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(54) Title: 2'-C-METHYL-3'-O-L-VALINE ESTER RIBOFURANOSYL CYTIDINE FOR TREATMENT OF FLAVIVIRIDAE INFECTIONS

(57) Abstract: The 3'-L-valine ester of β-D-2'-C-methyl-ribofuranosyl cytidine provides superior results against flaviviruses and pestiviruses, including hepatitis C virus. Based on this discovery, compounds, compositions, methods and uses are provided for the treatment of flaviviridae, including HCV, that include the administration of an effective amount of val-mCyd or its salt, ester, prodrug or derivative, optionally in a pharmaceutically acceptable carrier. In an alternative embodiment, val-mCyd is used to treat any virus that replicates through an RNA-dependent RNA polymerase.

2'-C-METHYL-3'-O-L-VALINE ESTER RIBOFURANOSYL CYTIDINE FOR TREATMENT OF FLAVIVIRIDAE INFECTIONS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of priority to U.S. Provisional application No. 60/392,351, filed June 28, 2002; U.S. Provisional Application No. 60/466,194, filed April 28, 2003; and U.S. Provisional application No. 60/470,949 entitled "Nucleosides for the Treatment of Infection by Coronaviruses, Togaviruses and Picornaviruses" filed May 14, 2003, the disclosures of each of which are incorporated herein by reference.

FIELD OF THE INVENTION

This invention is in the area of pharmaceutical chemistry and, in particular, is 2'-C-methyl-ribofuranosyl cytidine-3'-O-L-valine ester and pharmaceutically acceptable salts, derivatives and prodrugs thereof, their syntheses and their uses as anti-*Flaviviridae* agents in the treatment of hosts, notably humans, infected with a *Flaviviridae*, and in particular, hepatitis C, virus.

BACKGROUND OF THE INVENTION

Flaviviridae Viruses

The Flaviviridae family of viruses comprises at least three distinct genera: *pestiviruses*, which cause disease in cattle and pigs; *flaviviruses*, which are the primary cause of diseases such as dengue fever and yellow fever; and *hepaciviruses*, whose sole member is HCV. The flavivirus genus includes more than 68 members separated into groups on the basis of serological relatedness (Calisher et al., *J. Gen. Virol*, 1993, *70*, 37-43). Clinical symptoms vary and include fever, encephalitis and hemorrhagic fever (*Fields Virology*, Editors: Fields, B. N., Knipe, D. M., and Howley, P. M., Lippincott-Raven Publishers, Philadelphia, PA, 1996, Chapter 31, 931-959). Flaviviruses of global concern that are associated with human disease include the dengue hemorrhagic fever viruses (DHF), yellow fever virus, shock syndrome and

Japanese encephalitis virus (Halstead, S. B., *Rev. Infect. Dis.*, 1984, *6*, 251-264; Halstead, S. B., *Science*, 239:476-481, 1988; Monath, T. P., *New Eng. J. Med.*, 1988, *319*, 641-643).

The pestivirus genus includes bovine viral diarrhea virus (BVDV), classical swine fever virus (CSFV, also called hog cholera virus) and border disease virus (BDV) of sheep (Moennig, V. et al. *Adv. Vir. Res.* 1992, *41*, 53-98). Pestivirus infections of domesticated livestock (cattle, pigs and sheep) cause significant economic losses worldwide. BVDV causes mucosal disease in cattle and is of significant economic importance to the livestock industry (Meyers, G. and Thiel, H.-J., *Advances in Virus Research,* 1996, *47*, 53-118; Moennig V., et al, *Adv. Vir. Res.* 1992, *41*, 53-98). Human pestiviruses have not been as extensively characterized as the animal pestiviruses. However, serological surveys indicate considerable pestivirus exposure in humans.

Pestiviruses and *hepaciviruses* are closely related virus groups within the Flaviviridae family. Other closely related viruses in this family include the GB virus A, GB virus A-like agents, GB virus-B and GB virus-C (also called hepatitis G virus, HGV). The hepacivirus group (hepatitis C virus; HCV) consists of a number of closely related but genotypically distinguishable viruses that infect humans. There are approximately 6 HCV genotypes and more than 50 subtypes. Due to the similarities between pestiviruses and hepaciviruses, combined with the poor ability of hepaciviruses to grow efficiently in cell culture, bovine viral diarrhea virus (BVDV) is often used as a surrogate to study the HCV virus.

The genetic organization of pestiviruses and hepaciviruses is very similar. These positive stranded RNA viruses possess a single large open reading frame (ORF) encoding all the viral proteins necessary for virus replication. These proteins are expressed as a polyprotein that is co- and post-translationally processed by both cellular and virus-encoded proteinases to yield the mature viral proteins. The viral proteins responsible for the replication of the viral genome RNA are located within approximately the carboxy-terminal. Two-thirds of the ORF are termed nonstructural (NS) proteins. The genetic organization and polyprotein processing of the nonstructural protein portion of the ORF for pestiviruses and hepaciviruses is very similar. For both the pestiviruses and hepaciviruses, the mature nonstructural (NS) proteins, in sequential order from the amino-terminus of the nonstructural protein

coding region to the carboxy-terminus of the ORF, consist of p7, NS2, NS3, NS4A, NS4B, NS5A, and NS5B.

The NS proteins of pestiviruses and hepaciviruses share sequence domains that are characteristic of specific protein functions. For example, the NS3 proteins of viruses in both groups possess amino acid sequence motifs characteristic of serine proteinases and of helicases (Gorbalenya et al. (1988) Nature 333:22; Bazan and Fletterick (1989) Virology 171:637-639; Gorbalenya et al. (1989) Nucleic Acid Res. 17.3889-3897). Similarly, the NS5B proteins of pestiviruses and hepaciviruses have the motifs characteristic of RNA-directed RNA polymerases (Koonin, E.V. and Dolja, V.V. (1993) Crit. Rev. Biochem. Molec. Biol. 28:375-430).

The actual roles and functions of the NS proteins of pestiviruses and hepaciviruses in the lifecycle of the viruses are directly analogous. In both cases, the NS3 serine proteinase is responsible for all proteolytic processing of polyprotein precursors downstream of its position in the ORF (Wiskerchen and Collett (1991) Virology 184:341-350; Bartenschlager et al. (1993) J. Virol. 67:3835-3844; Eckart et al. (1993) Biochem. Biophys. Res. Comm. 192:399-406; Grakoui et al. (1993) J. Virol. 67:2832-2843; Grakoui et al. (1993) *Proc. Natl. Acad. Sci.* USA 90:10583-10587; Hijikata et al. (1993) J. Virol. 67:4665-4675; Tome et al. (1993) J. Virol. 67:4017-4026). The NS4A protein, in both cases, acts as a cofactor with the NS3 serine protease (Bartenschlager et al. (1994) J. Virol. 68:5045-5055; Failla et al. (1994) J. Virol. 68: 3753-3760; Lin et al. (1994) 68:8147-8157; Xu et al. (1997) J. Virol. 71:5312-5322). The NS3 protein of both viruses also functions as a helicase (Kim et al. (1995) Biochem. Biophys. Res. Comm. 215: 160-166; Jin and Peterson (1995) Arch. Biochem. Biophys., 323:47-53; Warrener and Collett (1995) J. Virol. 69:1720-1726). Finally, the NS5B proteins of pestiviruses and hepaciviruses have the predicted RNA-directed RNA polymerases activity (Behrens et al.(1996) EMBO J. 15:12-22; Lchmannet al.(1997) J. Virol. 71:8416-8428; Yuan et al.(1997) Biochem. Biophys. Res. Comm. 232:231-235; Hagedorn, PCT WO 97/12033; Zhong et al.(1998) J. Virol. 72.9365-9369).

Hepatitis C Virus

The hepatitis C virus (HCV) is the leading cause of chronic liver disease worldwide. (Boyer, N. *et al. J. Hepatol.* 32:98-112, 2000). HCV causes a slow

growing viral infection and is the major cause of cirrhosis and hepatocellular carcinoma (Di Besceglie, A. M. and Bacon, B. R., *Scientific American*, Oct.: 80-85, (1999); Boyer, N. *et al. J. Hepatol.* 32:98-112, 2000). An estimated 170 million persons are infected with HCV worldwide. (Boyer, N. *et al. J. Hepatol.* 32:98-112, 2000). Cirrhosis caused by chronic hepatitis C infection accounts for 8,000-12,000 deaths per year in the United States, and HCV infection is the leading indication for liver transplantation.

HCV is known to cause at least 80% of posttransfusion hepatitis and a substantial proportion of sporadic acute hepatitis. Preliminary evidence also implicates HCV in many cases of "idiopathic" chronic hepatitis, "cryptogenic" cirrhosis, and probably hepatocellular carcinoma unrelated to other hepatitis viruses, such as Hepatitis B Virus (HBV). A small proportion of healthy persons appear to be chronic HCV carriers, varying with geography and other epidemiological factors. The numbers may substantially exceed those for HBV, though information is still preliminary; how many of these persons have subclinical chronic liver disease is unclear. (The Merck Manual, ch. 69, p. 901, 16th ed., (1992)).

HCV is an enveloped virus containing a positive-sense single-stranded RNA genome of approximately 9.4kb. The viral genome consists of a 5' untranslated region (UTR), a long open reading frame encoding a polyprotein precursor of approximately 3011 amino acids, and a short 3' UTR. The 5' UTR is the most highly conserved part of the HCV genome and is important for the initiation and control of polyprotein translation. Translation of the HCV genome is initiated by a cap-independent mechanism known as internal ribosome entry. This mechanism involves the binding of ribosomes to an RNA sequence known as the internal ribosome entry site (IRES). An RNA pseudoknot structure has recently been determined to be an essential structural element of the HCV IRES. Viral structural proteins include a nucleocapsid core protein (C) and two envelope glycoproteins, E1 and E2. HCV also encodes two proteinases, a zinc-dependent metalloproteinase encoded by the NS2-NS3 region and a serine proteinase encoded in the NS3 region. These proteinases are required for cleavage of specific regions of the precursor polyprotein into mature peptides. The carboxyl half of nonstructural protein 5, NS5B, contains the RNA-dependent RNA polymerase. The function of the remaining nonstructural proteins, NS4A and NS4B, and that of NS5A (the amino-terminal half of nonstructural protein 5) remain unknown.

A significant focus of current antiviral research is directed to the development of improved methods of treatment of chronic HCV infections in humans (Di Besceglie, A. M. and Bacon, B. R., *Scientific American*, Oct.: 80-85, (1999)).

Treatment of HCV Infection with Interferon

Interferons (IFNs) have been commercially available for the treatment of chronic hepatitis for nearly a decade. IFNs are glycoproteins produced by immune cells in response to viral infection. IFNs inhibit replication of a number of viruses, including HCV, and when used as the sole treatment for hepatitis C infection, IFN can in certain cases suppress serum HCV-RNA to undetectable levels. Additionally, IFN can normalize serum amino transferase levels. Unfortunately, the effect of IFN is temporary and a sustained response occurs in only 8%-9% of patients chronically infected with HCV (Gary L. Davis. *Gastroenterology* 118:S104-S114, 2000). Most patients, however, have difficulty tolerating interferon treatment, which causes severe flu-like symptoms, weight loss, and lack of energy and stamina.

A number of patents disclose Flaviviridae, including HCV, treatments, using interferon-based therapies. For example, U.S. Patent No. 5,980,884 to Blatt *et al.* discloses methods for retreatment of patients afflicted with HCV using consensus interferon. U.S. Patent No. 5,942,223 to Bazer *et al.* discloses an anti-HCV therapy using ovine or bovine interferon-tau. U.S. Patent No. 5,928,636 to Alber *et al.* discloses the combination therapy of interleukin-12 and interferon alpha for the treatment of infectious diseases including HCV. U.S. Patent No. 5,849,696 to Chretien *et al.* discloses the use of thymosins, alone or in combination with interferon, for treating HCV. U.S. Patent No. 5,830,455 to Valtuena *et al.* discloses a combination HCV therapy employing interferon and a free radical scavenger. U.S. Patent No. 5,738,845 to Imakawa discloses the use of human interferon tau proteins for treating HCV. Other interferon-based treatments for HCV are disclosed in U.S. Patent No. 5,676,942 to Testa *et al.*, U.S. Patent No. 5,372,808 to Blatt *et al.*, and U.S. Patent No. 5,849,696. A number of patents also disclose pegylated forms of interferon, such as, U.S. Patent Nos. 5,747,646, 5,792,834 and 5,834,594 to Hoffmann-La Roche Inc; PCT Publication No. WO 99/32139 and WO 99/32140 to Enzon; WO 95/13090 and US Patent Nos. 5,738,846 and 5,711,944 to Schering; and U.S. Patent No. 5,908,621 to Glue *et al.*.

Interferon alpha-2a and interferon alpha-2b are currently approved as monotherapy for the treatment of HCV. ROFERON®-A (Roche) is the recombinant form of interferon alpha-2a. PEGASYS® (Roche) is the pegylated (i.e. polyethylene glycol modified) form of interferon alpha -2a. INTRON®A (Schering Corporation) is the recombinant form of Interferon alpha-2b, and PEG-INTRON® (Schering Corporation) is the pegylated form of interferon alpha-2b.

Other forms of interferon alpha, as well as interferon beta, gamma, tau and omega are currently in clinical development for the treatment of HCV. For example, INFERGEN (interferon alphacon-1) by InterMune, OMNIFERON (natural interferon) by Viragen, ALBUFERON by Human Genome Sciences, REBIF (interferon beta-1a) by Ares-Serono, Omega Interferon by BioMedicine, Oral Interferon Alpha by Amarillo Biosciences, and interferon gamma, interferon tau, and interferon gamma-1b by InterMune are in development.

Ribivarin

Ribavirin (1-β-D-ribofuranosyl-1-1,2,4-triazole-3-carboxamide) is a synthetic, non-interferon-inducing, broad spectrum antiviral nucleoside analog sold under the trade name, Virazole (The Merck Index, 11th edition, Editor: Budavari, S., Merck & Co., Inc., Rahway, NJ, p1304, 1989). United States Patent No. 3,798,209 and RE29,835 disclose and claim ribavirin. Ribavirin is structurally similar to guanosine, and has in vitro activity against several DNA and RNA viruses including *Flaviviridae* (Gary L. Davis. *Gastroenterology* 118:S104-S114, 2000).

Ribavirin reduces serum amino transferase levels to normal in 40% of patients, but it does not lower serum levels of HCV-RNA (Gary L. Davis. *Gastroenterology* 118:S104-S114, 2000). Thus, ribavirin alone is not effective in reducing viral RNA levels. Additionally, ribavirin has significant toxicity and is known to induce anemia.

Ribavirin is not approved fro monotherapy against HCV. It has been approved in combination with interferon alpha-2a or interferon alpha-2b for the treatment of HCV.

Combination of Interferon and Ribavirin

The current standard of care for chronic hepatitis C is combination therapy with an alpha interferon and ribavirin. The combination of interferon and ribavirin for the treatment of HCV infection has been reported to be effective in the treatment of interferon naïve patients (Battaglia, A.M. *et al.*, *Ann. Pharmacother.* 34:487-494, 2000), as well as for treatment of patients when histological disease is present (Berenguer, M. *et al. Antivir. Ther.* 3(Suppl. 3):125-136, 1998). Studies have show that more patients with hepatitis C respond to pegylated interferon-alpha/ribavirin combination therapy than to combination therapy with unpegylated interferon alpha. However, as with monotherapy, significant side effects develop during combination therapy, including hemolysis, flu-like symptoms, anemia, and fatigue. (Gary L. Davis. *Gastroenterology* 118:S104-S114, 2000).

Combination therapy with PEG-INTRON® (peginterferon alpha-2b) and REBETOL® (Ribavirin, USP) Capsules is available from Schering Corporation. REBETOL® (Schering Corporation) has also been approved in combination with INTRON® A (Interferon alpha-2b, recombinant, Schering Corporation). Roche's PEGASYS® (pegylated interferon alpha-2a) and COPEGUS® (ribavirin) are also approved for the treatment of HCV.

PCT Publication Nos. WO 99/59621, WO 00/37110, WO 01/81359, WO 02/32414 and WO 03/024461 by Schering Corporation disclose the use of pegylated interferon alpha and ribavirin combination therapy for the treatment of HCV. PCT Publication Nos. WO 99/15194, WO 99/64016, and WO 00/24355 by Hoffmann-La Roche Inc also disclose the use of pegylated interferon alpha and ribavirin combination therapy for the treatment of HCV.

Additional Methods to Treat Flaviviridae Infections

The development of new antiviral agents for flaviviridae infections, especially hepatitis C, is currently underway. Specific inhibitors of HCV-derived enzymes such as protease, helicase, and polymerase inhibitors are being developed. Drugs that inhibit other steps in HCV replication are also in development, for example, drugs that block production of HCV antigens from the RNA (IRES inhibitors), drugs that prevent the normal processing of HCV proteins (inhibitors of glycosylation), drugs that block entry of HCV into cells (by blocking its receptor) and nonspecific

cytoprotective agents that block cell injury caused by the virus infection. Further, molecular approaches are also being developed to treat hepatitis C, for example, ribozymes, which are enzymes that break down specific viral RNA molecules, and antisense oligonucleotides, which are small complementary segments of DNA that bind to viral RNA and inhibit viral replication, are under investigation. A number of HCV treatments are reviewed by Bymock *et al.* in *Antiviral Chemistry & Chemotherapy*, 11:2; 79-95 (2000) and De Francesco et al. in *Antiviral Research*, 58: 1-16 (2003).

Examples of classes of drugs that are being developed to treat Flaviviridae infections include:

(1) Protease inhibitors

Substrate-based NS3 protease inhibitors (Attwood *et al.*, *Antiviral peptide derivatives*, PCT WO 98/22496, **1998**; Attwood *et al.*, *Antiviral Chemistry and Chemotherapy* **1999**, *10*, 259-273; Attwood *et al., Preparation and use of amino acid derivatives as anti-viral agents,* German Patent Pub. DE 19914474; Tung *et al. Inhibitors of serine proteases, particularly hepatitis C virus NS3 protease*, PCT WO 98/17679), including alphaketoamides and hydrazinoureas, and inhibitors that terminate in an electrophile such as a boronic acid or phosphonate (Llinas-Brunet et al, *Hepatitis C inhibitor peptide analogues,* PCT WO 99/07734) are being investigated.

Non-substrate-based NS3 protease inhibitors such as 2,4,6-trihydroxy-3-nitro-benzamide derivatives (Sudo K. *et al.*, *Biochemical and Biophysical Research Communications*, **1997**, *238*, 643-647; Sudo K. *et al. Antiviral Chemistry and Chemotherapy*, **1998**, *9*, 186), including RD3-4082 and RD3-4078, the former substituted on the amide with a 14 carbon chain and the latter processing a *para*-phenoxyphenyl group are also being investigated.

Sch 68631, a phenanthrenequinone, is an HCV protease inhibitor (Chu M. *et al.*, *Tetrahedron Letters* 37:7229-7232, 1996). In another example by the same authors, Sch 351633, isolated from the fungus *Penicillium griseofulvum,* was identified as a protease inhibitor (Chu M. *et al.*, *Bioorganic and Medicinal Chemistry Letters* 9:1949-1952). Nanomolar potency against the HCV NS3 protease enzyme has

been achieved by the design of selective inhibitors based on the macromolecule eglin c. Eglin c, isolated from leech, is a potent inhibitor of several serine proteases such as S. griseus proteases A and B, α-chymotrypsin, chymase and subtilisin. Qasim M.A. *et al., Biochemistry* 36:1598-1607, 1997.

Several U.S. patents disclose protease inhibitors for the treatment of HCV. For example, U.S. Patent No. 6,004,933 to Spruce *et al.* discloses a class of cysteine protease inhibitors for inhibiting HCV endopeptidase 2. U.S. Patent No. 5,990,276 to Zhang *et al.* discloses synthetic inhibitors of hepatitis C virus NS3 protease. The inhibitor is a subsequence of a substrate of the NS3 protease or a substrate of the NS4A cofactor. The use of restriction enzymes to treat HCV is disclosed in U.S. Patent No. 5,538,865 to Reyes *et al.* Peptides as NS3 serine protease inhibitors of HCV are disclosed in WO 02/008251 to Corvas International, Inc, and WO 02/08187 and WO 02/008256 to Schering Corporation. HCV inhibitor tripeptides are disclosed in US Patent Nos. 6,534,523, 6,410,531, and 6,420,380 to Boehringer Ingelheim and WO 02/060926 to Bristol Myers Squibb. Diaryl peptides as NS3 serine protease inhibitors of HCV are disclosed in WO 02/48172 to Schering Corporation. Imidazoleidinones as NS3 serine protease inhibitors of HCV are disclosed in WO 02/08198 to Schering Corporation and WO 02/48157 to Bristol Myers Squibb. WO 98/17679 to Vertex Pharmaceuticals and WO 02/48116 to Bristol Myers Squibb also disclose HCV protease inhibitors.

