is intended to disclose each of the forms individually. Where the structure requires a linking group, the Markush variables listed for that group are understood to be linking groups. For example, if the structure requires a linking group and the Markush group definition for that variable lists "alkyl" or "aryl" then it is understood that the "alkyl" or "aryl" represents a linking alkylene group or arylene group, respectively.

The term "substituted" means that an atom or group of atoms formally replaces hydrogen as a "substituent" attached to another group. The term "substituted," unless otherwise indicated, refers to any level of substitution, e.g., mono-, di-, tri-, tetra- or penta-substitution, where such substitution is permitted. The substituents are independently selected, and substitution may be at any chemically accessible position. It is to be understood that substitution at a given atom is limited by valency. It is to be understood that substitution at a given atom results in a chemically stable molecule. The phrase "optionally substituted" means unsubstituted or substituted. The term "substituted" means that a hydrogen atom is removed and replaced by a substituent. A single divalent substituent, e.g., oxo, can replace two hydrogen atoms.

The term " C_{n-m} " indicates a range which includes the endpoints, wherein n and m are integers and indicate the number of carbons. Examples include C_{1-4} , C_{1-6} and the like.

The term "alkyl" employed alone or in combination with other terms, refers to a saturated hydrocarbon group that may be straight-chained or branched. The term " C_{n-m} alkyl," refers to an alkyl group having n to m carbon atoms. An alkyl group formally corresponds to an alkane with one C-H bond replaced by the point of attachment of the alkyl group to the remainder of the compound. In some embodiments, the alkyl group contains from 1 to 6 carbon atoms, from 1 to 4 carbon atoms, from 1 to 3 carbon atoms, or 1 to 2 carbon atoms. Examples of alkyl moieties include, but are not limited to, chemical groups such as methyl, ethyl, *n*-propyl, isopropyl, *n*-butyl, *tert*-butyl, isobutyl, *sec*-butyl; higher homologs such as 2-methyl-1-butyl, *n*-pentyl, 3-pentyl, *n*-hexyl, 1,2,2-trimethylpropyl and the like.

The term "alkenyl" employed alone or in combination with other terms, refers to a straight-chain or branched hydrocarbon group corresponding to an alkyl group having one or more double carbon-carbon bonds. An alkenyl group formally corresponds to an alkene with one C-H bond replaced by the point of attachment of the alkenyl group to the remainder of the compound. The term " C_{n-m} alkenyl" refers to an alkenyl group having n to m carbons. In some embodiments, the alkenyl moiety contains 2 to 6, 2 to 4, or 2 to 3 carbon atoms. Example alkenyl groups include, but are not limited to, ethenyl, *n*-propenyl, isopropenyl, *n*-butenyl, *sec*-butenyl and the like.

The term “alkynyl” employed alone or in combination with other terms, refers to a straight-chain or branched hydrocarbon group corresponding to an alkyl group having one or more triple carbon-carbon bonds. An alkynyl group formally corresponds to an alkyne with one C-H bond replaced by the point of attachment of the alkyl group to the remainder of the compound. The term “C_{n-m} alkynyl” refers to an alkynyl group having n to m carbons. Example alkynyl groups include, but are not limited to, ethynyl, propyn-1-yl, propyn-2-yl and the like. In some embodiments, the alkynyl moiety contains 2 to 6, 2 to 4, or 2 to 3 carbon atoms.

The term “alkoxy,” employed alone or in combination with other terms, refers to a group of formula -O-alkyl, wherein the alkyl group is as defined above. The term “C_{n-m} alkoxy” refers to an alkoxy group, the alkyl group of which has n to m carbons. Example alkoxy groups include methoxy, ethoxy, propoxy (e.g., *n*-propoxy and isopropoxy), *t*-butoxy and the like. In some embodiments, the alkyl group has 1 to 6, 1 to 4, or 1 to 3 carbon atoms. The term “C_{n-m} dialkoxy” refers to a linking group of formula -O-(C_{n-m} alkyl)-O-, the alkyl group of which has n to m carbons. Example dialkoxy groups include -OCH₂CH₂O- and OCH₂CH₂CH₂O-. In some embodiments, the two O atoms of a C_{n-m} dialkoxy group may be attached to the same B atom to form a 5- or 6- membered heterocycloalkyl group.

The terms “halo” or “halogen,” used alone or in combination with other terms, refers to fluoro, chloro, bromo and iodo. In some embodiments, “halo” refers to a halogen atom selected from F, Cl, or Br. In some embodiments, halo groups are F.

The term “haloalkyl” as used herein refers to an alkyl group in which one or more of the hydrogen atoms has been replaced by a halogen atom. The term “C_{n-m} haloalkyl” refers to a C_{n-m} alkyl group having n to m carbon atoms and from at least one up to {2(n to m)+1} halogen atoms, which may either be the same or different. In some embodiments, the halogen atoms are fluoro atoms. In some embodiments, the haloalkyl group has 1 to 6 or 1 to 4 carbon atoms. Example haloalkyl groups include CF₃, C₂F₅, CHF₂, CH₂F, CCl₃, CHCl₂, C₂Cl₅ and the like. In some embodiments, the haloalkyl group is a fluoroalkyl group.

The term “aromatic” refers to a carbocycle or heterocycle having one or more polyunsaturated rings having aromatic character (*i.e.*, having (4n + 2) delocalized π (pi) electrons where n is an integer).

The term “aryl,” employed alone or in combination with other terms, refers to an aromatic hydrocarbon group, which may be monocyclic or polycyclic (e.g., having 2 fused rings). The term “C_{n-m} aryl” refers to an aryl group having from n to m ring carbon atoms. Aryl groups include, e.g., phenyl, naphthyl, and the like. In some embodiments, aryl groups have from 6 to about 10 carbon atoms. In some embodiments, aryl groups have 6 carbon atoms. In some embodiments, aryl groups have 10 carbon atoms. In some embodiments, the aryl group is phenyl. In some embodiments, the aryl group is naphthyl.

The term "heteroaryl" or "heteroaromatic," employed alone or in combination with other terms, refers to a monocyclic or polycyclic aromatic heterocycle having at least one heteroatom ring member selected from sulfur, oxygen and nitrogen. In some embodiments, the heteroaryl ring has 1, 2, 3 or 4 heteroatom ring members independently selected from nitrogen, sulfur and oxygen. In some embodiments, any ring-forming N in a heteroaryl moiety can be an N-oxide. In some embodiments, the heteroaryl has 5-14 ring atoms including carbon atoms and 1, 2, 3 or 4 heteroatom ring members independently selected from nitrogen, sulfur and oxygen. In some embodiments, the heteroaryl has 5-10 ring atoms including carbon atoms and 1, 2, 3 or 4 heteroatom ring members independently selected from nitrogen, sulfur and oxygen. In some embodiments, the heteroaryl has 5-6 ring atoms and 1 or 2 heteroatom ring members independently selected from nitrogen, sulfur and oxygen. In some embodiments, the heteroaryl is a five-membered or six-membered heteroaryl ring. In other embodiments, the heteroaryl is an eight-membered, nine-membered or ten-membered fused bicyclic heteroaryl ring. Example heteroaryl groups include, but are not limited to, pyridinyl (pyridyl), pyrimidinyl, pyrazinyl, pyridazinyl, pyrrolyl, pyrazolyl, azolyl, oxazolyl, isoxazolyl, thiazolyl, imidazolyl, furanyl, thiophenyl, quinolinyl, isoquinolinyl, naphthyridinyl (including 1,2-, 1,3-, 1,4-, 1,5-, 1,6-, 1,7-, 1,8-, 2,3- and 2,6-naphthyridine), indolyl, isoindolyl, benzothiophenyl, benzofuranyl, benzisoxazolyl, imidazo[1,2-*b*]thiazolyl, purinyl, and the like. In some embodiments, the heteroaryl group is pyridone (e.g., 2-pyridone).

A five-membered heteroaryl ring is a heteroaryl group having five ring atoms wherein one or more (e.g., 1, 2 or 3) ring atoms are independently selected from N, O and S. Exemplary five-membered ring heteroaryls include thienyl, furyl, pyrrolyl, imidazolyl, thiazolyl, oxazolyl, pyrazolyl, isothiazolyl, isoxazolyl, 1,2,3-triazolyl, tetrazolyl, 1,2,3-thiadiazolyl, 1,2,3-oxadiazolyl, 1,2,4-triazolyl, 1,2,4-thiadiazolyl, 1,2,4-oxadiazolyl, 1,3,4-triazolyl, 1,3,4-thiadiazolyl and 1,3,4-oxadiazolyl.

A six-membered heteroaryl ring is a heteroaryl group having six ring atoms wherein one or more (e.g., 1, 2 or 3) ring atoms are independently selected from N, O and S. Exemplary six-membered ring heteroaryls are pyridyl, pyrazinyl, pyrimidinyl, triazinyl, isoindolyl, and pyridazinyl.

The compounds described herein can be asymmetric (e.g., having one or more stereocenters). All stereoisomers, such as enantiomers and diastereomers, are intended unless otherwise indicated. Compounds provided herein that contain asymmetrically substituted carbon atoms can be isolated in optically active or racemic forms. Methods on how to prepare optically active forms from optically inactive starting materials are known in the art, such as by resolution of racemic mixtures or by stereoselective synthesis. Many geometric isomers of olefins, C=N double bonds and the like can also be present in the

compounds described herein, and all such stable isomers are contemplated in the present disclosure. *Cis* and *trans* geometric isomers of the compounds of the present disclosure are described and may be isolated as a mixture of isomers or as separated isomeric forms.

Resolution of racemic mixtures of compounds can be carried out by any of numerous methods known in the art. One method includes fractional recrystallization using a chiral resolving acid which is an optically active, salt-forming organic acid. Suitable resolving agents for fractional recrystallization methods are, e.g., optically active acids, such as the D and L forms of tartaric acid, diacetyltartaric acid, dibenzoyltartaric acid, mandelic acid, malic acid, lactic acid or the various optically active camphorsulfonic acids such as β -camphorsulfonic acid. Other resolving agents suitable for fractional crystallization methods include stereoisomerically pure forms of α -methylbenzylamine (e.g., *S* and *R* forms, or diastereomerically pure forms), 2-phenylglycinol, norephedrine, ephedrine, *N*-methylephedrine, cyclohexylethylamine, 1,2-diaminocyclohexane and the like.

Resolution of racemic mixtures can also be carried out by elution on a column packed with an optically active resolving agent (e.g., dinitrobenzoylphenylglycine). Suitable elution solvent composition can be determined by one skilled in the art.

In some embodiments, the compounds provided herein have the (*R*)-configuration. In other embodiments, the compounds have the (*S*)-configuration. In compounds with more than one chiral centers, each of the chiral centers in the compound may be independently (*R*) or (*S*), unless otherwise indicated.

Compounds provided herein also include tautomeric forms. Tautomeric forms result from the swapping of a single bond with an adjacent double bond together with the concomitant migration of a proton. Tautomeric forms include prototropic tautomers which are isomeric protonation states having the same empirical formula and total charge. Example prototropic tautomers include ketone – enol pairs, amide - imidic acid pairs, lactam – lactim pairs, enamine – imine pairs, and annular forms where a proton can occupy two or more positions of a heterocyclic system, e.g., 1*H*- and 3*H*-imidazole, 1*H*-, 2*H*- and 4*H*-1,2,4-triazole, 1*H*- and 2*H*- isoindole and 1*H*- and 2*H*-pyrazole. Tautomeric forms can be in equilibrium or sterically locked into one form by appropriate substitution.

Compounds provided herein can also include all isotopes of atoms occurring in the intermediates or final compounds. Isotopes include those atoms having the same atomic number but different mass numbers. For example, isotopes of hydrogen include tritium and deuterium. One or more constituent atoms of the compounds provided herein can be replaced or substituted with isotopes of the atoms in natural or non-natural abundance. In some embodiments, the compound includes at least one deuterium atom. For example, one or more hydrogen atoms in a compound of the present disclosure can be replaced or

substituted by deuterium. In some embodiments, the compound includes two or more deuterium atoms. In some embodiments, the compound includes 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 or 12 deuterium atoms. Synthetic methods for including isotopes into organic compounds are known in the art (Deuterium Labeling in Organic Chemistry by Alan F. Thomas (New York, N.Y., Appleton-Century-Crofts, 1971; The Renaissance of H/D Exchange by Jens Atzrodt, Volker Derdau, Thorsten Fey and Jochen Zimmermann, Angew. Chem. Int. Ed. 2007, 7744-7765; The Organic Chemistry of Isotopic Labelling by James R. Hanson, Royal Society of Chemistry, 2011). Isotopically labeled compounds can be used in various studies such as NMR spectroscopy, metabolism experiments, and/or assays.

Substitution with heavier isotopes such as deuterium, may afford certain therapeutic advantages resulting from greater metabolic stability, for example, increased *in vivo* half-life or reduced dosage requirements, and hence may be preferred in some circumstances. (A. Kerekes et.al. *J. Med. Chem.* **2011**, *54*, 201-210; R. Xu et.al. *J. Label Compd. Radiopharm.* **2015**, *58*, 308-312).

The term "compound" as used herein is meant to include all stereoisomers, geometric isomers, tautomers and isotopes of the structures depicted. The term is also meant to refer to compounds provided herein, regardless of how they are prepared, e.g., synthetically, through biological process (e.g., metabolism or enzyme conversion), or a combination thereof.

All compounds, and pharmaceutically acceptable salts thereof, can be found together with other substances such as water and solvents (e.g., hydrates and solvates) or can be isolated. When in the solid state, the compounds described herein and salts thereof may occur in various forms and may, e.g., take the form of solvates, including hydrates. The compounds may be in any solid state form, such as a polymorph or solvate, so unless clearly indicated otherwise, reference in the specification to compounds and salts thereof should be understood as encompassing any solid state form of the compound.

In some embodiments, the compounds provided herein, or salts thereof, are substantially isolated. By "substantially isolated" is meant that the compound is at least partially or substantially separated from the environment in which it was formed or detected.

Partial separation can include, e.g., a composition enriched in the compounds provided herein. Substantial separation can include compositions containing at least about 50%, at least about 60%, at least about 70%, at least about 80%, at least about 90%, at least about 95%, at least about 97%, or at least about 99% by weight of the compounds provided herein, or salt thereof.

The phrase "pharmaceutically acceptable" is employed herein to refer to those compounds, materials, compositions and/or dosage forms that are, within the scope of sound medical judgment, suitable for use in contact with the tissues of human beings and

animals without excessive toxicity, irritation, allergic response, or other problem or complication, commensurate with a reasonable benefit/risk ratio.

The present disclosure also includes pharmaceutically acceptable salts of the compounds described herein. The term “pharmaceutically acceptable salts” refers to derivatives of the disclosed compounds wherein the parent compound is modified by converting an existing acid or base moiety to its salt form. Examples of pharmaceutically acceptable salts include, but are not limited to, mineral or organic acid salts of basic residues such as amines; alkali or organic salts of acidic residues such as carboxylic acids; and the like. The pharmaceutically acceptable salts of the present disclosure include the non-toxic salts of the parent compound formed, e.g., from non-toxic inorganic or organic acids. The pharmaceutically acceptable salts of the present disclosure can be synthesized from the parent compound which contains a basic or acidic moiety by conventional chemical methods. Generally, such salts can be prepared by reacting the free acid or base forms of these compounds with a stoichiometric amount of the appropriate base or acid in water or in an organic solvent, or in a mixture of the two; generally, non-aqueous media like ether, ethyl acetate, alcohols (e.g., methanol, ethanol, iso-propanol or butanol) or acetonitrile (MeCN) are preferred. Lists of suitable salts are found in *Remington's Pharmaceutical Sciences*, 17th Ed., (Mack Publishing Company, Easton, 1985), p. 1418, Berge *et al.*, *J. Pharm. Sci.*, **1977**, 66(1), 1-19 and in Stahl *et al.*, *Handbook of Pharmaceutical Salts: Properties, Selection, and Use*, (Wiley, 2002). In some embodiments, the compounds described herein include the N-oxide forms.

As used herein, the phrase “pharmaceutically acceptable carrier or excipient” refers to a pharmaceutically-acceptable material, composition, or vehicle, such as a liquid or solid filler, diluent, solvent, or encapsulating material. Excipients or carriers are generally safe, non-toxic and neither biologically nor otherwise undesirable and include excipients or carriers that are acceptable for veterinary use as well as human pharmaceutical use. In one embodiment, each component is “pharmaceutically acceptable” as defined herein. See, e.g., *Remington: The Science and Practice of Pharmacy*, 21st ed.; Lippincott Williams & Wilkins: Philadelphia, Pa., 2005; *Handbook of Pharmaceutical Excipients*, 6th ed.; Rowe *et al.*, Eds.; The Pharmaceutical Press and the American Pharmaceutical Association: 2009; *Handbook of Pharmaceutical Additives*, 3rd ed.; Ash and Ash Eds.; Gower Publishing Company: 2007; *Pharmaceutical Preformulation and Formulation*, 2nd ed.; Gibson Ed.; CRC Press LLC: Boca Raton, Fla., 2009.

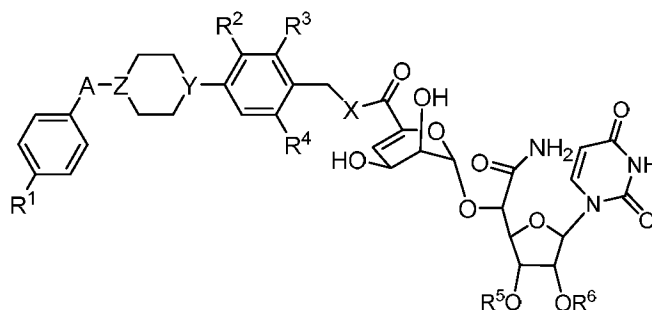
As used herein, the term “treating” or “treatment” refers to inhibiting a disease; for example, inhibiting a disease, condition, or disorder in an individual who is experiencing or displaying the pathology or symptomology of the disease, condition, or disorder (*i.e.*, arresting further development of the pathology and/or symptomology) or ameliorating the

disease; for example, ameliorating a disease, condition, or disorder in an individual who is experiencing or displaying the pathology or symptomology of the disease, condition, or disorder (*i.e.*, reversing the pathology and/or symptomology) such as decreasing the severity of the disease.

- 5 The term “prevent,” “preventing,” or “prevention” as used herein, comprises the prevention of at least one symptom associated with or caused by the state, disease or disorder being prevented.

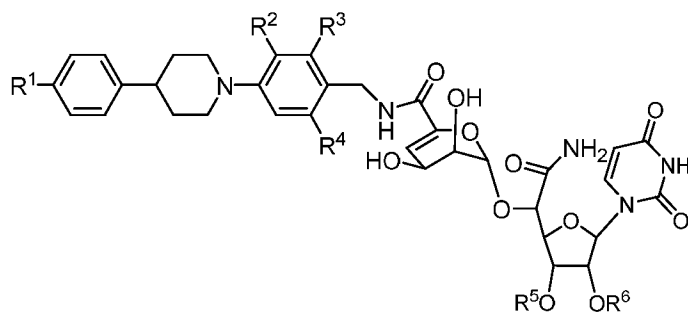
Compounds

In an aspect, provided herein is a compound of Formula I:



(I)

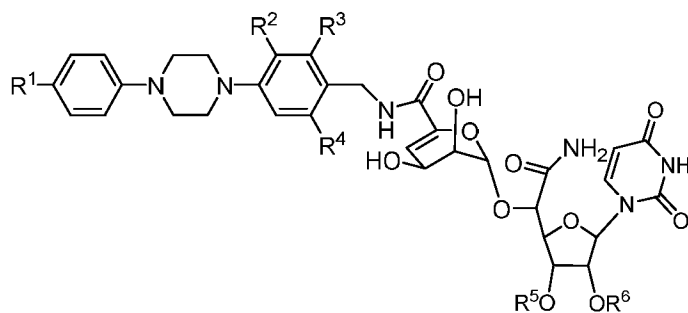
- 10 or a pharmaceutically acceptable salt thereof;
 wherein
 X is NH, O, or $-(CH_2)_m-$;
 Y is CH or N;
 Z is CH or N;
 15 A is absent, O, or NH;
 R¹ is OR⁷ or $-(CH_2)_nNHR^7$;
 R² is H or halo;
 R³ is selected from the group consisting of H, halo, C₁-C₆ alkyl, C₂-C₆ alkenyl, C₂-C₆
 alkynyl, C₁-C₆ alkoxy, and C₁-C₆ haloalkyl;
 20 R⁴ is H or halo;
 R⁵ and R⁶ are each independently selected from the group consisting of H, C₁-C₆
 alkyl, and C(O)C₁-C₆ alkyl;
 R⁷ is selected from the group consisting of H, C₁-C₆ alkyl, C₁-C₆ haloalkyl, C₆-C₁₀
 aryl, and 5-10 membered heteroaryl; wherein aryl and heteroaryl are each optionally
 25 substituted one, two, or three times with OC₁-C₆ haloalkyl; and
 m and n are, independently at each occurrence, 0, 1, 2, or 3.
 In an embodiment, the compound of Formula I is a compound of Formula II:



(II)

or a pharmaceutically acceptable salt thereof.

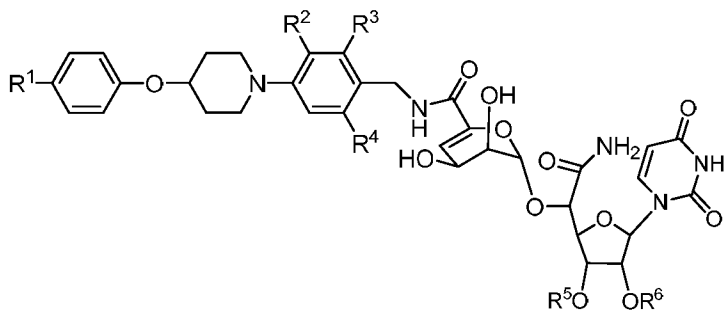
In another embodiment, the compound of Formula I is a compound of Formula III:



(III)

or a pharmaceutically acceptable salt thereof.

In yet another embodiment, the compound of Formula I is a compound of Formula IV:



(IV)

or a pharmaceutically acceptable salt thereof.

In still another embodiment, R^1 is OR^7 . In an embodiment, R^1 is $-(CH_2)_nNHR^7$. In

- 5 another embodiment, R^7 is selected from the group consisting of C_1 - C_6 alkyl, C_1 - C_6 haloalkyl, and phenyl, wherein phenyl is optionally substituted one time with OC_1 - C_6 haloalkyl. In yet another embodiment, R^7 is selected from the group consisting of methyl, ethyl, C_3 alkyl, C_4 alkyl, CF_3 , and phenyl- OCF_3 .

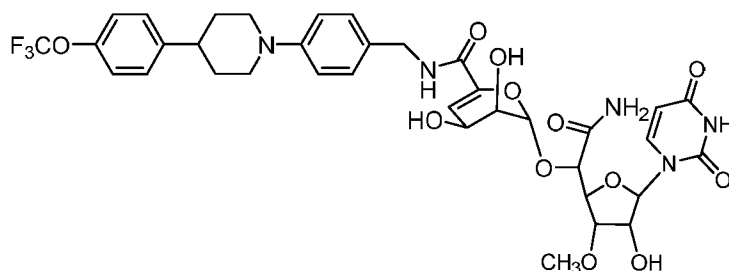
In an embodiment, R^2 is H. In another embodiment, R^2 is fluoro.

In yet another embodiment, R^3 is selected from the group consisting of H, fluoro, methyl, methoxy, C_2 alkenyl, and C_2 alkynyl. In still another embodiment, R^3 is H.

In an embodiment, R^4 is H. In another embodiment, R^4 is fluoro.

In yet another embodiment, R^5 is methyl. In still another embodiment, R^6 is H or methyl. In an embodiment, R^6 is H.

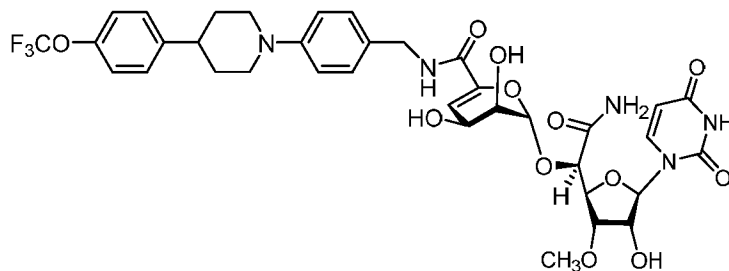
In another embodiment, the compound of Formula I is CPPB:



(CPPB)

or a pharmaceutically acceptable salt thereof.

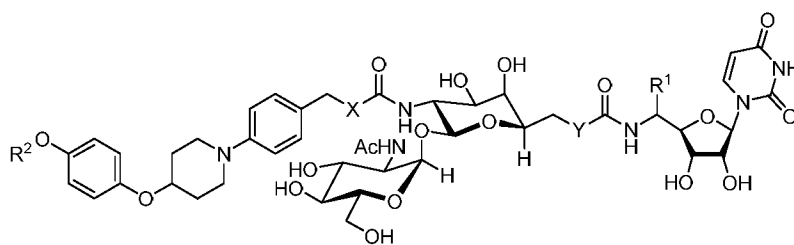
In yet another embodiment, the compound of Formula I is CPPB1:



(CPPB1)

or a pharmaceutically acceptable salt thereof.