(2) Thiazolidine derivatives which show relevant inhibition in a reverse-phase HPLC assay with an NS3/4A fusion protein and NS5A/5B substrate (Sudo K. *et al., Antiviral Research*, **1996**, *32*, 9-18), especially compound RD-1-6250, possessing a fused cinnamoyl moiety substituted with a long alkyl chain, RD4 6205 and RD4 6193;

(3) Thiazolidines and benzanilides identified in Kakiuchi N. *et al. J. EBS Letters 421*, 217-220; Takeshita N. *et al. Analytical Biochemistry*, **1997**, *247*, 242-246;

(4) A phenan-threnequinone possessing activity against protease in a SDS-PAGE and autoradiography assay isolated from the fermentation culture broth of *Streptomyces* sp., Sch 68631 (Chu M. *et al., Tetrahedron Letters*,

1996, *37*, 7229-7232), and Sch 351633, isolated from the fungus *Penicillium griseofulvum* , which demonstrates activity in a scintillation proximity assay (Chu M. *et al.*, *Bioorganic and Medicinal Chemistry Letters 9*, 1949-1952);

(5) Helicase inhibitors (Diana G.D. *et al.*, *Compounds, compositions and methods for treatment of hepatitis C*, U.S. Pat. No. 5,633,358; Diana G.D. *et al., Piperidine derivatives, pharmaceutical compositions thereof and their use in the treatment of hepatitis C*, PCT WO 97/36554);

(6) Nucleotide polymerase inhibitors and gliotoxin (Ferrari R. *et al. Journal of Virology*, **1999**, *73*, 1649-1654), and the natural product cerulenin (Lohmann V. *et al.*, *Virology*, **1998**, *249*, 108-118);

(7) Antisense phosphorothioate oligodeoxynucleotides (S-ODN) complementary to sequence stretches in the 5' non-coding region (NCR) of the virus (Alt M. *et al.*, *Hepatology*, **1995**, *22*, 707-717), or nucleotides 326-348 comprising the 3' end of the NCR and nucleotides 371-388 located in the core coding region of the HCV RNA (Alt M. *et al.*, *Archives of Virology*, **1997**, *142*, 589-599; Galderisi U. *et al.*, *Journal of Cellular Physiology*, **1999**, *181*, 251-257);

(8) Inhibitors of IRES-dependent translation (Ikeda N *et al.*, *Agent for the prevention and treatment of hepatitis C,* Japanese Patent Pub. JP-08268890; Kai Y. *et al. Prevention and treatment of viral diseases*, Japanese Patent Pub. JP-10101591);

(9) Ribozymes, such as nuclease-resistant ribozymes (Maccjak, D. J. *et al.*, *Hepatology* **1999**, *30*, abstract 995) and those disclosed in U.S. Patent No. 6,043,077 to Barber *et al.*, and U.S. Patent Nos. 5,869,253 and 5,610,054 to Draper *et al.*; and

(10) Nucleoside analogs have also been developed for the treatment of Flaviviridae infections.

Idenix Pharmaceuticals disclosed the use of branched nucleosides in the treatment of flaviviruses (including HCV) and pestiviruses in International Publication Nos. WO 01/90121 and WO 01/92282. Specifically, a method for the treatment of hepatitis C infection (and flaviviruses and pestiviruses) in humans and other host animals is disclosed in the Idenix publications that includes administering an effective amount of a biologically active 1', 2', 3' or 4'-branched β-D or β-L nucleosides or a pharmaceutically acceptable salt or derivative thereof, administered either alone or in combination with another antiviral agent, optionally in a pharmaceutically acceptable carrier.

Other patent applications disclosing the use of certain nucleoside analogs to treat hepatitis C virus include: PCT/CA00/01316 (WO 01/32153; filed November 3, 2000) and PCT/CA01/00197 (WO 01/60315; filed February 19, 2001) filed by BioChem Pharma, Inc. (now Shire Biochem, Inc.); PCT/US02/01531 (WO 02/057425; filed January 18, 2002) and PCT/US02/03086 (WO 02/057287; filed January 18, 2002) filed by Merck & Co., Inc., PCT/EP01/09633 (WO 02/18404; published August 21, 2001) filed by Roche, and PCT Publication Nos. WO 01/79246 (filed April 13, 2001), WO 02/32920 (filed October 18, 2001) and WO 02/48165 by Pharmasset, Ltd.

PCT Publication No. WO 99/43691 to Emory University, entitled "2'-Fluoronucleosides" discloses the use of certain 2'-fluoronucleosides to treat HCV.

Eldrup et al. (Oral Session V, Hepatitis C Virus, Flaviviridae; 16th International Conference on Antiviral Research (April 27, 2003, Savannah, Ga.)) described the structure activity relationship of 2'-modified nucleosides for inhibition of HCV.

Bhat et al. (Oral Session V, Hepatitis C Virus, Flaviviridae, 2003 (Oral Session V, Hepatitis C Virus, Flaviviridae; 16th International Conference on Antiviral Research (April 27, 2003, Savannah, Ga.); p A75) described the synthesis and pharmacokinetic properties of nucleoside analogues as possible inhibitors of HCV RNA replication. The authors report that 2'-modified nucleosides demonstrate potent inhibitory activity in cell-based replicon assays.

Olsen et al. (Oral Session V, Hepatitis C Virus, Flaviviridae; 16th International Conference on Antiviral Research (April 27, 2003, Savannah, Ga.) p A76) also described the effects of the 2'-modified nucleosides on HCV RNA replication.

(11) Other miscellaneous compounds including 1-amino-alkylcyclohexanes (U.S. Patent No. 6,034,134 to Gold *et al.*), alkyl lipids (U.S. Pat. No. 5,922,757 to Chojkier *et al.*), vitamin E and other antioxidants (U.S. Pat. No. 5,922,757 to Chojkier *et al.*), squalene, amantadine, bile acids (U.S. Pat. No. 5,846,964 to Ozeki *et al.*), N-(phosphonoacetyl)-L-aspartic acid, (U.S. Pat. No. 5,830,905 to Diana *et al.*), benzenedicarboxamides (U.S. Pat. No. 5,633,388 to Diana *et al.*), polyadenylic acid derivatives (U.S. Pat. No. 5,496,546 to Wang *et al.*), 2',3'-dideoxyinosine (U.S. Pat. No. 5,026,687 to Yarchoan *et al.*), benzimidazoles (U.S. Pat. No. 5,891,874 to Colacino *et al.*), plant extracts (U.S. Patent No. 5,837,257 to Tsai *et al.*, U.S. Patent No. 5,725,859 to Omer *et al.*, and U.S. Patent No. 6,056,961), and piperidenes (U.S. Patent No. 5,830,905 to Diana *et al.*).

(12) Other compounds currently in preclinical or clinical development for treatment of hepatitis C virus include: Interleukin-10 by Schering-Plough, IP-501 by Interneuron, Merimebodib (VX-497) by Vertex, AMANTADINE® (Symmetrel) by Endo Labs Solvay, HEPTAZYME® by RPI, IDN-6556 by Idun Pharma., XTL-002 by XTL., HCV/MF59 by Chiron, CIVACIR® (Hepatitis C Immune Globulin) by NABI, LEVOVIRIN® by ICN/Ribapharm, VIRAMIDINE® by ICN/Ribapharm, ZADAXIN® (thymosin alpha-1) by Sci Clone, thymosin plus pegylated interferon by Sci Clone, CEPLENE® (histamine dihydrochloride) by Maxim, VX 950 / LY 570310 by Vertex/Eli Lilly, ISIS 14803 by Isis Pharmaceutical/Elan, IDN-6556 by Idun Pharmaceuticals, Inc., JTK 003 by AKROS Pharma, BILN-2061 by Boehringer Ingelheim, CellCept (mycophenolate mofetil) by Roche, T67, a β-tubulin inhibitor, by Tularik, a therapeutic vaccine directed to E2 by Innogenetics, FK788 by Fujisawa Healthcare, Inc., IdB 1016 (Siliphos, oral silybin-phosphatdylcholine phytosome), RNA replication inhibitors (VP50406) by ViroPharma/Wyeth, therapeutic vaccine by Intercell, therapeutic vaccine by Epimmune/Genencor, IRES inhibitor by Anadys, ANA 245 and ANA 246 by Anadys, immunotherapy (Therapore) by Avant, protease inhibitor by Corvas/SChering, helicase inhibitor by Vertex, fusion inhibitor by Trimeris, T cell therapy by CellExSys, polymerase inhibitor by Biocryst, targeted RNA chemistry by PTC Therapeutics, Dication by Immtech, Int., protease inhibitor by Agouron, protease inhibitor by Chiron/Medivir, antisense therapy by AVI BioPharma, antisense therapy by Hybridon, hemopurifier by Aethlon Medical,

therapeutic vaccine by Merix, protease inhibitor by Bristol-Myers Squibb/Axys, Chron-VacC, a therapeutic vaccine, by Tripep, UT 231B by United Therapeutics, protease, helicase and polymerase inhibitors by Genelabs Technologies, IRES inhibitors by Immusol, R803 by Rigel Pharmaceuticals, INFERGEN® (interferon alphacon-1) by InterMune, OMNIFERON® (natural interferon) by Viragen, ALBUFERON® by Human Genome Sciences, REBIF (interferon beta-1a) by Ares-Serono, Omega Interferon by BioMedicine, Oral Interferon Alpha by Amarillo Biosciences, interferon gamma, interferon tau, and Interferon gamma- 1b by InterMune.

Nucleoside prodrugs have been previously described for the treatment of other forms of hepatitis. WO 01/96353 (filed June 15, 2001) to Idenix Pharmaceuticals, discloses 2'-deoxy-β-L-nucleosides and their 3'-prodrugs for the treatment of HBV. U.S. Patent No. 4,957,924 to Beauchamp discloses various therapeutic esters of acyclovir.

In light of the fact that HCV infection has reached epidemic levels worldwide, and has tragic effects on the infected patient, there remains a strong need to provide new effective pharmaceutical agents to treat hepatitis C that have low toxicity to the host.

Further, given the rising threat of other flaviviridae infections, there remains a strong need to provide new effective pharmaceutical agents that have low toxicity to the host.

Therefore, it is an object of the present invention to provide a compound, method and composition for the treatment of a host infected with hepatitis C virus.

It is another object of the present invention to provide a method and composition generally for the treatment of patients infected with *pestiviruses*, *flaviviruses*, or *hepaciviruses*.

SUMMARY OF THE INVENTION

It has been discovered that the 3'-L-valine ester of β-D-2'-C-methyl-ribofuranosyl cytidine (referred to alternatively below as val-mCyd) provides superior results against flaviviruses and pestiviruses, including hepatitis C virus. Based on this discovery, compounds, compositions, methods and uses are provided for the treatment of flaviviridae, including HCV, that include the administration of an effective amount

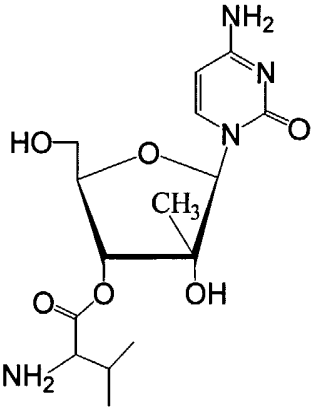
of val-mCyd or its salt, ester, prodrug or derivative, optionally in a pharmaceutically acceptable carrier. In an alternative embodiment, val-mCyd is used to treat any virus that replicates through an RNA-dependent RNA polymerase.

Therefore, a first embodiment provides a compound of Formula (I), β-D-2'-C-methyl-ribofuranosyl cytidine or a pharmaceutically acceptable salt thereof, and its uses in medical therapy and in the manufacture of a medicant to treat hosts, particularly humans, infected with a flavivirus or pestivirus, including HCV.

The compound val-mCyd is converted to the parent MCyd through de-esterification in the gastrointestinal mucosa, blood or liver, and is actively transported from the gastrointestinal lumen after oral delivery into the bloodstream by an amino acid transporter function in the mucosa of the gastrointestinal tract. This accounts for the increase in oral bioavailability compared to the parent 2'-branched nucleoside that is transported primarily by a nucleoside transporter function. There is also reduced competition with other nucleosides or nucleoside analogs that are transported by the nucleoside transporter function and not the amino acid transporter function. As partial de-esterification occurs prior to complete absorption, the mono or divaline ester continues to be absorbed using the amino acid transporter function. Therefore, the superior outcome of better absorption, bioavailability, and reduced competition with other nucleosides or nucleoside analogs for uptake into the bloodstream is achieved.

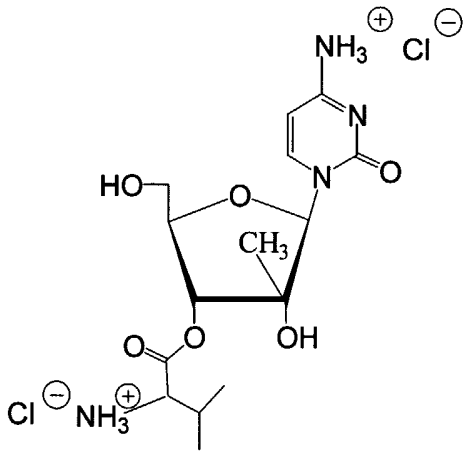
In hepatitis C infected chimpanzees, val-mCyd reduced the mean HCV RNA level by 0.83 $\log_{10}$ copies/ml (8.3 mg/kg/day) and 1.05 $\log_{10}$ copies/ml (16.6 mg/kg/day) in seven days. The chimps exhibited no drug-related safety issues.

The parent nucleoside (mCyd) framework can exist as a β-D or β-L nucleoside. In a preferred embodiment, the pharmaceutically acceptable compound is administered in a form that is at least 90% of the β-D enantiomer. In another embodiment, val-mCyd is at least 95% of the β-D enantiomer. The valine ester also has enantiomeric forms. In a preferred embodiment, the valine moiety is at least 90% of the L-enantiomer. In another embodiment, the valine moiety is at least 95% of the L-enantiomer. In alternative embodiments, the compounds are used as racemic mixtures or as any combination of β-D or β-L parent nucleoside and L or D amino acid.



Formula (I)

In one specific embodiment, the compound of Formula (I) is β-D-2'-C-methyl-ribofuranosyl cytidine-3'-O-L- valine ester·HCl salt. In another specific embodiment, the compound of Formula (II), the β-D-2'-C-methyl-ribofuranosyl cytidine dihydrochloride salt, is provided for administration to a host, particularly a human, infected with a flavivirus or pestivirus infection. In other embodiments, tosylate, methanesulfonate, acetate, citrate, malonate, tartarate, succinate, benzoate, ascorbate, α-ketoglutarate, and α-glycerophosphate, formate, fumarate, propionate, glycolate, lactate, pyruvate, oxalate, maleate, salicyate, sulfate, sulfonate, nitrate, bicarbonate, hydrobromate, hydrobromide, hydroiodide, carbonate, and phosphoric acid salts are provided. A particularly preferred embodiment is the mono or dihydrochloride salt.



Formula (II)

In another embodiment, a pharmaceutical composition comprising 2'-C-methyl-cytidine-3'-O-L-valine ester·or its pharmaceutically acceptable salt, including a mono or di HCl salt, ester, prodrug or derivative thereof together with a pharmaceutically acceptable carrier, excipient or diluent is provided.

In an alternative embodiment, the 5'-hydroxyl group is replaced with a 5'-OR, wherein R is phosphate (including monophosphate, diphosphate, triphosphate, or a stabilized phosphate prodrug); acyl (including lower acyl); alkyl (including lower alkyl); sulfonate ester including alkyl or arylalkyl sulfonyl including methanesulfonyl and benzyl, wherein the phenyl group is optionally substituted with one or more substituents as described in the definition of aryl given herein; a lipid, including a phospholipids; an amino acid; a carbohydrate; a peptide; cholesterol; or other pharmaceutically acceptable leaving group which when administered *in vivo* is capable of providing a compound wherein R is independently H or phosphate.

The active compounds of the present invention can be administered in combination or alternation with another agent that is active against a flavivirus or pestivirus, including HCV (including any described or referred to in the Background of the Invention), or other useful biological agent. Thus another principal embodiment is a pharmaceutical composition that includes β-D-2'-C-methyl-ribofuranosyl cytidine-3'-O-L- valine ester·or a pharmaceutically acceptable salt (including a mono- or di-HCl salt), ester, prodrug or pharmaceutically acceptable derivative thereof, together with one or more other effective antiviral agents, optionally with a pharmaceutically acceptable carrier or diluent. In another embodiment, a method is provided that includes administering β-D-2'-C-methyl-ribofuranosyl cytidine-3'-O-L- valine ester or a salt, ester, prodrug or derivative thereof, in combination or in alternation with one or more second antiviral agents, optionally with a pharmaceutically acceptable carrier or diluent.

Any second antiviral agent may be selected that imparts the desired biological effect. Nonlimiting examples include interferon, ribavirin, an interleukin, an NS3 protease inhibitor, a cysteine protease inhibitor, phenanthrenequinone, a thiazolidine derivative, thiazolidine, benzanilide, a helicase inhibitor, a polymerase inhibitor, a nucleotide analogue, gliotoxin, cerulenin, antisense phosphorothioate oligodeoxynucleotides, inhibitor of IRES-dependent translation, or ribozyme. In one particular embodiment, the second antiviral agent is selected from natural interferon,

interferon alpha (including interferon-alpha-2a and interferon-alpha-2b), interferon beta (including interferon beta-1a), omega interferon, interferon gamma (including interferon gamma-1b), interferon tau, and consensus interferon. Any of these interferons can be stabilized or otherwise modified to improve the tolerance and biological stability or other biological properties. One common modification is pegylation (modification with polyethylene glycol). In one particular embodiment, the second antiviral agent is pegylated or unpegylated interferon 2-alpha.

In an alternative embodiment, the active compound is a 3'-amino acid ester of β-D-2'-C-methyl-ribofuranosyl cytidine, wherein the amino acid can be natural or synthetic and can be in a D or L stereoconfiguration. In another embodiment, the active compound is a 3'-acyl ester of β-D-2'-C-methyl-ribofuranosyl cytidine.

BRIEF DESCRIPTION OF THE FIGURES

Figures 1a and 1b are illustration of two processes for the preparation of β-D-2'-C-methyl-ribofuranosyl cytidine-3'-O-L- valine ester dihydrochloride, as described in Example 1.

Figure 2 is a photocopy of a gel illustrating the site-specific chain termination of *in vitro* RNA synthesis by β-D-2'-C-methyl-ribofuranosyl cytidine triphosphate at specified guanine residues in RNA templates, as described in Example 9.

Figure 3 is a graph of the the titer of bovine viral diarrhea virus (BVDV) over number of passages of BVDV infected MDBK cells, indicating eradication of a persistent BVDV infection by prolonged treatment with β-D-2'-C-methyl-ribofuranosyl cytidine (16uM) as described in Example 10. Arrows indicate points at which a portion of cells were withdrawn from drug treatment.

Figures 4a and 4b are graphs of the concentration of bovine viral diarrhea virus (BVDV) in MDBK cells persistently infected with the virus, as described in Example 11. These graphs indicate the synergy between β-D-2'-C-methyl-ribofuranosyl cytidine and interferon alpha 2b (IntronA) in reducing the viral titer. Figure 4a is a graph of the effect of β-D-2'-C-methyl-ribofuranosyl cytidine and IntronA on BVDV (strain NY-1) titers in persistently infected

MDBK cells over time. Figure 4b is a graph of the effect of β-D-2'-C-methyl-ribofuranosyl cytidine in combination with IntronA on BVDV (strain I-N-dIns) titers in persistently-infected MDBK cells.