In another aspect, provided herein is a compound of Formula V:



(V)

or a pharmaceutically acceptable salt thereof;

wherein

X and Y are independently O or NH;

R^1 is selected from the group consisting of H, OH, $C(O)NH_2$, CO_2H , $C(O)H$, and

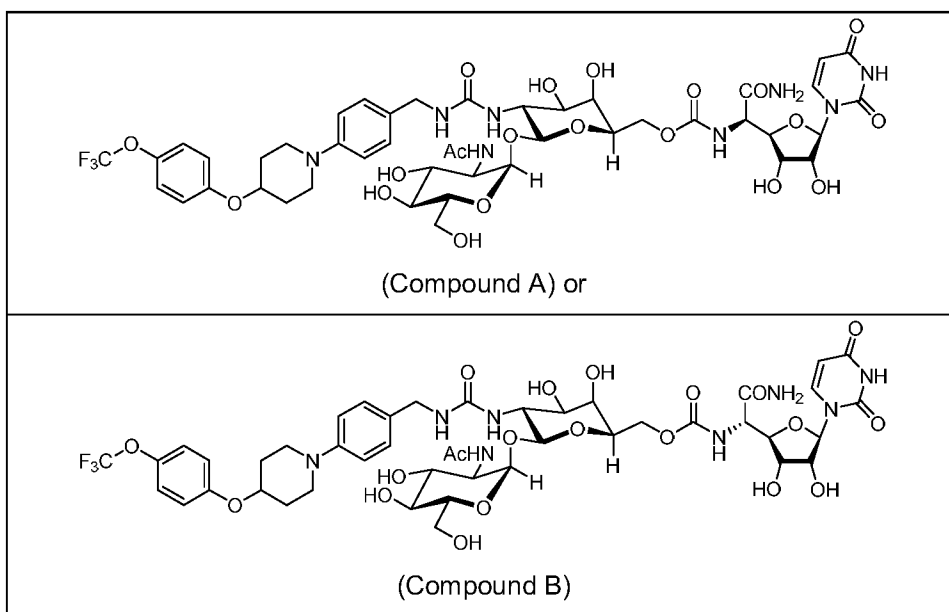
$C(O)halo$; and

R^2 is selected from the group consisting of H, C_1 - C_6 alkyl, C_1 - C_6 haloalkyl, C_6 - C_{10} aryl, and 5-10 membered heteroaryl.

In an embodiment, X is O. In another embodiment, X is NH. In yet another embodiment Y is O. In still another embodiment, Y is NH.

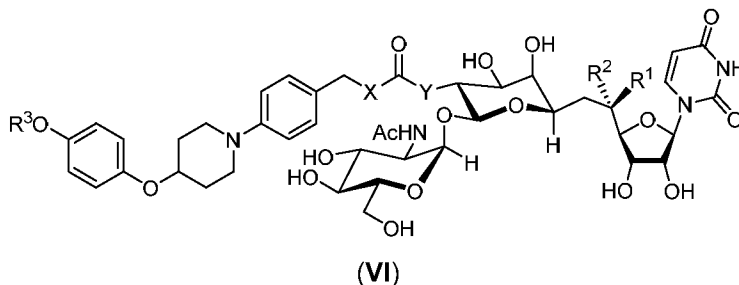
5 In an embodiment, R^1 is $C(O)NH_2$. In another embodiment, R^2 is C_1 - C_6 haloalkyl.

In another embodiment, the compound of Formula V is



or a pharmaceutically acceptable salt thereof.

In yet another aspect, provided herein is a compound of Formula VI:



10

or a pharmaceutically acceptable salt thereof;

wherein

X and Y are independently O or NH;

R^1 and R^2 are each independently selected from H and OH; and

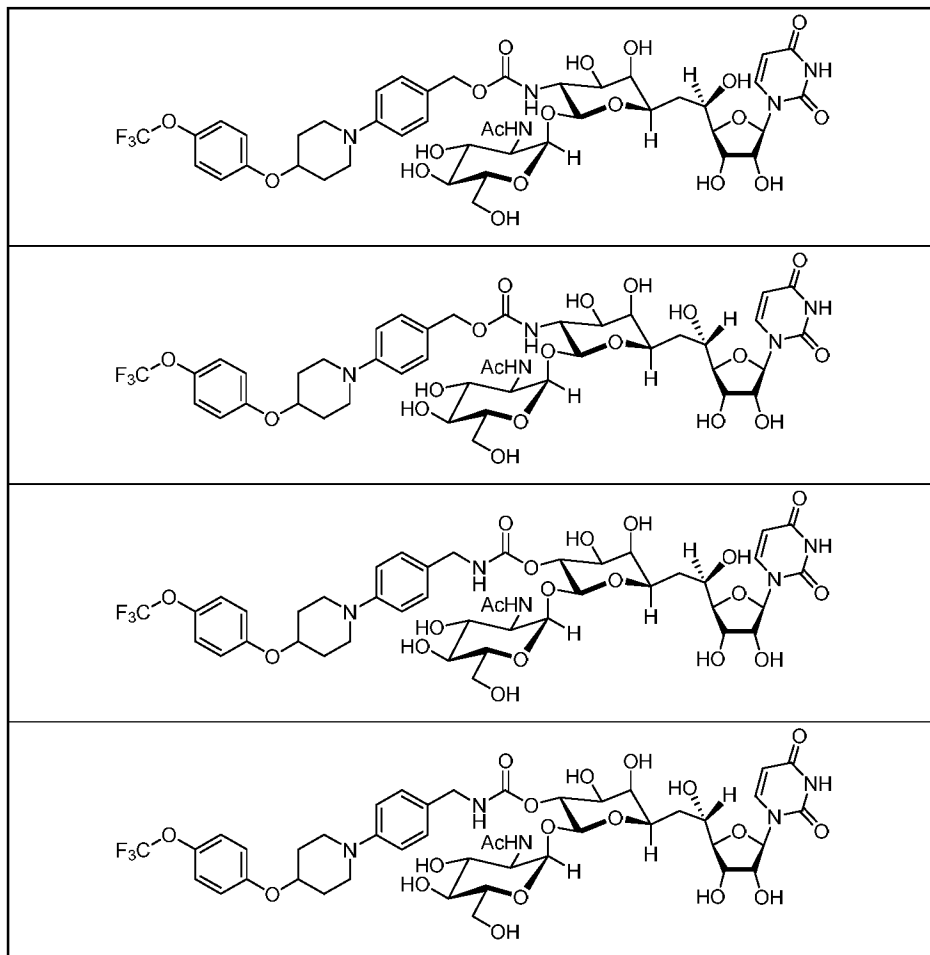
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R^3 is selected from the group consisting of H, C_1 - C_6 alkyl, C_1 - C_6 haloalkyl, C_6 - C_{10} aryl, and 5-10 membered heteroaryl.

In an embodiment, X and Y are NH. In another embodiment, X is NH and Y is O. In yet another embodiment, X is O and Y is NH.

In still another embodiment, R^3 is C_1 - C_6 haloalkyl.

In an embodiment, the compound of Formula VI is selected from the group consisting of:



or a pharmaceutically acceptable salt thereof.

In another aspect, provided herein is a pharmaceutical composition comprising a
5 compound disclosed herein, and at least one pharmaceutically acceptable carrier.

In an embodiment, the pharmaceutical composition further comprises an additional
therapeutic agent.

In another embodiment, the additional therapeutic agent is selected from the group
consisting of paclitaxel, tunicamycin, capuramycin, erlotinib, capecitabine, fluorouracil, and
10 gemcitabine. In yet another embodiment, the additional therapeutic agent is paclitaxel.

Methods of Treatment

In yet another aspect, provided herein is a method of inhibiting dolichyl-phosphate *N*-
acetylglucosaminophosphotransferase (DPAGT1) in a subject in need thereof, comprising
15 administering to the subject a therapeutically effective amount of a compound disclosed
herein or a pharmaceutical composition comprising a compound disclosed herein.

In still another aspect, provided herein is a method of treating cancer in a subject in need thereof, comprising administering to the subject a therapeutically effective amount of a compound of the present disclosure or a pharmaceutical composition comprising a compound disclosed herein.

5 In an embodiment, the cancer is selected from hematological cancers, sarcomas, lung cancers, brain cancers, gastrointestinal cancers, genitourinary tract cancers, liver cancers, bone cancers, nervous system cancers, gynecological cancers, and skin cancers.

In another embodiment, the lung cancer is selected from non-small cell lung cancer (NSCLC), small cell lung cancer, bronchogenic carcinoma, squamous cell bronchogenic
10 carcinoma, undifferentiated small cell bronchogenic carcinoma, undifferentiated large cell bronchogenic carcinoma, adenocarcinoma, bronchogenic carcinoma, alveolar carcinoma, bronchiolar carcinoma, bronchial adenoma, chondromatous hamartoma, mesothelioma, pavicellular and non-pavicellular carcinoma, bronchial adenoma, and pleuropulmonary blastoma.

15 In yet another embodiment, the lung cancer is non-small cell lung cancer (NSCLC). In still another embodiment, the lung cancer is adenocarcinoma.

In an embodiment, the gastrointestinal cancer is selected from esophagus squamous cell carcinoma, esophagus adenocarcinoma, esophagus leiomyosarcoma, esophagus lymphoma, stomach carcinoma, stomach lymphoma, stomach leiomyosarcoma, exocrine
20 pancreatic carcinoma, pancreatic ductal adenocarcinoma, pancreatic insulinoma, pancreatic glucagonoma, pancreatic gastrinoma, pancreatic carcinoid tumors, pancreatic vipoma, small bowel adenocarcinoma, small bowel lymphoma, small bowel carcinoid tumors, Kaposi's sarcoma, small bowel leiomyoma, small bowel hemangioma, small bowel lipoma, small bowel neurofibroma, small bowel fibroma, large bowel adenocarcinoma, large bowel tubular
25 adenoma, large bowel villous adenoma, large bowel hamartoma, large bowel leiomyoma, colorectal cancer, gall bladder cancer, and anal cancer.

In an embodiment, the gastrointestinal cancer is colorectal cancer.

In another embodiment, the brain cancer is selected from acoustic neuroma, astrocytoma, choroid plexus carcinoma, craniopharyngioma, embryonal tumors,
30 ependymoma, glioblastoma, glioma, medulloblastoma, meningioma, oligodendroglioma, pineoblastoma, mixed glioma, mixed glial and neuronal tumors, and primitive neuroectodermal tumors.

In another embodiment, the cancer is a carcinoma. In yet another embodiment, the carcinoma is selected from pancreatic carcinoma, colorectal carcinoma, lung carcinoma,
35 bladder carcinoma, gastric carcinoma, esophageal carcinoma, breast carcinoma, head and neck carcinoma, cervical skin carcinoma, and thyroid carcinoma.

In still another embodiment, the cancer is a hematopoietic malignancy. In an embodiment, the hematopoietic malignancy is selected from multiple myeloma, acute myelogenous leukemia, and myeloproliferative neoplasms.

5 In another embodiment, the cancer is a neoplasm. In yet another embodiment, the neoplasm is glioblastoma or sarcomas.

In an embodiment, the cancer is selected from the group consisting of hematological cancers, sarcomas, lung cancers, gastrointestinal cancers, genitourinary tract cancers, liver cancers, bone cancers, nervous system cancers, gynecological cancers, and skin cancers.

10 In an embodiment, the cancer is selected from the group consisting of pancreatic cancer, cervical cancer, colon cancer, ovarian cancer, breast cancer, pancreatic cancer, carcinoma, and adenocarcinoma.

In another embodiment, the cancer is pancreatic cancer. In yet another embodiment, the cancer is a solid tumor.

In an embodiment of the methods, the subject is human.

15 As used herein, the term "individual," "subject," or "patient," used interchangeably, refers to any animal, including mammals, preferably mice, rats, other rodents, rabbits, dogs, cats, swine, cattle, sheep, horses, or primates, and most preferably humans.

As used herein, the phrase "therapeutically effective amount" refers to the amount of active compound or pharmaceutical agent such as an amount of any of the solid forms or salts thereof as disclosed herein that elicits the biological or medicinal response in a tissue, system, animal, individual or human that is being sought by a researcher, veterinarian, medical doctor or other clinician. An appropriate "effective" amount in any individual case may be determined using techniques known to a person skilled in the art.

20

It is appreciated that certain features of the invention, which are, for clarity, described in the context of separate embodiments, can also be provided in combination in a single embodiment (while the embodiments are intended to be combined as if written in multiply dependent form). Conversely, various features of the invention which are, for brevity, described in the context of a single embodiment, can also be provided separately or in any suitable subcombination.

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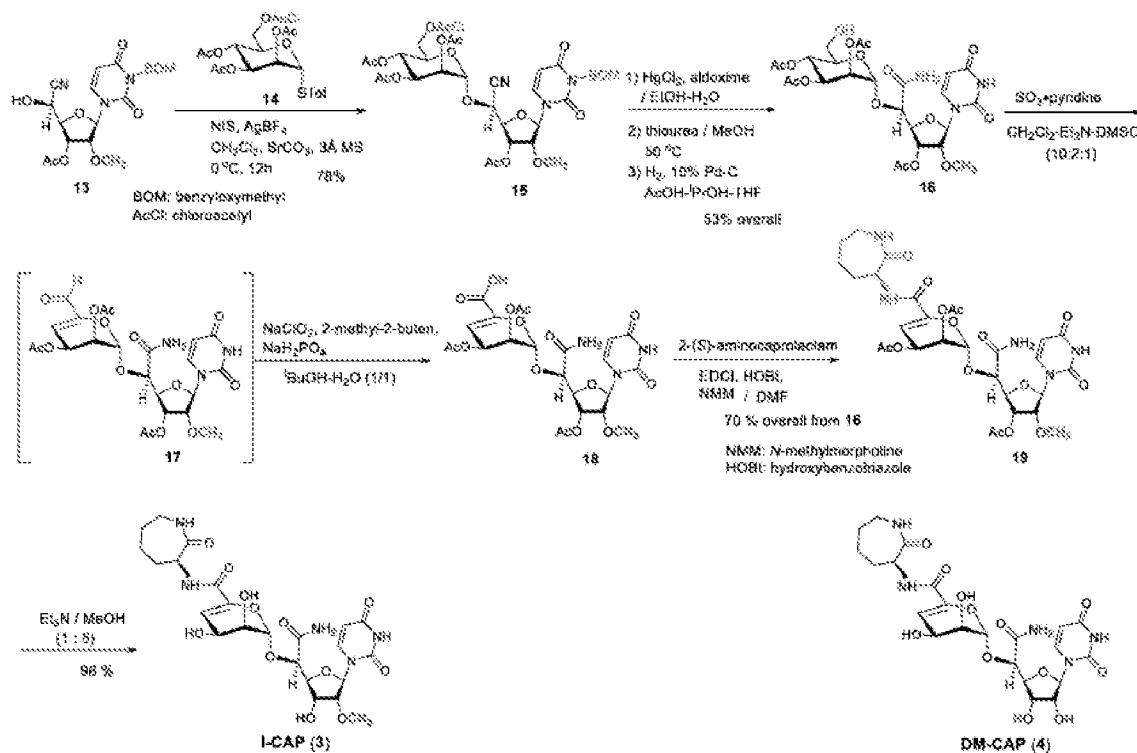
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EXAMPLES

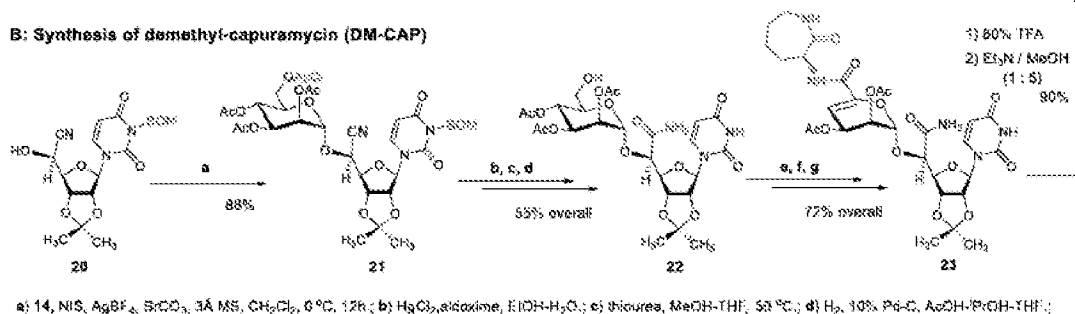
Example 1: Synthetic Procedures

Scheme 1

A: Synthesis of *iso*-capuramycin (*I*-CAP)



B: Synthesis of demethyl-capuramycin (DM-CAP)



- 5 The (S)-cyanohydrin (**13**) was subjected to NIS-AgBF₄ promoted α -selective mannosylation with the thioglycoside (**14**) to yield the α -mannosylated cyanohydrin (**15**) in 78% yield. The cyano group of **15** was hydrated using HgCl₂-aldoxime in aq. EtOH, and the BOM and chloroacetyl groups of the generated amide were deprotected stepwisely: dechloro-
- 10 provided the C6''-free alcohol **16** in 53% overall yield. Oxidation-elimination reaction of **16** with SO₃•pyridine in a solvent system (CH₂Cl₂/Et₃N/DMSO = 10/2/1) provided the α,β - unsaturated aldehyde **17** in quantitative yield (determined by ¹H NMR analysis). After all volatiles were removed, the aldehyde **17** was oxidized to the corresponding carboxylic acid

18 by using NaClO_2 in the presence of NaH_2PO_4 and 2-methyl-2-butene. The resulting carboxylic acid **18** was coupled with (2S)-aminocaprolactam by using a standard peptide-forming reaction condition (HOBt, EDCI, and NMM) to yield the coupling product **19** in 70% overall yield from **16**. Saponification of **19** by using Et_3N in MeOH provided I-Cap (**3**) in 5 quantitative yield. Similarly, dimethyl-capuramycin (DM-CAP) was synthesized in 31% overall yield from the cyanohydrin-acetonide **20**.

(2S,3S,4S,5R,6R)-2-((1S)-((2R,5R)-3-Acetoxy-5-(3-((benzyloxy)methyl)-2,4-dioxo-3,4-dihydropyrimidin-1(2H)-yl)-4-methoxytetrahydrofuran-2-yl)(cyano)methoxy)-6-((2-chloro-acetoxy)methyl)-tetrahydro-2H-pyran-3,4,5-triyl triacetate (15). To a stirred suspension of **13** (0.17 g, 0.38 mmol), **14** (0.37 g, 0.75 mmol), MS 3Å (0.50 g) and SrCO_3 (0.28 g, 1.88 mmol) in CH_2Cl_2 (9.4 mL) were added AgBF_4 (0.037 g, 0.19 mmol) and NIS (0.25 g, 1.13 mmol) at 0 °C. After being stirred for 19h, the reaction mixture was added Et_3N (1.0 mL) and passed through a silica gel pad (hexanes/ EtOAc = 1/4). The filtrate was concentrated *in vacuo*. 10 The crude mixture was purified by silica gel column chromatography (hexanes/ EtOAc = 2/1 to 1/2) to afford **15** (0.24 g, 78%): ^1H NMR (400 MHz, Chloroform-*d*) δ 7.40 – 7.27 (m, 6H), 6.07 (d, J = 4.7 Hz, 1H), 6.00 (d, J = 8.2 Hz, 1H), 5.51 (d, J = 9.8 Hz, 1H), 5.47 (d, J = 9.6 Hz, 1H), 5.37 (dd, J = 3.4, 2.0 Hz, 1H), 5.28 (d, J = 10.2 Hz, 1H), 5.22 – 5.15 (m, 2H), 4.84 (d, J = 3.2 Hz, 1H), 4.71 (s, 2H), 4.41 (dd, J = 5.5, 3.2 Hz, 1H), 4.39 – 4.35 (m, 1H), 4.33 (d, J = 6.0 Hz, 1H), 4.27 (d, 15 J = 2.3 Hz, 1H), 4.14 (d, J = 1.7 Hz, 2H), 4.03 – 4.01 (m, 1H), 3.93 (ddd, J = 8.9, 5.9, 2.4 Hz, 1H), 3.47 (s, 3H), 2.20 (s, 3H), 2.19 (s, 3H), 2.07 (s, 3H), 2.02 (s, 3H); ^{13}C NMR (101 MHz, CDCl_3) δ 170.20, 169.84, 169.50, 166.92, 162.19, 150.97, 137.75, 137.46, 128.32 (2C), 127.72, 127.69 (2C), 113.96, 103.58, 96.29, 88.68, 80.93, 80.09, 72.30, 70.42, 69.60, 68.46, 67.94, 65.16, 64.35, 63.58, 59.26, 40.61, 31.58, 20.70, 20.66, 20.62, 20.57; HRMS (ESI+) m/z calcd for 20 $\text{C}_{35}\text{H}_{41}\text{ClN}_3\text{O}_{17}$ [M + H] 810.2125, found: 810.2151.

(2R,3S,4S,5R,6R)-2-((1R)-1-((2S,5R)-3-Acetoxy-5-(2,4-dioxo-3,4-dihydropyrimidin-1(2H)-yl)-4-methoxy-tetrahydrofuran-2-yl)-2-amino-2-oxoethoxy)-6-(hydroxymethyl)tetrahydro-2H-pyran-3,4,5-triyl triacetate (16). To a stirred solution of **15** (0.24 g, 0.29 mmol) in a 9:1 mixture of EtOH and H_2O (2.9 mL) were added HgCl_2 (0.16 g, 0.59 mmol) and acetaldoxime (0.18 mL, 2.9 mmol). After being stirred for 13h at r.t., the reaction mixture was concentrated *in vacuo*. The residue was quenched with aq. NaHCO_3 , and extracted with CHCl_3 . The combined organic extracts were dried over Na_2SO_4 and concentrated *in vacuo*. The crude product was purified by silica gel column chromatography (hexanes/ EtOAc = 1/2 to $\text{CHCl}_3/\text{MeOH}$ = 96/4) to afford the 30 amide (0.21 g, 87%). To a solution of the amide (0.21 g, 0.26 mmol) in a 1:1 mixture of THF and MeOH (2.6 mL) was added thiourea (0.059 g, 0.77 mmol). After being stirred for 11h at 50 °C, the reaction mixture was concentrated *in vacuo*. The residue was diluted with H_2O and extracted

with CHCl_3 . The combined organic extracts were dried over Na_2SO_4 and concentrated *in vacuo*. The crude product was purified by silica gel column chromatography ($\text{CHCl}_3/\text{MeOH} = 98/2$ to $97/3$ to $96/4$) to afford the primary alcohol (0.15 g, 75%). To a stirred solution of the primary alcohol (0.15 g, 0.19 mmol) and AcOH (0.040 mL) in a 1:1 mixture of THF and $i\text{PrOH}$ (2.0 mL) was added 10% Pd/C (0.12 g) under N_2 . H_2 gas was introduced and the reaction mixture was stirred under H_2 atmosphere for 3h, the solution was filtered through Celite and concentrated *in vacuo*. The crude product was purified by silica gel column chromatography ($\text{CHCl}_3/\text{MeOH} = 97/3$ to $92/8$) to afford **16** (0.10 g, 81%): ^1H NMR (400 MHz, Chloroform- d) δ 9.08 (brs, 1H), 7.60 (d, $J = 8.2$ Hz, 1H), 6.87 (brs, 1H), 6.12 (brs, 1H), 6.00 (d, $J = 8.1$ Hz, 1H), 5.87 (d, $J = 3.6$ Hz, 1H), 5.55 – 5.52 (m, 1H), 5.26 – 5.22 (m, 2H), 5.20 (t, $J = 6.0$ Hz, 1H), 5.00 (d, $J = 1.7$ Hz, 1H), 4.53 (dd, $J = 6.5, 2.3$ Hz, 1H), 4.46 (d, $J = 2.3$ Hz, 1H), 4.06 (dd, $J = 5.5, 3.7$ Hz, 1H), 3.76 – 3.71 (m, 1H), 3.69 – 3.57 (m, 2H), 3.44 (s, 3H), 2.17 (s, 3H), 2.15 (s, 3H), 2.09 (s, 3H), 2.04 (s, 3H); ^{13}C NMR (101 MHz, CDCl_3) δ 171.42, 170.46, 170.46, 170.40, 163.10, 150.03, 139.50, 103.61, 97.15, 96.95, 88.50, 81.26, 80.96, 75.33, 72.91, 69.67, 68.89, 65.54, 61.27, 59.05, 50.86, 20.82, 20.75, 20.67, 20.59; HRMS (ESI+) m/z calcd for $\text{C}_{25}\text{H}_{34}\text{N}_3\text{O}_{16}$ [$\text{M} + \text{H}$] 632.1939, found: 632.1963.

(2S,3S,4S)-3,4-Diacetoxy-2-((1R)-1-((2S,5R)-3-acetoxy-5-(2,4-dioxo-3,4-dihydropyrimidin-1(2H)-yl)-4-methoxytetrahydrofuran-2-yl)-2-amino-2-oxoethoxy)-3,4-dihydro-2H-pyran-6-carboxylic acid (18). To a stirred solution of **16** (0.10 g, 0.16 mmol) and DMSO (0.11 mL, 1.57 mmol) in a 5:1 mixture of CH_2Cl_2 and Et_3N (0.80 mL) was added $\text{SO}_3 \cdot \text{pyridine}$ (0.25 g, 1.57 mmol). After being stirred for 3h at r.t., the reaction mixture was added H_2O (0.16 mL) and passed through a silica gel pad ($\text{CHCl}_3/\text{MeOH} = 92/8$) to provide the crude **17**. To a stirred solution of the crude mixture in $i\text{BuOH}$ (1.0 mL) and 2-methyl-2-butene (0.5 mL) was added a solution of NaClO_2 (0.071 g, 0.78 mmol) and $\text{NaH}_2\text{PO}_4 \cdot 2\text{H}_2\text{O}$ (0.12 g, 0.78 mmol) in H_2O (1.0 mL). After being stirred for 4h at r.t., the reaction was quenched with H_2O and extracted with $\text{CHCl}_3/\text{MeOH}$ (9/1). The combined organic extracts were dried over Na_2SO_4 and concentrated *in vacuo*. The crude product was purified by silica gel column chromatography ($\text{CHCl}_3/\text{MeOH} = 9/1$) to afford **18** (0.078 g, 85%): ^1H NMR (400 MHz, Methanol- d_4) δ 7.77 (d, $J = 8.1$ Hz, 1H), 5.94 (d, $J = 11.7$ Hz, 1H), 5.94 (s, 1H), 5.78 (t, $J = 2.1$ Hz, 1H), 5.66 (dd, $J = 4.5, 2.5$ Hz, 1H), 5.56 (ddd, $J = 4.7, 3.2, 1.6$ Hz, 1H), 5.32 (d, $J = 3.3$ Hz, 1H), 4.99 (t, $J = 5.2$ Hz, 1H), 4.85 (d, $J = 2.1$ Hz, 1H), 4.60 (dd, $J = 5.2, 2.0$ Hz, 1H), 3.95 (t, $J = 5.0$ Hz, 1H), 3.39 (s, 3H), 2.13 (s, 3H), 2.08 (s, 3H), 2.05 (s, 3H); ^{13}C NMR (101 MHz, MeOD) δ 172.79, 172.06, 171.60, 167.79, 166.01, 152.05, 148.16, 140.97, 104.23, 103.98, 97.91, 88.13, 83.38, 82.91, 76.56, 71.95, 65.17, 65.06, 59.41, 20.75, 20.63, 20.57; HRMS (ESI+) m/z calcd for $\text{C}_{23}\text{H}_{28}\text{N}_3\text{O}_{15}$ [$\text{M} + \text{H}$] 586.1520, found: 586.1549.