Figures 5a-d illustrate the results of experiments studying the development of resistance to β-D-2'-C-methyl-ribofuranosyl cytidine treated MDBK cells, infected with bovine viral diarrhea virus (BVDV), as described in Example 12. Figure 5a is a graph of a representative experiment showing the effect over twenty eight days of β-D-2'-C-methyl-ribofuranosyl cytidine or IntronA treatment on BVDV (strain I-N-dIns) titers in persistently infected MDBK cells. Figure 5b is a photocopy of a dish plated with infected MDBK cells that illustrates the size of the foci formed by phenotypes of the wild-type BVDV (strain I-N-dIns), versus the β-D-2'-C-methyl-ribofuranosyl cytidine-resistant BVDV (I-N-dIns 107R), indicating that the resistant virus formed much smaller foci than the wild-type, I-N-dIns strain. Figure 5c is a graph of the titer of BVDV strains I-N-dIns or I-N-dIns-107R over hours post-infection in infected MDBK cells. Figure 5d is a graph of the effect of Intron A on the BVDV viral titer yield in *de novo*-infected MDBK cells treated with IntronA.

Figure 6 is a graph of the concentration of hepatitis C virus (Log_{10}) in individual chimpanzees over days of treatment with β-D-2'-C-methyl-ribofuranosyl cytidine-3'-O-L- valine ester as described in Example 13.

Figure 7 is a graph of the concentration of hepatitis C virus in individual chimpanzees over days of treatment with β-D-2'-C-methyl-ribofuranosyl cytidine-3'-O-L-valine ester as compared to baseline, as described in Example 13.

Figure 8 is a graph of percent of total β-D-2'-C-methyl-ribofuranosyl cytidine-3'-O-L-valine ester remaining in samples over time after incubation of the drug in human plasma at 4°C, 21°C, and 37°C, as described in Example 14.

Figure 9a is a graph showing the relative levels of the di- and tri-phosphate derivatives of β-D-2'-C-methyl-ribofuranosyl cytidine and β-D-2'-C-methyl-

ribofuranosyl uridine (mUrd) after incubation of HepG2 cells with 10 μM β-D-2'-C-methyl-ribofuranosyl cytidine over time, as described in Example 14. Figure 9b is a graph of the decay of the tri-phosphate derivative of β-D-2'-C-methyl-ribofuranosyl cytidine after incubation of HepG2 cells with 10 μM β-D-2'-C-methyl-ribofuranosyl cytidine over time. Figure 9c is a graph of the concentration of the di- and tri-phosphate derivatives of β-D-2'-C-methyl-ribofuranosyl cytidine and β-D-2'-C-methyl-ribofuranosyl uridine (mUrd) after incubation of HepG2 cells with 10μM β-D-2'-C-methyl-ribofuranosyl cytidine at increasing concentrations of the drug (μM).

Figure 10 is a graph of the concentration (ng/ml) of β-D-2'-C-methyl-ribofuranosyl cytidine in human serum after administration of β-D-2'-C-methyl-ribofuranosyl cytidine-3'-O-L- valine ester to patients, as described in Example 17.

Figure 11 is a graph of the median change of the titer of hepatitis C virus in human patients after administration of β-D-2'-C-methyl-ribofuranosyl cytidine-3'-O-L- valine ester, as described in Example 17. The graph indicates change from baseline in Log_{10} HCV RNA by patient visit.

DETAILED DESCRIPTION OF THE INVENTION

It has been discovered that the 3'-L-valine ester of β-D-2'-C-methyl-ribofuranosyl cytidine (referred to alternatively below as val-mCyd) provides superior results against flaviviruses and pestiviruses, including hepatitis C virus. Based on this discovery, compounds, compositions, methods and uses are provided for the treatment of flaviviridae, including HCV, that include the administration of an effective amount of val-mCyd or its salt, ester, prodrug or derivative, optionally in a pharmaceutically acceptable carrier. In an alternative embodiment, val-mCyd is used to treat any virus that replicates through an RNA-dependent RNA polymerase.

The disclosed compounds or their pharmaceutically acceptable derivatives or salts or pharmaceutically acceptable formulations containing these compounds are useful in the prevention and treatment of flaviviridae (including HCV) infections and

other related conditions such as anti-HCV antibody positive and HCV-positive conditions, and hepatitis C related hepatic cancer (e.g., hepatocellular carcinoma) and hepatic tumors. In addition, these compounds or formulations can be used prophylactically to prevent or retard the progression of clinical illness in individuals who are anti-HCV (or more generally anti-flaviviridae) antibody or HCV-antigen or flaviviridae-antigen positive, or who have been exposed to HCV or another flaviviridae virus.

In summary, the present invention includes the following features:

(a) 3'-L-valine ester of β-D-2'-C-methyl-ribofuranosyl cytidine, and pharmaceutically acceptable prodrugs, derivatives and salts thereof, including specifically the mono- and di-hydrochloride salts;

(b) 3'-L-valine ester of β-D-2'-C-methyl-ribofuranosyl cytidine, and pharmaceutically acceptable prodrugs, derivatives and salts thereof for use in medical therapy, for example for the treatment or prophylaxis of an flaviridae (including HCV) infection;

(c) use of the 3'-L-valine ester of β-D-2'-C-methyl-ribofuranosyl cytidine, and pharmaceutically acceptable prodrugs, derivatives and salts thereof in the manufacture of a medicament for treatment of a flaviviridae (including HCV) infection;

(d) pharmaceutical formulations comprising the 3'-L-valine ester of β-D-2'-C-methyl-ribofuranosyl cytidine, and pharmaceutically acceptable prodrugs, derivatives and salts thereof together with a pharmaceutically acceptable carrier or diluent;

(e) processes for the preparation of the 3'-L-valine ester of β-D-2'-C-methyl-ribofuranosyl cytidine;

(f) use of the 3'-L-valine ester of β-D-2'-C-methyl-ribofuranosyl in the treatment of infections caused by viruses that replicate through an RNA dependent RNA polymerase; and

(g) use of the 3'-L-valine ester of β-D-2'-C-methyl-ribofuranosyl in the treatment of viral infections by administration in combination or alternation with another antiviral agent.

In an alternative embodiment, the active compound is a 3'-amino acid ester of β-D-2'-C-methyl-ribofuranosyl cytidine, wherein the amino acid can be natural or synthetic and can be in a D or L stereoconfiguration. In another embodiment, the active compound is a 3'-acyl ester of β-D or β-L 2'-C-methyl-ribofuranosyl cytidine. The compounds of this invention either possess antiviral activity, or are metabolized to a compound that exhibits such activity.

Although not to be bound by theory, *in vitro* mechanism-of-action studies suggest that mCyd is a specific inhibitor of genomic RNA replication. Moreover, the intracellular 5'-triphosphate moiety, mCyd-TP, appears to directly inhibit the NS5B RNA-dependent-RNA polymerase. Analysis of RNA synthesis in the presence of mCyd-TP suggests that mCyd-TP acts as a specific chain terminator of viral RNA synthesis through as yet unidentified mechanisms. Antiviral nucleosides and nucleoside analogs are generally converted into the active metabolite, the 5'-triphosphate (TP) derivatives by intracellular kinases. The nucleoside-TPs then exert their antiviral effect by inhibiting the viral polymerase during virus replication. In cultured cells, intracellular phosphorylation converts mCyd predominantly into the active species, mCyd-triphosphate (mCyd-TP), along with low levels of mCyd-diphosphate. Additionally, a second TP product, 2'-C-methyl-uridine TP (mUrd-TP), is found and is thought to arise via intracellular deamination of mCyd or mCyd-5'-phosphate species.

Flaviviruses included within the scope of this invention are discussed generally in *Fields Virology*, Editors: Fields, .N., Knipe, D.M. and Howley, P.M.; Lippincott-Raven Pulishers, Philadelphia, PA; Chapter 31 (1996). Specific flaviviruses include, without limitation: Absettarov; Alfuy; Apoi; Aroa; Bagaza; Banzi; Bououi; Bussuquara; Cacipacore; Carey Island; Dakar bat; Dengue viruses 1, 2, 3 and 4; Edge Hill; Entebbe bat; Gadgets Gully; Hanzalova; Hypr; Ilheus; Israel turkey meningoencephalitis; Japanese encephalitis; Jugra; Jutiapa; Kadam; Karshi; Kedougou; Kokoera; Koutango; Kumlinge; Kunjin; Kyasanur Forest disease; Langat; Louping ill; Meaban; Modoc; Montana myotis leukoencephalitis; Murray valley encephalitis; Naranjal; Negishi; Ntaya; Omsk hemorrhagic fever; Phnom-Penh bat; Powassan; Rio Bravo; Rocio; Royal Farm; Russian spring-summer encephalitis; Saboya; St. Louis encephalitis; Sal Vieja; San Perlita; Saumarez Reef; Sepik;

Sokuluk; Spondweni; Stratford; Temusu; Tyuleniy; Uganda S, Usutu, Wesselsbron; West Nile; Yaounde; Yellow fever; and Zika.

Pestiviruses included within the scope of this invention are also discussed generally in *Fields Virology* (Id.). Specific pestiviruses include, without limitation: bovine viral diarrhea virus ("VDV"); classical swine fever virus ("CSFV") also known as hog cholera virus); and border disease virus ("DV").

Definitions

The term alkyl, as used herein, unless otherwise specified, refers to a saturated straight, branched, or cyclic, primary, secondary, or tertiary hydrocarbon of typically C_1 to C_{10}, and specifically includes CF_3, CCl_3, $CFCl_2$, CF_2Cl, CH_2CF_3, CF_2CF_3, methyl, ethyl, propyl, isopropyl, cyclopropyl, butyl, isobutyl, secbutyl, *t*-butyl, pentyl, cyclopentyl, isopentyl, neopentyl, hexyl, isohexyl, cyclohexyl, cyclohexylmethyl, 3-methylpentyl, 2,2-dimethylbutyl, and 2,3-dimethylbutyl. The term includes both substituted and unsubstituted alkyl groups, and particularly includes halogenated alkyl groups, and even more particularly fluorinated alkyl groups. Non-limiting examples of moieties with which the alkyl group can be substituted are selected from the group consisting of halogen (fluoro, chloro, bromo or iodo), hydroxyl, amino, alkylamino, arylamino, alkoxy, aryloxy, nitro, cyano, sulfonic acid, sulfate, phosphonic acid, phosphate, or phosphonate, either unprotected, or protected as necessary, as known to those skilled in the art, for example, as taught in Greene, *et al.*, Protective Groups in Organic Synthesis, John Wiley and Sons, Second Edition, 1991, hereby incorporated by reference.

The term lower alkyl, as used herein, and unless otherwise specified, refers to a C_1 to C_4 saturated straight, branched, or a cyclic (for example, cyclopropyl) alkyl group, including both substituted and unsubstituted forms. Unless otherwise specifically stated in this application, when alkyl is a suitable moiety, lower alkyl is preferred. Similarly, when alkyl or lower alkyl is a suitable moiety, unsubstituted alkyl or lower alkyl is preferred.

The term alkylamino or arylamino refers to an amino group that has one or two alkyl or aryl substituents, respectively.

The term "protected" as used herein and unless otherwise defined refers to a group that is added to an oxygen, nitrogen, or phosphorus atom to prevent its further

reaction or for other purposes. A wide variety of oxygen and nitrogen protecting groups are known to those skilled in the art of organic synthesis.

The term aryl, as used herein, and unless otherwise specified, refers to phenyl, biphenyl, or naphthyl, and preferably phenyl. The term includes both substituted and unsubstituted moieties. The aryl group can be substituted with any desired moiety, including, but not limited to, one or more moieties selected from the group consisting of halogen (fluoro, chloro, bromo or iodo), hydroxyl, amino, alkylamino, arylamino, alkoxy, aryloxy, nitro, cyano, sulfonic acid, sulfate, phosphonic acid, phosphate, or phosphonate, either unprotected, or protected as necessary, as known to those skilled in the art, for example, as taught in Greene, *et al.*, Protective Groups in Organic Synthesis, John Wiley and Sons, Second Edition, 1991.

The term alkaryl or alkylaryl refers to an alkyl group with an aryl substituent. The term aralkyl or arylalkyl refers to an aryl group with an alkyl substituent.

The term halo, as used herein, includes a specific description of chloro, bromo, iodo, and fluoro individually.

The term purine or pyrimidine base includes, but is not limited to, adenine, N^6-alkylpurines, N^6-acylpurines (wherein acyl is C(O)(alkyl, aryl, alkylaryl, or arylalkyl), N^6-benzylpurine, N^6-halopurine, N^6-vinylpurine, N^6-acetylenic purine, N^6-acyl purine, N^6-hydroxyalkyl purine, N^6-alkylaminopurine, N^6-thioalkyl purine, N^2-alkylpurines, N^2-alkyl-6-thiopurines, thymine, cytosine, 5-fluorocytosine, 5-methylcytosine, 6-azapyrimidine, including 6-azacytosine, 2- and/or 4-mercaptopyrmidine, uracil, 5-halouracil, including 5-fluorouracil, C^5-alkylpyrimidines, 5-iodo-pyrimidine, 6-iodo-pyrimidine, 2-Br-vinyl-5-pyrimidine, 2-Br-vinyl-6-pyrimidine, C^5-benzylpyrimidines, C^5-halopyrimidines, C^5-vinylpyrimidine, C^5-acetylenic pyrimidine, C^5-acyl pyrimidine, C^5-hydroxyalkyl purine, C^5-amidopyrimidine, C^5-cyanopyrimidine, C^5-nitropyrimidine, C^5-amino-pyrimidine, N^2-alkylpurines, N^2-alkyl-6-thiopurines, 5-azacytidinyl, 5-azauracilyl, triazolopyridinyl, imidazolopyridinyl, pyrrolopyrimidinyl, and pyrazolopyrimidinyl. Purine bases include, but are not limited to, guanine, adenine, hypoxanthine, 2,6-diaminopurine, and 6-chloropurine. Functional oxygen and nitrogen groups on the base can be protected as necessary or desired. Suitable protecting groups are well known to those skilled in the art, and include trimethylsilyl, dimethylhexylsilyl, *t*-butyldimethylsilyl, and *t*-butyldiphenylsilyl, trityl, alkyl groups, and acyl groups such as acetyl and propionyl, methanesulfonyl, and p-toluenesulfonyl.

The term acyl or O-linked ester refers to a group of the formula C(O)R', wherein R' is an straight, branched, or cyclic alkyl (including lower alkyl), carboxylate residue of an amino acid, aryl including phenyl, heteroaryl, alkaryl, aralkyl including benzyl, alkoxyalkyl including methoxymethyl, aryloxyalkyl such as phenoxymethyl; or substituted alkyl (including lower alkyl), aryl including phenyl optionally substituted with chloro, bromo, fluoro, iodo, C_1 to C_4 alkyl or C_1 to C_4 alkoxy, sulfonate esters such as alkyl or aralkyl sulphonyl including methanesulfonyl, the mono, di or triphosphate ester, trityl or monomethoxy-trityl, substituted benzyl, alkaryl, aralkyl including benzyl, alkoxyalkyl including methoxymethyl, aryloxyalkyl such as phenoxymethyl. Aryl groups in the esters optimally comprise a phenyl group. In nonlimiting embodiments, acyl groups include acetyl, trifluoroacetyl, methylacetyl, cyclopropylacetyl, cyclopropyl- carboxy, propionyl, butyryl, isobutyryl, hexanoyl, heptanoyloctanoyl, neo-heptanoyl, phenylacetyl, 2-acetoxy-2-phenylacetyl, diphenylacetyl, α-methoxy-α-trifluoromethyl-phenylacetyl, bromoacetyl, 2-nitro-benzeneacetyl, 4-chloro-benzeneacetyl, 2-chloro-2,2-diphenylacetyl, 2-chloro-2-phenylacetyl, trimethylacetyl, chlorodifluoroacetyl, perfluoroacetyl, fluoroacetyl, bromodifluoroacetyl, methoxyacetyl, 2-thiopheneacetyl, chlorosulfonylacetyl, 3-methoxyphenylacetyl, phenoxyacetyl, tert-butylacetyl, trichloroacetyl, monochloro-acetyl, dichloroacetyl, 7H-dodecafluoro-heptanoyl, perfluoro-heptanoyl, 7H-dodeca-fluoroheptanoyl, 7-chlorododecafluoro-heptanoyl, 7-chloro-dodecafluoro-heptanoyl, 7H-dodecafluoroheptanoyl, 7H-dodeca-fluoroheptanoyl, nona-fluoro-3,6-dioxa-heptanoyl, nonafluoro-3,6-dioxaheptanoyl, perfluoroheptanoyl, methoxybenzoyl, methyl 3-amino-5-phenylthiophene-2-carboxyl, 3,6-dichloro-2-methoxy-benzoyl, 4-(1,1,2,2-tetrafluoro-ethoxy)-benzoyl, 2-bromo-propionyl, omega-aminocapryl, decanoyl, n-pentadecanoyl, stearyl, 3-cyclopentyl-propionyl, 1-benzene-carboxyl, O-acetylmandelyl, pivaloyl acetyl, 1-adamantane-carboxyl, cyclohexane-carboxyl, 2,6-pyridinedicarboxyl, cyclopropane-carboxyl, cyclobutane-carboxyl, perfluorocyclohexyl carboxyl, 4-methylbenzoyl, chloromethyl isoxazolyl carbonyl, perfluorocyclohexyl carboxyl, crotonyl, 1-methyl-1H-indazole-3-carbonyl, 2-propenyl, isovaleryl, 1-pyrrolidinecarbonyl, 4-phenylbenzoyl.

The term amino acid includes naturally occurring and synthetic α, β, γ, or δ amino acids, and includes but is not limited to, amino acids found in proteins, *i.e.* glycine, alanine, valine, leucine, isoleucine, methionine, phenylalanine, tryptophan,

proline, serine, threonine, cysteine, tyrosine, asparagine, glutamine, aspartate, glutamate, lysine, arginine and histidine. In a preferred embodiment, the amino acid is in the L-configuration, but can also be used in the D-configuration. Alternatively, the amino acid can be a derivative of alanyl, valinyl, leucinyl, isoleuccinyl, prolinyl, phenylalaninyl, tryptophanyl, methioninyl, glycinyl, serinyl, threoninyl, cysteinyl, tyrosinyl, asparaginyl, glutaminyl, aspartoyl, glutaroyl, lysinyl, argininyl, histidinyl, β-alanyl, β-valinyl, β-leucinyl, β-isoleuccinyl, β-prolinyl, β-phenylalaninyl, β-tryptophanyl, β-methioninyl, β-glycinyl, β-serinyl, β-threoninyl, β-cysteinyl, β-tyrosinyl, β-asparaginyl, β-glutaminyl, β-aspartoyl, β-glutaroyl, β-lysinyl, β-argininyl or β-histidinyl.

As used herein, the term "substantially free of" or "substantially in the absence of" refers to a nucleoside composition that includes at least 85 or 90% by weight, preferably 95%, 98, 99% or 100% by weight, of the designated enantiomer of that nucleoside.

Similarly, the term "isolated" refers to a nucleoside composition that includes at least 85 or 90% by weight, preferably 95%, 98%, 99% or 100% by weight, of the nucleoside.

The term host, as used herein, refers to an unicellular or multicellular organism in which the virus can replicate, including cell lines and animals, and preferably a human. Alternatively, the host can be carrying a part of the *Flaviviridae* viral genome, whose replication or function can be altered by the compounds of the present invention. The term host specifically refers to infected cells, cells transfected with all or part of the *Flaviviridae* genome and animals, in particular, primates (including chimpanzees) and humans. In most animal applications of the present invention, the host is a human patient. Veterinary applications, in certain indications, however, are clearly anticipated by the present invention (such as chimpanzees).

The term "pharmaceutically acceptable salt or prodrug" is used throughout the specification to describe any pharmaceutically acceptable form (such as an ester, phosphate ester, salt of an ester or a related group) of a nucleoside compound which, upon administration to a patient, provides the nucleoside compound. Pharmaceutically acceptable salts include those derived from pharmaceutically acceptable inorganic or organic bases and acids. Suitable salts include those derived from alkali metals such as potassium and sodium, alkaline earth metals such as

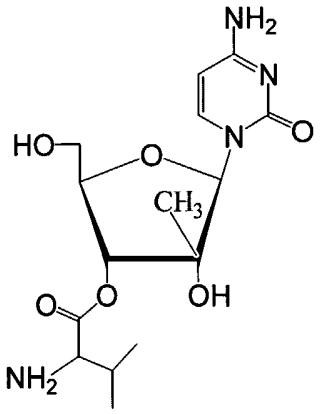
calcium and magnesium, among numerous other acids well known in the pharmaceutical art. Pharmaceutically acceptable prodrugs refer to a compound that is metabolized, for example hydrolyzed or oxidized, in the host to form the compound of the present invention. Typical examples of prodrugs include compounds that have biologically labile protecting groups on a functional moiety of the active compound. Prodrugs include compounds that can be oxidized, reduced, aminated, deaminated, hydroxylated, dehydroxylated, hydrolyzed, dehydrolyzed, alkylated, dealkylated, acylated, deacylated, phosphorylated, dephosphorylated to produce the active compound. The compounds of this invention possess antiviral activity against a *Flaviviridae*, or are metabolized to a compound that exhibits such activity.