(2S,3S,4S)-2-((1R)-1-((2S,5R)-3-Acetoxy-5-(2,4-dioxo-3,4-dihydropyrimidin-1(2H)-yl)-4-methoxy-tetrahydrofuran-2-yl)-2-amino-2-oxoethoxy)-6-(((S)-2-oxoazepan-3-yl)carbamoyl)-3,4-dihydro-2H-pyran-3,4-diyl diacetate (19).

To a stirred solution of **18** (31 mg, 0.053 mmol), 2-(S)-aminocaprolactam (26 mg, 0.16 mmol), HOBt (21 mg, 0.16 mmol) and NMM (58 μ L, 0.53 mmol) in DMF (0.26 mL) was added EDCI (51 mg, 0.26 mmol). After being stirred for 6h at r.t., the reaction was quenched with aq. NaHCO₃, and extracted with CHCl₃/MeOH (9/1). The combined organic extracts were dried over Na₂SO₄ and concentrated *in vacuo*. The crude product was purified by silica gel column chromatography (CHCl₃/MeOH = 95/5) to afford **19** (30 mg, 82%): ¹H NMR (400 MHz, Methanol-*d*₄) δ 7.68 (d, *J* = 8.2 Hz, 1H), 6.02 (t, *J* = 2.1 Hz, 1H), 5.91 (d, *J* = 4.2 Hz, 1H), 5.89 (d, *J* = 6.3 Hz, 1H), 5.73 (dd, *J* = 4.4, 2.5 Hz, 1H), 5.68 – 5.65 (m, 1H), 5.51 (d, *J* = 3.0 Hz, 1H), 5.01 (d, *J* = 4.6 Hz, 1H), 4.76 (d, *J* = 2.0 Hz, 1H), 4.62 (d, *J* = 12.5 Hz, 1H), 4.60 – 4.57 (m, 1H), 3.98 (d, *J* = 6.1 Hz, 1H), 3.35 (s, 3H), 2.11 (s, 3H), 2.08 (s, 3H), 2.05 (s, 3H), 2.03 – 1.98 (m, 2H), 1.91 – 1.83 (m, 2H), 1.65 – 1.56 (m, 2H), 1.44 – 1.37 (m, 2H); ¹³C NMR (101 MHz, MeOD) δ 176.12, 172.32, 171.66, 171.29, 171.21, 165.96, 160.96, 151.90, 144.61, 141.42, 106.25, 103.54, 98.81, 88.77, 83.41, 79.28, 77.39, 74.79, 64.91, 64.49, 59.26, 57.36, 53.25, 42.36, 32.19, 29.75, 28.94, 20.54, 20.41, 20.32; HRMS (ESI+) *m/z* calcd for C₂₉H₃₈N₅O₁₅ [M + H] 696.2364, found: 696.2391.

(2S,3S,4S)-2-((1R)-2-Amino-1-((2S,5R)-5-(2,4-dioxo-3,4-dihydropyrimidin-1(2H)-yl)-3-hydroxy-4-methoxytetrahydrofuran-2-yl)-2-oxoethoxy)-3,4-dihydroxy-N-(((S)-2-oxoazepan-3-yl)-3,4-dihydro-2H-pyran-6-carboxamide (3).

A solution of **19** (30 mg, 0.043 mmol) in a 5:1 mixture of MeOH and Et₃N (0.60 mL) was stirred for 5h at r.t., and concentrated *in vacuo*. The crude mixture was purified by reverse-phase HPLC [column: Luna® (C18, 10 μ m, 100 Å, 250 x 10 mm), solvents: 15:85 MeOH:H₂O, flow rate: 3.0 mL/min, UV: 254 nm, retention time: 20 min] to afford I-CAP (**3**, 24 mg, 98%): ¹H NMR (400 MHz, Methanol-*d*₄) δ 7.92 (d, *J* = 8.1 Hz, 1H), 6.02 (d, *J* = 3.8 Hz, 1H), 5.88 (d, *J* = 5.1 Hz, 1H), 5.74 (d, *J* = 8.1 Hz, 1H), 5.23 (d, *J* = 5.6 Hz, 1H), 4.67 (d, *J* = 2.0 Hz, 1H), 4.59 – 4.54 (m, 2H), 4.38 (t, *J* = 4.2 Hz, 1H), 4.29 (t, *J* = 5.1 Hz, 1H), 3.98 (t, *J* = 5.0 Hz, 1H), 3.84 (t, *J* = 4.6 Hz, 1H), 3.43 (s, 3H), 2.06 – 1.99 (m, 2H), 1.89 – 1.81 (m, 2H), 1.62 – 1.45 (m, 2H), 1.44 – 1.33 (m, 2H); ¹³C NMR (101 MHz, MeOD) δ 176.27, 173.46, 166.15, 161.85, 152.32, 144.23, 141.91, 109.37, 102.82, 101.22, 90.27, 83.49, 81.02, 78.93, 74.54, 68.51, 63.53, 58.67, 53.35, 42.48, 32.36, 29.91, 29.06; HRMS (ESI+) *m/z* calcd for C₂₃H₃₂N₅O₁₂ [M + H] 570.2048, found: 570.2071.

(2S,3S,4S,5R,6R)-2-((S)-((3aR,4R,6R,6aR)-6-(3-((Benzyloxy)methyl)-2,4-dioxo-3,4-dihydropyrimidin-1(2H)-yl)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)(cyano)methoxy)-6-((2-chloroacetoxy)-methyl)tetrahydro-2H-pyran-3,4,5-triyl triacetate (21). To a stirred suspension of **20** (0.24 g, 0.56 mmol), **14** (0.55 g, 1.12 mmol), MS 3Å (0.72 g), and SrCO₃ (0.41 g, 2.80 mmol) in CH₂Cl₂ (14.0 mL) were added AgBF₄ (0.055 g, 0.28 mmol) and NIS (0.25 g, 1.12 mmol) at 0 °C. After being stirred for 12h, the reaction mixture was added Et₃N (1.0 mL), and passed through a silica gel pad (hexanes/EtOAc = 1/4). The filtrate was concentrated *in vacuo*. The crude mixture was purified by silica gel column chromatography (hexanes/EtOAc = 6/4 - 4/6) to afford **21** (0.39 g, 88%): ¹H NMR (400 MHz, Chloroform-*d*) δ 7.37 – 7.28 (m, 5H), 7.20 (d, *J* = 8.1 Hz, 1H), 5.82 (d, *J* = 8.1 Hz, 1H), 5.61 (d, *J* = 1.6 Hz, 1H), 5.50 (d, *J* = 9.8 Hz, 1H), 5.42 (d, *J* = 9.8 Hz, 1H), 5.35 – 5.27 (m, 1H), 5.23 (dd, *J* = 10.0, 3.3 Hz, 1H), 5.07 (d, *J* = 1.9 Hz, 1H), 5.00 (d, *J* = 3.5 Hz, 1H), 4.98 (dd, *J* = 6.4, 1.6 Hz, 1H), 4.84 (d, *J* = 7.1 Hz, 1H), 4.69 (s, 2H), 4.43 (dd, *J* = 7.1, 3.6 Hz, 1H), 4.20 (dd, *J* = 12.2, 4.3 Hz, 1H), 4.17 – 4.07 (m, 2H), 4.05 (d, *J* = 1.6 Hz, 2H), 3.97 – 3.92 (m, 1H), 2.16 (s, 3H), 2.02 (s, 3H), 1.98 (s, 3H), 1.59 (s, 3H), 1.39 (s, 3H); ¹³C NMR (101 MHz, CDCl₃) δ 169.80, 169.57, 169.47, 166.80, 162.08, 150.84, 140.89, 137.67, 128.33 (2C), 127.91, 127.77, 127.63 (2C), 115.23, 114.72, 102.84, 96.56, 96.30, 86.55, 84.15, 80.95, 72.42, 70.41, 69.41, 68.39 (2C), 66.04, 65.35, 62.90, 40.52, 27.03, 25.20, 20.73, 20.64, 20.59; HRMS (ESI+) *m/z* calcd for C₃₅H₄₁ClN₃O₁₆ [M + H] 794.2175, found: 794.2198.

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(2R,3S,4S,5R,6R)-2-((R)-2-Amino-1-((3aR,4S,6R,6aR)-6-(2,4-dioxo-3,4-dihydropyrimidin-1(2H)-yl)-2,2-dimethyltetrahydrofuro[3,4-d][1,3]dioxol-4-yl)-2-oxoethoxy)-6-(hydroxymethyl)-tetrahydro-2H-pyran-3,4,5-triyl triacetate (22). To a stirred solution of **21** (0.39 g, 0.49 mmol) in a 9:1 mixture of EtOH and H₂O (4.9 mL) were added HgCl₂ (0.27 g, 0.98 mmol) and acetaldoxime (0.30 mL, 4.9 mmol) at rt. After being stirred for 12h at r.t., the reaction mixture was concentrated *in vacuo*. The residue was diluted with aq. NaHCO₃, and extracted with CHCl₃. The combined organic extracts were dried over Na₂SO₄ and concentrated *in vacuo*. The crude product was purified by silica gel column chromatography (hexanes/EtOAc = 1/2 to CHCl₃/MeOH = 97/3) to afford the amide (0.36 g, 91%). To a solution of the amide (0.36 g, 0.45 mmol) in a 1:1 mixture of THF and MeOH (4.5 mL) was added thiourea (0.10 g, 1.34 mmol). After being stirred for 11h at 50 °C, the reaction mixture was concentrated *in vacuo*. The residue was diluted with H₂O, and extracted with CHCl₃. The combined organic extracts were dried over Na₂SO₄ and concentrated *in vacuo*. The crude product was purified by silica gel column chromatography (CHCl₃/MeOH = 98/2 to 97/3 to 96/4) to afford the primary alcohol (0.25 g, 76%). To a stirred solution of the alcohol (0.25 g, 0.34 mmol) and AcOH (0.08 mL) in a 1:1 mixture of THF and ⁱPrOH (4.0 mL) was added 10% Pd/C (0.20 g) under N₂. H₂ gas was introduced and the reaction mixture was stirred under H₂

atmosphere at rt. After being stirred for 4h, the reaction mixture was filtered through Celite and concentrated *in vacuo*. The crude product was purified by silica gel column chromatography (CHCl₃/MeOH = 96/4 to 92/8) to afford **22** (0.17 g, 80%): ¹H NMR (400 MHz, Chloroform-*d*) δ 9.45 (brs, 1H), 7.34 (d, *J* = 8.0 Hz, 1H), 6.72 (brs, 1H), 6.17 (brs, 1H), 5.78 (d, *J* = 8.0 Hz, 1H), 5.60 (d, *J* = 1.7 Hz, 1H), 5.43 (dd, *J* = 10.1, 3.5 Hz, 1H), 5.33 (dd, *J* = 3.5, 1.7 Hz, 1H), 5.20 (t, *J* = 10.1 Hz, 1H), 5.12 – 5.05 (m, 1H), 5.03 (dd, *J* = 6.4, 1.7 Hz, 1H), 4.98 (s, 1H), 4.46 (d, *J* = 5.8 Hz, 1H), 4.33 (t, *J* = 5.1 Hz, 1H), 3.88 (dt, *J* = 10.1, 4.0 Hz, 1H), 3.60 – 3.53 (m, 2H), 2.14 (s, 3H), 2.07 (s, 3H), 2.02 (s, 3H), 1.55 (s, 3H), 1.35 (s, 3H); ¹³C NMR (101 MHz, CDCl₃) δ 170.68, 170.40, 170.28, 170.24, 163.27, 150.13, 142.81, 114.72, 102.85, 96.39, 87.34, 84.26, 80.35, 71.92, 69.35, 68.64, 66.03, 61.16, 27.25, 25.42, 20.83, 20.77, 20.74; HRMS (ESI+) *m/z* calcd for C₂₅H₃₄N₃O₁₅ [M + H] 616.1990, found: 616.2018.

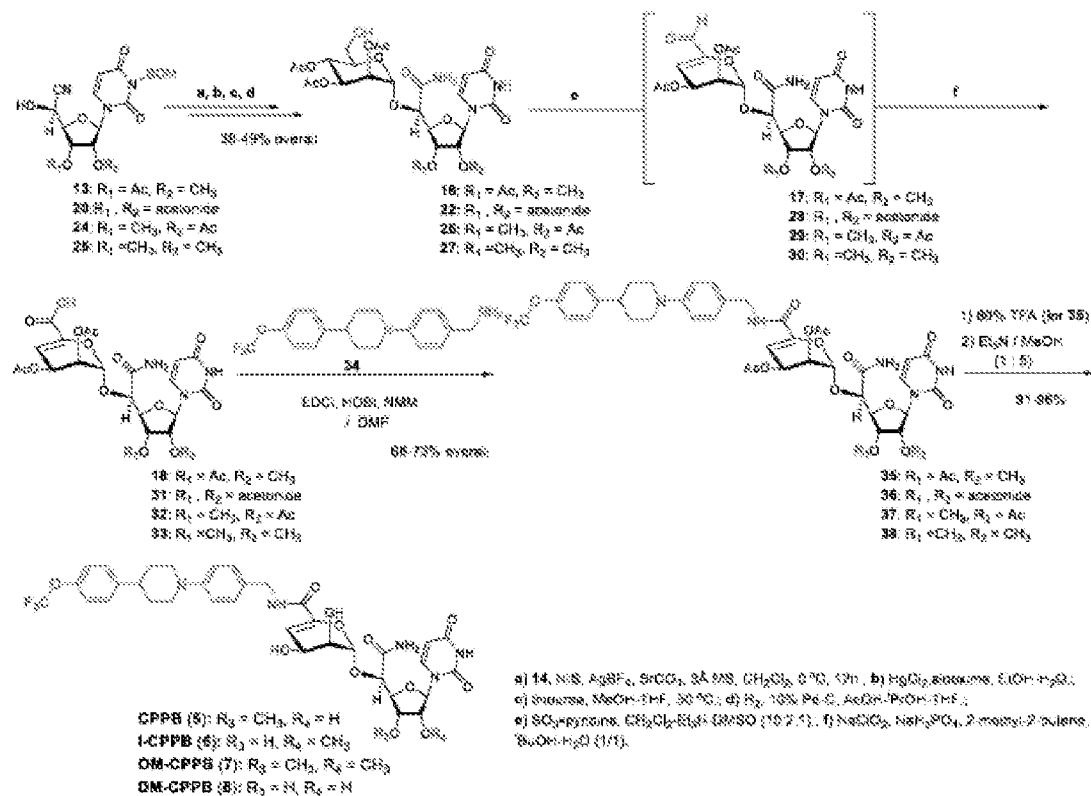
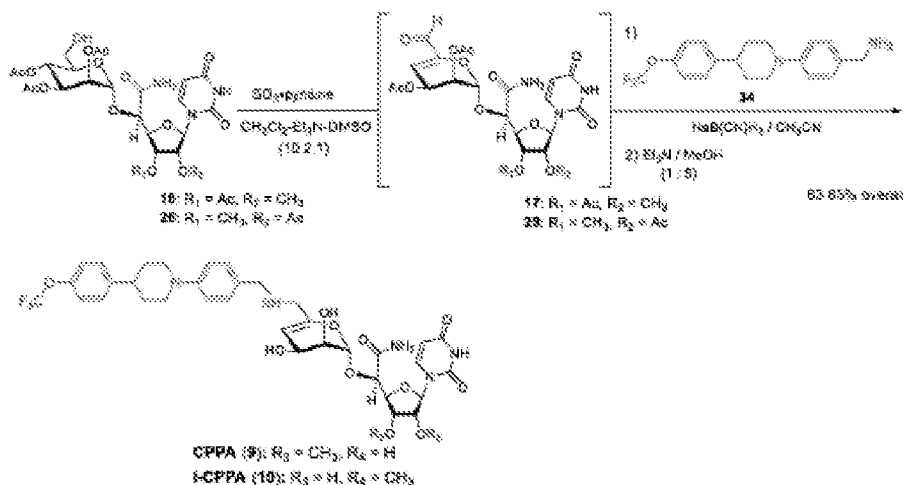
(2S,3S,4S)-2-((R)-2-Amino-1-((3aR,4S,6R,6aR)-6-(2,4-dioxo-3,4-dihydropyrimidin-1(2H)-yl)-2,2-dimethyltetrahydrofuro[3,4-*d*][1,3]dioxol-4-yl)-2-oxoethoxy)-6-(((S)-2-oxoazepan-3-yl)-carbamoyl)-3,4-dihydro-2H-pyran-3,4-diyl diacetate (23). To a stirred solution of **22** (0.17 g, 0.27 mmol) and DMSO (0.19 mL, 2.72 mmol) in a 5:1 mixture of CH₂Cl₂ and Et₃N (1.4 mL) was added SO₃•pyridine (0.43 g, 2.72 mmol). After being stirred for 3h at r.t., the reaction mixture was added H₂O (0.27 mL) and passed through a silica gel pad (CHCl₃/MeOH = 92/8). To a stirred solution of the crude mixture in ^tBuOH (1.0 mL) and 2-methyl-2-butene (0.5 mL) was added a solution of NaClO₂ (0.12 g, 1.36 mmol) and NaH₂PO₄•2H₂O (0.21 g, 1.36 mmol) in H₂O (1.0 mL). After being stirred for 5h at r.t., the reaction was extracted with CHCl₃/MeOH (9/1). The combined organic extracts were dried over Na₂SO₄ and concentrated *in vacuo*. The crude product was purified by silica gel column chromatography (CHCl₃/MeOH = 9/1) to afford the acid (0.13 g, 81%). To a stirred solution of the acid (28 mg, 0.049 mmol), 2-(S)-aminocaprolactam (24 mg, 0.15 mmol), HOBt (20 mg, 0.15 mmol) and NMM (54 μL, 0.49 mmol) in DMF (0.25 mL) was added EDCI (47 mg, 0.25 mmol). After being stirred for 14h at r.t., the reaction was quenched with aq. NaHCO₃, and extracted with CHCl₃/MeOH (9/1). The combined organic extracts were dried over Na₂SO₄ and concentrated *in vacuo*. The crude product was purified by silica gel column chromatography (CHCl₃/MeOH = 95/5) to afford **23** (30 mg, 89%): ¹H NMR (400 MHz, Methanol-*d*₄) δ 7.79 (d, *J* = 8.0 Hz, 1H), 5.98 (t, *J* = 2.0 Hz, 1H), 5.84 (d, *J* = 2.8 Hz, 1H), 5.78 (d, *J* = 8.0 Hz, 1H), 5.62 (dd, *J* = 4.5, 2.6 Hz, 1H), 5.51 – 5.48 (m, 1H), 5.45 (d, *J* = 3.1 Hz, 1H), 4.74 (d, *J* = 2.8 Hz, 1H), 4.71 (dd, *J* = 6.2, 2.9 Hz, 1H), 4.65 (dd, *J* = 6.2, 3.3 Hz, 1H), 4.59 – 4.55 (m, 2H), 3.76 – 3.67 (m, 4H), 2.09 (s, 3H), 2.04 (s, 3H), 1.86 (d, *J* = 13.4 Hz, 3H), 1.63 – 1.52 (m, 3H), 1.51 (s, 3H), 1.45 – 1.34 (m, 3H), 1.25 (s, 3H); ¹³C NMR (101 MHz, MeOD) δ 176.35, 172.24, 171.62, 171.28, 166.24, 161.14, 151.99, 144.75, 142.76, 115.34, 106.38, 102.91, 98.75, 93.55, 87.12, 85.94, 82.02, 78.13, 67.16, 64.99, 64.46, 56.04,

53.46, 46.10, 42.52, 42.43, 32.25, 29.89, 29.08, 27.47, 25.47, 20.61, 20.52; HRMS (ESI+) m/z calcd for $C_{29}H_{38}N_5O_{14}$ [M + H] 680.2415, found: 680.2432.

(2S,3S,4S)-2-((1R)-2-Amino-1-((2S,5R)-5-(2,4-dioxo-3,4-dihydropyrimidin-1(2H)-yl)-3,4-dihydroxy-tetrahydrofuran-2-yl)-2-oxoethoxy)-3,4-dihydroxy-N-((S)-2-oxoazepan-3-yl)-3,4-dihydro-2H-pyran-6-carboxamide (4). A solution of **23** (30 mg, 0.044 mmol) in a 4:1 mixture of TFA and H_2O (0.88 mL) was stirred for 4h at r.t., and concentrated *in vacuo*. A solution of the crude diol in a 5:1 mixture of MeOH and Et₃N (0.88 mL) was stirred for 9h at r.t., filtered, and concentrated *in vacuo*. The crude mixture was purified by reverse-phase HPLC [column: Luna® (C18, 10 μ m, 100 Å, 250 x 10 mm), solvents: 15:85 MeOH: H_2O , flow rate: 3.0 mL/min, UV: 254 nm, retention time: 16 min] to afford DM-CAP (**4**, 22 mg, 90%): ¹H NMR (400 MHz, Methanol-*d*₄) δ 7.94 (d, J = 8.1 Hz, 1H), 6.03 (d, J = 4.5 Hz, 1H), 5.85 (d, J = 3.7 Hz, 1H), 5.73 (d, J = 8.2 Hz, 1H), 5.19 (d, J = 6.7 Hz, 1H), 4.68 (d, J = 1.7 Hz, 1H), 4.61 (dd, J = 11.2, 1.4 Hz, 1H), 4.54 (dd, J = 5.8, 1.7 Hz, 1H), 4.36 (t, J = 4.5 Hz, 1H), 4.30 (t, J = 5.5 Hz, 1H), 4.12 (t, J = 4.4 Hz, 1H), 3.97 (t, J = 5.7 Hz, 1H), 3.90 (t, J = 6.5 Hz, 1H), 3.43 – 3.38 (m, 1H), 3.03 (t, J = 7.0 Hz, 1H), 2.70 – 2.64 (m, 1H), 2.07 – 1.97 (m, 2H), 1.81 (d, J = 15.2 Hz, 2H), 1.62 (q, J = 11.9, 10.7 Hz, 1H), 1.39 (s, 1H); ¹³C NMR (101 MHz, MeOD) δ 176.85, 174.05, 166.21, 162.02, 152.21, 144.60, 141.91, 108.72, 102.50, 101.60, 90.76, 84.77, 79.50, 75.68, 71.40, 63.63, 60.06, 53.44, 42.50, 31.89, 29.82, 29.14; HRMS (ESI+) m/z calcd for $C_{22}H_{30}N_5O_{12}$ [M + H] 556.1891, found: 556.1912.

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Scheme 2.

A: Synthesis of capuramycin phenoxypiperidinbenzylamide analogues, CPPB, *iso*-CPPB (*l*-CPPB), and demethyl-CPPB (DM-CPPB)B: Synthesis of capuramycin phenoxypiperidinbenzylamine analogues, CPPA, *iso*-CPPA (*l*-CPPA),

The carboxylic acid intermediate **32** for CAP (**1**) was subjected to peptide coupling reaction with (((trifluoromethoxy)phenoxy) piperidin-1-yl)phenyl)methylamine (**34**), providing the protected CPPB, **37**. Saponification of **37** and purification by reverse HPLC yielded CPPB (**5**) in 95% overall yield from **37**. Similarly, *l*-CPPB (**6**), OM-CPPB (**7**), and DM-CPPB (**8**) were synthesized from the cyanohydrins **18**, **33**, and **31** in 24-34% overall yield. Capuramycin phenoxypiperidinbenzylamine analogues, CPPA (**9**) and *l*-CPPA (**10**), were synthesized via

reductive aminations of the aldehydes **29** and **18** with the amine **34**, furnishing the desired products in 63-65% overall yield from **26** and **16** after saponification.