I. Active Compounds, Physiologically Acceptable Salts and Prodrugs Thereof

Methods and compositions for the treatment of pestivirus, flavivirus and hepatitis C virus infection are described that include administering an effective amount of 2'-C-methyl-cytidine-3'-O-L-valine, or a pharmaceutically acceptable salt, ester or prodrug thereof to a host in need thereof.

In one embodiment, a hydrochloride salt of the compound of Formula (I) is used. In another embodiment, a dihydrochloride salt of the compound of Formula (I) is preferred. However, the active compound can be administered as any salt or prodrug that upon administration to the recipient is capable of providing directly or indirectly the parent compound, or that exhibits activity itself. Nonlimiting examples are the pharmaceutically acceptable salts, which are alternatively referred to as "physiologically acceptable salts", and a compound that has been alkylated, acylated or otherwise modified at the 5'-position or on the purine or pyrimidine base, thereby forming a type of "pharmaceutically acceptable prodrug". Further, the modifications can affect the biological activity of the compound, in some cases increasing the activity over the parent compound. This can easily be assessed by preparing the salt or prodrug and testing its antiviral activity according to the methods described herein, or other methods known to those skilled in the art.

In a first principal embodiment, a compound of the Formula (I), or a pharmaceutically acceptable salt or prodrug thereof, is provided:



Formula (I)

It is to be understood that all stereoisomeric, tautomeric and polymorphic forms of the compounds are included herein. The 2'- methyl substitution also may be other alkyl groups such as ethyl, propyl, or, alternatively, ethenyl.

In an alternative embodiment, the active compound is a 3'-amino acid ester of β-D-2'-C-methyl-ribofuranosyl cytidine, wherein the amino acid can be natural or synthetic and can be in a D or L stereoconfiguration. In another embodiment, the active compound is a 3'-acyl ester of β-D-2'-C-methyl-ribofuranosyl cytidine.

In another alternative embodiment, the 5'-hydroxyl group is replaced with a 5'-OR, wherein R is phosphate (including monophosphate, diphosphate, triphosphate, or a stabilized phosphate prodrug); a stabilized phosphate prodrug; acyl (including lower acyl); alkyl (including lower alkyl); sulfonate ester including alkyl or arylalkyl sulfonyl including methanesulfonyl and benzyl, wherein the phenyl group is optionally substituted with one or more substituents as described in the definition of aryl given herein; a lipid, including a phospholipids; an amino acid; a carbohydrate; a peptide; cholesterol; or other pharmaceutically acceptable leaving group which when administered *in vivo* is capable of providing a compound wherein R is independently H or phosphate.

II. Synthesis of Active Compounds

The compound of the present invention can be synthesized by means known in the art. For example, in one embodiment, a nucleoside, nucleoside analog, or a salt, prodrug, stereoisomer or tautomer thereof, that is disubstituted at the 2' C is prepared.

In another embodiment, β-D-2'-C-methyl-cytidine (4-amino-1-(3,4-dihydroxy-5-hydroxymethyl-3-C-methyl-tetrahydro-furan-2-yl)-*1H*-pyrimidine-2-one), which has value as an active nucleoside or is used as a process intermediate is prepared. In yet another embodiment, 3'-*O*-valinyl ester of β-D-2'-C-methyl-cytidine (2-amino-3-methyl-butyric acid 5-(4-amino-2-oxo-*2H*-pyrimidin-1-yl)-4-hydroxy-4-C-methyl-2-hydroxymethyl-tetrahydro-furan-3-yl ester) or a hydrochloride salt form is prepared. Nucleosides, nucleoside analogs, salts or ester prodrugs prepared may be used as intermediates in the preparation of a wide variety of other nucleoside analogues, or may be used directly as antiviral and/or antineoplastic agents.

EXAMPLE 1: SYNTHESIS OF β-D-2'-C-METHYL-RIBOFURANOSYL CYTIDINE-3'-O-L- VALINE ESTER

In one synthesis method, depicted in Figure 1a, the synthesis comprises reacting cytosine, BSA and $SnCl_4$/acetonitrile with 1,2,3,5-tetra-*O*-benzoyl-2-C-methyl-β-D-ribofuranose (1) to form 4-amino-1-(3,4-dibenzoyloxy-5-benzoyloxymethyl-3-methyl-tetrahydro-furan-2-yl)-*1H*-pyrimidin-2-one (2); and reacting (2) with NaOMe/MeOH to provide 4-amino-1-(3,4-dihydroxy-5-hydroxymethyl-3-methyl-tetrahydro-furan-2-yl)-*1H*-pyrimidin-2-one (3), also known as 2-C-methyl- β-D-ribofuranose. The use of cytosine as a starting material rather than benzoyl-cytosine improves the "atom economy" of the process and simplifies purification at later steps.

The next steps in this process comprise reacting (3) with $Me_2NCH(OMe)_2$ in DMF to form (4), *N*-[1-(3,4-dihydroxy-5-hydroxymethyl-3-methyl-tetrahydro-furan-2-yl)-2-oxo-1, 2-dihydro-pyrimidin-4-yl]-*N,N*-dimethyl-formamidine, which is the amino-protected form of (3); reacting (4) with TBDPSCl and imidazole in DCM to provide the 5'-silyl-protected form of (4) as *N*'-{1-[5-(*tert*-butyl-diphenyl-silanyloxymethyl)-3,4-dihydroxy-3-methyl-tetrahydro-furan-2-yl]-2-oxo-1, 2-dihydro-pyrimidin-4-yl}-*N,N*-dimethyl-formamidine (5), where the use of DCM provides the advantage of having greater control over disilyl by-product formation; reacting (5) with *N*-Boc-*L*-valine, EDC and DMAP in DCM at room temperature to form 2-*tert*-butoxycarbonylamino-3-methyl-butyric acid 2-(*tert*-butyl-diphenyl-silanyloxy-methyl)-5-[4-(dimethylamino-methyleneamino)-2-oxo-*2H*-pyrimidin-1-yl]-4-hydroxy-4-methyl-tetrahydro-furan-3-yl ester (6); removing the silyl and amino-

protecting groups by reacting (**6**) with NH_4F in MeOH in the presence of approximately 10 mole equivalents of ethyl acetate to prevent cleavage of the 3'-O-valinyl ester by liberated ammonia, and refluxing the mixture to provide 2-*tert*-butoxycarbonylamino-3-methyl-butyric acid 5-(4-amino-2-oxo-*2H*-pyrimidin-1-yl)-4-hydroxy-2-hydroxymethyl-4-methyl-tetrahydro-furan-3-yl ester to provide (**7**); and finally, reacting (**7**) with HCl in EtOH to provide 2-amino-3-methyl-butyric acid 5-(4-amino-2-oxo-*2H*-pyrimidin-1-yl)-4-hydroxy-2-hydroxymethyl-4-methyl-tetrahydro-furan-3-yl ester, dihydrochloride salt (**8**) as a final product.

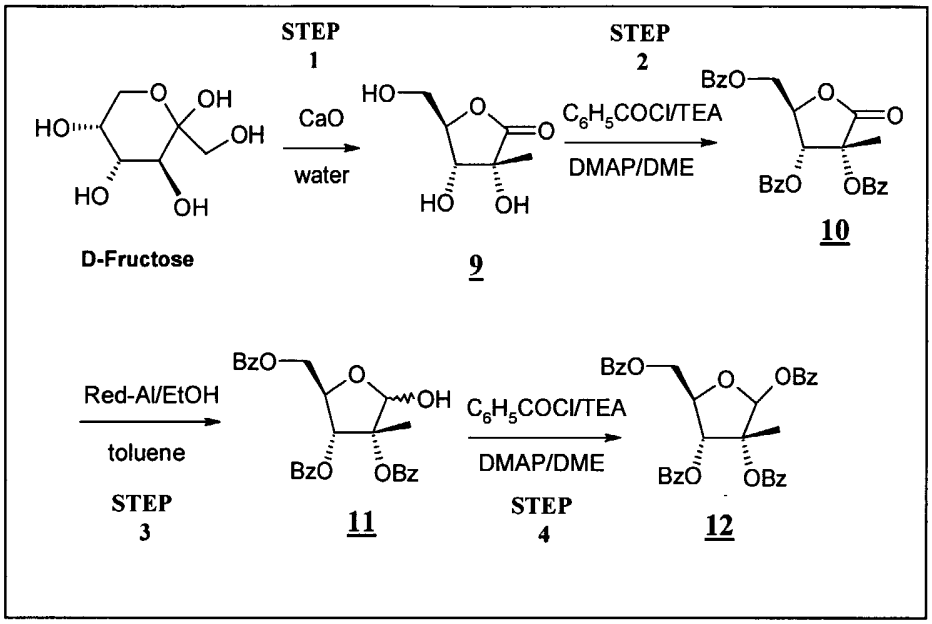
Alternative Synthesis

In another method to synthesize the compounds of the invention, shown in Figure 1b, benzoylcytosine, BSA and $SnCl_4$/acetonitrile are reacted with 1,2,3,5-tetra-*O*-benzoyl-2-C-methyl-β-D-ribofuranose (**1**) to form 4-benzoylamino-1-(3,4-dibenzoyloxy-5-benzoyloxymethyl-3-methyl-tetrahydro-furan-2-yl)-*1H*-pyrimidin-2-one (**2a**); reacting (**2a**) with NH_3 in methanol and chromatographically separating the product, 4-amino-1-(3,4-dihydroxy-5-hydroxymethyl-3-methyl-tetrahydro-furan-2-yl)-*1H*-pyrimidin-2-one (**3**), also known as β-D-2'-C-methyl-cytidine; reacting (**3**) with $Me_2NCH(OMe)_2$ in DMF at room temperature for 1.5 hours to form *N*-[1-(3,4-dihydroxy-5-hydroxymethyl-3-methyl-tetrahydro-furan-2-yl)-2-oxo-1,2-dihydro-pyrimidin-4-yl]-*N,N*-dimethyl-formamidine (**4**); reacting (**4**) with TBDPSCl and pyridine at room temperature for 6 hours to provide *N*'-{1-[5-(*tert*-butyl-diphenyl-silanyloxymethyl)-3,4-dihydroxy-3-methyl-tetrahydro-furan-2-yl]-2-oxo-1,2-dihydro-pyrimidin-4-yl}-*N,N*-dimethyl-formamidine (**5**); reacting (**5**) with *N*-Boc-*L*-valine, DEC and DMAP in THF/DMF at room temperature for 2 days and subjecting the product formed from this reaction to HPLC in order to provide 2-*tert*-butoxycarbonylamino-3-methyl-butyric acid 2-(*tert*-butyl-diphenyl-silanyloxy-methyl)-5-[4-(dimethylaminomethyleneamino)-2-oxo-*2H*-pyrimidin-1-yl]-4-hydroxy-4-methyl-tetrahydro-furan-3-yl ester (**6**); refluxing (**6**) with NH_4F in MeOH for about 3 hours to remove the silyl and amino-protecting groups, and subjecting the product to chromatographic purification to provide 2-*tert*-butoxycarbonylamino-3-methyl-butyric acid 5-(4-amino-2-oxo-*2H*-pyrimidin-1-yl)-4-hydroxy-2-hydroxymethyl-4-methyl-tetrahydro-furan-3-yl ester (**7**); and finally reacting (**7**) with HCl in EtOAc at room temperature to provide 2-amino-3-methyl-butyric acid 5-(4-amino-2-oxo-*2H*-

pyrimidin-1-yl)-4-hydroxy-2-hydroxymethyl-4-methyl-tetrahydro-furan-3-yl ester, dihydrochloride salt (8) as a final product.

EXAMPLE 2: SYNTHESIS OF 2'-C-METHYL-CYTIDINE-3'-O-L-VALINE ESTER (VAL-mCyd)

Scheme 1



Step 1: Synthesis of compound 9: 2-C-Methyl-D-ribonic-γ-lactone

De-ionized water (100 mL) was stirred in a 250 mL 3-necked round bottom flask, equipped with an overhead stirrer, a stirring shaft, a digital temperature read-out device and an argon line. Argon was bubbled into water for thirty minutes and D-fructose (20.0 g, 0.111 mole) was added and the solution became clear in a few minutes. Calcium oxide (12.5 g, 0.223 mole) was added in portions over a period of five minutes and the mixture was vigorously stirred. An exotherm was observed and reaction temperature reached 39.6 °C after 10 minutes from the start of the calcium oxide addition. After about fifteen minutes, the reaction mixture developed a yellow color that deepened with time. After three hours, an aliquot was withdrawn for TLC analysis. The aliquot was acidified to pH 2 using saturated aqueous solution of oxalic acid. The resulting white suspension was evaporated under reduced pressure to remove the water. Toluene (2 mL) was added to the residue and the mixture was evaporated under reduced pressure (at 45-50 °C) to remove any trace of water. The

residual solid was re-constituted in 2 mL of 1:1 tetrahydrofuran : methanol mixture. After thorough mixing, the suspension was allowed to settle and the supernatant clear solution was spotted for TLC (silica plate was developed in 2% methanol in ethyl acetate and stained in 1% alkaline potassium permanganate dip. The plate was then heated, using a heat gun, until the appearance of yellowish spots on the pink background). The desired lactone typically appears at an R_f value of 0.33 under the above conditions. More polar by-products and unreacted material are detected in the R_f value range of 0.0 to 0.2.

Although product formation was observed after 3 hours, the reaction was allowed to continue for 22 hours during which time the reaction mixture was stirred at 25 °C. At the end of this period, pH of the mixture was 13.06. Carbon dioxide gas was bubbled into the reaction mixture for about 2.5 hours (pH was 7.25). The formed calcium carbonate solid was removed by vacuum filtration, filter cake washed with 50 mL of de-ionized water. The aqueous layers were combined and treated with oxalic acid (5.0 g, 0.056 mole) and the mixture was vigorously stirred at 25 °C for 30 minutes (The initial dark color largely disappeared and the mixture turned into a milky white slurry). The pH of the mixture at this stage is typically 2-3. The slurry mixture was stirred at 45-50 °C overnight. The mixture was then evaporated under reduced pressure and at 45-50 °C to remove 75 mL of water. Sodium chloride (30 g) and tetrahydrofuran (100 mL) were added to the aqueous slurry (about 75 mL) and the mixture was vigorously stirred at 25 °C for 30 minutes. The layers were separated and the aqueous layer was stirred for 10 minutes with 75 mL of fresh tetrahydrofuran. This process was repeated for three times and the tetrahydrofuran solutions were combined and stirred with 10 g of anhydrous magnesium sulfate for 30 minutes. The mixture was filtered and the magnesium sulfate filter cake was washed with 60 mL of tetrahydrofuran. The filtrate was evaporated under reduced pressure and at 40 °C to give 10.86 g of crude product as a dark orange semisolid. (For scale up runs tetrahydrofuran will be replaced with acetone instead of evaporation of crude product to dryness). Crude product was stirred with acetone (20 mL) at 20 °C for 3 hours. Product was collected by vacuum filtration and the filter cake washed with 12 mL of acetone to give the desired product 9 as white crystalline solid. Product was dried in vacuum to give 2.45 g (13.6% yield). Melting point of compound 9: 158-162 °C (literature melting point: 160-161 °C). ^{1}H NMR (DMSO-d_6) δ ppm 5.69 (s, 1H, exch.

With D_2O), 5.41 (d, 1H, exch. With D_2O), 5.00 (t, 1H, exch. With D_2O), 4.15 (m, 1H), 3.73 (m, 2H), 3.52 (m, 1H), 1.22 (s, 3H). ^{13}C NMR (DMSO-d_6) δ ppm 176.44, 82.95, 72.17, 72.02, 59.63, 20.95. ($C_6H_{10}O_5$: calcd C, 44.45; H, 6.22. Found: C, 44.34; H, 6.30).

Step 2: Synthesis of compound 10: 2,3,5-Tri-O-benzoyl-2-C-methyl-D-ribonic-γ-lactone

A mixture of lactone 1 (3.0 g, 18.50 mmol.), 4-dimethylaminopyridine (0.45 g, 3.72 mmol.) and triethylamine (25.27 g, 249.72 mmol.) in 1,2-dimethoxy ethane(50 mL) was stirred at 25 °C under argon atmosphere for thirty minutes. This white suspension was cooled to 5 °C and benzoyl chloride (11.7 g, 83.23 mmol.) was added over a period of fifteen minutes. The mixture was stirred at 25 °C for two hours. TLC analysis (silica, 2% methanol in ethyl acetate) indicated complete consumption of starting material. Ice cold water (100 g) was added to the reaction mixture and stirring was continued for thirty minutes. The formed white solids were collected by vacuum filtration and filter cake washed with cold water (50 mL). This crude product was stirred with tert-butyl methyl ether (60 mL) at 20 °C for thirty minutes, then filtered, filter cake washed with tert-butyl methyl ether (25 mL) and dried in vacuum to give 7.33 g (83.4% yield) of compound 10 as a white solid in 97.74% purity (HPLC/AUC). Melting point of compound 10: 137-140 °C (literature melting point: 141-142 °C). ^1H NMR ($CDCl_3$) δ ppm 8.04 (d, 2H), 7.92 (d, 2H), 7.73 (d, 2H), 7.59 (t, 1H), 7.45 (m, 4H), 7.32 (t, 2H), 7.17 (t, 2H), 5.51 (d, 1H), 5.17 (m, 1H), 4.82-4.66 (d of an AB quartet, 2H) 1.95, (s, 3H). ^{13}C NMR ($CDCl_3$) δ ppm 172.87, 166.17, 166.08, 165.58, 134.06, 133.91, 133.72, 130.09, 129.85, 129.80, 129.37, 128.78, 128.60, 128.49, 127.96, 127.89, 79.67, 75.49, 72.60, 63.29, 23.80. TOF MS ES+ (M+1: 475).

Step 3: Synthesis of compound 11: 2,3,5-Tri-O-benzoyl-2-C-methyl-β-D-ribofuranose:

A solution of Red-Al (65wt.% in toluene, 2.0 mL, 6.56 mmol.) in anhydrous toluene (2.0 mL) was stirred at 0 °C under argon atmosphere. A solution of anhydrous ethanol (0.38 mL, 6.56 mmol.) in anhydrous toluene (1.6 mL) was added to the toluene solution over a period of five minutes. The resulting mixture was stirred at 0 °C for fifteen minutes and 2 mL (2.18 mmol.) of this Red-Al/ethanol reagent was added to a cold (-5 °C) solution of 2,3,5-tri-O-benzoyl-2-C-methyl-D-ribonolactone 2 (475 mg, 1.0 mmol.) in anhydrous toluene (10 mL) over a period of 10 minutes. The

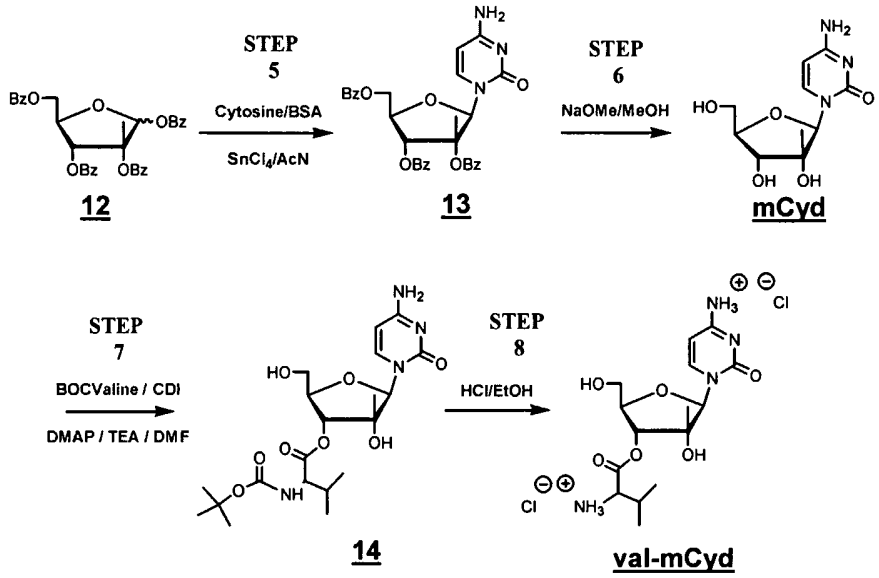
reaction mixture was stirred at -5 °C for forty minutes. TLC analysis (silica plates, 35% ethyl acetate in heptane) indicated complete consumption of starting material. HPLC analysis indicated only 0.1% of starting material remaining. The reaction was quenched with acetone (0.2 mL), water (15 mL) and 1 N HCl (15 mL) at 0 °C and allowed to warm to room temperature. 1 N HCl (5 mL) was added to dissolve the inorganic salts (pH : 2-3). The mixture was extracted with ethyl acetate (3 x 25 mL) and the organic solution washed with brine (25 mL), dried (anhydrous sodium sulfate, 10 g) and solvent removed under reduced pressure and at temperature of 40 °C to give the desired product 11 in quantitative yield (480 mg). This material was used as is for the subsequent step.

Step 4: Synthesis of compound 12: 1,2,3,5-tetra-O-benzoyl-2-C-methyl-β-D-ribofuranose:

Benzoyl chloride (283 mg, 2.0 mmol.) was added, over a period of five minutes, to a cold solution (5 °C) of compound 11 (480 mg, 1.0 mmol.), 4-dimethylaminopyridine (12.3 mg, 0.1 mmol.) and triethylamine (506 mg, 5.0 mmol.) in anhydrous tetrahydrofuran (5 mL). The reaction mixture was stirred at room temperature and under argon atmosphere overnight. HPLC analysis indicated 0.25% of un-reacted starting material. The reaction was quenched by adding ice-cold water (10 g) and saturated aqueous solution of sodium bicarbonate. Tetrahydrofuran was removed under reduced pressure and the mixture was extracted with ethyl acetate (50 mL). The organic solution was washed with water (25 mL), brine (25 mL), dried (anhydrous sodium sulfate, 12 g) and solvent removed under reduced pressure to give 650 mg of thick oily product. This crude product was stirred with 5 mL of tert-butyl methyl ether for 5 minutes and heptane (5 mL) and water (0.1 mL) were added and stirring was continued for an additional period of two hours at 20 °C. Solids were collected by vacuum filtration and filter caked washed with 1:1 heptane:tert-butyl methyl ether solution (6 mL) and tert-butyl methyl ether (2 mL). Drying the solid in vacuum gave 300 mg (52%) of desired product 12 (98.43% pure by HPLC/AUC) as a white solid that melted at 154-156.3 °C (literature melting point: 155-156 °C). ^{1}H NMR ($CDCl_3$) δ ppm 8.13 (m, 4H), 8.07 (d, 2H), 7.89 (d, 2H), 7.63 (m, 3H), 7.48 (m, 6H), 7.15 (m, 3H), 7.06 (s, 1H), 5.86 (dd, 1H), 4.79 (m, 1H), 4.70-4.52 (d of an AB quartet, 2H), 1.95, (s, 3H). ^{13}C NMR ($CDCl_3$) δ ppm 166.31, 165.83, 165.01, 164.77, 134.01, 133.86, 133.70, 133.17, 130.44, 130.13, 129.97, 129.81, 129.59,

129.39, 129.07, 128.84, 128.76, 128.37, 98.01, 86.87, 78.77, 76.35, 64.05, 17.07. ($C_{34}H_{28}O_9$: calcd C, 70.34; H, 4.86. Found: C, 70.20; H, 4.95).

Scheme 2



Step 5: Synthesis of compound 13: 4-Amino-1-(3,4-dibenzoyloxy-5-benzyloxymethyl-3-methyl-tetrahydro-furan-2-yl)-*1H*-pyrimidine-2-one

Cytosine (89 g, 0.80 mol) was suspended in acetonitrile (900 ml) in a 12 L round bottomed flask equipped with a reflux condenser, overhead stirrer and an argon inlet adapter. The suspension was stirred at 20 °C under argon atmosphere and N,O-bis(trimethylsilyl)acetamide (537 ml, 2.2 mol) was added in one portion. The resulting solution was heated to 80 ° C and stirred for an additional hour at the same temperature. 1,2,3,5-tetra-O-benzoyl-2-C-methyl-β-D-ribofuranose (425.0 g, 0.73 mol) was suspended in acetonitrile (4000 ml) and added to the reaction mixture. The reaction mixture became clear after a few minutes and the temperature dropped to ca. 50 ° C. Tin(IV) chloride (154 ml, 1.31 mol) was added over a period of 15 minutes and stirring was continued at 80 °. After one hour, an aliquot of reaction mixture was quenched by adding aqueous sodium bicarbonate solution and extracting the aqueous layer with ethyl acetate. The ethyl acetate layer was examined by TLC (silica gel, 20% ethyl acetate in heptane, R_f for sugar derivative: 0.40). TLC analysis indicated the complete consumption of the sugar derivative. Desired product was detected by TLC using 10% methanol in dichloromethane (R_f : 0.37). The reaction was also

monitored by HPLC (Method # 2). Reaction mixture was cooled to 20 °C and quenched by adding saturated aqueous sodium bicarbonate solution (3000 ml) over a period of 30 minutes (observed an exotherm when added the first few drops of the sodium bicarbonate solution). Solid sodium bicarbonate (1350 g) was added in portions to avoid foaming. The mixture was checked to make sure that its pH is $\geq$ 7. Agitation was stopped and layers were allowed to separate for 20 minutes. The aqueous layer was drained and stirred with ethyl acetate (1500 ml) and the mixture was allowed to separate (30 minutes). The organic layer was isolated and combined with the acetonitrile solution. The organic solution was washed with brine (500 ml) and then solvent stripped to a volume of ca. 750 ml. Product can be used as is in the subsequent reaction. It may also be further stripped to white foamy solid, in quantitative yield. Structure of compound 10 was confirmed by ^{1}H NMR analysis.

Step 6: Synthesis of compound mCyd: 4-Amino-1-(3,4-dihydroxy-5-hydroxymethyl-3-methyl-tetrahydro-furan-2-yl)-*1H*-pyrimidine-2-one

Sodium methoxide (13.8 g, 0.26 mol) was added to a solution of compound 10 (416 g, 0.73mol) in methanol (2000 ml). The reaction mixture was stirred at room temperature and monitored by TLC (silica gel, 10% methanol in dichloromethane, R_f of compound 9: 0.53) and (silica gel, 30% methanol in dichloromethane, R_f of compound 11: 0.21). Product started to precipitate after 30 minutes and TLC indicated reaction completion after two hours. The reaction was also monitored by HPLC (Method # 2). Methanol was removed under reduced pressure to a volume of ca. 500 ml chased with ethanol (2 x 500 ml) to a volume of ca. 500 ml. The residual thick slurry was diluted with 750 ml of ethanol and the mixture was stirred at 20 ° C for one hour. Product was collected by filtration, filter cake washed with ethanol (100 ml) and tert-butyl-methyl ether (100 ml) and dried to give 168 g (90% yield for the two steps) of product 11 in purity of > 97% (HPLC/AUC). Product was also analyzed by ^{1}H and ^{13}C NMR.

Step 7: Synthesis of compound 14: 2-*Tert*-butoxycarbonylamino-3-methyl-butyric acid 5-(4-amino-2-oxo-*2H*-pyrimidin-1-yl)-4-hydroxy-2-hydroxymethyl-4-methyl-tetrahydro-furan-3-yl ester

A solution of N-(tert-butoxycarbonyl)-L-valine (46.50 g, 214 mmol.), carbonyldiimidazole (34.70 g, 214 mmol.), and anhydrous tetrahydrofuran (1000 mL)

in a 2 L round bottom flask, was stirred at 25 °C under argon for 1.5 hours and then at 40-50 °C for 20 minutes. In a separate 5 L 5-necked round bottom flask, equipped with an overhead stirrer, cooling tower, temperature probe, addition funnel, and an argon line was added 4-amino-1-(3,4-dihydroxy-5-hydroxymethyl-3-methyl-tetrahydro-furan-2-yl)-*1H*-pyrimidine-2-one (50.0 g, 195 mmol.) and anhydrous N,N-dimethylformamide (1000 mL). This mixture was heated at 100 °C for 20 minutes until all of the pyrimidine-2-one derivative compound went into solution, and then triethyl amine (500 mL) and 4-dimethylaminopyridine (2.38 g, 19 mmol) were added to the solution. The mixture was next heated at 97 ° C for 20 minutes and the tetrahydrofuran solution was added slowly through an addition funnel over a period of 2 hours, maintaining the temperature no lower than 82 °C. The reaction mixture was heated at 82 °C for 1 hour and monitored by HPLC (product = 68%, SM = 11%, and impurity at about 12 min = 17%, excluding dimethylaminopyridine). The reaction mixture was cooled to room temperature and then triethylamine and tetrahydrofuran were removed under vacuum at 30 °C. The solution was then neutralized with acetic acid to a pH of 7.69. N,N-dimethylformamidine was removed under vacuum at 35 °C and chased with ethyl acetate (2 x 200 mL). The crude product was stirred with ethyl acetate (500 mL) and water (300 mL). The two layers were separated and the aqueous layer was extracted with ethyl acetate (500 mL). The combined organic layers were washed with an aqueous saturated brine solution (500 mL). Next the organic layer was extracted with an aqueous solution of malonic acid (4 x 400 mL, 10wt.%). The organic layer was checked by TLC (silica, 20% methanol in dichloromethane) to make sure that all the desired product was removed from the organic layer. The acidic aqueous extracts were combined and cooled in an ice bath and neutralized with triethylamine to a pH of 7.40 so that the solids fell out of solution. Ethyl acetate then was added to the aqueous layer. The white solids were collected by vacuum filtration. Drying the obtained solids in vacuum gave 81.08 g of 99.01 pure (HPLC) first crop.

Step 8: Synthesis of val-mCyd - 2-Amino-3-methyl-butyric acid 5-(4-amino-2-oxo-*2H*-pyrimidine-1-yl)-4-hydroxy-2 hydroxy-methyl-4-methyl-tetrahydro-furan-3-yl ester (dihydrochloride salt)

A solution of compound 14 (21.0 g, 0.046 mol) in ethanol (168 ml) was stirred in a round bottomed flask equipped with an overhead stirrer, temperature probe, argon

line and hydrogen chloride gas bubbler. Hydrogen chloride gas (22 g) was bubbled into the clear solution over a period of one hour. The reaction temperature was kept below 30 °C using an ice-water bath. Solid formation started after a few minutes of introducing the hydrogen chloride gas. After 4 hours, HPLC (method # 3) showed only 0.8% of starting material. Solids were collected by filtration and filter cake washed with ethanol (20 ml) and di-ethyl ether (100 ml). After drying product under vacuum for 16 hours, 19.06 g (96.5%) of val-mCyd was obtained in 97.26% purity (HPLC, method # 3); m.p. 210°C (brown), 248-250°C (melted); ^{1}H NMR (DMSO-d_6) δ ppm 10.0 (s, 1H, 1/2NH_2, D_2O exchangeable), 8.9-8.6 (2 br s, 4H, 1/2NH_2, NH_3, D_2O exchangeable), 8.42 (d, 1H, *H*-6, J_{5-6}= 7.9 Hz), 6.24 (d, 1H, *H*-5, J_{5-6}= 7.9 Hz), 5.84 (s, 1H, *H*-1'), 5.12 (d, 1H, *H*-3', $J_{3'-4'}$= 8.8 Hz), 4.22 (d, 1H, *H*-4, $J_{3'-4'}$= 8.7 Hz), 4.0-3.9 (m, 1H, C*H*), 3.8-3.5 (m, 2H, *H*-5', *H*-5''), 2.3-2.1 (m, 1H, C*H*), 1.16 (s, 3H, CH_3), 1.0 (m, 6H, (CH_3)$_2$CH); FAB>0 (GT) 713 $(2M+H)^+$, 449 $(M+G+H)^+$, 357 $(M+H)^+$, 246 $(S)^+$, 112 $(B+2H)^+$; FAB<0 (GT) 747 $(2M+Cl)^-$, 483 $(M+G+Cl)^-$, 391 $(M+Cl)^-$, 355 $(M-H)^-$, 116 $(Val)^-$, 110 $(B)^-$, 35 $(Cl)^-$.

Two different HPLC methods were used to analyze the above compounds. Both methods use the following reverse phase column:

Method 1

254 nm. 1.00 ml / min flow rate of an acetonitrile/ water linear gradient as described below. 20 minute run time. Five-minute equilibration between runs.

Table 1: Retention time of key intermediates:

Compound	Retention Time
Compound 10	10.2 min
Compound 11	9.4 min
Compound 12	12.9 min

Method 2:

Identification is determined at 272 nm. The column used is a Waters Novapak® C18, 3.9 x 150 mm ID, 4μm particle size, 60Å pore size or equivalent. The chromatographic conditions are as follows: injection volume = 10μl, column temperature = 25°C, flow rate = 1.00 ml / min, ultraviolet detector at 272 nm, run

time is 35 minutes. The system suitability requirement for the percent relative standard deviation for the reference standard is not more than 1.0%.

Table 2a: Purity and impurities are determined at 272 nm:

Time (minutes)	Solvent A – 20nM triethylammonium acetate buffer	Solvent B – Acetonitrile, HPLC grade.
0.00	100.0	0.0
10.00	85.0	15.0
25.00	5.0	95.0
35.0	5.0	95.0

Table 2b: Retention times of key intermediates and final drug substance:

Compound	Retention Time (minutes)
Compound mCyd	2.7 - 2.8
Compound 14	15.5
val-mCyd	9.1

Stereochemistry

It is appreciated that nucleosides of the present invention have several chiral centers and may exist in and be isolated in optically active and racemic forms. Some compounds may exhibit polymorphism. It is to be understood that the present invention encompasses any racemic, optically-active, diastereomeric, polymorphic, or stereoisomeric form, or mixtures thereof, of a compound of the invention, which possess the useful properties described herein. It being well known in the art how to prepare optically active forms (for example, by resolution of the racemic form by recrystallization techniques, by synthesis from optically-active starting materials, by chiral synthesis, or by chromatographic separation using a chiral stationary phase).

In particular, since the 1' and 4' carbons of the nucleoside are chiral, their nonhydrogen substituents (the base and the CHOR groups, respectively) can be either

cis (on the same side) or trans (on opposite sides) with respect to the sugar ring system. The four optical isomers therefore are represented by the following configurations (when orienting the sugar moiety in a horizontal plane such that the oxygen atom is in the back): cis (with both groups "up", which corresponds to the configuration of naturally occurring ß-D nucleosides), cis (with both groups "down", which is a nonnaturally occurring ß-L configuration), trans (with the C2' substituent "up" and the C4' substituent "down"), and trans (with the C2' substituent "down" and the C4' substituent "up"). The "D-nucleosides" are cis nucleosides in a natural configuration and the "L-nucleosides" are cis nucleosides in the nonnaturally occurring configuration.

Likewise, most amino acids are chiral (designated as L or D, wherein the L enantiomer is the naturally occurring configuration) and can exist as separate enantiomers.

Examples of methods to obtain optically active materials are known in the art, and include at least the following.

i) physical separation of crystals - a technique whereby macroscopic crystals of the individual enantiomers are manually separated. This technique can be used if crystals of the separate enantiomers exist, i.e., the material is a conglomerate, and the crystals are visually distinct;

ii) simultaneous crystallization - a technique whereby the individual enantiomers are separately crystallized from a solution of the racemate, possible only if the latter is a conglomerate in the solid state;

iii) enzymatic resolutions - a technique whereby partial or complete separation of a racemate by virtue of differing rates of reaction for the enantiomers with an enzyme exists;

iv) enzymatic asymmetric synthesis - a synthetic technique whereby at least one step of the synthesis uses an enzymatic reaction to obtain an enantiomerically pure or enriched synthetic precursor of the desired enantiomer;

v) chemical asymmetric synthesis - a synthetic technique whereby the desired enantiomer is synthesized from an achiral precursor

under conditions that produce asymmetry (i.e., chirality) in the product, which may be achieved using chiral catalysts or chiral auxiliaries;

vi) diastereomer separations - a technique whereby a racemic compound is reacted with an enantiomerically pure reagent (the chiral auxiliary) that converts the individual enantiomers to diastereomers. The resulting diastereomers are then separated by chromatography or crystallization by virtue of their now more distinct structural differences and the chiral auxiliary later removed to obtain the desired enantiomer;

vii) first- and second-order asymmetric transformations - a technique whereby diastereomers from the racemate equilibrate to yield a preponderance in solution of the diastereomer from the desired enantiomer or where preferential crystallization of the diastereomer from the desired enantiomer perturbs the equilibrium such that eventually in principle all the material is converted to the crystalline diastereomer from the desired enantiomer. The desired enantiomer is then released from the diastereomer;

viii) kinetic resolutions - this technique refers to the achievement of partial or complete resolution of a racemate (or of a further resolution of a partially resolved compound) by virtue of unequal reaction rates of the enantiomers with a chiral, non-racemic reagent or catalyst under kinetic conditions;

ix) enantiospecific synthesis from non-racemic precursors - a synthetic technique whereby the desired enantiomer is obtained from non-chiral starting materials and where the stereochemical integrity is not or is only minimally compromised over the course of the synthesis;

x) chiral liquid chromatography - a technique whereby the enantiomers of a racemate are separated in a liquid mobile phase by virtue of their differing interactions with a stationary phase. The stationary phase can be made of chiral material or

the mobile phase can contain an additional chiral material to provoke the differing interactions;

xi) chiral gas chromatography - a technique whereby the racemate is volatilized and enantiomers are separated by virtue of their differing interactions in the gaseous mobile phase with a column containing a fixed non-racemic chiral adsorbent phase;

xii) extraction with chiral solvents - a technique whereby the enantiomers are separated by virtue of preferential dissolution of one enantiomer into a particular chiral solvent;

xiii) transport across chiral membranes - a technique whereby a racemate is placed in contact with a thin membrane barrier. The barrier typically separates two miscible fluids, one containing the racemate, and a driving force such as concentration or pressure differential causes preferential transport across the membrane barrier. Separation occurs as a result of the non-racemic chiral nature of the membrane which allows only one enantiomer of the racemate to pass through.

III. Pharmaceutical Compositions

Hosts, including humans, infected with pestivirus, flavivirus, HCV or another organism replicating through a RNA-dependent RNA viral polymerase, or for treating any other disorder described herein, can be treated by administering to the patient an effective amount of the active compound or a pharmaceutically acceptable prodrug or salt thereof in the presence of a pharmaceutically acceptable carrier or dilutent. The active materials can be administered by any appropriate route, for example, orally, parenterally, intravenously, intradermally, subcutaneously, or topically, in liquid or solid form.

A preferred dose of the compound for pestivirus, flavivirus or HCV will be in the range from about 1 to 50 mg/kg, preferably 1 to 20 mg/kg, of body weight per day, more generally 0.1 to about 100 mg per kilogram body weight of the recipient per day. Lower doses may be preferable, for example doses of 0.5-100 mg, 0.5-50 mg, 0.5-10 mg, or 0.5-5 mg per kilogram body weight per day. Even lower doses may be useful, and thus ranges can include from 0.1-0.5 mg per kilogram body weight

per day. The effective dosage range of the pharmaceutically acceptable salts and prodrugs can be calculated based on the weight of the parent nucleoside to e delivered. If the salt or prodrug exhibits activity in itself, the effective dosage can be estimated as above using the weight of the salt or prodrug, or by other means known to those skilled in the art.

The compound is conveniently administered in unit any suitable dosage form, including but not limited to one containing 7 to 3000 mg, preferably 70 to 1400 mg of active ingredient per unit dosage form. An oral dosage of 50-1000 mg is usually convenient, including in one or multiple dosage forms of 50, 100, 200, 250, 300, 400, 500, 600, 700, 800, 900 or 1000 mgs. Lower doses may be preferable, for example from 10-100 or 1-50 mg. Also contemplated are doses of 0.1-50 mg, or 0.1-20 mg or 0.1-10.0 mg. Furthermore, lower doses may be utilized in the case of administration by a non-oral route, as, for example, by injection or inhalation.