(2S,3S,4S)-2-((1R)-1-((2S,5R)-4-Acetoxy-5-(2,4-dioxo-3,4-dihydropyrimidin-1(2H)-yl)-3-methoxy-tetrahydrofuran-2-yl)-2-amino-2-oxoethoxy)-6-((4-(4-(trifluoromethoxy)-phenyl)-piperidin-1-yl)benzyl)carbamoyl)-3,4-dihydro-2H-pyran-3,4-diyl diacetate (37**)**. To a stirred solution of **32** (55 mg, 0.094 mmol), **34** (0.10 g, 0.28 mmol), HOBt (38 mg, 0.28 mmol) and NMM (95 μ L, 0.94 mmol) in DMF (0.47 mL) was added EDCI (90 mg, 0.47 mmol). After being stirred for 7h at r.t., the reaction mixture was quenched with aq. NaHCO₃, and extracted with CHCl₃/MeOH (9/1). The combined organic extracts were dried over Na₂SO₄ and concentrated *in vacuo*. The crude product was purified by silica gel column chromatography (CHCl₃/MeOH = 95/5) to afford **37** (76 mg, 87%): ¹H NMR (400 MHz, Methanol-*d*₄) δ 7.71 (d, *J* = 8.1 Hz, 1H), 7.23 (d, *J* = 8.5 Hz, 2H), 7.19 (d, *J* = 8.8 Hz, 2H), 7.03 (d, *J* = 9.1 Hz, 2H), 6.97 (d, *J* = 8.7 Hz, 2H), 5.97 (t, *J* = 2.1 Hz, 1H), 5.91 (d, *J* = 8.1 Hz, 1H), 5.87 (d, *J* = 3.8 Hz, 1H), 5.74 (dd, *J* = 4.5, 2.4 Hz, 1H), 5.67 (ddd, *J* = 4.5, 2.8, 1.7 Hz, 1H), 5.43 (d, *J* = 2.8 Hz, 1H), 5.28 (dd, *J* = 5.1, 3.8 Hz, 1H), 4.70 (d, *J* = 1.9 Hz, 1H), 4.54 (dq, *J* = 7.5, 3.8 Hz, 1H), 4.42 (d, *J* = 14.5 Hz, 1H), 4.38 (dd, *J* = 6.2, 1.9 Hz, 1H), 4.33 (d, *J* = 14.4 Hz, 1H), 3.82 – 3.79 (m, 1H), 3.48 (td, *J* = 9.0, 6.8, 3.5 Hz, 3H), 3.13 – 3.06 (m, 2H), 3.05 (s, 3H), 2.09 (s, 3H), 2.09 (s, 3H), 2.06 (s, 3H), 1.87 (dtd, *J* = 12.3, 8.2, 3.6 Hz, 3H); ¹³C NMR (101 MHz, MeOD) δ 172.85, 171.84, 171.43, 171.17, 166.07, 162.39, 157.61, 152.11, 151.92, 144.94, 143.92, 141.57, 130.89, 130.02 (2C), 123.59 (2C), 118.04 (2C), 117.98 (2C), 106.19, 103.75, 98.26, 89.36, 83.17, 78.98, 76.60, 74.71, 73.98, 64.75, 59.35, 48.18, 48.16, 31.43 (2C), 20.70, 20.52, 20.49; HRMS (ESI+) *m/z* calcd for C₄₂H₄₇F₃N₅O₁₅ [M + H] 918.3021, found 918.3049.

(2S,3S,4S)-2-((1R)-2-Amino-1-((2S,5R)-5-(2,4-dioxo-3,4-dihydropyrimidin-1(2H)-yl)-4-hydroxy-3-methoxytetrahydrofuran-2-yl)-2-oxoethoxy)-3,4-dihydroxy-N-(4-(4-(trifluoromethoxy)-phenyl)piperidin-1-yl)benzyl)-3,4-dihydro-2H-pyran-6-carboxamide (5**)**. A solution of **37** (76 mg, 0.082 mmol) in a 5:1 mixture of MeOH and Et₃N (1.6 mL) was stirred for 6h at r.t., and concentrated *in vacuo*. The crude mixture was purified by reverse-phase HPLC [column: Luna® (C18, 10 μ m, 100 Å, 250 x 10 mm), solvents: 65:35 MeOH:H₂O, flow rate: 3.0 mL/min, UV: 254 nm, retention time: 18 min] to afford CPPB (**5**, 63 mg, 95%): ¹H NMR (400 MHz, Methanol-*d*₄) δ 7.86 (d, *J* = 8.1 Hz, 1H), 7.20 (dd, *J* = 10.9, 8.6 Hz, 4H), 7.02 (d, *J* = 9.1 Hz, 2H), 6.97 (d, *J* = 8.7 Hz, 2H), 5.98 (dd, *J* = 3.3, 1.0 Hz, 1H), 5.80 (d, *J* = 4.4 Hz, 1H), 5.76 (d, *J* = 8.2 Hz, 1H), 5.21 (d, *J* = 4.6 Hz, 1H), 4.68 (d, *J* = 2.0 Hz, 1H), 4.54 (dp, *J* = 7.3, 3.6 Hz, 1H), 4.48 (dd, *J* = 5.2, 2.0 Hz, 1H), 4.44 (d, *J* = 14.5 Hz, 1H), 4.39 (t, *J* = 3.9 Hz, 1H), 4.33 (d, *J* = 14.6 Hz, 1H), 4.20 (t, *J* = 4.7 Hz, 1H), 4.06 – 4.02

(m, 1H), 3.66 (t, $J = 5.1$ Hz, 1H), 3.52 – 3.45 (m, 3H), 3.19 (s, 3H), 3.08 (ddd, $J = 12.3, 8.6, 3.4$ Hz, 3H), 2.15 – 2.07 (m, 2H), 1.86 (dtd, $J = 12.2, 8.3, 3.5$ Hz, 3H); ^{13}C NMR (101 MHz, MeOD) δ 173.68, 166.16, 163.31, 157.62, 152.18, 152.08, 144.15, 141.83, 130.91, 129.76 (2C), 123.58 (2C), 118.03 (4C), 109.58, 102.74, 100.64, 90.83, 83.32, 80.35, 77.51, 74.27, 74.01, 67.61, 63.48, 58.61, 48.20 (2C), 43.51, 31.47 (2C); HRMS (ESI+) m/z calcd for $\text{C}_{36}\text{H}_{41}\text{F}_3\text{N}_5\text{O}_{12}$ [M + H] 792.2704, found 792.2733.

(2S,3S,4S)-2-((1R)-1-((2S,5R)-3-Acetoxy-5-(2,4-dioxo-3,4-dihydropyrimidin-1(2H)-yl)-4-methoxytetrahydrofuran-2-yl)-2-amino-2-oxoethoxy)-6-((4-(4-(trifluoromethoxy)phenyl)-piperidin-1-yl)benzyl)carbamoyl)-3,4-dihydro-2H-pyran-3,4-diyl diacetate (35). To a stirred solution of **18** (33 mg, 0.056 mmol), **34** (62 mg, 0.17 mmol), HOBt (23 mg, 0.17 mmol) and NMM (62 μL , 0.56 mmol) in DMF (0.28 mL) was added EDCI (54 mg, 0.28 mmol). After being stirred for 14h at r.t., the reaction was quenched with aq. NaHCO_3 , and extracted with $\text{CHCl}_3/\text{MeOH}$ (9/1). The combined organic extracts were dried over Na_2SO_4 and concentrated *in vacuo*. The crude product was purified by silica gel column chromatography ($\text{CHCl}_3/\text{MeOH} = 95/5$) to afford **35** (43 mg, 82%): ^1H NMR (400 MHz, Methanol- d_4) δ 7.69 (d, $J = 8.2$ Hz, 1H), 7.22 (d, $J = 8.5$ Hz, 2H), 7.19 (d, $J = 8.6$ Hz, 2H), 7.02 (d, $J = 9.0$ Hz, 2H), 6.98 (d, $J = 8.4$ Hz, 2H), 5.99 – 5.97 (m, 1H), 5.95 (d, $J = 5.8$ Hz, 1H), 5.91 (d, $J = 8.1$ Hz, 1H), 5.74 – 5.71 (m, 1H), 5.66 – 5.63 (m, 1H), 5.46 (d, $J = 3.2$ Hz, 1H), 5.05 (t, $J = 4.7$ Hz, 1H), 4.78 (d, $J = 2.0$ Hz, 1H), 4.57 – 4.52 (m, 1H), 4.49 (d, $J = 14.5$ Hz, 1H), 4.39 – 4.34 (m, 1H), 4.30 (d, $J = 14.7$ Hz, 1H), 3.84 – 3.80 (m, 1H), 3.64 (s, 3H), 3.53 – 3.45 (m, 2H), 3.13 – 3.06 (m, 2H), 2.83 (t, $J = 6.5$ Hz, 1H), 2.10 (s, 3H), 2.07 (s, 3H), 2.06 (s, 3H), 1.87 (dtd, $J = 12.7, 8.5, 3.5$ Hz, 3H); ^{13}C NMR (101 MHz, MeOD) δ 172.92, 171.74, 171.36, 170.39, 166.18, 162.23, 157.56, 152.06, 151.81, 145.05, 140.90, 130.78, 129.96 (2C), 123.52 (2C), 117.96 (2C), 117.92 (2C), 105.75, 103.47, 98.22, 88.92, 82.72, 78.21, 76.44, 73.95, 67.92, 64.42, 61.21, 58.65, 58.20, 48.10 (2C), 43.57, 31.38 (2C), 20.60, 20.44, 20.39; HRMS (ESI+) m/z calcd for $\text{C}_{42}\text{H}_{47}\text{F}_3\text{N}_5\text{O}_{15}$ [M + H] 918.3021, found 918.3038.

(2S,3S,4S)-2-((1R)-2-Amino-1-((2S,5R)-5-(2,4-dioxo-3,4-dihydropyrimidin-1(2H)-yl)-3-hydroxy-4-methoxytetrahydrofuran-2-yl)-2-oxoethoxy)-3,4-dihydroxy-N-(4-(4-(trifluoro-methoxy)phenyl)-piperidin-1-yl)benzyl)-3,4-dihydro-2H-pyran-6-carboxamide (6). A solution of **35** (43 mg, 0.046 mmol) in a 5:1 mixture of MeOH and Et_3N (0.92 mL) was stirred for 6h at r.t., and concentrated *in vacuo*. The crude mixture was purified by reverse-phase HPLC [column: Luna® (C18, 10 μm , 100 Å, 250 x 10 mm), solvents: 65:35 MeOH:H $_2$ O, flow rate: 3.0 mL/min, UV: 254 nm, retention time: 19 min] to afford I-CPPB (**6**, 35 mg, 93%): ^1H NMR (400 MHz, Methanol- d_4) δ 7.79 (d, $J = 8.2$ Hz, 1H), 7.19 (d, $J = 8.6$ Hz, 4H), 7.02 (d, J

= 9.1 Hz, 2H), 6.98 (d, J = 8.5 Hz, 2H), 5.98 (d, J = 3.6 Hz, 1H), 5.94 (d, J = 5.1 Hz, 1H), 5.77 (d, J = 8.0 Hz, 1H), 5.36 (d, J = 5.8 Hz, 1H), 4.67 – 4.65 (m, 1H), 4.61 (d, J = 2.8 Hz, 1H), 4.48 (dd, J = 8.6, 4.6 Hz, 1H), 4.36 – 4.33 (m, 1H), 4.27 (dd, J = 5.4, 2.7 Hz, 1H), 3.71 – 3.65 (m, 2H), 3.51 (d, J = 4.4 Hz, 2H), 3.48 (s, 3H), 3.25 – 3.18 (m, 2H), 2.13 – 2.00 (m, 3H), 1.92 – 1.76 (m, 3H); ^{13}C NMR (101 MHz, MeOD) δ 173.68, 166.15, 163.30, 157.62, 152.18, 152.08, 144.15, 141.83, 130.90, 129.76 (2C), 123.58 (2C), 118.10 (2C), 118.02 (2C), 109.57, 102.73, 100.63, 90.83, 83.32, 80.35, 77.51, 74.27, 74.01, 67.61, 63.48, 58.61, 48.20 (2C), 43.51, 31.47 (2C); HRMS (ESI+) m/z calcd for $\text{C}_{36}\text{H}_{41}\text{F}_3\text{N}_5\text{O}_{12}$ [$\text{M} + \text{H}$] 792.2704, found 792.2728.

(2S,3S,4S)-2-((1R)-2-Amino-1-((2S,5R)-5-(2,4-dioxo-3,4-dihydropyrimidin-1(2H)-yl)-3,4-dimethoxytetrahydrofuran-2-yl)-2-oxoethoxy)-6-((4-(4-(trifluoromethoxy)phenyl)piperidin-1-yl)benzyl)-carbamoyl)-3,4-dihydro-2H-pyran-3,4-diyl diacetate (38). To a stirred solution of **33** (38 mg, 0.068 mmol), **34** (75 mg, 0.20 mmol), HOBt (28 mg, 0.20 mmol) and NMM (75 μL , 0.68 mmol) in DMF (0.34 mL) was added EDCI (65 mg, 0.34 mmol). After being stirred for 7h at r.t., the reaction was quenched with aq. NaHCO_3 , and extracted with $\text{CHCl}_3/\text{MeOH}$ (9/1). The combined organic extracts were dried over Na_2SO_4 and concentrated *in vacuo*. The crude product was purified by silica gel column chromatography ($\text{CHCl}_3/\text{MeOH}$ = 95/5) to afford **38** (53 mg, 86%): ^1H NMR (400 MHz, Methanol- d_4) δ 7.75 (d, J = 8.2 Hz, 1H), 7.24 (d, J = 8.6 Hz, 2H), 7.19 (d, J = 8.8 Hz, 2H), 7.02 (d, J = 9.1 Hz, 2H), 6.98 (d, J = 8.5 Hz, 2H), 5.98 (d, J = 2.0 Hz, 1H), 5.96 (d, J = 8.1 Hz, 1H), 5.85 (d, J = 2.9 Hz, 1H), 5.71 – 5.66 (m, 2H), 5.43 (d, J = 2.3 Hz, 1H), 4.70 (d, J = 1.9 Hz, 1H), 4.57 – 4.51 (m, 1H), 4.45 – 4.40 (m, 2H), 4.34 (d, J = 14.4 Hz, 1H), 3.86 (dd, J = 4.9, 2.9 Hz, 1H), 3.79 (t, J = 6.5 Hz, 1H), 3.60 (dd, J = 6.9, 4.9 Hz, 1H), 3.50 (td, J = 7.6, 7.0, 3.3 Hz, 2H), 3.46 (s, 3H), 3.11 (dd, J = 8.9, 3.6 Hz, 1H), 3.08 (s, 3H), 2.83 (t, J = 6.5 Hz, 1H), 2.14 (dd, J = 8.7, 5.4 Hz, 1H), 2.10 (s, 3H), 2.07 (s, 3H), 1.87 (dtd, J = 12.5, 8.2, 3.5 Hz, 2H); ^{13}C NMR (101 MHz, MeOD) δ 172.98, 171.81, 171.42, 166.22, 162.30, 157.62, 152.12, 151.87, 145.11, 140.96, 130.85, 130.02 (2C), 123.58 (2C), 118.03 (2C), 117.98 (2C), 105.81, 103.54, 98.28, 88.98, 82.79, 82.54, 78.28, 76.50, 74.02, 64.59, 64.49, 61.28, 58.72, 58.27, 48.17 (2C), 43.64, 42.08, 31.45 (2C), 20.67, 20.51; HRMS (ESI+) m/z calcd for $\text{C}_{41}\text{H}_{47}\text{F}_3\text{N}_5\text{O}_{15}$ [$\text{M} + \text{H}$] 906.3021, found 906.3045.

(2S,3S,4S)-2-((1R)-2-Amino-1-((2S,5R)-5-(2,4-dioxo-3,4-dihydropyrimidin-1(2H)-yl)-3,4-dimethoxy-tetrahydrofuran-2-yl)-2-oxoethoxy)-3,4-dihydroxy-N-(4-(4-(trifluoromethoxy)-phenyl)piperidin-1-yl)benzyl)-3,4-dihydro-2H-pyran-6-carboxamide (7). A solution of **38** (53 mg, 0.059 mmol) in a 5:1 mixture of MeOH and Et_3N (1.2 mL) was stirred for 6h at r.t., and concentrated *in vacuo*. The crude mixture was purified by reverse-phase HPLC [column: Luna® (C18, 10 μm , 100 Å, 250 x 10 mm), solvents: 65:35 MeOH: H_2O ,

flow rate: 3.0 mL/min, UV: 254 nm, retention time: 21 min] to afford OM-CPPB (**7**, 46 mg, 96%): ¹H NMR (400 MHz, Methanol-*d*₄) δ 7.89 (d, *J* = 8.1 Hz, 1H), 7.22 (d, *J* = 8.4 Hz, 2H), 7.19 (d, *J* = 8.7 Hz, 2H), 7.02 (d, *J* = 9.1 Hz, 2H), 6.96 (d, *J* = 8.5 Hz, 2H), 5.98 (dd, *J* = 3.0, 1.2 Hz, 1H), 5.85 (d, *J* = 3.3 Hz, 1H), 5.76 (d, *J* = 8.1 Hz, 1H), 5.22 (d, *J* = 4.1 Hz, 1H), 4.67 (d, *J* = 1.9 Hz, 1H), 4.57 – 4.51 (m, 1H), 4.46 (dd, *J* = 6.8, 2.0 Hz, 1H), 4.43 (d, *J* = 14.9 Hz, 1H), 4.40 (d, *J* = 3.7 Hz, 1H), 4.32 (d, *J* = 14.5 Hz, 1H), 4.08 (t, *J* = 4.2 Hz, 1H), 3.90 (t, *J* = 4.1 Hz, 1H), 3.70 (t, *J* = 5.5 Hz, 1H), 3.52 – 3.47 (m, 2H), 3.45 (s, 3H), 3.13 (s, 3H), 3.08 (td, *J* = 9.1, 4.6 Hz, 2H), 2.15 – 2.09 (m, 2H), 1.91 – 1.82 (m, 2H); ¹³C NMR (101 MHz, MeOD) δ 173.61, 166.17, 163.21, 157.62, 152.09, 151.92, 144.02, 141.57, 130.94, 129.89 (2C), 123.59 (2C), 118.03 (2C), 117.98 (2C), 109.78, 102.61, 100.76, 88.94, 83.23, 82.71, 78.58, 77.02, 74.02, 67.27, 63.42, 60.07, 58.70, 58.37, 48.18, 47.87, 45.76, 43.53, 31.46 (2C); HRMS (ESI+) *m/z* calcd for C₃₇H₄₃F₃N₅O₁₃ [M + H] 822.2809, found 822.2838.

(2S,3S,4S)-2-((R)-2-Amino-1-((3aR,4S,6R,6aR)-6-(2,4-dioxo-3,4-dihydropyrimidin-1(2H)-yl)-2,2-dimethyltetrahydrofuro[3,4-*d*][1,3]dioxol-4-yl)-2-oxoethoxy)-6-((4-(4-(trifluoromethoxy)phenyl)piperidin-1-yl)benzyl)carbamoyl)-3,4-dihydro-2H-pyran-3,4-diyl diacetate (36**).** To a stirred solution of **31** (27 mg, 0.047 mmol), **34** (52 mg, 0.14 mmol), HOBt (19 mg, 0.14 mmol) and NMM (52 μL, 0.47 mmol) in DMF (0.24 mL) was added EDCI (45 mg, 0.24 mmol). After being stirred for 11 h at r.t., the reaction was quenched with aq. NaHCO₃, and extracted with CHCl₃/MeOH (9/1). The combined organic extracts were dried over Na₂SO₄ and concentrated *in vacuo*. The crude product was purified by silica gel column chromatography (CHCl₃/MeOH = 95/5) to afford **36** (37 mg, 84%): ¹H NMR (400 MHz, Methanol-*d*₄) δ 7.69 (d, *J* = 8.1 Hz, 1H), 7.20 (t, *J* = 9.5 Hz, 4H), 7.02 (d, *J* = 9.2 Hz, 2H), 6.98 (d, *J* = 8.5 Hz, 2H), 5.99 (t, *J* = 2.0 Hz, 1H), 5.87 (d, *J* = 3.0 Hz, 1H), 5.83 (d, *J* = 8.1 Hz, 1H), 5.66 (dd, *J* = 4.4, 2.5 Hz, 1H), 5.57 – 5.54 (m, 1H), 5.41 (d, *J* = 3.0 Hz, 1H), 4.78 (d, *J* = 2.3 Hz, 1H), 4.70 (dd, *J* = 6.3, 3.1 Hz, 1H), 4.63 (dd, *J* = 6.4, 3.5 Hz, 1H), 4.57 – 4.52 (m, 1H), 4.39 (s, 2H), 3.79 (t, *J* = 6.5 Hz, 1H), 3.64 (s, 1H), 3.49 (ddd, *J* = 10.9, 6.4, 3.6 Hz, 2H), 3.09 (ddd, *J* = 12.4, 8.6, 3.4 Hz, 2H), 2.83 (t, *J* = 6.5 Hz, 1H), 2.16 – 2.09 (m, 2H), 2.08 (s, 3H), 2.05 (s, 3H), 1.87 (dtd, *J* = 12.1, 8.1, 3.5 Hz, 2H), 1.53 (s, 3H), 1.21 (s, 3H); ¹³C NMR (101 MHz, MeOD) δ 172.59, 171.76, 171.36, 166.16, 162.38, 157.61, 152.04, 151.92, 145.03, 142.46, 130.80, 129.66 (2C), 123.59 (2C), 118.05 (2C), 118.02 (2C), 115.67, 106.20, 103.33, 98.57, 92.78, 86.55, 85.61, 81.72, 77.88, 73.99, 64.84, 64.58, 61.28, 48.20 (2C), 43.59, 31.47 (2C), 27.52, 25.45, 20.66, 20.51; HRMS (ESI+) *m/z* calcd for C₄₂H₄₇F₃N₅O₁₄ [M + H] 902.3072, found 902.3098.

(2S,3S,4S)-2-((1R)-2-Amino-1-((2S,5R)-5-(2,4-dioxo-3,4-dihydropyrimidin-1(2H)-yl)-3,4-dihydroxy-tetrahydrofuran-2-yl)-2-oxoethoxy)-3,4-dihydroxy-N-(4-(4-(trifluoromethoxy)phenyl)-piperidin-1-yl)benzyl)-3,4-dihydro-2H-pyran-6-carboxamide (8**).** A solution of **35**

(37 mg, 0.040 mmol) in a 4:1 mixture of TFA and H₂O (0.80 mL) was stirred for 4h at r.t., and concentrated *in vacuo*. A solution of the crude alcohol in a 5:1 mixture of MeOH and Et₃N (0.80 mL) was stirred for 10h at r.t., and concentrated *in vacuo*. The crude mixture was purified by reverse-phase HPLC [column: Luna® (C18, 10 µm, 100 Å, 250 x 10 mm), solvents: 35:65 MeOH:H₂O, flow rate: 3.0 mL/min, UV: 254 nm, retention time: 15 min] to afford DM-CPPB (**8**, 29 mg, 91%): ¹H NMR (400 MHz, Methanol-*d*₄) δ 7.92 (d, *J* = 8.1 Hz, 1H), 7.20 (d, *J* = 3.1 Hz, 2H), 7.18 (d, *J* = 3.5 Hz, 2H), 7.02 (d, *J* = 9.1 Hz, 2H), 6.96 (d, *J* = 8.6 Hz, 2H), 6.01 (d, *J* = 4.4 Hz, 1H), 5.80 (d, *J* = 3.0 Hz, 1H), 5.73 (d, *J* = 8.1 Hz, 1H), 5.14 (d, *J* = 6.7 Hz, 1H), 4.66 (d, *J* = 1.8 Hz, 1H), 4.57 – 4.51 (m, 1H), 4.50 (dd, *J* = 6.7, 1.7 Hz, 1H), 4.41 – 4.31 (m, 3H), 4.16 (dd, *J* = 6.6, 5.0 Hz, 1H), 4.04 (dd, *J* = 4.9, 3.0 Hz, 1H), 3.88 (dd, *J* = 6.7, 4.5 Hz, 1H), 3.47 (t, *J* = 6.2 Hz, 2H), 3.27 (d, *J* = 7.2 Hz, 1H), 3.07 (ddd, *J* = 17.0, 8.1, 4.0 Hz, 2H), 2.37 – 2.29 (m, 1H), 2.16 – 2.07 (m, 2H), 1.86 (dtd, *J* = 12.3, 8.2, 3.5 Hz, 2H); ¹³C NMR (101 MHz, MeOD) δ 174.07, 170.14, 166.22, 163.14, 157.62, 152.12, 151.99, 144.89, 141.84, 131.07, 129.64 (2C), 123.58 (2C), 118.08 (2C), 118.03 (2C), 116.78, 108.52, 102.45, 101.32, 91.15, 84.20, 78.81, 75.49, 74.02, 71.19, 69.27, 63.69, 60.09, 47.81 (2C), 31.46 (2C); HRMS (ESI+) *m/z* calcd for C₃₅H₃₉F₃N₅O₁₂ [M + H] 778.2547, found 778.2573.

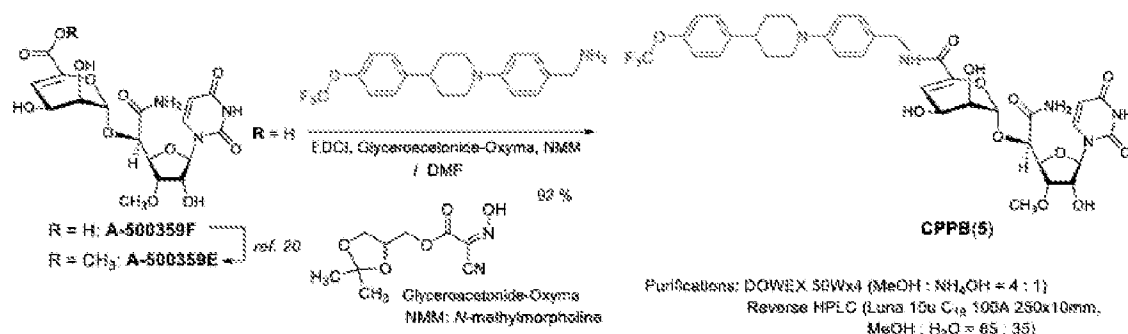
(2R)-2-(((2S,3S,4S)-3,4-Dihydroxy-6-(((4-(4-(trifluoromethoxy)phenyl)piperidin-1-yl)benzyl)-amino)-methyl)-3,4-dihydro-2H-pyran-2-yl)oxy)-2-((2S,5R)-5-(2,4-dioxo-3,4-dihydropyrimidin-1(2H)-yl)-4-hydroxy-3-methoxytetrahydrofuran-2-yl)acetamide (9**)**. To a stirred solution of **16** (5.8 mg, 0.0092 mmol) and DMSO (0.065 mL, 0.92 mmol) in a 5:1 mixture of CH₂Cl₂ and Et₃N (0.5 mL) was added SO₃·pyridine (15 mg, 0.092 mmol). After being stirred for 2h at r.t., the reaction mixture was added H₂O (0.1 mL) and passed through a silica gel pad (CHCl₃/MeOH = 93/7) to afford the crude **17**: this was used without purification. To a stirred solution of the crude **17** and **34** (17 mg, 0.046 mmol) in CH₃CN (0.5 mL) was added NaB(CN)H₃ (5.8 mg, 0.092 mol). After being stirred for 3h at r.t., the reaction was quenched with aq. NaHCO₃, and extracted with CHCl₃/MeOH (9/1). The combined organic extracts were dried over Na₂SO₄ and concentrated *in vacuo*. The crude product was passed through a silica gel pad (CHCl₃/MeOH = 9/1). The solution of the crude product in a 5:1 mixture of MeOH and Et₃N (0.5 mL) was stirred for 8h at r.t., and concentrated *in vacuo*. The crude mixture was purified by reverse-phase HPLC [column: Luna® (C18, 10 µm, 100 Å, 250 x 10 mm), solvents: 65:35 MeOH:H₂O, flow rate: 3.0 mL/min, UV: 254 nm, retention time: 15 min] to afford CPPA (**9**, 4.6 mg, 65% for 3 steps): ¹H NMR (400 MHz, Methanol-*d*₄) δ 8.02 (d, *J* = 8.1 Hz, 1H), 7.24 (d, *J* = 8.5 Hz, 2H), 7.19 (d, *J* = 8.5 Hz, 2H), 7.03 (d, *J* = 8.9 Hz, 2H), 6.99 (d, *J* = 8.5 Hz, 2H), 5.90 (d, *J* = 5.4 Hz, 1H), 5.76 (d, *J* = 7.8 Hz, 1H), 5.73 (d, *J* = 8.1 Hz, 1H), 5.06 (d, *J* = 6.6 Hz, 1H), 4.57 (dd, *J* = 6.4, 3.0 Hz, 1H), 4.52 (td, *J* = 4.4, 1.7 Hz, 1H), 4.33 (t, *J* = 5.2 Hz, 1H), 4.26

(d, $J = 26.3$ Hz, 1H), 4.18 (d, $J = 1.6$ Hz, 1H), 3.90 – 3.77 (m, 3H), 3.55 – 3.50 (m, 2H), 3.49 (s, 3H), 3.15 – 3.06 (m, 3H), 2.16 – 2.07 (m, 3H), 1.86 (m, $J = 8.8, 4.3$ Hz, 3H); ^{13}C NMR (101 MHz, MeOD) δ 174.07, 165.86, 163.68, 157.58, 151.26, 144.88, 142.07, 131.25, 129.37 (2C), 123.22 (2C), 118.03 (4C), 109.57, 102.60, 100.40, 90.92, 83.37, 80.46, 77.56, 74.63, 73.77, 73.15, 67.78, 63.30, 58.33, 48.19 (2C), 43.21, 30.74 (2C); HRMS (ESI+) m/z calcd for $\text{C}_{36}\text{H}_{43}\text{N}_3\text{F}_5\text{O}_{12}$ [M + H] 794.2860, found 794.2877.

(2R)-2-(((2S,3S,4S)-3,4-dihydroxy-6-(((4-(4-(trifluoromethoxy)phenyl)piperidin-1-yl)-benzyl)amino)methyl)-3,4-dihydro-2H-pyran-2-yl)oxy)-2-((2S,5R)-5-(2,4-dioxo-3,4-dihydro-pyrimidin-1(2H)-yl)-3-hydroxy-4-methoxytetrahydrofuran-2-yl)acetamide (10).

To a stirred solution of **26** (4.6 mg, 0.0073 mmol) and DMSO (0.052 mL, 0.73 mmol) in a 5:1 mixture of CH_2Cl_2 and Et_3N (0.5 mL) was added $\text{SO}_3 \cdot \text{pyridine}$ (12 mg, 0.073 mmol). After being stirred for 2h at r.t., the reaction mixture was added H_2O (0.1 mL) and passed through a silica gel pad ($\text{CHCl}_3/\text{MeOH} = 93/7$) to afford the crude **29**. To a stirred solution of the crude **29** and **34** (13 mg, 0.036 mmol) in CH_3CN (0.5 mL) was added $\text{NaB}(\text{CN})\text{H}_3$ (4.6 mg, 0.073 mol). After being stirred for 3h at r.t., the reaction was quenched with aq. NaHCO_3 , and extracted with $\text{CHCl}_3/\text{MeOH}$ (9/1). The combined organic extracts were dried over Na_2SO_4 and concentrated *in vacuo*. The crude product was passed through a silica gel pad ($\text{CHCl}_3/\text{MeOH} = 9/1$). A solution of the crude product in a 5:1 mixture of MeOH and Et_3N (0.5 mL) was stirred for 8h at r.t., and concentrated *in vacuo*. The crude mixture was purified by reverse-phase HPLC [column: Luna® (C18, 10 μm , 100 Å, 250 x 10 mm), solvents: 65:35 MeOH: H_2O , flow rate: 3.0 mL/min, UV: 254 nm, retention time: 15 min] to afford I-CPPA (**10**, 3.6 mg, 63% for 3 steps): ^1H NMR (400 MHz, Methanol- d_4) δ 8.04 (d, $J = 8.1$ Hz, 1H), 7.23 (d, $J = 8.4$ Hz, 2H), 7.19 (d, $J = 8.7$ Hz, 2H), 7.03 (d, $J = 9.1$ Hz, 2H), 6.98 (d, $J = 8.5$ Hz, 2H), 5.94 (d, $J = 3.6$ Hz, 1H), 5.74 (d, $J = 8.1$ Hz, 1H), 5.72 (d, $J = 8.1$ Hz, 1H), 5.06 (s, 1H), 4.59 – 4.52 (m, 2H), 4.43 – 4.38 (m, 1H), 4.28 (t, $J = 5.4$ Hz, 1H), 4.25 (t, $J = 4.4$ Hz, 1H), 4.21 (d, $J = 1.5$ Hz, 1H), 4.14 (dd, $J = 8.3, 4.9$ Hz, 1H), 3.88 – 3.85 (m, 2H), 3.82 (d, $J = 8.2$ Hz, 2H), 3.53 (s, 3H), 3.13 (ddd, $J = 12.3, 8.7, 3.3$ Hz, 2H), 2.11 (d, $J = 9.7$ Hz, 3H), 1.87 (ddt, $J = 13.3, 8.9, 4.1$ Hz, 3H); ^{13}C NMR (101 MHz, MeOD) δ 173.92, 165.98, 162.46, 157.87, 151.93, 143.90, 140.73, 130.53, 129.43 (2C), 123.29 (2C), 118.10 (2C), 117.87 (2C), 109.98, 103.08, 100.53, 91.27, 83.47, 80.53, 78.03, 74.70, 73.54, 67.84, 63.75, 58.42, 57.46, 48.20, 43.48 (2C), 31.49 (2C); HRMS (ESI+) m/z calcd for $\text{C}_{36}\text{H}_{43}\text{N}_3\text{F}_5\text{O}_{12}$ [M + H] 794.2860, found 794.2885.

Scheme 3.



Previously, a natural product A-5003659E was used to develop novel capuramycin analogues with strong MraY inhibitory activity (Hotoda et. al. 2003). Its free-carboxylic acid analogue, A-500359F was also isolated from the capuramycin-producing strain, *Streptomyces griseus* Sank 60196. Although, the currently available synthetic schemes for capuramycin analogues (e.g., Scheme 2) include a relatively short number of chemical steps, a semi-synthetic approach is more feasible to deliver large quantities of CPPB for pharmacological studies. To establish semi-synthesis of CPPB, A-500359F was first synthesized from the CAP-synthetic intermediate **32** (Scheme 2) in a single step. Amide-forming reaction of synthetic A-500359F with (((trifluoromethoxy)-phenoxy) piperidin-1-yl)phenyl)methylamine (**34**) was performed under an optimized condition using EDCI, glyceracetone-Oxyma, and NMM in DMF. All coupling reagents could be removed by partitions between CHCl₃ and water and evaporation. The crude product was passed through DOWEX 50Wx4 column (MeOH:NH₄OH = 4:1) to provide CPPB with >95% purity, which was further purified by C18-reverse HPLC (MeOH:H₂O = 65:35) to yield pure CPPB (Scheme 3).

(2S,3S,4S)-2-((1R)-2-amino-1-((2S,5R)-5-(2,4-dioxo-3,4-dihydropyrimidin-1(2H)-yl)-4-hydroxy-3-methoxytetrahydrofuran-2-yl)-2-oxoethoxy)-3,4-dihydroxy-3,4-dihydro-2H-pyran-6-carboxylic acid (A-500359F). A solution of **32** (18 mg, 29 μmol) in a 5:1 mixture of MeOH and Et₃N (0.5 mL) was stirred for 5h at r.t., and concentrated *in vacuo*. The crude mixture was purified by reverse-phase HPLC [column: Luna® (C18, 10 μm, 100 Å, 250 x 10 mm), solvents: 15:85 MeOH:H₂O, flow rate: 3.0 mL/min, UV: 254 nm, retention time: 14 min] to afford A-500359F (12 mg, 96%): ¹H NMR (400 MHz, Deuterium Oxide) δ 7.75 (d, *J* = 8.1 Hz, 1H), 5.88 (d, *J* = 8.1 Hz, 1H), 5.80 (dd, *J* = 2.5, 1.6 Hz, 1H), 5.78 (d, *J* = 4.0 Hz, 1H), 5.25 (d, *J* = 3.2 Hz, 1H), 4.71 (d, *J* = 2.1 Hz, 1H), 4.48 (dd, *J* = 5.7, 2.1 Hz, 1H), 4.43 (dd, *J* = 4.5, 2.5 Hz, 1H), 4.30 (dd, *J* = 5.1, 4.0 Hz, 1H), 4.12 (ddd, *J* = 4.8, 3.3, 1.7 Hz, 1H), 3.73 (t, *J* = 5.4 Hz, 1H), 3.35 (s, 3H); ¹³C NMR (101 MHz, D₂O) δ 173.32, 168.26, 166.06, 151.29, 144.11, 140.79,

108.44, 101.93, 98.62, 89.42, 81.99, 78.20, 75.00, 72.10, 64.43, 62.19, 57.93; HRMS (ESI+) m/z calcd for C₁₇H₂₂N₃O₁₂ [M + H] 460.1204, found 460.1215.

Synthesis of CPPB (5). To a stirred solution of A-500359F (11 mg, 0.024 mmol), **34** (26 mg, 0.072 mmol), Glyceroacetone-Oxyma (16 mg, 0.072 mmol) and NMM (26 mL, 0.24 mmol) in DMF (0.49 mL) was added EDCI (23 mg, 0.12 mmol). After being stirred for 5h at r.t., the reaction mixture was filtered, and diluted with water. The product was extracted with CHCl₃/MeOH (9/1). The combined extracts were derived over Na₂SO₄, and concentrated *in vacuo*. The crude mixture was purified by DOWEX 50Wx4 (MeOH : NH₄OH = 4 : 1) followed by reverse-phase HPLC [column: Luna (C18, 10 mm, 100 Å, 250 x 10 mm), solvents: 65:35 MeOH : H₂O, flow rate: 3.0 mL/min, UV: 254 nm, retention time: 18 min] to afford **5** (17 mg, 92%). All physical data were identical to that of CPPB synthesized in Scheme 2.

((2R,4R,5R,6S)-6-(((2R,3S,4S,5S,6S)-3-acetamido-4,5-dihydroxy-6-(hydroxymethyl)tetrahydro-2H-pyran-2-yl)oxy)-3,4-dihydroxy-5-(3-(4-(4-(trifluoromethoxy)phenoxy)piperidin-1-yl)benzyl)ureido)tetrahydro-2H-pyran-2-yl)methyl ((1R)-2-amino-1-((2R,3R,5R)-5-(2,4-dioxo-3,4-dihydropyrimidin-1(2H)-yl)-3,4-dihydroxytetrahydrofuran-2-yl)-2-oxoethyl)carbamate (Compound A)

¹H NMR (400 MHz, Methanol-*d*₄) δ 7.60 (d, *J* = 6.4 Hz, 1H), 7.23 (d, *J* = 8.1 Hz, 2H), 7.19 (d, *J* = 8.8 Hz, 2H), 7.02 (d, *J* = 9.5 Hz, 4H), 5.80 (d, *J* = 3.9 Hz, 1H), 5.69 (d, *J* = 8.0 Hz, 1H), 5.36 (d, *J* = 6.2 Hz, 1H), 4.93 (d, *J* = 4.7 Hz, 1H), 4.84 (d, *J* = 8.1 Hz, 1H), 4.60 (d, *J* = 11.2 Hz, 1H), 4.53 (dt, *J* = 7.8, 4.0 Hz, 1H), 4.49 – 4.07 (m, 4H), 3.91 – 3.89 (m, 1H), 3.88 – 3.85 (m, 1H), 3.83 – 3.79 (m, 2H), 3.77 – 3.70 (m, 2H), 3.66 – 3.46 (m, 8H), 3.25 (t, *J* = 7.3 Hz, 1H), 3.03 (ddd, *J* = 12.1, 8.7, 3.2 Hz, 2H), 2.17 – 2.08 (m, 2H), 1.89 (s, 3H), 1.92 – 1.83 (m, 2H).

¹³C NMR (101 MHz, MeOD) δ 176.7, 175.6, 170.7, 157.6, 155.9, 154.1, 153.0, 152.0, 143.9, 142.1, 131.3, 129.6 (2C), 123.6 (2C), 118.1 (2C), 118.1 (2C), 105.1, 103.8, 102.7, 101.3, 91.7, 84.9, 80.2, 76.7, 75.4, 74.0, 73.2, 72.5, 71.3, 69.4, 66.0, 65.0, 62.2, 60.5, 54.5, 45.5 (2C), 43.7, 31.5 (2C), 27.3.

((2R,4R,5R,6S)-6-(((2R,3S,4S,5S,6S)-3-acetamido-4,5-dihydroxy-6-(hydroxymethyl)tetrahydro-2H-pyran-2-yl)oxy)-3,4-dihydroxy-5-(3-(4-(4-(trifluoromethoxy)phenoxy)piperidin-1-yl)benzyl)ureido)tetrahydro-2H-pyran-2-yl)methyl ((1S)-2-amino-1-((2R,3R,5R)-5-(2,4-dioxo-3,4-dihydropyrimidin-1(2H)-yl)-3,4-dihydroxytetrahydrofuran-2-yl)-2-oxoethyl)carbamate (Compound B)

¹H NMR (400 MHz, Methanol-*d*₄) δ 7.61 (d, *J* = 7.3 Hz, 1H), 7.23 (d, *J* = 8.1 Hz, 2H), 7.19 (d, *J* = 8.8 Hz, 2H), 7.02 (d, *J* = 9.5 Hz, 4H), 5.81 (d, *J* = 4.3 Hz, 1H), 5.74 (d, *J* = 8.0 Hz, 1H), 5.42 (d, *J* = 3.6 Hz, 1H), 4.94 (d, *J* = 5.1 Hz, 1H), 4.80 (d, *J* = 8.1 Hz, 1H), 4.57 (d, *J* = 11.3 Hz, 1H),

4.53 (dt, $J = 7.8, 4.0$ Hz, 1H), 4.49 – 4.07 (m, 4H), 3.91 – 3.89 (m, 1H), 3.88 – 3.85 (m, 1H), 3.83 – 3.79 (m, 2H), 3.77 – 3.70 (m, 2H), 3.66 – 3.46 (m, 8H), 3.25 (t, $J = 7.3$ Hz, 1H), 3.03 (ddd, $J = 12.1, 8.7, 3.2$ Hz, 2H), 2.17 – 2.08 (m, 2H), 1.97 (s, 3H), 1.92 – 1.83 (m, 2H).

^{13}C NMR (101 MHz, MeOD) δ 177.3, 175.6, 170.7, 157.6, 156.7, 154.1, 153.0, 152.0, 143.9, 142.1, 131.3, 129.6 (2C), 123.6 (2C), 118.1 (2C), 118.1 (2C), 105.1, 103.8, 102.7, 101.3, 91.7, 84.9, 80.2, 77.5, 75.4, 74.0, 73.2, 72.5, 71.3, 70.6, 66.0, 65.0, 62.2, 60.5, 56.8, 45.5 (2C), 43.7, 31.5 (2C), 27.3.

Example 2: Enzymatic Inhibition

CAP (**1**) and its three analogues, OM-CAP (**2**), I-CAP (**3**), and DM-CAP (**4**) were evaluated in enzyme inhibitory assays against bacterial phosphotransferases, MraY and WecA, and archaeal and human dolichyl-phosphate GlcNAc-1-phosphotransferases, AgIH and DPAGT1. CAP is a selective MraY inhibitor that does not display inhibitory activity against WecA, AgIH, and DPAGT1 (Table 1). Previously, OM-CAP (**2**) was identified as a selective WecA inhibitor (IC_{50} 0.060 μM) that does not possess MraY inhibitory activity (IC_{50} >50 μM (entry 2 in Table 1). OM-CAP (**2**) was shown to have inhibitory activity against AgIH and DPAGT1 with the IC_{50} values of 13.5 and 3.5 μM , respectively (entry 2). I-CAP (**3**) showed enzyme inhibitory activity against MraY, WecA, AgIH, and DPAGT1 with the IC_{50} between 7.5-20 μM concentrations (entry 3). On the contrary, DM-CAP (**4**) showed only a weak WecA inhibitory activity (IC_{50} 35.0 μM) (entry 4).

MraY, WecA, AgIH, and DPAGT1 enzyme inhibitory activity assays for the six (((trifluoromethoxy)phenoxy) piperidin-1-yl)phenyl)methylamine analogues revealed that CPPB (**5**) and I-CPPB (**6**) are high nM range DPAGT1 inhibitors (entries 5 and 6 in Table 1), however, the O-methylation and demethylation analogues (OM-CPPB (**7**) and DM-CPPB (**8**)) turned out to be very low- or no-DPAGT1 inhibitor (entries 7 and 8). The secondary amine analogues, CPPA (**9**) and I-CPPA (**10**), did not inhibit all phosphotransferases tested in Table 1 at 50 μM concentration (entries 9 and 10). CPPB was determined to be three times stronger DPAGT1 inhibitor (IC_{50} 0.20 μM) than I-CPPB (entry 5 vs. 6). I-CPPB did not display MraY inhibitory activity, but showed a very weak WecA and AgIH enzyme inhibitory activity (entry 6). Interestingly, difference in these phosphotransferase inhibitory profiles between CPPB and I-CPPB correlate with their antimycobacterial activity: CPPB possessing MraY/WecA inhibitory activity killed *Mycobacterium tuberculosis* H37Rv, *Mycobacterium avium* 2285, *Mycobacterium smegmatis* (ATCC607) with the MIC values 6.25-12.5 $\mu\text{g/mL}$. In contrast, I-CPPB, which does not have MraY inhibitory activity, did not show growth inhibitory activity against these *Mycobacterium* spp. at 50 $\mu\text{g/mL}$.

Table 1.

Entry	Compound	IC ₅₀ (μM)			
		MraY (<i>Hydrogenivirga</i> sp.)	WecA (<i>E. coli</i>)	AgIH (<i>M. jannaschii</i>)	DPAGT1 (Human)
1	Capuramycin	0.13	>50	>50	>50
2	O-Methyl capuramycin	>50	0.060	2.5	4.5
3	iso-Capuramycin	8.5	30.0	20.0	11.5
4	Dimethyl capuramycin	>50	35.0	>50	>50
5	Capuramycin phenoxy-piperidin-benzylamide (CPPB)	10.3	0.10	0.15	0.20
6	iso-Capuramycin phenoxy-piperidinbenzylamide (I-CPPB, 6)	>50	20.0	15.0	0.60
7	O-Methyl capuramycin phenoxy-piperidinbenzylamide (OM-CPPB, 7)	5.0	10.0	30.0	20.0
8	Demethyl capuramycin phenoxy-piperidinbenzylamide (DM-CPPB, 8)	>50	30.0	>50	>50
9	Capuramycin phenoxy-piperidin-benzylamine (CPPA, 9)	>50	>50	>50	>50
10	iso-Capuramycin phenoxy-piperidin-benzylamine (I-CPPA, 10)	>50	>50	>50	>50
11	Tunicamycin (11)	2.9	0.15	13.2	1.5

Expression and purification of HyMraY. The gene *mraY* of *Hydrogenivirga* spp. 128-5-R1-1 was cloned with a *N*-terminal His6 tag into a pET22b vector. The plasmid was transformed and expressed in *E. coli* NiCo21(DE3) pLEMO competent cells. The proteins were purified using a nickel, cation exchange, and size exclusion chromatography. The final storage buffer was 20 mM HEPES pH 7.5, 100 mM NaCl, 10% glycerol, 5 mM 3ME, 0.15% decyl 3-D-maltopyranoside (DM).

Expression and purification of MjAgIH. The gene *mj1113* of *Methanocaldococcus jannaschii* DSM 2661 was cloned with a *N*-terminal His9 tag into a pET33b-derived vector. The plasmid was transformed and expressed in *E. coli* NiCo21(DE3) pLEMO competent cells. The proteins were purified using cobalt and size exclusion chromatography. The final

storage buffer was 20 mM Tris-HCl, pH 7.5, 100 mM NaCl, 5% glycerol, 5 mM 3ME, 0.15% DM.

Preparation of membrane fraction P-60 containing WecA. *E. coli* B21 *wecA* strain were harvested by centrifugation (4,700 rpm) at 4 °C followed by washing with 0.9% saline solution (thrice). The washed cell pellets were washed with homogenization buffer (containing 50 mM K₂HPO₄, 5 mM MgCl₂, 5 mM 1,4-dithio-DL-threitol, and 10% glycerol, pH = 7.2) (thrice), and approximately 5 g of pellet (wet weight) was collected. The washed cell pellets were suspended in homogenization buffer and disrupted by probe sonication on ice (5s on and 2s off for 1 min, then cool down for 1.5min., 5 cycles, cool down for 15 min, and then, 5s on and 2s off for 1min., cool down for 1.5min, 5 cycles). The resulting suspension was centrifuged at 4,700 x g for 15min. at 4 °C to remove unbroken cells. The lysate was centrifuged at 25,000 x g for 20min. at 4 °C. The supernatant was subjected to ultracentrifugation at 60,000 x g for 1h at 4 °C. The supernatant was discarded, and the membrane fraction containing WecA enzyme (P-60) was suspended in the Tris-HCl buffer (pH = 7.5). Total protein concentrations were approximately 8 to 10 mg/mL. Aliquots were stored in Eppendorf tubes at -80 °C.

DPAGT1 expression and purification. DPAGT1 was expressed in suspended Expi293 cells for 36h. The cells were lysed by drawing through a 26g needle (10 times) and membrane protein was extracted using buffer containing 1% decyl f3-D-maltopyranoside detergent. DPAGT1 was purified using HA-agarose resin and a superdex 200 size exclusion column.

MraY assay. MraY assay substrates, Park's nucleotide-N^ε-C6-dansylthiourea, neryl phosphate, were chemically synthesized according to the reported procedures.⁷ Park's nucleotide-N^ε-C6-dansylthiourea (2 mM stock solution, 1.88 μ L), MgCl₂ (0.5 M, 5 μ L), KCl (2 M, 5 μ L), Triton X-100 (0.5%, 5.63 μ L), Tris buffer (pH 8.0, 50 mM), neryl phosphate (0.1 M, 2.25 μ L), and inhibitor molecule (0 - 50 μ g/mL in Tris buffer) were placed in a 1.5 mL Eppendorf tube. To a reaction mixture, P-60 (10 μ L) was added (total volume of reaction mixture: 50 μ L adjust with Tris buffer). The reaction mixture was incubated for 2h at r.t. (26 °C) and quenched with CHCl₃ (100 μ L). Two phases were mixed via vortex and centrifuged at 25,000 xg for 10 min. The aqueous phase was assayed via reverse-phase HPLC. The water phase (10 μ L) was injected into HPLC (solvent: CH₃CN/0.05 M aq. NH₄HCO₃ = 25:75; UV: 350 nm; flow rate: 0.5 mL/min; column: Kinetex 5 μ M C8, 100 A, 150 x 4.60 mm), and the area of the peak for lipid l-neryl derivative was quantified to obtain the IC₅₀ value. The IC₅₀ values were calculated from plots of the percentage product inhibition versus the inhibitor.

WecA assay. WecA assay substrate, UDP-Glucosamine-C6-FITC was chemically synthesized according to the reported procedures.^{9,11,58} UDP-Glucosamine-C6-FITC (UDP-

GlcN-C6-FITC, 2 mM stock solution, 0.56 μ L), $MgCl_2$ (0.5 M, 4 μ L), β -mercaptoethanol (50 mM, 5 μ L), CHAPS (5%, 11.3 μ L), Tris buffer (pH 8.0, 50 mM), undecaprenyl phosphate (4 mM, 1.4 μ L), and inhibitor molecule (0 - 50 μ g/mL in Tris buffer) were placed in a 1.5 μ L Eppendorf tube. To a reaction mixture, P-60 (10 μ L) was added (total volume of reaction mixture: 50 μ L adjust with Tris buffer). The reaction mixture was incubated for 2 h at 37 $^{\circ}$ C and quenched with n-butanol (150 μ L). Two phases were mixed via vortex and centrifuged at 10,000 $\times g$ for 3 min. The upper organic phase was assayed via reverse-phase HPLC. The organic phase (30 μ L) was injected into HPLC (solvent: gradient elution of 85:15 to 95:5 MeOH/0.05 M aq. NH_4HCO_3 ; UV: 485 nm; flow rate: 0.5 mL/min; column: Kinetex 5 μ m C8, 100 $\text{\AA}$, 150 $\times$ 4.60 mm), and the area of the peak for C_{55} -P-P-GlcN-C6-FITC was quantified to obtain the IC_{50} value. The IC_{50} values were calculated from plots of the percentage product inhibition versus the inhibitor concentration.