Ideally the active ingredient should be administered to achieve peak plasma concentrations of the active compound of from about 0.2 to 70 μM, preferably about 1.0 to 10 μM. This may be achieved, for example, by the intravenous injection of a 0.1 to 5% solution of the active ingredient, optionally in saline, or administered as a bolus of the active ingredient.

The concentration of active compound in the drug composition will depend on absorption, inactivation and excretion rates of the drug as well as other factors known to those of skill in the art. It is to be noted that dosage values will also vary with the severity of the condition to be alleviated. It is to be further understood that for any particular subject, specific dosage regimens should be adjusted over time according to the individual need and the professional judgment of the person administering or supervising the administration of the compositions, and that the concentration ranges set forth herein are exemplary only and are not intended to limit the scope or practice of the claimed composition. The active ingredient may be administered at once, or may be divided into a number of smaller doses to be administered at varying intervals of time, with or without other anti-viral agents.

A preferred mode of administration of the active compound is oral. Oral compositions will generally include an inert diluent or an edible carrier. They may be enclosed in gelatin capsules or compressed into tablets. For the purpose of oral therapeutic administration, the active compound can be incorporated with excipients

and used in the form of tablets, troches, or capsules. Pharmaceutically compatible binding agents, and/or adjuvant materials can e included as part of the composition.

The tablets, pills, capsules, troches and the like can contain any of the following ingredients, or compounds of a similar nature: a binder such as microcrystalline cellulose, gum tragacanth or gelatin; an excipient such as starch or lactose, a disintegrating agent such as alginic acid, Primogel, or corn starch; a lubricant such as magnesium stearate or Sterotes; a glidant such as colloidal silicon dioxide; a sweetening agent such as sucrose or saccharin; or a flavoring agent such as peppermint, methyl salicylate, or orange flavoring. When the dosage unit form is a capsule, it can contain, in addition to material of the above type, a liquid carrier such as a fatty oil. In addition, dosage unit forms can contain various other materials which modify the physical form of the dosage unit, for example, coatings of sugar, shellac, or other enteric agents.

The compound can be administered as a component of an elixir, suspension, syrup, wafer, chewing gum or the like. A syrup may contain, in addition to the active compounds, sucrose as a sweetening agent and certain preservatives, dyes and colorings and flavors.

The compound or a pharmaceutically acceptable prodrug or salt thereof can also be mixed with other active materials that do not impair the desired action, or with materials that supplement the desired action, such as antibiotics, antifungals, anti-inflammatories, or other antivirals, including other nucleoside compounds. Solutions or suspensions used for parenteral, intradermal, subcutaneous, or topical application can include the following components: a sterile diluent such as water for injection, saline solution, fixed oils, polyethylene glycols, glycerine, propylene glycol or other synthetic solvents; antibacterial agents such as benzyl alcohol or methyl parabens; antioxidants such as ascorbic acid or sodium bisulfite; chelating agents such as ethylenediaminetetraacetic acid; buffers such as acetates, citrates or phosphates and agents for the adjustment of tonicity such as sodium chloride or dextrose. The parental preparation can be enclosed in ampoules, disposable syringes or multiple dose vials made of glass or plastic.

If administered intravenously, preferred carriers are physiological saline or phosphate buffered saline (PBS).

In a preferred embodiment, the active compounds are prepared with carriers that will protect the compound against rapid elimination from the body, such as a

controlled release formulation, including implants and microencapsulated delivery systems, biodegradable, biocompatible polymers can be used, such as ethylene vinyl acetate, polyanhydrides, polyglycolic acid, collagen, polyorthoesters and polylactic acid. Methods for preparation of such formulations will be apparent to those skilled in the art. The materials can also be obtained commercially from Alza Corporation.

Liposomal suspensions (including liposome's targeted to infected cells with monoclonal antibodies to viral antigens) are also preferred as pharmaceutically acceptable carriers. These may be prepared according to methods known to those skilled in the art, for example, as described in U.S. Patent No. 4,522,811 (which is incorporated herein by reference in its entirety). For example, liposome formulations may be prepared by dissolving appropriate lipid(s), such as sterol phosphatidyl ethanolamine, stearoyl phosphatidyl choline, arachadoyl phosphatidyl choline, and cholesterol, in an inorganic solvent that is then evaporated, leaving behind a thin film of dried lipid on the surface of the container. An aqueous solution of the active compound or its monophosphate, diphosphate, and/or triphosphate derivatives is then introduced into the container. The container is then swirled by hand to free lipid material from the sides of the container and to disperse lipid aggregates, thereby forming the liposomal suspension.

IV. Prodrugs and Derivatives

Salt Formulations

Administration of the nucleoside as a pharmaceutically acceptable salt is within the scope of the invention. Examples of pharmaceutically acceptable salts are organic acid addition salts formed with acids, which provide a physiological acceptable anion. These include, for example, tosylate, methanesulfonate, acetate, citrate, malonate, tartarate, succinate, benzoate, ascorbate, α-ketoglutarate, and α-glycerophosphate, formate, fumarate, propionate, glycolate, lactate, pyruvate, oxalate, maleate, and salicyate. Suitable inorganic salts may also be formed, including, sulfate, nitrate, bicarbonate, hydrobromate, carbonate salts, and phosphoric acid. A particularly preferred embodiment is the mono or dihydrochloride salt.

Pharmaceutically acceptable salts may be obtained using standard procedures well known in the art, for example by reacting a sufficiently basic compound such as an amine with a suitable acid affording a physiologically acceptable anion. Alkali

metal (for example, sodium, potassium or lithium) or alkaline earth metal (for example calcium) salts of carboxylic acids can also be made. In one embodiment, the salt is a hydrochloride salt of the compound. In a further embodiment, the pharmaceutically acceptable salt is a dihydrochloride salt of the compound of Formula (I). The compounds of this invention possess antiviral activity against flavivirus, pestivirus or HCV, or are metabolized to a compound that exhibits such activity.

Nucleotide Prodrugs

The nucleosides described herein can be administered as a nucleotide prodrug to increase the activity, bioavailability, stability or otherwise alter the properties of the nucleoside. A number of nucleotide prodrug ligands are known. In general, alkylation, acylation or other lipophilic modification of the mono-, di- or triphosphate of the nucleoside reduces polarity and allows passage into cells. Examples of substituent groups that can replace one or more hydrogens on the phosphate moiety are alkyl, aryl, steroids, carbohydrates, including sugars, and alcohols, such as 1,2-diacylglycerol. Many are described in R. Jones and N. Bischoferger, *Antiviral Research*, 1995, *27*:1-17. Any of these can be used in combination with the disclosed nucleosides to achieve a desired effect.

The active nucleoside can also be provided as a 5'-phosphoether lipid or a 5'-ether lipid. Non-limiting examples are disclosed in the following references, which are incorporated by reference herein: Kucera, L.S., N. Iyer, E. Leake, A. Raen, Modest E.K., D.L.W., and C. Piantadosi. 1990. "Novel membrane-interactive ether lipid analogs that inhibit infectious HIV-1 production and induce defective virus formation." *AIDS Res. Hum. Retro Viruses.* 6:491-501; Piantadosi, C., J. Marasco C.J., S.L. Morris-Natschke, K.L. Meyer, F. Gumus, J.R. Surles, K.S. Ishaq, L.S. Kucera, N. Iyer, C.A. Wallen, S. Piantadosi, and E.J. Modest. 1991. "Synthesis and evaluation of novel ether lipid nucleoside conjugates for anti-HIV activity." *J. Med. Chem.* 34:1408.1414; Hosteller, K.Y., D.D. Richman, D.A. Carson, L.M. Stuhmiller, G.M. T. van Wijk, and H. van den Bosch., 1992. "Greatly enhanced inhibition of human immunodeficiency virus type 1 replication in CEM and HT4-6C cells by 3'-deoxythymidine diphosphate dimyristoylglycerol, a lipid prodrug of 3-deoxythymidine." *Antimicro. Agents Chemother.* 36:2025.2029; Hosetler, K.Y., L.M. Stuhmiller, H.. Lenting, H. van den Bosch, and D.D. Richman, 1990.

"Synthesis and antiretroviral activity of phospholipid analogs of azidothymidine and other antiviral nucleosides." *J. Biol. Chem.* 265:61127.

Nonlimiting examples of U.S. patents that disclose suitable lipophilic substituents that can be covalently incorporated into the nucleoside, preferably at the 5'-OH position of the nucleoside or lipophilic preparations thereof, include U.S. Patent Nos. 5,149,794 (Sep. 22, 1992, Yatvin *et al.*); 5,194,654 (Mar. 16, 1993, Hostetler *et al.*, 5,223,263 (June 29, 1993, Hostetler *et al.*); 5,256,641 (Oct. 26, 1993, Yatvin *et al.*); 5,411,947 (May 2, 1995, Hostetler *et al.*); 5,463,092 (Oct. 31, 1995, Hostetler *et al.*); 5,543,389 (Aug. 6, 1996, Yatvin *et al.*); 5,543,390 (Aug. 6, 1996, Yatvin *et al.*); 5,543,391 (Aug. 6, 1996, Yatvin *et al.*); and 5,554,728 (Sep. 10, 1996; Basava *et al.*), all of which are incorporated herein by reference. Foreign patent applications that disclose lipophilic substituents that can be attached to the nucleosides of the present invention, or lipophilic preparations, include WO 89/02733, W0 90/00555, W0 91/16920, W0 91/18914, W0 93/00910, W0 94/26273, W0 96/15132, EP 0 350 287, EP 93917054.4, and W0 91/19721.

V. Combination or Alternation Therapy

The active compounds of the present invention can be administered in combination or alternation with another anti-flavivirus or pestivirus agent, or in particular an anti-HCV agent. In combination therapy, effective dosages of two or more agents are administered together, whereas in alternation or sequential-step therapy, an effective dosage of each agent is administered serially or sequentially. The dosages given will depend on absorption, inactivation and excretion rates of the drug as well as other factors known to those of skill in the art. It is to be noted that dosage values will also vary with the severity of the condition to be alleviated. It is to be further understood that for any particular subject, specific dosage regimens and schedules should be adjusted over time according to the individual need and the professional judgment of the person administering or supervising the administration of the compositions. In preferred embodiments, an anti-HCV (or anti-pestivirus or anti-flavivirus) compound that exhibits an EC_{50} of 10-15 μM, or preferably less than 1-5 μM, is desirable.

It has been recognized that drug-resistant variants of flaviviruses, pestiviruses or HCV can emerge after prolonged treatment with an antiviral agent. Drug

resistance most typically occurs by mutation of a gene that encodes for an enzyme used in viral replication. The efficacy of a drug against the viral infection can be prolonged, augmented, or restored by administering the compound in combination or alternation with a second, and perhaps third, antiviral compound that induces a different mutation from that caused by the principle drug. Alternatively, the pharmacokinetics, biodistribution or other parameters of the drug can be altered by such combination or alternation therapy. In general, combination therapy is typically preferred over alternation therapy because it induces multiple simultaneous stresses on the virus.

Any of the viral treatments described in the Background of the Invention can be used in combination or alternation with the compounds described in this specification. Nonlimiting examples include:

(1) Protease inhibitors

Examples include substrate-based NS3 protease inhibitors (Attwood *et al.*, *Antiviral peptide derivatives*, PCT WO 98/22496, **1998**; Attwood *et al.*, *Antiviral Chemistry and Chemotherapy* **1999**, *10*, 259-273; Attwood *et al., Preparation and use of amino acid derivatives as anti-viral agents,* German Patent Pub. DE 19914474; Tung *et al. Inhibitors of serine proteases, particularly hepatitis C virus NS3 protease*, PCT WO 98/17679), including alphaketoamides and hydrazinoureas, and inhibitors that terminate in an electrophile such as a boronic acid or phosphonate (Llinas-Brunet et al, *Hepatitis C inhibitor peptide analogues,* PCT WO 99/07734); Non-substrate-based NS3 protease inhibitors such as 2,4,6-trihydroxy-3-nitro-benzamide derivatives (Sudo K. *et al.*, *Biochemical and Biophysical Research Communications*, **1997**, *238*, 643-647; Sudo K. *et al. Antiviral Chemistry and Chemotherapy*, **1998**, *9*, 186), including RD3-4082 and RD3-4078, the former substituted on the amide with a 14 carbon chain and the latter processing a *para*-phenoxyphenyl group; and Sch 68631, a phenanthrenequinone, an HCV protease inhibitor (Chu M. *et al.*, *Tetrahedron Letters* 37:7229-7232, 1996).

Sch 351633, isolated from the fungus *Penicillium griseofulvum* , was identified as a protease inhibitor (Chu M. *et al.*, *Bioorganic and Medicinal Chemistry Letters* 9:1949-1952). Eglin c, isolated from leech, is a potent inhibitor of several

serine proteases such as S. griseus proteases A and B, α-chymotrypsin, chymase and subtilisin. Qasim M.A. *et al.*, *Biochemistry* 36:1598-1607, 1997.

U.S. patents disclosing protease inhibitors for the treatment of HCV include, for example, U.S. Patent No. 6,004,933 to Spruce *et al.* which discloses a class of cysteine protease inhibitors for inhibiting HCV endopeptidase 2; U.S. Patent No. 5,990,276 to Zhang *et al.* which discloses synthetic inhibitors of hepatitis C virus NS3 protease; U.S. Patent No. 5,538,865 to Reyes *et a;* WO 02/008251 to Corvas International, Inc, and WO 02/08187 and WO 02/008256 to Schering Corporation. HCV inhibitor tripeptides are disclosed in US Patent Nos. 6,534,523, 6,410,531, and 6,420,380 to Boehringer Ingelheim and WO 02/060926 to Bristol Myers Squibb. Diaryl peptides as NS3 serine protease inhibitors of HCV are disclosed in WO 02/48172 to Schering Corporation. Imidazolidindiones as NS3 serine protease inhibitors of HCV are disclosed in WO 02/08198 to Schering Corporation and WO 02/48157 to Bristol Myers Squibb. WO 98/17679 to Vertex Pharmaceuticals and WO 02/48116 to Bristol Myers Squibb also disclose HCV protease inhibitors.

(2) Thiazolidine derivatives which show relevant inhibition in a reverse-phase HPLC assay with an NS3/4A fusion protein and NS5A/5B substrate (Sudo K. *et al., Antiviral Research*, **1996**, *32*, 9-18), especially compound RD-1-6250, possessing a fused cinnamoyl moiety substituted with a long alkyl chain, RD4 6205 and RD4 6193;

(3) Thiazolidines and benzanilides identified in Kakiuchi N. *et al. J. EBS Letters 421*, 217-220; Takeshita N. *et al. Analytical Biochemistry*, **1997**, *247*, 242-246;

(4) A phenan-threnequinone possessing activity against protease in a SDS-PAGE and autoradiography assay isolated from the fermentation culture broth of *Streptomyces* sp., Sch 68631 (Chu M. *et al., Tetrahedron Letters*, **1996**, *37*, 7229-7232), and Sch 351633, isolated from the fungus *Penicillium griseofulvum* , which demonstrates activity in a scintillation proximity assay (Chu M. *et al., Bioorganic and Medicinal Chemistry Letters 9*, 1949-1952);

(5) Helicase inhibitors (Diana G.D. *et al.*, *Compounds, compositions and methods for treatment of hepatitis C*, U.S. Pat. No. 5,633,358; Diana G.D. *et al.*, *Piperidine derivatives, pharmaceutical compositions thereof and their use in the treatment of hepatitis C*, PCT WO 97/36554);

(6) Nucleotide polymerase inhibitors and gliotoxin (Ferrari R. *et al. Journal of Virology*, **1999**, *73*, 1649-1654), and the natural product cerulenin (Lohmann V. *et al.*, *Virology*, **1998**, *249*, 108-118);

(7) Antisense phosphorothioate oligodeoxynucleotides (S-ODN) complementary to sequence stretches in the 5' non-coding region (NCR) of the virus (Alt M. *et al.*, *Hepatology*, **1995**, *22*, 707-717), or nucleotides 326-348 comprising the 3' end of the NCR and nucleotides 371-388 located in the core coding region of the HCV RNA (Alt M. *et al.*, *Archives of Virology*, **1997**, *142*, 589-599; Galderisi U. *et al.*, *Journal of Cellular Physiology*, **1999**, *181*, 251-257);

(8) Inhibitors of IRES-dependent translation (Ikeda N *et al.*, *Agent for the prevention and treatment of hepatitis C,* Japanese Patent Pub. JP-08268890; Kai Y. *et al. Prevention and treatment of viral diseases*, Japanese Patent Pub. JP-10101591);

(9) Ribozymes, such as nuclease-resistant ribozymes (Maccjak, D. J. *et al.*, *Hepatology* **1999**, *30*, abstract 995) and those disclosed in U.S. Patent No. 6,043,077 to Barber *et al.*, and U.S. Patent Nos. 5,869,253 and 5,610,054 to Draper *et al.*; and

(10) Nucleoside analogs have also been developed for the treatment of Flaviviridae infections.

(11) Any of the compounds described by Idenix Pharmaceuticals in International Publication Nos. WO 01/90121 and WO 01/92282;

(12) Other patent applications disclosing the use of certain nucleoside analogs to treat hepatitis C virus include: PCT/CA00/01316 (WO 01/32153; filed November 3, 2000) and PCT/CA01/00197 (WO 01/60315; filed February 19, 2001) filed by BioChem Pharma, Inc. (now Shire Biochem, Inc.); PCT/US02/01531 (WO 02/057425; filed January 18, 2002) and PCT/US02/03086 (WO 02/057287; filed January 18, 2002) filed by Merck & Co., Inc., PCT/EP01/09633 (WO 02/18404; published August 21, 2001) filed by Roche, and PCT Publication Nos. WO 01/79246 (filed April 13, 2001), WO 02/32920 (filed October 18, 2001) and WO 02/48165 by Pharmasset, Ltd.

(13) PCT Publication No. WO 99/43691 to Emory University, entitled "2'-Fluoronucleosides" discloses the use of certain 2'-fluoronucleosides to treat HCV.

(14) Other miscellaneous compounds including 1-amino-alkylcyclohexanes (U.S. Patent No. 6,034,134 to Gold *et al.*), alkyl lipids (U.S. Pat. No. 5,922,757 to Chojkier *et al.*), vitamin E and other antioxidants (U.S. Pat. No. 5,922,757 to Chojkier *et al.*), squalene, amantadine, bile acids (U.S. Pat. No. 5,846,964 to Ozeki *et al.*), N-(phosphonoacetyl)-L-aspartic acid, (U.S. Pat. No. 5,830,905 to Diana *et al.*), benzenedicarboxamides (U.S. Pat. No. 5,633,388 to Diana *et al.*), polyadenylic acid derivatives (U.S. Pat. No. 5,496,546 to Wang *et al.*), 2',3'-dideoxyinosine (U.S. Pat. No. 5,026,687 to Yarchoan *et al.*), benzimidazoles (U.S. Pat. No. 5,891,874 to Colacino *et al.*), plant extracts (U.S. Patent No. 5,837,257 to Tsai *et al.*, U.S. Patent No. 5,725,859 to Omer *et al.*, and U.S. Patent No. 6,056,961), and piperadines (U.S. Patent No. 5,830,905 to Diana *et al.*).