AgIH assay. AgIH assays were performed as the procedure described for WecA assays, but used *Mj*AgIH and α -dihydroundecaprenyl phosphate (C_{55} -dolichyl phosphate) instead of WecA and undecaprenyl phosphate. UDP-GlcN-C6-FITC (2 mM stock solution, 0.56 μ L), $MgCl_2$ (0.5 M, 4 μ L), β -mercaptoethanol (50 mM, 5 μ L), CHAPS (5%, 11.3 μ L), Tris buffer (pH 8.0, 50 mM), C_{55} -dolichyl phosphate (4 mM, 1.4 μ L), and inhibitor molecule (0 - 50 μ g/mL in Tris buffer) were placed in a 1.5 μ L Eppendorf tube. To a reaction mixture, AgIH solution (10 μ L) was added (total volume of reaction mixture: 50 μ L adjust with Tris buffer). The reaction mixture was incubated for 2 h at 37 $^{\circ}$ C and quenched with n-butanol (150 μ L). Two phases were mixed via vortex and centrifuged at 10,000 $\times g$ for 3 min. The upper organic phase was assayed via reverse-phase HPLC. The organic phase (30 μ L) was injected into HPLC (solvent: gradient elution of 85:15 to 95:5 MeOH/0.05 M aq. NH_4HCO_3 ; UV: 485 nm; flow rate: 0.5 mL/min; column: Kinetex 5 μ m C8, 100 $\text{\AA}$, 150 $\times$ 4.60 mm), and the area of the peak for C_{55} -P-P-GlcN-C6-FITC was quantified to obtain the IC_{50} value. The IC_{50} values were calculated from plots of the percentage product inhibition versus the inhibitor concentration.

DPAGT1 assay. DPAGT1 assays were performed as the procedure described for AgIH assays, but used DPAGT1.

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Example 3: Cytotoxicity of new capuramycin analogues, CPPB (5) and I-CPPB (6)

In the capuramycin analogue series, the degree of *MraY* inhibitory activity correlates with their antimycobacterial activity. Antimycobacterial capuramycin analogues display low *in vitro* cytotoxicity against mammalian cells, and have been recognized as safe drug leads that have acceptable tolerability in animal models. The toxicity of tunicamycin has been studied extensively *in vitro*: tunicamycin inhibits growth in many cancer cell lines without selectivity,

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and has a narrow therapeutic window demonstrated in *in vivo* studies using mice. The toxicity of tunicamycin is believed to be attributable to its ability to inhibit DPAGT1 enzyme function. Tunicamycin's toxicity, however, cannot be explained solely by its inhibition of DPAGT1.

Capuramycin-based DPAGT1 inhibitors, CPPB (5) and I-CPPB (6) inhibited DPAGT1 enzyme with the IC₅₀ values of 0.2 and 0.6 μ M, respectively. Unlike the MraY-antimycobacterial activity relationship observed for CAP analogues, the DPAGT1 inhibitors, CPPB and I-CPPB, did not show antiproliferative activity against L1210 (a leukemia cell), HPNE (a normal pancreatic ductal cell), and Vero (a normal kidney cell) at 50 μ M. They showed various levels of growth inhibitory activity several against solid cancer cell lines such as KB (HeLa, a cervix carcinoma), SiHa (a cervical squamous cell carcinoma), HCT-116 (a colorectal adenocarcinoma), DLP-1 (a colorectal adenocarcinoma), Capan-2 (a pancreatic ductal adenocarcinoma), PANC-1 (a pancreatic ductal carcinoma), AsPC-1 (a pancreatic adenocarcinoma), PD002 (a patient-derived pancreatic adenocarcinoma) in MTT assays (IC₅₀ 15-40 μ M, Table 2). A lower DPAGT1 inhibitor, tunicamycin (11), showed growth inhibition of all cell lines in Table 2 with the IC₅₀ values of 0.78-7.5 μ M concentrations (entry 5 in Table 2). Cellular behavior and morphological changes of PD002 treated with CPPB were monitored over time via IncuCyte® live cell analysis imaging system (Figure 2A).

Interestingly, 10-13% of phase area confluent of PD002 culture (time 0h) remained the same after 72h for the CPPB-treated cells (50 μ M), whereas, ca. 70% of confluence was reached for the control PD002 culture (PBS) (Figures 2B and 2C). Although morphological changes were subtle over time (0-72h), cell viability assessed by the MTT reduction assay revealed that PD002 cells treated with CPPB (50 μ M) was significantly decreased (Table 2). Exposure of CPPB (0.2-20 μ M) inhibited cell proliferation of PD002: ca. 20% of cell proliferation was inhibited at time 72h. These results indicate that DPAGT1 inhibitors may have cytostatic effect again certain cancerous tumors that require DPAGT1 overexpression for their growth.

Table 2.

No.	Compound	IC ₅₀ (μ M)										
		L1210	KB	SiHa	HCT-116	DLD-1	Capan-2	PANC-1	AsPC-1	PD002	HPNE	Vero
1	CAP (1)	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50
2	OM-CAP (2)	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50
3	CPPB (5)	>50	35.0	15.0	15.0	25.0	30.0	35.0	25.0	35.0	>50	>50

4	I-CPPB (6)	>50	35.0	25.0	25.0	35.0	40.0	45.0	30.0	50.0	>50	>50
5	Tunicamycin (11)	1.70	2.50	0.92	0.92	1.25	1.50	1.50	0.45	1.50	7.5	0.78

Cell lines. The human primary PDAC cell lines PANC-1 (ATCC CRL 1469); Capan-2 (ATCC HTB-80) and metastatic PDAC cell lines Capan-1 (ATCC HTB-79), AsPC-1 (ATCC CRL-1682), L1210 (ATCC CCL-219), KB (ATCC CCL-17), HeLa, SiHa (ATCC HTB-35), HCT-116 (ATCC CCL-247), DLD-1 (ATCC CCL221), hTERT-HPNE (ATCC CRL-4023), Vero (ATCC CCL-81) were purchased from the ATCC. The cell lines were cultured and maintained in the media as recommended by the supplier. The cell lines were regularly tested for mycoplasma contamination and authenticated. In addition to ATCC cell lines, Dr. Glazer's lab generated patient-derived PDAC cell line, PD002. PD002 Cells were maintained and cultured in DMEM medium supplemented with 20% FBS and 100 IU/mL penicillin and incubated at 37°C with 5% CO₂.

MTT cytotoxicity assay. To study the effect of treatment with DPAGT1 inhibitors on the growth and proliferation of cells, a fixed number of cells (5×10^4 cells/well, 196 μ L) were plated in a 96 well plate. Into each well 5 μ L of drug concentration was added. After 72 h of incubation with drugs at 37 °C, 5% CO₂, 10 μ L of MTT solution (5 mg/mL in PBS) was added and incubated another 3 h at 37 °C, 5% CO₂. The medium was removed, and DMSO (200 μ L/well) was added. Viability was assessed on the basis of cellular conversion of MTT into a purple formazan product. The absorbance of the colored formazan product was measured at 570 nm by BioTek Synergy HT Spectrophotometer.

Kinetic Proliferation Assay. To study the effect of treatment with DPAGT1 inhibitors on the growth and proliferation of cells, a fixed number of cells (2×10^4) were plated in multiple wells of a 96 well plate, incubated for 24 h to let cells settle down. Then, CPPB (5) was added (0-50 μ M). Images were obtained every 4 h using an IncuCyte Live-Cell Imaging System (Essen BioScience, Ann Arbor, MI). After 72 h, cell proliferation was quantified using the metric phase object confluence (POC), a measurement of the area of the field of view that is covered by cells, which is calculated by the integrated software.

Scratch Assay. A confluent monolayer was formed in 24-well plates. The monolayer was scratched by a sterile 200 μ L pipette tip and washed with PBS to remove cell debris. Complete medium with CPPB (5) (0, 0.05, 0.1, 0.2 μ M) were added and scratched areas were photographed with microscope. The scratched cells were incubated at 37 °C, 5% CO₂. After 24 h, medium was removed and cells were stained with a 1:1 mixture of crystal violet and PBS for 5 min., washed with PBS twice, and photographed with microscope. Wound areas were measured and recovered areas were calculated.

Example 4: Cell migratory inhibition by CPPB (5)

DPAGT1 catalyzes the first step in *N*-glycan biosynthesis of mammalian cells (Figure 1). Aberrant *N*-glycosylation is common in many solid cancers and important for the epithelial to mesenchymal transition program (EMT, a mechanism of metastases). High levels of DPAGT1 protein expression were found in a series of pancreatic cancers (e.g., Panc-1, CAPAN-2, and AsPC-1). Dysregulation of DPAGT1 enzyme leads to disturbances in cell-cell adhesions and may increase epithelial to mesenchymal transition (EMT): these processes increase migratory and invasive capabilities of malignant neoplasms that are the initiation of metastasis in cancer progression, especially pancreatic cancer. Interestingly, there is significant crosstalk between DPAGT1 and the Wnt/ β -catenin and Snail pathway where DPAGT1 overexpression leads to 1) accumulation of β -catenin in the cytoplasm and then translocation into the nucleus, and 2) reduction of the Snail expression levels, preventing epithelial-mesenchymal transition.

As such, aberrations in these pathways occur in numerous cancers, thus, discovery of small molecules directed towards inhibition of the Wnt and Snail pathways represents an important area of anticancer therapeutics. The degree of cell migration in several commercially available cell lines (Capan-2, PANC-1, and AsPC-1) were observed when treated with the compounds provided herein to determine the effects on cellular motility. After 24 h of three treatment doses (0.05, 0.1, and 0.2 μ M) with CPPB (5), inhibition of migration (closing the gap) was measured in a scratch assay (wound healing assay) (Figures 3A and 3B). The pancreatic cancer cell lines treated with CPPB migrated far less than the PBS treated (control) cells (Figure 3A). In these assays, the wound-healing rate of the untreated PD002 cells was 63% in 24 h. In sharp contrast, CPPB treated cells inhibited the wound-healing effectively at its IC₅₀ level against DPAGT1 (0.2 μ M): the wound-healing rate was approximately 20% (Figure 3B). The migration inhibition ability of CPPB was thoroughly evaluated compared to gemcitabine, one of the main chemotherapy drugs used to treat pancreatic cancer, and tunicamycin using PD002 cells.

Gemcitabine shows a wound-healing rate of 43% at 0.2 μ M, and tunicamycin shows 35% at 0.2 μ M. Thus, it was concluded that CPPB is more effective in inhibiting cancer cell migration than gemcitabine and tunicamycin. These trends were further confirmed by an endpoint migration assays via Boyden chambers for PD002. In these assays, the cell migrations of PD002 treated with CPPB (0.1 μ M) were inhibited on a higher level compared to those with tunicamycin and gemcitabine at the same concentration (0.1 μ M) (Figure 4).

Cell migration assays using Transwell chamber. Cell migration assay was performed using Boyden chamber (thermo fisher). PD002 cells ($\sim 10^4$ cells/mL) were seeded in 96-wells plate (Corning, HTS Transwell-96 Well Permeable Supports, pore size: 8 μ m) in FBS free media and the lower chambers were filled with 10% FBS medium. CPPB, tunicamycin, or gemcitabine (0.1 μ M) was added to the upper chamber. The cells were incubated for 18 h at 37 °C under 5% CO₂. The cells were fixed using 4% paraformaldehyde for 0.5 h and stained with 0.05% crystal violet (300 μ L/well), after 0.5 h, images were captured via 10X magnification microscopy.

10 *Example 5: Inhibition of a zinc-finger transcription factor, Snail1 (Snail) in the selected cancer cell lines by CPPB*

Snail protein is one of the most important transcription factors that induces epithelial to mesenchymal transition (EMT), which converts epithelial cells into migratory mesenchymal cells that are more efficient at metastasizing. EMT induced by overexpression of Snail produces cancer stem-like properties in a number of solid organ cancers. Aberrant expression of Snail leads to loss of expression of E-cadherin, a cell-cell adhesion glycoprotein. Thus, suppression of Snail expression or inhibition of Snail functions represents a potent targeted therapeutic strategy for many cancers.

Immunofluorescence assays using an anti-Snail antibody revealed that the fluorescence intensity of Snail was strong in a series of pancreatic cancer cells (PANC-1, AsPC-1, Capan-2, and PD002), and the expression of Snail was decreased by the treatment with CPPB in a concentration dependent manner. Among pancreatic cancer cell lines, only the data for PD002 and PANC-1 are shown in Figure 5. The Snail expression level of a non-metastatic pancreatic cancer, PANC-1, was much lower than metastatic pancreatic cancers (e.g., PD002 and Capan-2). A few other types of cancer cells such as a colorectal cancer (HCT-116) and a cervical cancer (SiHa) were examined by similarly designed immunofluorescence assays or Western blot assays (Figures 5 and 6). The Snail expression in SiHa was inhibited by treatment of CPPB in a concentration dependent manner; at the IC₅₀ concentration (0.2 μ M against DPAGT1), CPPB effectively inhibited the Snail expression (Figure 6). In contrast, the Snail expression level in HCT-116 was not noticeably changed by the treatment of CPPB between 0.05 and 2.0 μ M concentrations.

Interestingly, cell migration of HCT-116 was not inhibited by CPPB demonstrated in the wound healing (scratch) assays (Figure 3). At the concentrations tested in the scratch assays (0.05-2.0 μ M), the E-cadherin expression levels of PD002, PANC-1, and HCT-116 were not changed significantly (Figure 7).

Example 6: Inhibition of DPAGT1 by CPPB

CPPB decreased the DPAGT1 expression level in all pancreatic cancer cell lines examined in Figure 3: the DPAGT1 expression was apparently inhibited by the IC₅₀ concentration of CPPB (0.2 μM) (Figure 8). However, the DPAGT1 expression of the pancreatic cancer cell lines could not completely be inhibited at a high concentration of CPPB (2-20 μM). In MTT assays, all pancreatic cancers tested remained viable at 20 μM concentration of CPPB (Table 2). In contrast, the DPAGT1 expression levels of a colorectal adenocarcinoma, HCT-116, remained high even at a high concentration of CPPB (20 μM) (Figure 8). These data imply that the inhibitory effect of CPPB on cell migration varies depending on degree of inhibition of the DPAGT1 expression: at the IC₅₀ of CPPB (0.2 μM against DPAGT1), the degree of DPAGT1 expression was decreased by the following order: PANC-1 > PD002 >> HCT-116.

Migration inhibition observed in the scratched assays (Figure 3) is well-correlated with the degree of the DPAGT1 expression inhibition. Although CPPB decreased the protein expression of DPAGT1 without significantly decreasing its gene (*DPAGT1*) expression, tunicamycin decreased both the gene expression of *DPAGT1* and DPAGT1 protein expression (Figure 9). These down-regulation in *DPAGT1* gene expression by tunicamycin may be attributable to its high cytotoxicity against mammalian cells without selectivity.

Example 7: Synergistic effect of CPPB with paclitaxel

The FOLFIRINOX (a combination of folinic acid, 5-fluorouracil, irinotecan, and oxaliplatin) and nab-paclitaxel (albumin-bound paclitaxel)-gemcitabine regimens have been adopted into clinical practice for patients with metastatic pancreatic cancers. Median progression-free survival was reported in one study of patients with metastatic pancreatic cancer to be 6.4 months in the FOLFIRINOX group and 3.3 months in the gemcitabine group. Over the past years, the clinical data have not supported that FOLFIRINOX is associated with any better (or worse) survival rates compared to the nab-paclitaxel-gemcitabine regimen as there have been no head-to-head trials. However, the inclusion of paclitaxel and its derivatives in combination regimens remains an important therapeutic strategy in pancreatic cancer chemotherapy since nab-paclitaxel-gemcitabine is associated with less adverse effects (toxicity in patients) than FOLFIRINOX.

The synergistic or antagonistic activities of CPPB were assessed *in vitro* via checkerboard technique. In these experiments, CPPB displayed strong synergistic effects with paclitaxel in a wide range of concentrations against PD002. Table 3 summarizes the results of FIC index analyses for selected combinations of CPPB (IC₅₀ 35.0 μM) plus paclitaxel (IC₅₀ 1.25 μM) that showed synergistic combination (ΣFIC<0.5). The FIC index below 0.50 was observed

for 20 combinations of two molecules out of 96 different concentrations (see Supporting Information). The IC₅₀ value of paclitaxel against PD002 was lowered (0.024-0.61 μ M) in combination with CPPB (0.1-2.0 μ M).

5 **Table 3.**

Entry	Combination of A and B	IC ₅₀ (μ M) CA and CB	Σ FIC
1	A: CPPB	0.10	0.50
	B: Paclitaxel	0.63	
2	A: CPPB	0.10	0.13
	B: Paclitaxel	0.16	
3	A: CPPB	0.20	0.0096
	B: Paclitaxel	0.0049	
4	A: CPPB	0.20	0.021
	B: Paclitaxel	0.020	
5	A: CPPB	0.20	0.26
	B: Paclitaxel	0.031	
6	A: CPPB	2.0	0.021
	B: Paclitaxel	0.020	
7	A: CPPB	2.0	0.037
	B: Paclitaxel	0.039	
8	A: CPPB	2.0	0.26
	B: Paclitaxel	0.31	

CPPB showed ~7.5 times stronger DPAGT1 inhibitory activity than tunicamycin. However, unlike tunicamycin, CPPB did not inhibit growth of cancer cell lines at the IC₅₀ values observed for tunicamycin (0.45 -7.5 μ M). CPPB is a cell-permeable molecule which was demonstrated by IncuCyte® live cell analyses and immunofluorescence assays. The effectiveness of CPPB on the expression levels of Snail, E-cadherin, and DPAGT1 primary in pancreatic cancers has been shown in the present disclosure. CPPB decreased the Snail expression in commercially available pancreatic cancer cell lines (PANC-1, AsPC-1, and Capan-2) and a patient-derived pancreatic ductal adenocarcinoma cell line (PD002) in a dose dependent manner. On the other hand, the E-cadherin expression level was not noticeably changed in PD002 or slightly increased in Panc-1 at between 0.05-0.2 μ M of CPPB. These biochemical data support that a selective DPAGT1 inhibitor, CPPB, is effective in inhibiting migrations of the pancreatic cancer cells in migration (scratch) assays. Other than pancreatic cancers, a lower DPAGT1 expression cell, a colorectal adenocarcinoma (HCT-116) and a

higher DPAGT1 expression cell, a cervical carcinoma (SiHa) were examined. CPPB did not inhibit migration of HCT-116, but strongly inhibited migration of SiHa in scratch assays at its IC₅₀ concentration (0.2 μ M against DPAGT1).

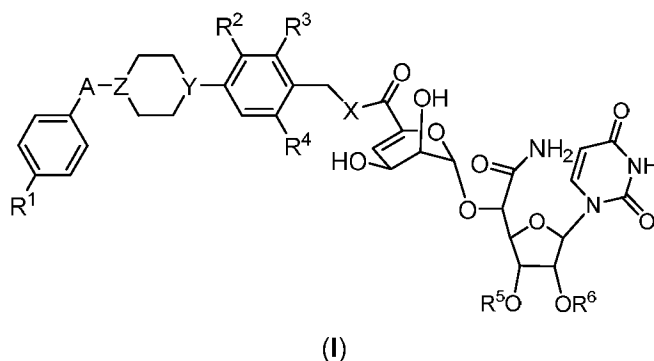
These observations were supported by the biochemical analyses of the Snail and E-cadherin expression levels. Snail plays an important role in cancer progression. The accumulated evidence on Snail indicates that over-expression of Snail promotes drug resistance, tumor recurrence and metastasis. Snail inhibitory activity of CPPB suggests that selective DPAGT1 inhibitors have the potential to develop into less toxic anticancer therapeutics than current anticancer agents that are cytotoxic to all dividing cells in the body.

CPPB is not cytotoxic against a series of cancer and healthy cell lines at 10 μ M or higher concentrations. However, it showed a strong synergistic effect with paclitaxel; cytostatic activity of paclitaxel is improved over 250-times against PD002 in combination with CPPB (0.2-2.0 μ M).

Various modifications of the invention, in addition to those described herein, will be apparent to those skilled in the art from the foregoing description. Such modifications are also intended to fall within the scope of the appended claims. Each reference, including without limitation all patent, patent applications, and publications, cited in the present application is incorporated herein by reference in its entirety.

CLAIMS

1. A compound of Formula I:



or a pharmaceutically acceptable salt thereof;

wherein

X is NH, O, or $-(CH_2)_m-$;

5 Y is CH or N;

Z is CH or N;

A is absent, O, or NH;

R¹ is OR⁷ or $-(CH_2)_nNHR^7$;

R² is H or halo;

10 R³ is selected from the group consisting of H, halo, C₁-C₆ alkyl, C₂-C₆ alkenyl, C₂-C₆ alkynyl, C₁-C₆ alkoxy, and C₁-C₆ haloalkyl;

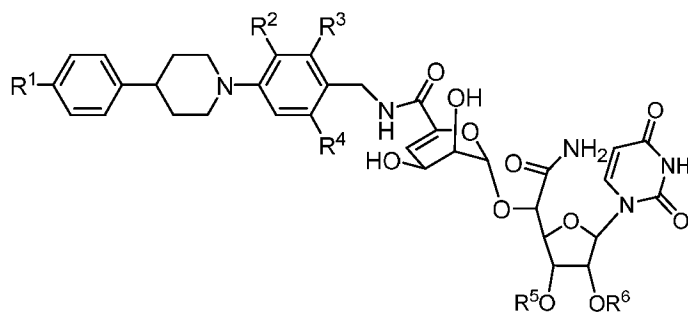
R⁴ is H or halo;

R⁵ and R⁶ are each independently selected from the group consisting of H, C₁-C₆ alkyl, and C(O)C₁-C₆ alkyl;

15 R⁷ is selected from the group consisting of H, C₁-C₆ alkyl, C₁-C₆ haloalkyl, C₆-C₁₀ aryl, and 5-10 membered heteroaryl; wherein aryl and heteroaryl are each optionally substituted one, two, or three times with OC₁-C₆ haloalkyl; and

m and n are, independently at each occurrence, 0, 1, 2, or 3.

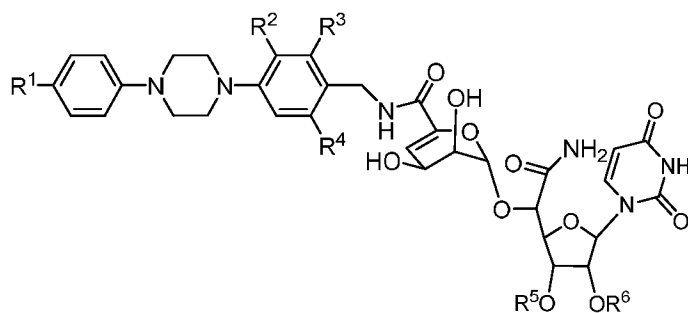
2. The compound of claim 1, wherein the compound of Formula I is a compound of Formula II:



(II)

or a pharmaceutically acceptable salt thereof.

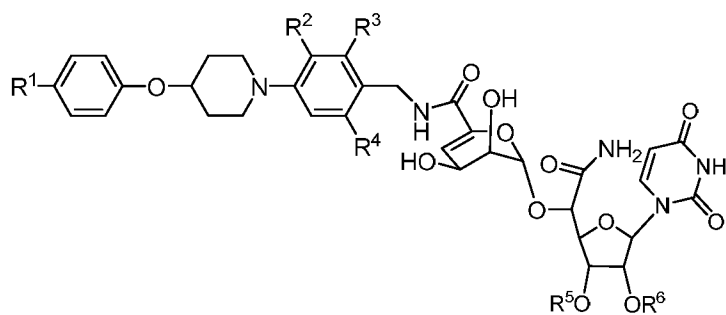
3. The compound of claim 1, wherein the compound of Formula I is a compound of Formula III:



(III)

or a pharmaceutically acceptable salt thereof.

4. The compound of claim 1, wherein the compound of Formula I is a compound of Formula IV:



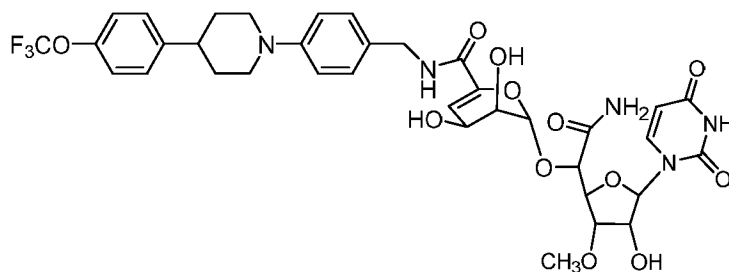
(IV)

or a pharmaceutically acceptable salt thereof.

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5. The compound of any one of claims 1-4, wherein R¹ is OR⁷.

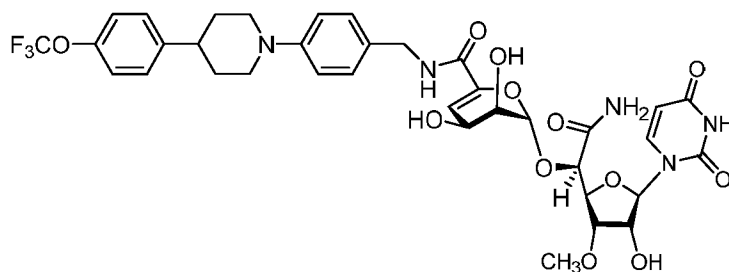
6. The compound of any one of claims 1-4, wherein R^1 is $-(CH_2)_nNHR^7$.
7. The compound of any one of claims 1-6, wherein R^7 is selected from the group consisting of C_1 - C_6 alkyl, C_1 - C_6 haloalkyl, and phenyl, wherein phenyl is optionally substituted one time with OC_1 - C_6 haloalkyl.
8. The compound of any one of claims 1-7, wherein R^7 is selected from the group consisting of methyl, ethyl, C_3 alkyl, C_4 alkyl, CF_3 , and phenyl- OCF_3 .
9. The compound of any one of claims 1-8, wherein R^2 is H.
10. The compound of any one of claims 1-8, wherein R^2 is fluoro.
11. The compound of any one of claims 1-10, wherein R^3 is selected from the group consisting of H, fluoro, methyl, methoxy, C_2 alkenyl, and C_2 alkynyl.
12. The compound of any one of claims 1-11, wherein R^3 is H.
13. The compound of any one of claims 1-12, wherein R^4 is H.
14. The compound of any one of claims 1-12, wherein R^4 is fluoro.
15. The compound of any one of claims 1-14, wherein R^5 is H or methyl.
16. The compound of any one of claims 1-15, wherein R^5 is methyl.
17. The compound of any one of claims 1-16, wherein R^6 is H or methyl.
18. The compound of any one of claims 1-17, wherein R^6 is H.
19. The compound of claim 1 or 2, wherein the compound of Formula I is CPPB:



(CPPB)

or a pharmaceutically acceptable salt thereof.

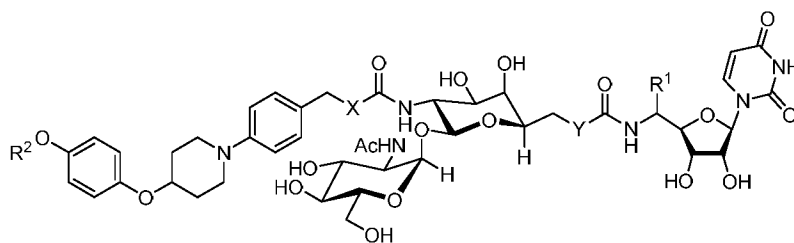
20. The compound of claim 19, wherein the compound of Formula I is CPPB1:



(CPPB1)

or a pharmaceutically acceptable salt thereof.

- 5 21. A compound of Formula V:



(V)

or a pharmaceutically acceptable salt thereof;

wherein

- 10 X and Y are independently O or NH;

R¹ is selected from the group consisting of H, OH, C(O)NH₂, CO₂H, C(O)H, and C(O)halo; and

R² is selected from the group consisting of H, C₁-C₆ alkyl, C₁-C₆ haloalkyl, C₆-C₁₀ aryl, and 5-10 membered heteroaryl.

- 15

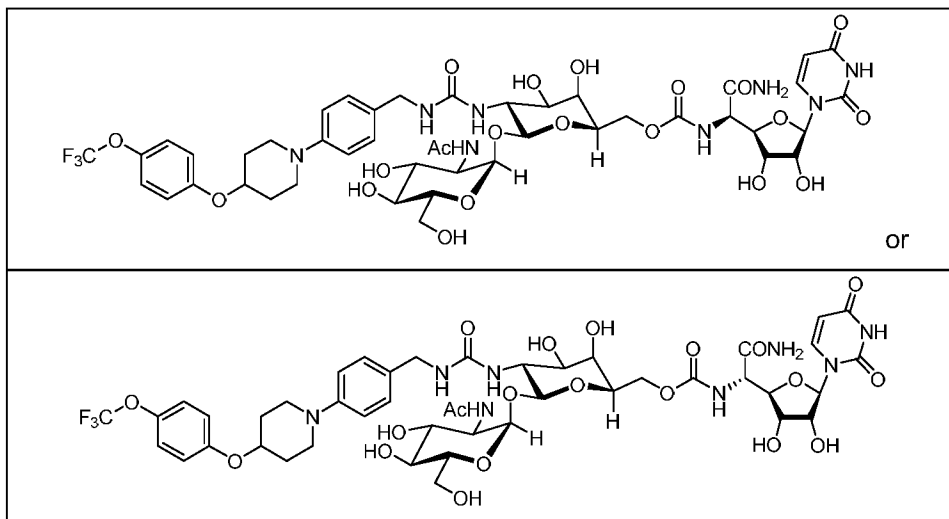
22. The compound of claim 21, wherein X is NH.

23. The compound of claim 21 or 22, wherein Y is O.

24. The compound of any one of claims 21-23, wherein R¹ is C(O)NH₂.

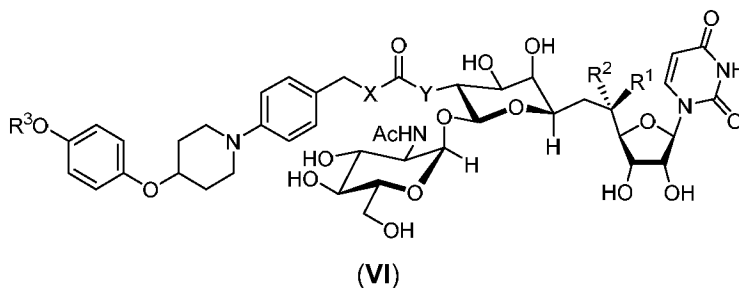
25. The compound of any one of claims 21-24, wherein R² is C₁-C₆ haloalkyl.

26. The compound of any one of claims 21-25, wherein the compound of Formula V is



or a pharmaceutically acceptable salt thereof.

27. A compound of Formula VI:



or a pharmaceutically acceptable salt thereof;

wherein

X and Y are independently O or NH;

R¹ and R² are each independently selected from H and OH; and

R³ is selected from the group consisting of H, C₁-C₆ alkyl, C₁-C₆ haloalkyl, C₆-C₁₀ aryl, and 5-10 membered heteroaryl.

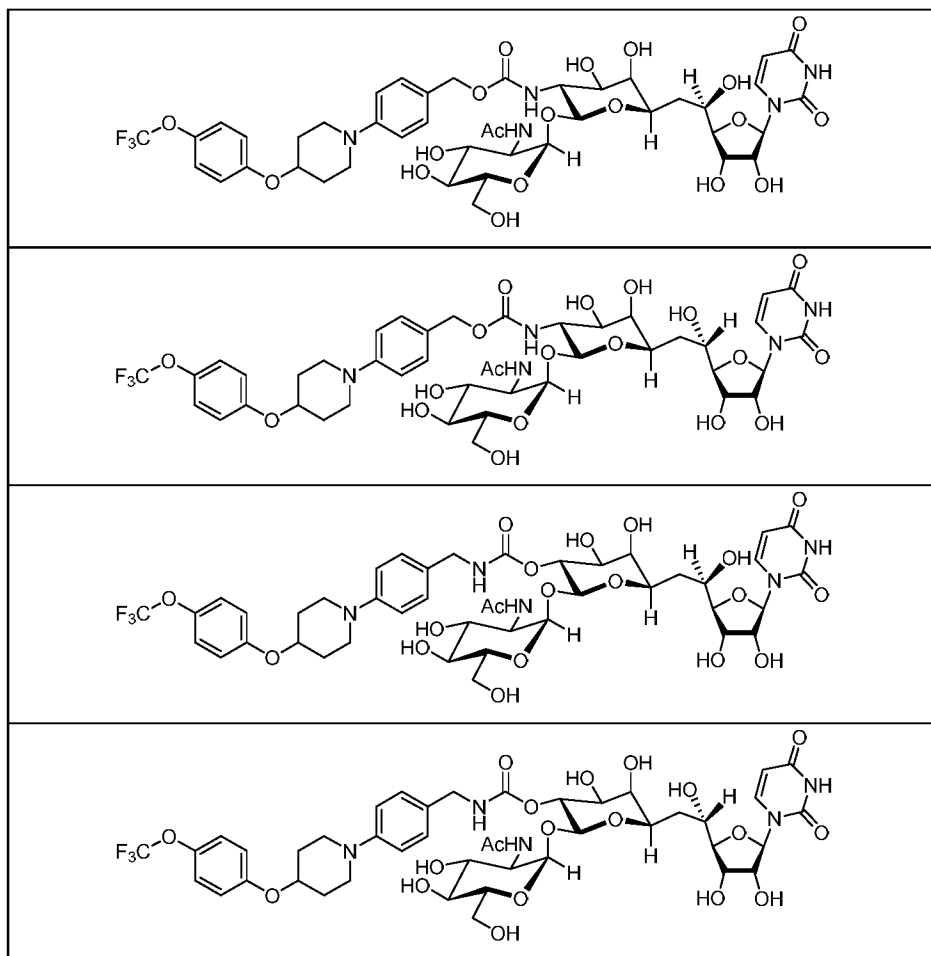
28. The compound of claim 27, wherein X and Y are NH.

29. The compound of claim 27, wherein X is NH and Y is O.

30. The compound of claim 27, wherein X is O and Y is NH.

31. The compound of any one of claims 27-30, wherein R³ is C₁-C₆ haloalkyl.

32. The compound of any one of claims 27-31, wherein the compound of Formula VI is selected from the group consisting of



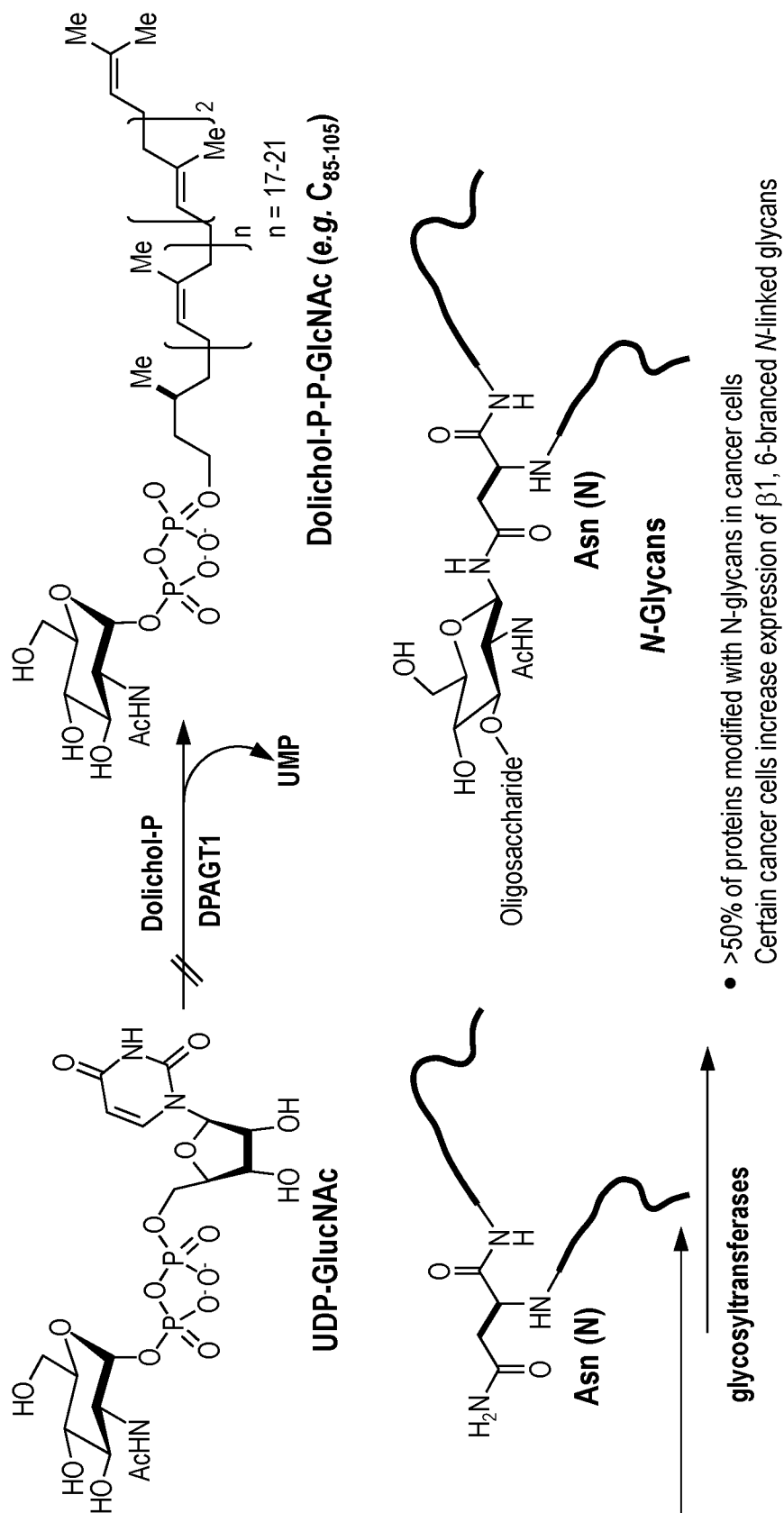
or a pharmaceutically acceptable salt thereof.

33. A pharmaceutical composition comprising a compound according to any one of claims 1-32, and at least one pharmaceutically acceptable carrier.

34. The pharmaceutical composition of claim 33, further comprising an additional therapeutic agent.

35. The pharmaceutical composition of claim 34, wherein the additional therapeutic agent is selected from the group consisting of paclitaxel, tunicamycin, capuramycin, erlotinib, capecitabine, fluorouracil, and gemcitabine.
- 5 36. The pharmaceutical composition of claim 34 or 35, wherein the additional therapeutic agent is paclitaxel.
37. A method of inhibiting dolichyl-phosphate *N*-acetylglucosaminophosphotransferase (DPAGT1) in a subject in need thereof, comprising administering to the subject a
10 therapeutically effective amount of a compound of any one of claims 1-32 or the pharmaceutical composition of any one of claims 33-36.
38. A method of treating cancer in a subject in need thereof, comprising administering to the subject a therapeutically effective amount of a compound of any one of claims 1-32 or
15 the pharmaceutical composition of any one of claims 33-36.
39. The method of claim 38, wherein the cancer is selected from the group consisting of pancreatic cancer, cervical cancer, brain cancer, colon cancer, ovarian cancer, breast cancer, pancreatic cancer, carcinoma, and adenocarcinoma.
20
40. The method of claim 38 or 39, wherein the cancer is pancreatic cancer.
41. The method of claim 38, wherein the cancer is a solid tumor.

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Fig. 1

- >50% of proteins modified with N-glycans in cancer cells
Certain cancer cells increase expression of β 1, 6-branched N-linked glycans

Fig. 2A

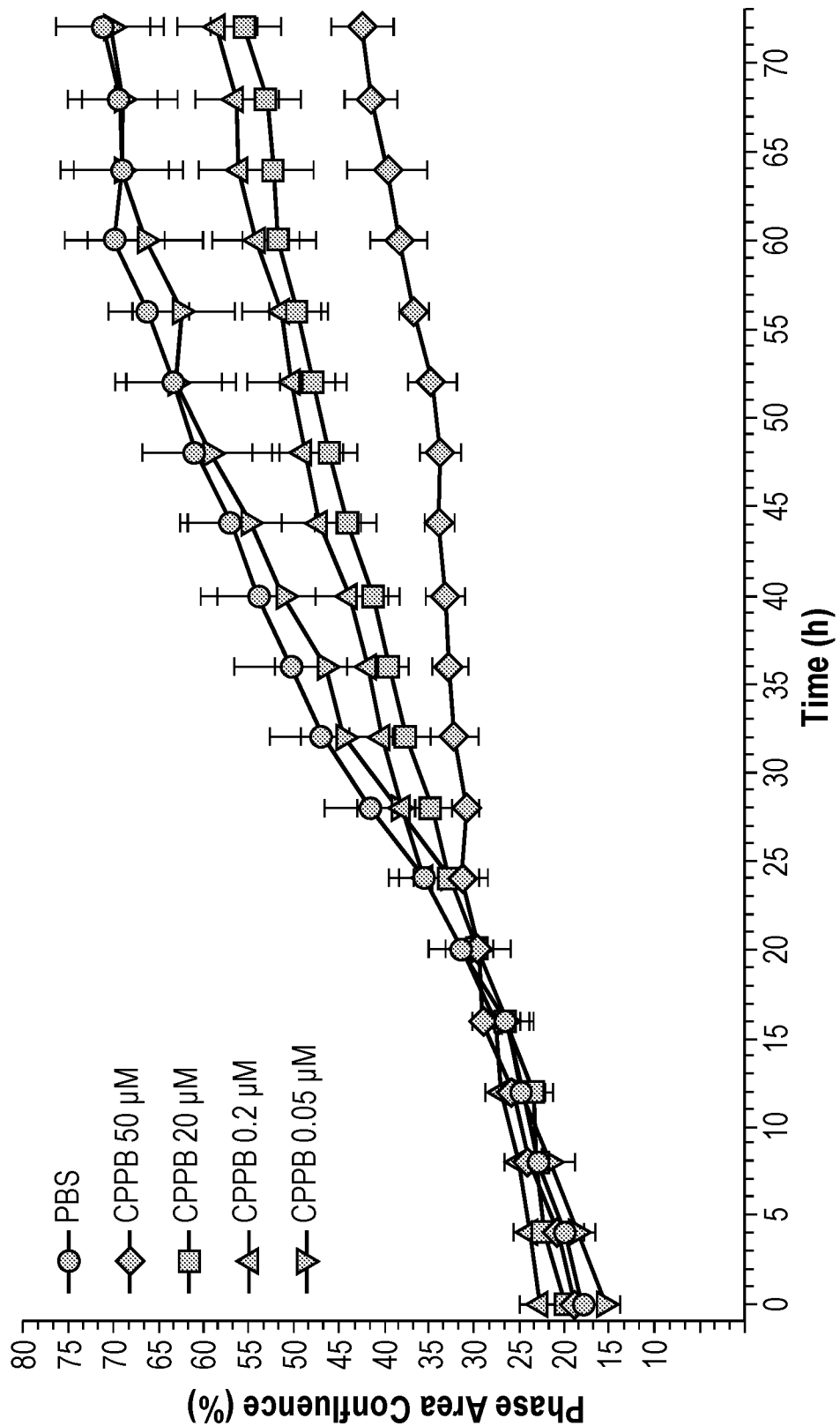
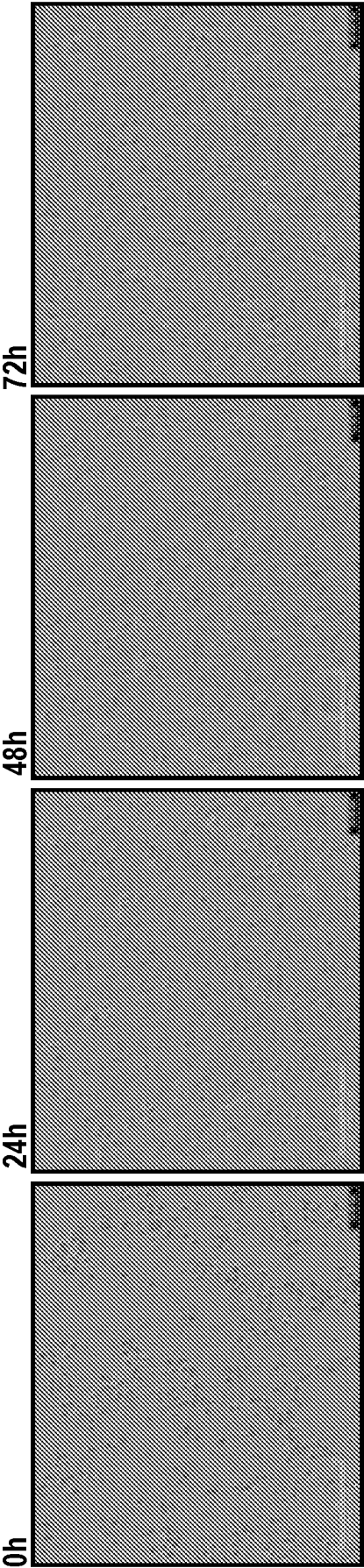


Fig. 2B and Fig. 2C

B: PD002 (PBS)



C: PD002 (CPPB 50 μ M)