(15) Any other compound currently in preclinical or clinical development for treatment of hepatitis C virus including: Interleukin-10 by Schering-Plough, IP-501 by Interneuron, Merimebodib (VX-497) by Vertex, AMANTADINE® (Symmetrel) by Endo Labs Solvay, HEPTAZYME® by RPI, IDN-6556 by Idun Pharma., XTL-002 by XTL., HCV/MF59 by Chiron, CIVACIR (Hepatitis C Immune Globulin) by NABI, LEVOVIRIN® by ICN/Ribapharm, VIRAMIDINE® by ICN/Ribapharm, ZADAXIN® (thymosin alpha-1) by Sci Clone, thymosin plus pegylated interferon by Sci Clone, CEPLENE® (histamine dihydrochloride) by Maxim, VX 950 / LY 570310 by Vertex/Eli Lilly, ISIS 14803 by Isis Pharmaceutical/Elan, IDN-6556 by Idun Pharmaceuticals, Inc., JTK 003 by AKROS Pharma, BILN-2061 by Boehringer Ingelheim, CellCept (mycophenolate mofetil) by Roche, T67, a β-tubulin inhibitor, by Tularik, a therapeutic vaccine directed to E2 by Innogenetics, FK788 by Fujisawa Healthcare, Inc., IdB 1016 (Siliphos, oral silybin-phosphatdylcholine phytosome), RNA replication inhibitors (VP50406) by ViroPharma/Wyeth, therapeutic vaccine by Intercell, therapeutic vaccine by Epimmune/Genencor, IRES inhibitor by Anadys, ANA 245 and ANA 246 by Anadys, immunotherapy (Therapore) by Avant, protease inhibitor by Corvas/SChering, helicase inhibitor by Vertex, fusion inhibitor by Trimeris, T cell therapy by CellExSys, polymerase inhibitor by Biocryst, targeted RNA chemistry by PTC Therapeutics, Dication by Immtech, Int., protease inhibitor by Agouron, protease inhibitor by Chiron/Medivir, antisense therapy by AVI BioPharma, antisense therapy by Hybridon, hemopurifier by Aethlon Medical, therapeutic vaccine by Merix, protease inhibitor by Bristol-Myers Squibb/Axys, Chron-VacC, a therapeutic vaccine, by Tripep, UT 231B by United Therapeutics, protease, helicase and polymerase inhibitors by Genelabs Technologies, IRES inhibitors by Immusol, R803 by Rigel Pharmaceuticals, INFERGEN® (interferon alphacon-1) by InterMune, OMNIFERON® (natural interferon) by Viragen, ALBUFERON® by Human Genome Sciences, REBIF (interferon

beta-1a) by Ares-Serono, Omega Interferon by BioMedicine, Oral Interferon Alpha by Amarillo Biosciences, interferon gamma, interferon tau, and Interferon gamma- 1b by InterMune.

V. Biological Data

Cell culture systems for determining antiviral activities

A useful cell-based assay to detect HCV and its inhibition assesses the levels of replicon RNA from Huh7 cells harboring the HCV replicon. These cells can be cultivated in standard media, for example DMEM medium (high glucose, no pyruvate), supplemented with 10% fetal bovine serum, 1× non-essential amino acids, Pen-Strep-Glu (100 units/liter, 100 microgram/liter, and 2.92 mg/liter, respectively), and G418 ($C_{20}H_{40}N_4O_{10}$; 500 to 1000 microgram/milliliter). Antiviral screening assays can be done in the same medium without G418. To keep the cells in the logarithmic growth phase, cells are seeded in 96-well plates at low density (for example, 1000 cells per well). The test compound is then added immediately after seeding the cells and they are incubated for 3 to 7 days at 37°C in an incubator. The medium is then removed, and the cells prepared for total RNA extraction (replicon RNA + host RNA). Replicon RNA can then be amplified in a real-time RT-PCR (Q-RT-PCR) protocol, and quantified.

The observed differences in quantification of replicon RNA are one way to express the antiviral potency of the test compound. In a typical experiment, a comparable amount of replicon is produced in the negative control and with non-active compounds. This can be concluded if the measured threshold-cycle for HCV RT-PCR in both setting is approximately the same. In such experiments, a way to express the antiviral effectiveness of a compound is to subtract the average threshold RT-PCR cycle of the negative control ($Ct_{negative}$) from the threshold RT-PCR cycle of the test compound ($Ct_{testcompound}$). This value is called ΔCt ($\Delta Ct = Ct_{testcompound} - Ct_{negative}$). A ΔCt value of 3.3 represents a 1-log reduction in replicon production. As a positive control, recombinant interferon alpha-2a (for example, Roferon-A, Hoffmann-Roche, NJ, USA) can be used alongside the test compound. Furthermore, the compounds can be tested in dilution series (typically at 100, 33, 10, 3 and 1 μM).

The ΔCt values for each concentration allow the calculation of the 50% effective concentration (EC_{50}).

The assay described above can be adapted to the other members of the *Flaviviridae* by changing the cell system and the viral pathogen. Methodologies to determine the efficacy of these antiviral compounds include modifications of the standard techniques as described by Holbrook MR *et al.* Virus Res. **2000**, *69*, 31; Markland W et al. Antimicrob. Agents. Chemother. **2000**, *44*, 859; Diamond MS et al., J. Virol. **2000**, *74*, 7814; Jordan I *et al.* J. Infect. Dis. **2000**, *182*, 1214; Sreenivasan V *et al.* J. Virol. Methods **1993**, *45* (1), 1; or Baginski SG *et al.* Proc. Natl. Acad. Sci. U.S.A. **2000,** *97* (14), 7981 or the real-time RT-PCR technology. As an example, an HCV replicon system in HuH7 cells (Lohmann V *et al.* Science, **1999**, *285* (5424), 110) or modifications thereof (Blight et *al.* **2000)** can be used.

Non-cell based assays adapted for detecting HCV

Nucleic acid amplification technology is now the method of choice for identification of a large and still growing number of microorganisms such as *Mycobacterium tuberculosis*, human immunodeficiency virus (HIV), and hepatitis C virus (HCV) in biological samples. Nucleic acid amplification techniques include the polymerase chain reaction (PCR), ligase chain reaction (LCR), nucleic acid sequence-based amplification (NASBA), strand-displacement amplification (SDA), and transcription-mediated amplification (TMA). Several FDA-approved diagnostic products incorporate these molecular diagnostic methods (see Table below). Nucleic acid amplification technology tests involve not only amplification, but detection methodologies as well. The promise of molecular diagnostics lies in the improvement of its specimen-processing, amplification, and target-detection steps, and in the integration of these steps into an automated format.

FDA- Approved Assays	Amplification Product: Detection Method	Nucleic Acid Amplification Method	Commercial Source
C. trachomatis,N. gonorrhoeae,M. tuberculosis,HIV-1	Heterogeneous: Colorimetric	PCR	Roche Diagnostics
C. trachomatis, N. gonorrhoeae	Heterogeneous: Chemiluminescence	LCR	Abbott Laboratories
C. trachomatis, N. gonorrhoeae	Homogeneous: Fluorescence	SDA	Becton Dickinson
C. trachomatis, M. tuberculosis	Homogeneous: Chemiluminescence (HPA)	TMA	Gen-Probe

Amplified-product detection schemes

Amplified-product detection schemes are of two basic types: heterogeneous and homogeneous. Heterogeneous detection is characterized by a distinct step, such as washing, designed to remove unhybridized probes from hybridized probes, whereas in homogeneous detection there is no physical separation step to remove free probe from bound probe. Multiple heterogeneous and homogeneous detection methods exist. Any of these heterogeneous or homogeneous assays can be utilized to assess the effectiveness of the compounds of the present invention versus an RNA-dependent RNA polymerase virus, such as HCV.

Heterogeneous Detection: Southern blotting, for example, is a heterogeneous detection technique. In Southern blotting, electrophoresis is used to separate amplification products by size and charge. The size-fractionated products are transferred to a membrane or filter by diffusion, vacuuming, or electroblotting. Labeled detection probes are then hybridized to the membrane-bound targets in solution, the filters are washed to remove any unhybridized probe, and the hybridized probe on the membrane is detected by any of a variety of methods.

Other types of heterogeneous detection are based on specific capture of the amplification products by means of enzyme-linked immunosorbent assays (ELISAs). One method used with PCR involves labeling one primer with a hapten or a ligand, such as biotin, and, after amplification, capturing it with an antibody- or streptavidin-coated microplate. The other primer is labeled with a reporter such as fluorescein, and detection is achieved by adding an antifluorescein antibody, horseradish peroxidase

(HRP) conjugate. This type of method is not as specific as using detection probes that hybridize to defined amplification products of interest.

The LCx probe system (Abbott Laboratories; Abbott Park, IL) and the Amplicor HIV-1 test (Roche Molecular Systems Inc.; Pleasanton, CA) are systems that use heterogeneous detection methods. In the LCx system, hapten-labeled oligonucleotide probes thermocycle in the ligase chain reaction. Either a capture hapten or a detection hapten is covalently attached to each of the four primer oligonucleotides. Upon amplification, each amplified product (amplicon) has one capture hapten and one detection hapten. When amplification is complete, the LCx system instrument transfers the reaction to a new well where antibody-coated microparticles bind the capture haptens. Each microparticle is then irreversibly bound to a glass-fiber matrix. A wash step removes from the microparticle any probe that contains only the detection hapten. The LCx instrument adds an alkaline phosphatase (AP)–antibody conjugate that binds to the detection hapten. A fluorigenic substrate for AP is 4-methylumbelliferyl. Dephosphorylation of 4-methylumbelliferyl by AP converts it to 4-methylumbelliferone, which is fluorescent.

The Amplicor HIV-1 test uses an ELISA format. After amplification by PCR, the amplicon is chemically denatured. Amplicon-specific oligonucleotide probes capture the denatured strands onto a coated microplate. The operator washes away any unincorporated primers and unhybridized material in a wash step and then adds an avidin-HRP conjugate to each well. The conjugate binds to the biotin-labeled amplicon captured on the plate. The operator then adds 3,3',5,5'-tetramethylbenzidine (TMB), a chromogenic HRP substrate. When hydrogen peroxide is present, HRP oxidizes TMB. The signal is determined colorimetrically.

Homogeneous Detection: Because hybridized and nonhybridized detection probes are not physically separated in homogeneous detection systems, these methods require fewer steps than heterogeneous methods and thus are less prone to contamination. Among the commercially available kits that use homogeneous detection of fluorescent and chemiluminescent labels are the TaqMan system (Applied Biosystems; Foster City, CA), BDProbeTecET system (Becton Dickinson; Franklin Lakes, NJ), QPCR System 5000 (Perkin-Elmer Corp.; Norwalk, CT), and Hybridization Protection Assay (Gen-Probe Inc.; San Diego).

The TaqMan system detects amplicon in real time. The detection probe, which hybridizes to a region inside the amplicon, contains a donor fluorophore such as

fluoroscein at its 5' end and a quencher moiety, for example, rhodamine, at its 3' end. When both quencher and fluorophore are on the same oligonucleotide, donor fluorescence is inhibited. During amplification the probe is bound to the target. Taq polymerase displaces and cleaves the detection probe as it synthesizes the replacement strand. Cleavage of the detection probe results in separation of the fluorophore from the quencher, leading to an increase in the donor fluorescence signal. During each cycle of amplification the process is repeated. The amount of fluorescent signal increases as the amount of amplicon increases.

Molecular beacons use quenchers and fluorophores also. Beacons are probes that are complementary to the target amplicon, but contain short stretches (approximately 5 nucleotides) of complementary oligonucleotides at each end. The 5' and 3' ends of the beacons are labeled with a fluorophore and a quencher, respectively. A hairpin structure is formed when the beacon is not hybridized to a target, bringing into contact the fluorophore and the quencher and resulting in fluorescent quenching. The loop region contains the region complementary to the amplicon. Upon hybridization to a target, the hairpin structure opens and the quencher and fluorophore separate, allowing development of a fluorescent signal.[14] A fluorometer measures the signal in real time.

The BDProbeTecET system uses a real-time detection method that combines aspects of TaqMan and molecular beacons. The probe has a hairpin loop structure and contains fluorescein and rhodamine labels. In this system, however, the region complementary to the target molecule is not within the loop but rather in the region 3' to the rhodamine label. Instead of containing the sequence complementary to the target, the single-stranded loop contains a restriction site for the restriction enzyme BsoBI. The single-stranded sequence is not a substrate for the enzyme. The fluorescein and rhodamine labels are near each other before amplification, which quenches the fluorescein fluorescence. Strand-displacement amplification converts the probe into a double-stranded molecule. The BsoBI restriction enzyme can then cleave the molecule, resulting in separation of the labels and an increase in the fluorescent signal.

The QPCR System 5000 employs electrochemiluminescence with ruthenium labels. A biotinylated primer is used. After amplification, the biotin products are captured on streptavidin-coated paramagnetic beads. The beads are transferred into an

electrochemical flow cell by aspiration and magnetically held to the surface of the electrode. Upon electrical stimulation, the ruthenium-labeled probe emits light.

The Hybridization Protection Assay is used in Gen-Probe's nonamplified PACE assays as well as in amplified *Mycobacterium tuberculosis* and *Chlamydia trachomatis* assays. The detection oligonucleotide probes in HPA are labeled with chemiluminescent acridinium ester (AE) by means of a linker arm. Hybridization takes place for 15 minutes at 60°C in the same tube in which the amplification occurred. The selection reagent, a mildly basic buffered solution added after hybridization, hydrolyzes the AE on any unhybridized probe, rendering it nonchemiluminescent. The AE on hybridized probes folds inside the minor groove of the double helix, thereby protecting itself from hydrolysis by the selection reagent. The AE emits a chemiluminescent signal upon hydrolysis by hydrogen peroxide followed by sodium hydroxide. A luminometer records the chemiluminescent signal for 2 seconds (a period termed a light-off) and reports the photons emitted in terms of relative light units (RLU).

Detection-probe design is critical in all methodologies that use probes to detect amplification products. Good detection probes hybridize only to specified amplification product and do not hybridize to nonspecific products. Other key issues in optimizing detection methodologies involve the labeling of probes and the maximization of sample throughput.

Labeling Methods and Reporter Molecules. Detection probes can be labeled several different ways. Enzymatic incorporation of ^{32}P or ^{35}S into the probes is the most common method for isotopic labeling. Following hybridization and washing, the signal is detected on autoradiographic film.

To perform nonradioactive detection, probes can be enzymatically labeled with a variety of molecules. Biotin can be incorporated enzymatically and then detected with streptavidin-conjugated alkaline phosphatase, using AP substrates like 5-bromo-4-chloro-3-indolyl phosphate (BCIP) and nitroblue tetrazolium (NBT). Chemiluminescent substrates such as Lumi-Phos 530 or Lumi-Phos Plus (Lumigen, Southfield, MI) can also be used with AP. In addition, digoxigenin-11-dUTP can be incorporated enzymatically into DNA or RNA, and antidigoxigenin AP conjugates can be used with colorimetric or chemiluminescent detection.

There are numerous other types of reporter molecules, including chemiluminescent moieties such as acridinium esters. Many fluorescent moieties are

available as well. Electrochemiluminescent compounds such as tris (2,2'-bipyridine) ruthenium (II) can be used also. Further discussions of these and similar techniques can be found in: Schiff ER, de Medina M, Kahn RS. *Semin Liver Dis.* **1999**;19(Suppl 1:3-15).

EXAMPLE 3: CELLULAR PHARMACOLOGY OF 2'-C-METHYL-CYTIDINE- 3'-O-L-VALINE ESTER (VAL-mCyd)

Phosphorylation Assay of Nucleoside to Active Triphosphate

To determine the cellular metabolism of the compounds, HepG2 cells are obtained from the American Type Culture Collection (Rockville, MD), and are grown in 225 cm^2 tissue culture flasks in minimal essential medium supplemented with non-essential amino acids, 1% penicillin-streptomycin. The medium is renewed every three days, and the cells are subcultured once a week. After detachment of the adherent monolayer with a 10 minute exposure to 30 mL of trypsin-EDTA and three consecutive washes with medium, confluent HepG2 cells are seeded at a density of 2.5 x 10^6 cells per well in a 6-well plate and exposed to 10 μM of [^{3}H] labeled active compound (500 dpm/pmol) for the specified time periods. The cells are maintained at 37°C under a 5% CO_2 atmosphere. At the selected time points, the cells are washed three times with ice-cold phosphate-buffered saline (PBS). Intracellular active compound and its respective metabolites are extracted by incubating the cell pellet overnight at –20°C with 60% methanol followed by extraction with an additional 20 μL of cold methanol for one hour in an ice bath. The extracts are then combined, dried under gentle filtered air flow and stored at –20°C until HPLC analysis.

Antiviral nucleosides and nucleoside analogs are generally converted into the active metabolite, the 5'-triphosphate (TP) derivatives by intracellular kinases. The nucleoside-TPs then exert their antiviral effect by inhibiting the viral polymerase during virus replication. In primary human hepatocyte cultures, in a human hepatoma cell line (HepG2), and in a bovine kidney cell line (MDBK), mCyd was converted into a major metabolite, 2'-C-methyl-cytidine-5'- triphosphate (mCyd-TP), along with smaller amounts of a uridine 5'-triphosphate derivative, 2'-C-methyl-uridine-5'-triphosphate (mUrd-TP). mCyd-TP is inhibitory when tested *in vitro* against the

BVDV replication enzyme, the NS5B RNA dependent RNA polymerase, and was thought to be responsible for the antiviral activity of mCyd.

The cellular metabolism of mCyd was examined using MDBK cells, HepG2 cells and human primary hepatocytes exposed to 10 μM [^{3}H]-mCyd. High-pressure liquid chromatography (HPLC) analysis demonstrated that mCyd was phosphorylated in all three cell types, with mCyd-TP being the predominant metabolite after 24 h. The metabolic profile obtained over a 48-hour exposure of human hepatoma HepG2 cells to 10 μM [^{3}H]-mCyd was tested. In HepG2 cells, levels of mCyd-TP peaked at 41.5 ± 13.4 μM after 24 hours (see Table 3) and fell slowly thereafter. In primary human hepatocytes, the peak mCyd-TP concentration at 24 hours was 4 fold lower at 10.7 ± 6.7 μM. MDBK bovine kidney cells yielded intermediate levels of mCyd-TP (30.1 ± 6.9 μM at 24 hours).

Exposure of hepatocytes to mCyd led to production of a second 5'-triphosphate derivative, mUrd-TP. In HepG2 cells exposed to 10 μM [^{3}H]-mCyd, the mUrd-TP level reached 1.9 ± 1.6 μM at 24 hours, compared to 8.1 ± 3.4 μM in MDBK cells and 3.2 ± 2.0 μM in primary human hepatocytes. While MDBK and HepG2 cells produced comparable total amounts of phosphorylated species (approximately 43 versus 47 μM, respectively) at 24h, mUrd-TP comprised 19% of the total product in MDBK cells versus only 4% in HepG2 cells. mUrd-TP concentration increased steadily over time, however reached a plateau or declined after 24 hours.

Table 3: Activation of mCyd (10 μM) in Hepatocytes and MDBK Cells

		Metabolite (μM)					
Cells[a]	n	mCyd-MP	mUrd-MP	mCyd-DP	mUrd-DP	mCyd-TP	mUrd-TP
HepG2	6	ND	ND	3.7 ± 2.1	ND	41.5 ± 13.4	1.9 ± 1.6
Human Primary Hepatocytes	5	ND	ND	1.15 ± 1.1	0.26 ± 0.4 C	10.7 ± 6.7	3.2 ± 2.0
MDBK Bovine Kidney Cells	7	ND	ND	4.2 ± 2.7	0.76 ± 0.95	30.1 ± 6.9	8.1 ± 3.4

a. Cells were incubated for 24 hours with [^{3}H]-mCyd, specific activity: HepG2 assay = 0.5 Ci/mmol; human and monkey hepatocyte assay = 1.0 Ci/mmol.

b. The concentrations of metabolites were determined as pmoles per million cells. One pmole per million cells is roughly equivalent to 1 μM.

ND, not detected.

The apparent intracellular half-life of the mCyd-TP was 13.9 ± 2.2 hours in HepG2 cells and 7.6 ± 0.6 hours in MDBK cells: the data were not suitable for calculating the half life of mUrd-TP. Other than the specific differences noted above, the phosphorylation pattern detected in primary human hepatocytes was qualitatively similar to that obtained using HepG2 or MDBK cells.

EXAMPLE 4: CELL CYTOTOXICITY

Mitochondria Toxicity Assay

HepG2 cells were cultured in 12-well plates as described above and exposed to various concentrations of drugs as taught by Pan-Zhou X-R, Cui L, Zhou X-J, Sommadossi J-P, Darley-Usmer VM. "Differential effects of antiretroviral nucleoside analogs on mitochondrial function in HepG2 cells" *Antimicrob. Agents Chemother.* 2000; 44:496-503. Lactic acid levels in the culture medium after 4 day drug exposure were measured using a Boehringer lactic acid assay kit. Lactic acid levels were normalized by cell number as measured by hemocytometer count.

Cytotoxicity Assays

Cells were seeded at a rate of between 5 x 10^3 and 5 x 10^4/well into 96-well plates in growth medium overnight at 37°C in a humidified CO_2 (5%) atmosphere. New growth medium containing serial dilutions of the drugs was then added. After incubation for 4 days, cultures were fixed in 50% TCA and stained with sulforhodamineB. The optical density was read at 550 nm. The cytotoxic concentration was expressed as the concentration required to reduce the cell number by 50% (CC_{50}).