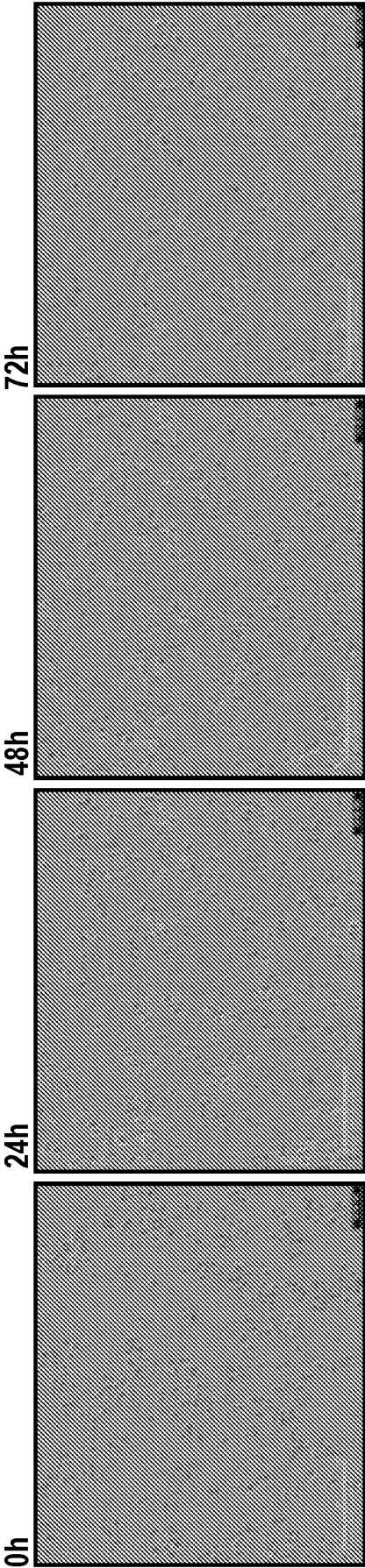


Fig. 3A

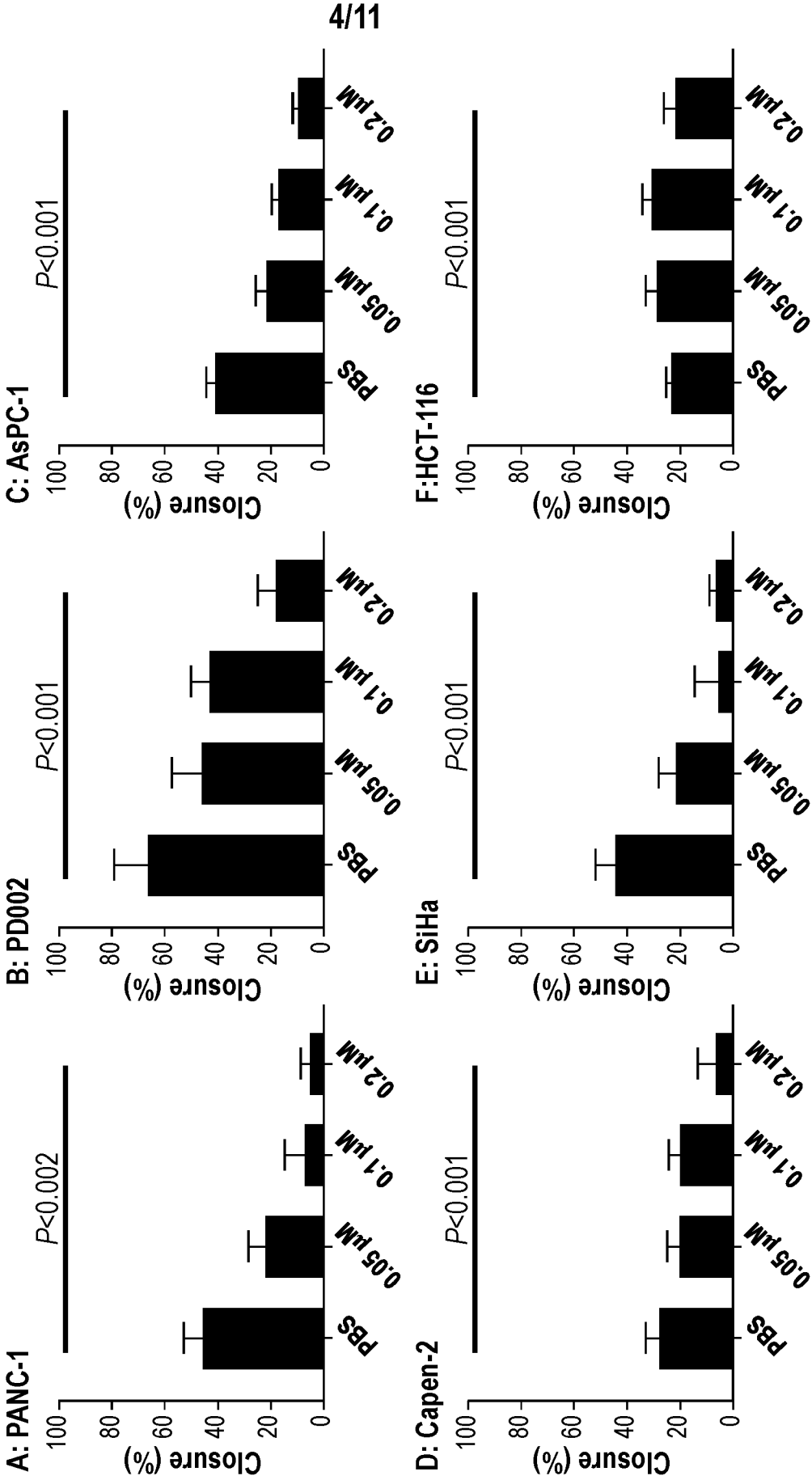


Fig. 3B

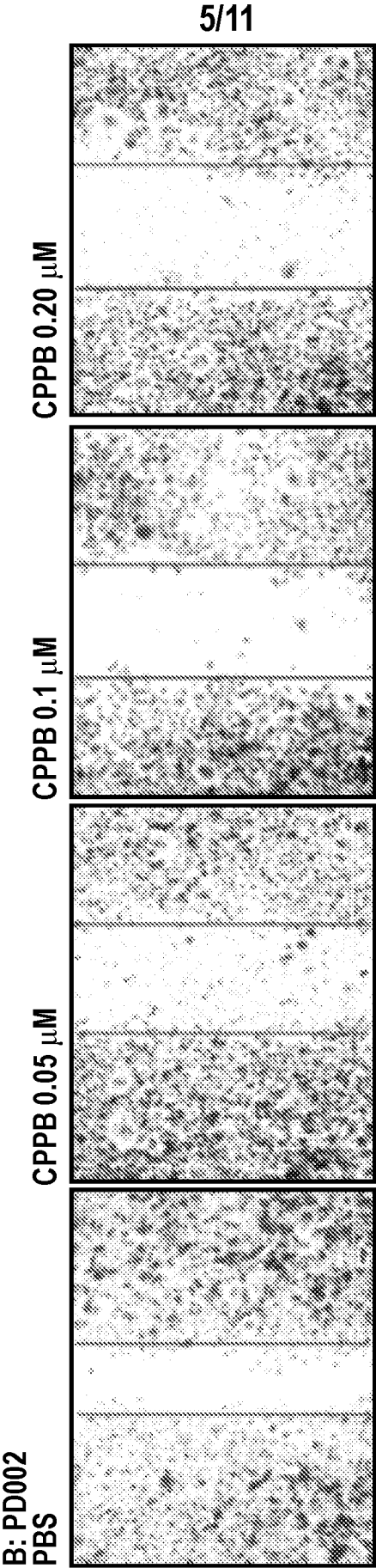


Fig. 4

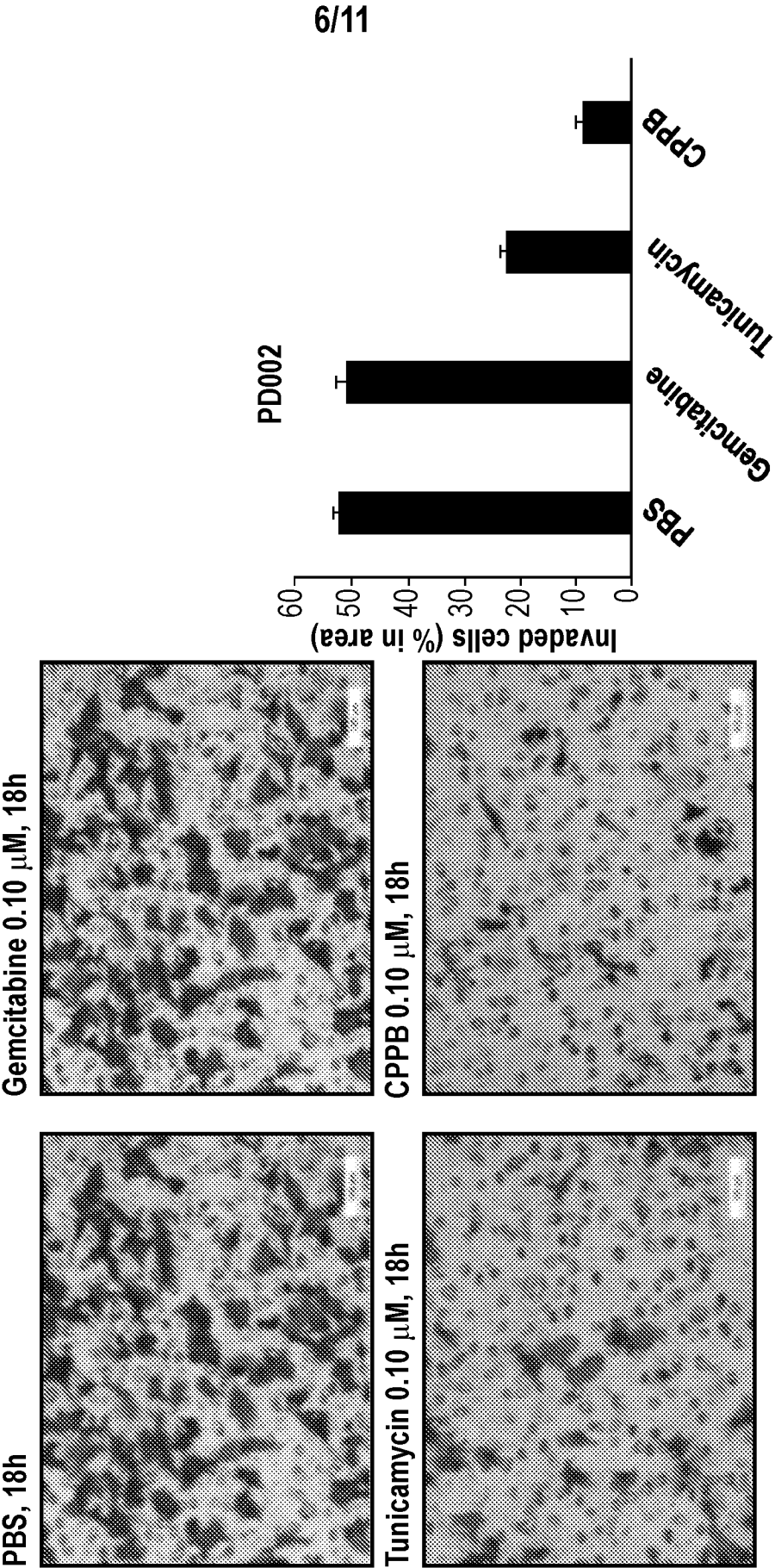


Fig. 5

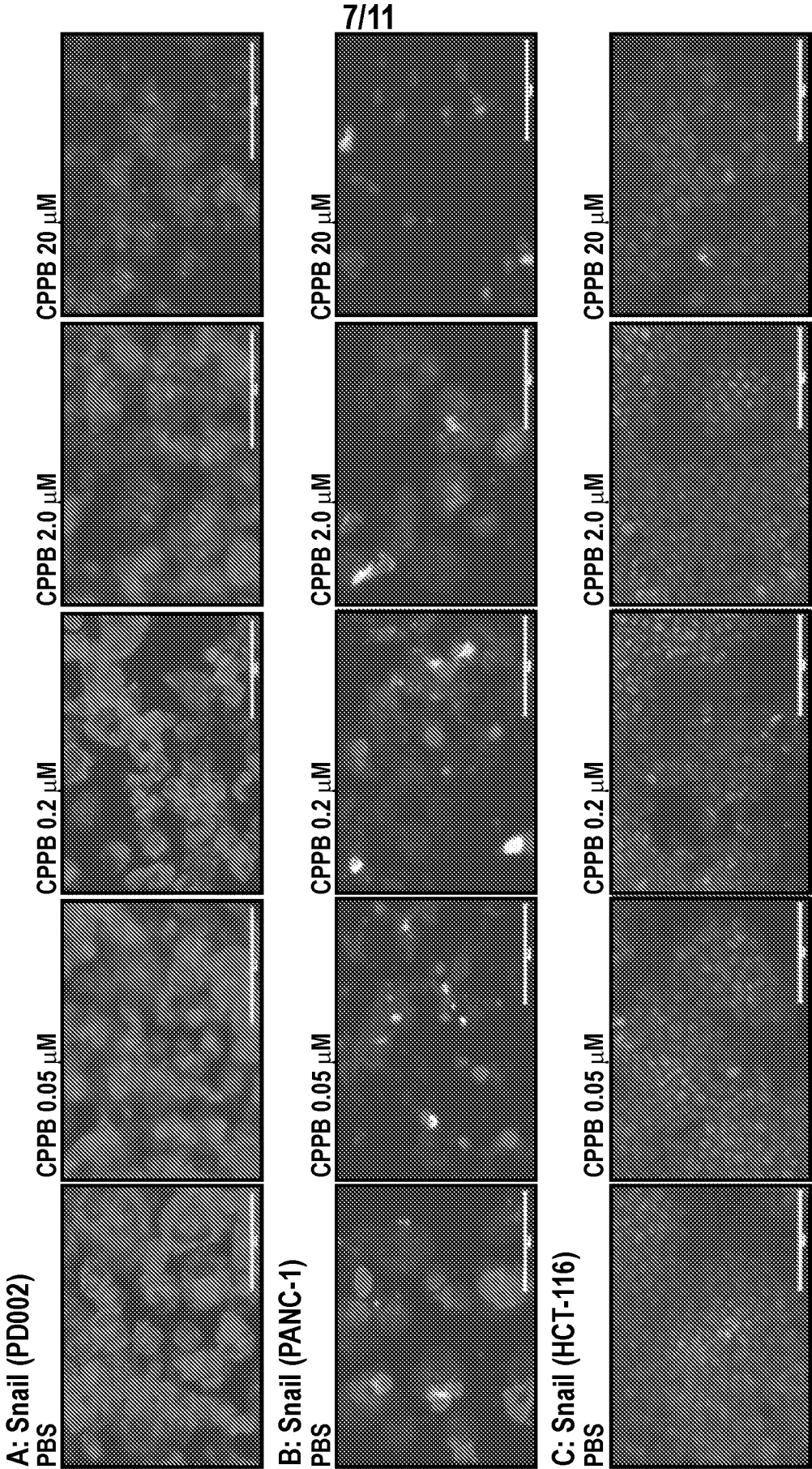


Fig. 6

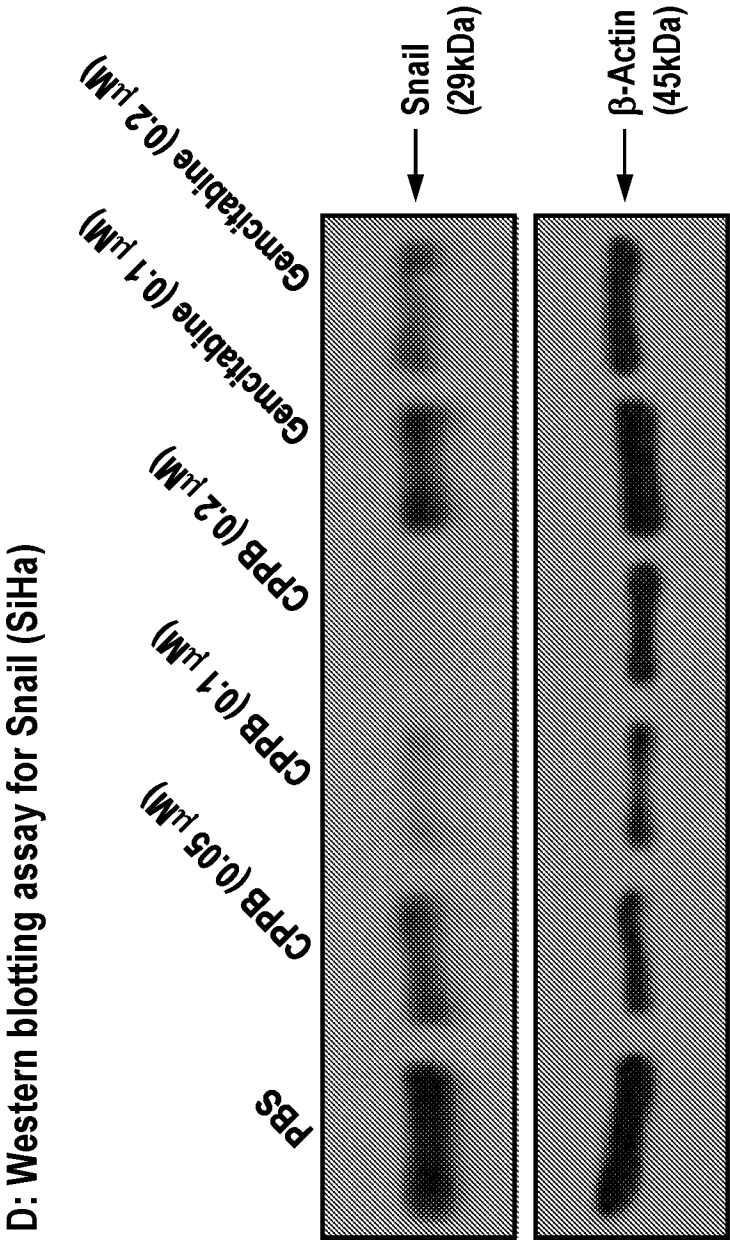


Fig. 7

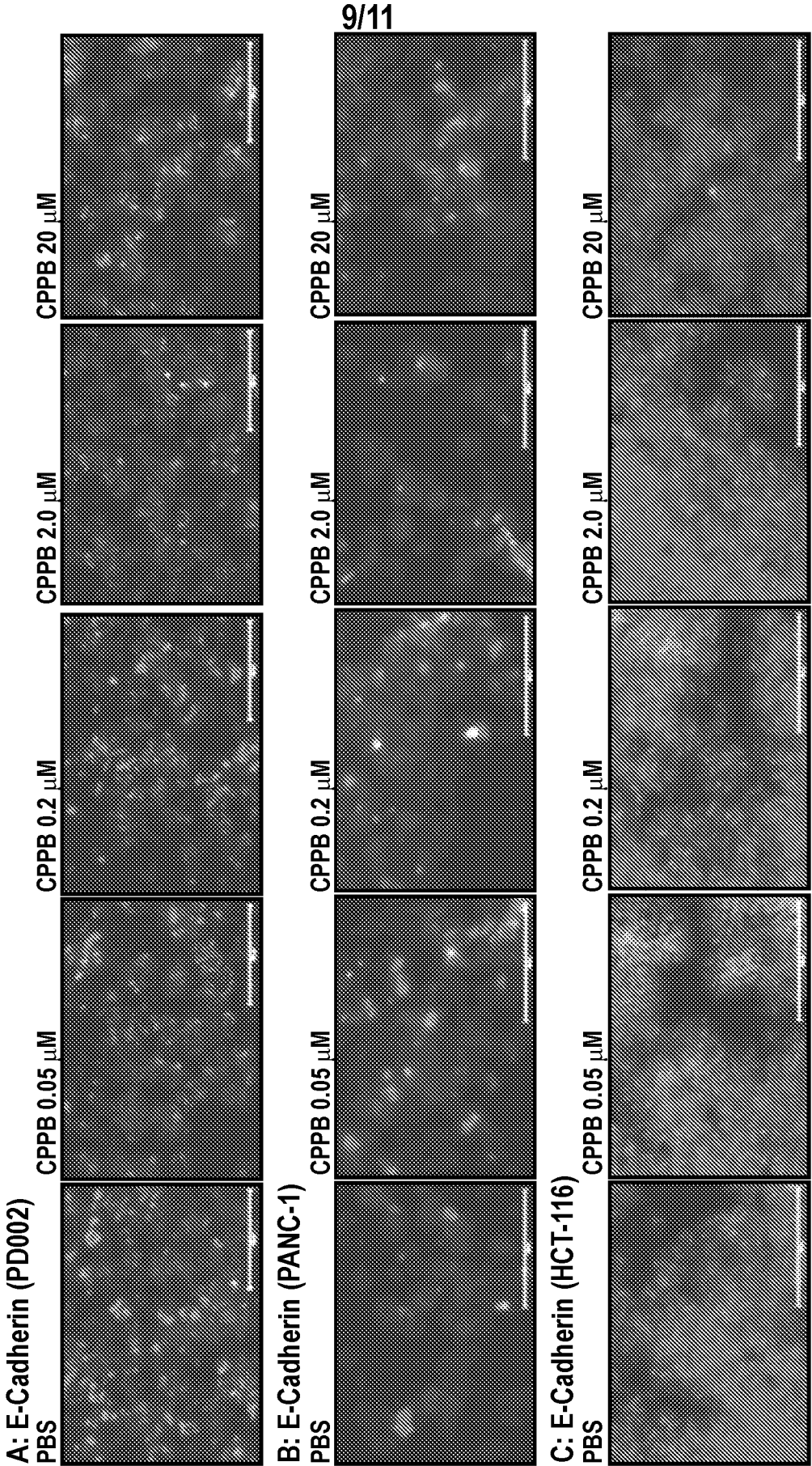
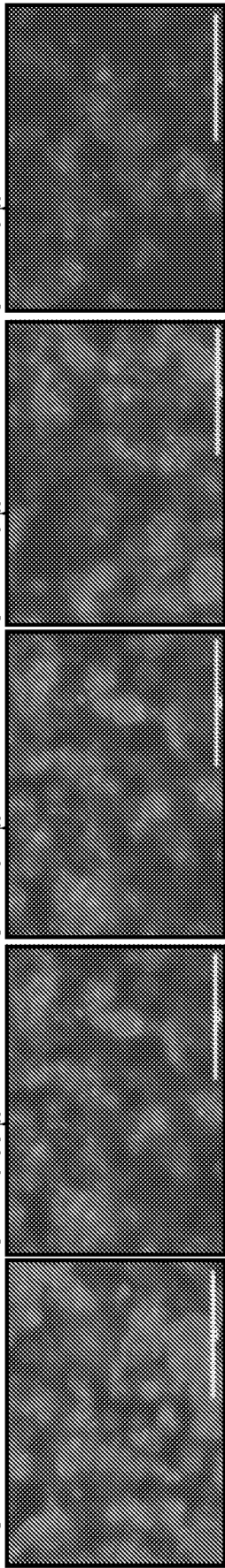


Fig. 8

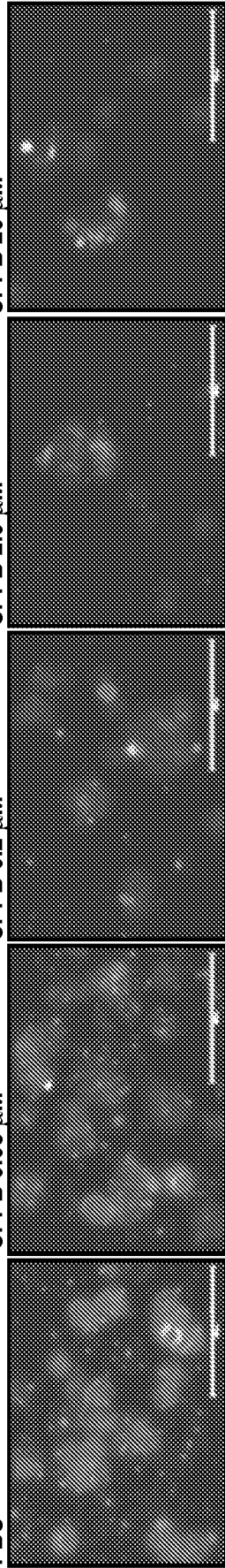
A: DPAGT1 (PD002)

PBS



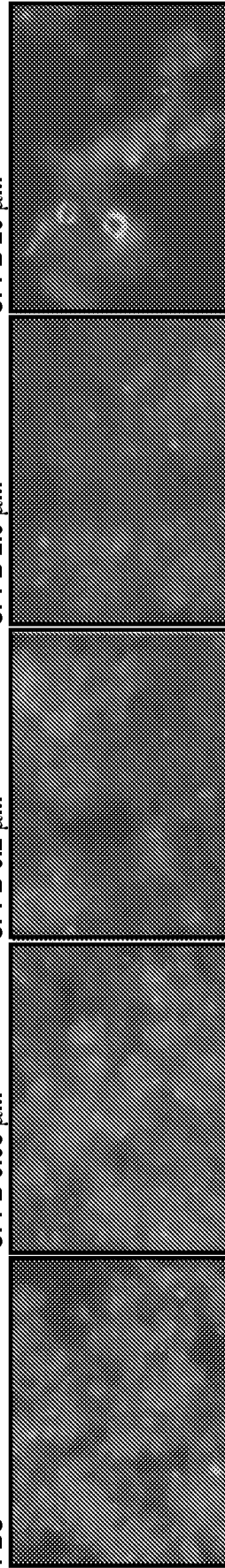
B: DPAGT1 (PANC-1)

PBS

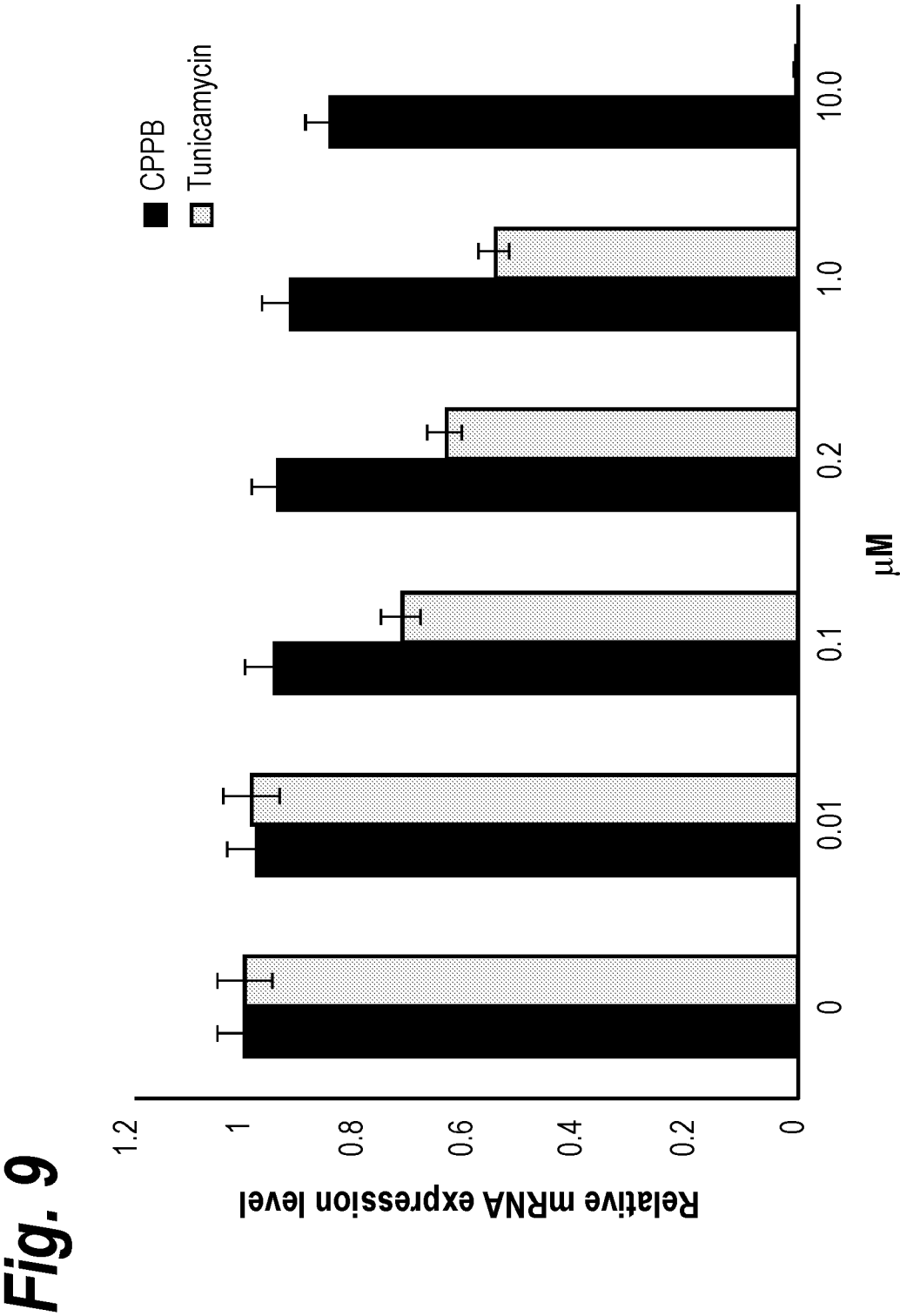


C: DPAGT1 (HCT-116)

PBS



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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 21/39826

A. CLASSIFICATION OF SUBJECT MATTER

IPC - C07H 1/00; C07H 19/06 (2021.01)

CPC - A61K 31/337; A61K 31/7068; A61K 31/7072; A61K 45/06

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

See Search History document

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

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	MITACHI et al. "A Semi-Synthesis of an Anticancer DPAGT1 Inhibitor from a Muraymycin Biosynthetic Intermediate", Org Lett. 2019. 21(4), pp 876-879, especially: pg 6, Figure 1, formula 1, APPB.	1-6,19-20
A	US 2003/0171330 A1 (HOTODA et al.) 11 September 2003 (11.09.2003), especially: para [0807], Example 47, Compound Number 2452.	1-6,19-20
A	SIRICILLA et al. "Discovery of a capuramycin analog that kills non-replicating Mycobacterium tuberculosis and its synergistic effects with translocase I inhibitors", J Antibiot (Tokyo). 2015. 68(4): pp 271-278, especially: pg 14, Figure 2, formula 2, SG641.	1-6,19-20
P/X	MITACHI et al. "DPAGT1 Inhibitors of Capuramycin Analogues and Their Antimigratory Activities of Solid Tumors", J Med Chem. September 2020. 63(19): pp 10855-10878, especially: abstract, formula CPPB.	1-6,19-20

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"D" document cited by the applicant in the international application

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

13 September 2021

Date of mailing of the international search report

NOV 30 2021

Name and mailing address of the ISA/US

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents
P.O. Box 1450, Alexandria, Virginia 22313-1450

Facsimile No. 571-273-8300

Authorized officer

Kari Rodriguez

Telephone No. PCT Helpdesk: 571-272-4300

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 21/39826

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☒ Claims Nos.: 7-18, 24-26 and 32-41
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
(see extra sheet)

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-6, 19-20

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 21/39826

--BOX III - LACK OF UNITY--

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

Group I: Claims 1-6 and 19-20, directed to a compound of Formula I.

Group II: Claims 21-23 and 27-31 directed to a compound of Formula V or Formula VI.

The inventions listed as Groups I and II do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

Special Technical Features

Group I requires a compound of Formula I, which is not required by Group II.

Group II requires a compound of Formula V or Formula VI, which is not required by Group I.

Shared Common Features

The only feature shared by Groups I and II that would otherwise unify the groups is a compound wherein uridine is connected to a fragment consisting of 4-(R3O-phenoxy)piperadinyphenyl by a linker group. However, this shared technical feature does not represent a contribution over prior art, because the shared technical feature is anticipated by the article entitled "A Semi-Synthesis of an Anticancer DPAGT1 Inhibitor from a Muraymycin Biosynthetic Intermediate" by Mitachi et al. (hereinafter 'MITACHI').

Mitachi teaches a compound wherein uridine is connected to a fragment consisting of 4-(R3O-phenoxy)piperadinyphenyl by a linker group (pg 6, Figure 1, formula 1, APPB).

As the technical features were known in the art at the time of the invention, this cannot be considered a special technical feature that would otherwise unify the groups. Groups I and II therefore lack unity under PCT Rule 13 because they do not share a same or corresponding special technical feature.

Note reg. item 4: Claims 7-18, 24-26 and 32-41 are unsearchable because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).