Conventional cell proliferation assays were used to assess the cytotoxicity of mCyd and its cellular metabolites in rapidly dividing cells. The inhibitory effect of mCyd was determined to be cytostatic in nature since mCyd showed no toxicity in confluent cells at concentrations far in excess of the corresponding CC_{50} for a specific cell line. mCyd was not cytotoxic to rapidly growing Huh7 human hepatoma cells or H9c2 rat myocardial cells at the highest concentration tested (CC_{50} >250 μM). The mCyd CC_{50} values were 132 and 161 μM in BHK-21 hamster kidney and HepG2 human hepatoma cell lines, respectively. The CC_{50} for mCyd in HepG2 cells increased to 200 μM when the cells were grown on collagen-coated plates for 4 or 10

days. For comparison, CC_{50} values of 35-36 μM were derived when ribavirin was tested in HepG2 and Huh7 cells. In the MDBK bovine kidney cells used for BVDV antiviral studies, the CC_{50} of mCyd was 36 μM. A similar CC_{50} value (34 μM) was determined for mCyd against MT-4 human T-lymphocyte cells. In addition, mCyd was mostly either non-cytotoxic or weakly cytotoxic (CC_{50} >50 to >200 μM) to numerous other cell lines of human and other mammalian origin, including several human carcinoma cell lines, in testing conducted by the National Institutes of Health (NIH) Antiviral Research and Antimicrobial Chemistry Program. Exceptions to this were rapidly proliferating HFF human foreskin fibroblasts and MEF mouse embryo fibroblasts, where mCyd showed greater cytotoxicity (CC_{50}s 16.9 and 2.4 μM, respectively). Again, mCyd was much less toxic to stationary phase fibroblasts.

The cytotoxic effect of increasing amounts of mCyd on cellular DNA or RNA synthesis was examined in HepG2 cells exposed to [^{3}H]-thymidine or [^{3}H]-uridine. In HepG2 cells, the CC_{50}s of mCyd required to cause 50% reductions in the incorporation of radiolabeled thymidine and uridine into cellular DNA and RNA, were 112 and 186 μM, respectively. The CC_{50} values determined for ribavirin (RBV) for DNA and RNA synthesis, respectively, were 3.16 and 6.85 μM. These values generally reflect the CC_{50}s of 161 and 36 μM determined for mCyd and RBV, respectively, in conventional cell proliferation cytotoxicity assays. To assess the incorporation of mCyd into cellular RNA and DNA, HepG2 cells were exposed to 10 μM [^{3}H]-mCyd or control nucleosides (specific activity 5.6 – 8.0 Ci/mmole, labeled in the base) for 30 hours. Labeled cellular RNA or DNA species were separately isolated and incorporation was determined by scintillation counting. Exposure of HepG2 cells to mCyd resulted in very low levels of incorporation of the ribonucleoside analog into either cellular DNA or RNA (0.0013 - 0.0014 pmole/μg of nucleic acid). These levels are similar to the 0.0009 and 0.0013 pmole/μg values determined for the incorporation of ZDV and ddC, respectively, into RNA: since these deoxynucleosides are not expected to incorporate into RNA, these levels likely reflect the assay background. The incorporation of ZDV and ddC into DNA was significantly higher (0.103 and 0.0055 pmole/μg, respectively). Ribavirin (RBV) incorporated into both DNA and RNA at levels 10-fold higher than mCyd.

Table 4a: Cellular Nucleic Acid Synthesis and Incorporation Studies in HepG2 Cells (10 μM Drug and Nucleoside Controls)

	CC_{50} (μM)		Incorporated drug amount	
Compound	**DNA ([^{3}H]Thymidine)**	**RNA ([^{3}H]Uridine)**	**pmole/μg DNA**	**pmole/μg RNA**
mCyd	112.3 ± 34.5	186.1 ± 28.2	0.0013 ± 0.0008[a]	0.0014 ± 0.0008[a]
ZDV	nd	nd	0.103 ± 0.0123[a]	0.0009 ± 0.0003[a]
ddC	nd	nd	0.0055[b]	0.0013[b]
Ribavirin	3.16 ± 0.13	6.85 ± 1.83	0.0120[b]	0.0132[c]

a. Data represent mean of three experiments
b. Data represent one experiment
c. Data represent mean of two experiments
nd, not determined

Table 4b: Cytotoxicity of mCyd in Mammalian Cell Lines

Cell Line[a]	**n**	**CC_{50} (μM)**
Huh 7	7	> 250
Hep G2	6	161 ± 19
Hep G2[b]	2	> 200
MDBK	7	36 ± 7
BHK-21	2	132 ± 6
H9c2	2	> 250

a. All cytotoxicity testing was done under conditions of rapid cell division
b. Cells were grown on collagen coated plates for 4 or 10 d

Effect on Human Bone Marrow Progenitor Cells

Bone Marrow Toxicity Assay

Human bone marrow cells were collected from normal healthy volunteers and the mononuclear population was separated by Ficoll-Hypaque gradient centrifugation as described previously by Sommadossi J-P, Carlisle R. "Toxicity of 3'-azido-3'-deoxythymidine and 9-(1,3-dihydroxy-2-propoxymethyl)guanine for normal human hematopoietic progenitor cells *in vitro*" *Antimicrobial Agents and Chemotherapy* 1987; 31:452-454; and Sommadossi J-P, Schinazi RF, Chu CK, Xie M-Y. "Comparison of cytotoxicity of the (-)- and (+)-enantiomer of 2',3'-dideoxy-3'-thiacytidine in normal human bone marrow progenitor cells" *Biochemical Pharmacology* 1992; 44:1921-1925. The culture assays for CFU-GM and BFU-E

were performed using a bilayer soft agar or methylcellulose method. Drugs were diluted in tissue culture medium and filtered. After 14 to 18 days at 37°C in a humidified atmosphere of 5% CO_2 in air, colonies of greater than 50 cells were counted using an inverted microscope. The results are presented as the percent inhibition of colony formation in the presence of drug compared to solvent control cultures.

Cell Protection Assay (CPA)

The assay was performed essentially as described by Baginski, S. G.; Pevear, D. C.; Seipel, M.; Sun, S. C. C.; Benetatos, C. A.; Chunduru, S. K.; Rice, C. M. and M. S. Collett "Mechanism of action of a pestivirus antiviral compound" *PNAS USA* **2000**, 97(14), 7981-7986. MDBK cells (ATCC) were seeded onto 96-well culture plates (4,000 cells per well) 24 hours before use. After infection with BVDV (strain NADL, ATCC) at a multiplicity of infection (MOI) of 0.02 plaque forming units (PFU) per cell, serial dilutions of test compounds were added to both infected and uninfected cells in a final concentration of 0.5% DMSO in growth medium. Each dilution was tested in quadruplicate. Cell densities and virus inocula were adjusted to ensure continuous cell growth throughout the experiment and to achieve more than 90% virus-induced cell destruction in the untreated controls after four days post-infection. After four days, plates were fixed with 50% TCA and stained with sulforhodamine B. The optical density of the wells was read in a microplate reader at 550 nm. The 50% effective concentration (EC_{50}) values are defined as the compound concentration that achieved 50% reduction of cytopathic effect of the virus.

The myelosuppressive effects of certain nucleoside analogs have highlighted the need to test for potential effects of investigational drugs on the growth of human bone marrow progenitor cells in clonogenic assays. In particular, anemia and neutropenia are the most common drug-related clinical toxicities associated with the anti-HIV drug zidovudine (ZDV) or the ribavirin (RBV) component of the standard of care combination therapy used for HCV treatment. These toxicities have been modeled in an *in vitro* assay that employed bone marrow cells obtained from healthy volunteers (Sommadossi J-P, Carlisle R. *Antimicrob. Agents Chemother.* **1987**;31(3): 452-454). ZDV has been previously shown to directly inhibit human granulocyte-

macrophage colony-forming (CFU-GM) and erythroid burst-forming (BFU-E) activity at clinically relevant concentrations of 1-2 μM in this model (Berman E, et al. *Blood* **1989**;74(4):1281-1286; Yoshida Y, Yoshida C. *AIDS Res. Hum. Retroviruses* **1990**;6(7):929-932.; Lerza R, et al. *Exp. Hematol.* **1997**;25(3):252-255; Dornsife RE, Averett DR. *Antimicrob. Agents Chemother.* **1996**;40(2):514-519; Kurtzberg J, Carter SG. *Exp. Hematol.* **1990**;18(10):1094-1096 ; Weinberg RS, et al. *Mt. Sinai. J. Med.* **1998**;65(1):5-13). Using human bone marrow clonogenic assays, the CC_{50} values of mCyd in CFU-GM and BFU-E were 14.1 ± 4.5 and 13.9 ± 3.2 μM (see Table 5). mCyd was significantly less toxic to bone marrow cells than both ZDV and RBV (Table 5).

Table 5: Bone Marrow Toxicity of mCyd in Granulocyte Macrophage Progenitor and Erythrocyte Precursor Cells

Compound	CFU-GM[a] CC_{50} (μM)	BFU-E[a] CC_{50} (μM)
mCyd	14.1 ± 4.5 μM	13.9 ± 3.2
ZDV	0.89 ± 0.47	0.35 ± 0.28
RBV	7.49 ± 2.20	0.99 ± 0.24

a. Data from 3 independent experiments for RBV and 5-8 independent experiments for mCyd and ZDV. All experiments were done in triplicate.

Effect on Mitochondrial Function

Antiviral nucleoside analogs approved for HIV therapy such as ZDV, stavudine (d4T), didanosine (ddI), and zalcitabine (ddC) have been occasionally associated with clinically limiting delayed toxicities such as peripheral neuropathy, myopathy, and pancreatitis (Browne MJ, et al. *J. Infect. Dis.* **1993**;167(1):21-29; Fischl MA, et al. *Ann. Intern. Med.* **1993**;18(10):762-769.; Richman DD, et al. *N. Engl. J. Med.* **1987**;317(4): 192-197; Yarchoan R, et al. *Lancet* **1990**;336(8714):526-529). These clinical adverse events have been attributed by some experts to inhibition of mitochondrial function due to reduction in mitochondrial DNA (mtDNA) content and nucleoside analog incorporation into mtDNA. In addition, one particular nucleoside analog, fialuridine (1,-2'-deoxy-2'-fluoro-1-β-D-arabinofuranosyl-5-iodo-uracil; FIAU) - caused hepatic failure, pancreatitis, neuropathy, myopathy and lactic acidosis due to direct mitochondrial toxicity (McKenzie R, et al. *N Engl J Med* **1995**;333(17):1099-1105). Drug-associated increases in lactic acid production can be

considered a marker of impaired mitochondrial function or oxidative phosphorylation. (Colacino, J. M. *Antiviral Res* **1996** 29(2-3): 125-39).

To assess the potential of mCyd to produce mitochondrial toxicity, several *in vitro* studies were conducted using the human hepatoma cell lines HepG2 or Huh7. These studies included analysis of lactic acid production, mtDNA content, and determination of changes in morphology (e.g., loss of cristae, matrix dissolution and swelling, and lipid droplet formation) of mitochondrial ultrastructure.

The effects of mCyd on mitochondria are presented in Table 6. No differences were observed in lactic acid production in mCyd-treated cells versus untreated cells at up to 50 μM mCyd in Huh7 cells or10 μM mCyd in HepG2 cells. A modest (38%) increase in lactic acid production was seen in HepG2 cells treated with 50 μM mCyd. The significance of this finding is unclear, particularly since mCyd is unlikely to attain a plasma concentration of 50 μM in the clinic. For comparison, lactic acid production increases by 100% over control cells in cells treated with 10 μM FIAU (Cui L, Yoon, et al. *J. Clin. Invest.* **1995**;95:555-563). Exposure of HepG2 cells to mCyd for 6 or 14 days at concentrations up to 50 μM had no negative effect on mitochondrial DNA content compared to a 56 or 80% reduction in ddC-treated cells, respectively.

Following 14 days of exposure to 10 μM mCyd, the ultrastructure of HepG2 cells, and in particular mitochondria, was examined by transmission electron microscopy. No changes in cell architecture, or in mitochondrial number or morphology (including cristae), were observed in the majority of cells. In 17% of the cells, 1 to 2 mitochondria out of an average of 25 per cell appeared enlarged. Such minor changes would be unlikely to have any significant impact on mitochondrial function. ddC-treated cells showed abnormal mitochondrial morphology with loss of cristae, and the accumulation of fat droplets. (Medina, D. J., C. H. Tsai, et al. *Antimicrob. Agents Chemother.* **1994** 38(8): 1824-8; Lewis W, et al. *J. Clin. Invest.* **1992**;89(4):1354-1360., Lewis, L. D., F. M. Hamzeh, et al. *Antimicrob. Agents Chemother.* **1992** 36(9): 2061-5).

Table 6: Effect of mCyd on Hepatocyte Proliferation, Mitochondrial Function, and Morphology in HepG2 Cells

		L-Lactate (% of Control[a])		mtDNA/nuclear DNA (% of Control[b])		Electron Microscopy[c]	
Agent	Conc (μM)	HepG2 Cells	Huh7 Cells	6 day Treatment	14 day Treatment	Lipid Droplet Form.	Mito.M orphol.
Cont.	0	100	100	100	100	Negative	Normal
mCyd	10	98.6 ± 7.3	98.0 ± 12.3	117.3 ± 17.5	99.7 ± 23.9	Negative	Normal[d]
	50	138.0 ± 8.9	97.1 ± 10.1	158.2 ± 17.5	83.0 ± 15.5	nd	nd
ddC	1	nd	nd	44.3 ± 9.3	19.6 ± 8.2	nd	nd
	10	nd	nd	nd	nd	Positive	Loss of Cristae

Effect on Human DNA Polymerases α, β, and γ

The cellular DNA polymerases are responsible for normal nuclear and mitochondrial DNA synthesis and repair. Nucleoside analog triphosphates are potential inhibitors of DNA polymerases and hence could disrupt critical cell functions. In particular, the inhibition of human polymerase γ, the enzyme responsible for mitochondrial DNA synthesis, has been linked to defects in mitochondrial function (Lewis, W., E. S. Levine, et al. *Proceedings of the National Academy of Sciences, USA* **1996** 93(8): 3592-7). Experiments were undertaken to determine if mCyd-TP inhibited human DNA polymerases. As shown in Table 7 mCyd-TP was not a substrate for human DNA polymerases α, β, or γ. Even 1 mM mCyd-TP failed to inhibit these enzymes by 50% in the majority of replicate assays and IC_{50} values could only be determined to be in excess of 880-1000 μM. In contrast, ddC was a potent inhibitor of all three human DNA polymerases and of polymerases β and γ in particular (IC_{50}s of 4.8 and 2.7 μM, respectively). Potent inhibition was also seen for the control drug, actinomycin D, a known inhibitor of DNA-dependent-DNA polymerases.

Table 7: Inhibition of Human Polymerases by mCyd-Triphosphate

	IC_{50} (μM)		
	mCyd-TP[a]	ddC-TP[b]	Act. D[a]
Pol α	>1000	78 ± 23.4	5.8 ± 3.1
Pol β	≥883.3 ± 165	4.8 ± 1	7.9 ± 3
Pol γ	≥929.3 ± 100	2.7 ± 1	15.5 ± 4

a. Mean ± S.D. from 4 data sets

b. Mean ± S.D. from 2 data sets

a. HepG2 or huh7 cells were treated with compounds for 4 days, data represent at least three independent experiments
b. HepG2 cells were treated with compounds for 6 and 14 days, data represents at least three independent experiments
c. HepG2 cells were treated with compounds for 14 days
d. 17% cells (11 of 64) contained 1 or 2 enlarged mitochondria out of 25 in two independent experiments
nd, not determined

EXAMPLE 5: *IN VITRO* ANTIVIRAL ACTIVITY AGAINST BVDV

Compounds can exhibit anti-flavivirus or pestivirus activity by inhibiting flavivirus or pestivirus polymerase, by inhibiting other enzymes needed in the replication cycle, or by other pathways.

Plaque Reduction Assay

For each compound the effective concentration was determined in duplicate 24-well plates by plaque reduction assays. Cell monolayers were infected with 100 PFU/well of virus. Then, serial dilutions of test compounds in MEM supplemented with 2% inactivated serum and 0.75% of methyl cellulose were added to the monolayers. Cultures were further incubated at 37°C for 3 days, then fixed with 50% ethanol and 0.8% Crystal Violet, washed and air-dried. Then plaques were counted to determine the concentration to obtain 90% virus suppression.

Yield Reduction Assay

For each compound the concentration to obtain a 6-log reduction in viral load was determined in duplicate 24-well plates by yield reduction assays. The assay was performed as described by Baginski, S. G.; Pevear, D. C.; Seipel, M.; Sun, S. C. C.; Benetatos, C. A.; Chunduru, S. K.; Rice, C. M. and M. S. Collett "Mechanism of action of a pestivirus antiviral compound" *PNAS USA* 2000, 97(14), 7981-7986, with minor modifications. Briefly, MDBK cells were seeded onto 24-well plates (2 x 105

cells per well) 24 hours before infection with BVDV (NADL strain) at a multiplicity of infection (MOI) of 0.1 PFU per cell. Serial dilutions of test compounds were added to cells in a final concentration of 0.5% DMSO in growth medium. Each dilution was tested in triplicate. After three days, cell cultures (cell monolayers and supernatants) were lysed by three freeze-thaw cycles, and virus yield was quantified by plaque assay. Briefly, MDBK cells were seeded onto 6-well plates (5 x 105 cells per well) 24 h before use. Cells were inoculated with 0.2 mL of test lysates for 1 hour, washed and overlaid with 0.5% agarose in growth medium. After 3 days, cell monolayers were fixed with 3.5% formaldehyde and stained with 1% crystal violet (w/v in 50% ethanol) to visualize plaques. The plaques were counted to determine the concentration to obtain a 6-log reduction in viral load.

Studies on the antiviral activity of mCyd in cultured cells were conducted. The primary assay used to determine mCyd antiviral potency was a BVDV-based cell-protection assay (CPA). This assay measures the ability of mCyd to protect growing MDBK bovine kidney cells from destruction by a cytopathic NADL strain of BVDV. The cytotoxicity of the test drug on uninfected cells was measured in parallel. The antiviral activities of mCyd and ribavirin in the CPA are compared in Table 8a. mCyd effectively protected *de novo*-infected MDBK cells in a concentration-dependent manner with an $EC_{50} = 0.67 \pm 0.22$ μM (Table 8a). mCyd afforded complete cytoprotection at concentrations well below the CC_{50} for mCyd in this assay (38 ± 9 μM). In the CPA, as well as in other assays described below, ribavirin showed no clear antiviral effect: significant (50% or more) cell protection was not achieved in most assays as the cytotoxicity of ribavirin overlapped and masked the protective effect. Thus, ribavirin gave a CC_{50} of 4.3 ± 0.6 μM and an $EC_{50} > 4.3$ μM in the CPA.

Table 8a: *In Vitro* Activity of mCyd Against BVDV in the Cell Protection Assay

Compound	n	EC_{50}, μM	CC_{50}, μM
mCyd	11	0.67 ± 0.22	38 ± 9
RBV	3	>4.3	4.3 ± 0.6

Table 8b: CC_{50} Test Results for β-D-2'-C-methyl-cytidine (Compound G), 3'-*O*-valinyl ester of β-D-2'-C-methyl-cytidine dihydrochloride salt (Compound M), and β-D-2'-C-methyl-uracil (Compound N)

	CC_{50}							
Compound		BVDV	YFV	DENV 2	WNV	CVB-2	Sb-1	REO
G	34	2.3	54	95	80	12	11.5	13
M	24	5.8	82	>100	82	12	14	22
N	>100	18	100	> or = 100	80	>100	55	>100

Note: Cell lines utilized include MT-4 for HIV; Vero 76, African green monkey kidney cells for SARS; BHK for Bovine Viral Diarrhea Virus; Sb-1 for poliovirus Sabin type-1; CVB-2, CVB-3, CVB-4, and CVA-9 for Coxsackieviruses B-2, B-3, B-4 and A-9; and REO-1 for double-stranded RNA viruses.

Table 8c. CC_{50} and EC_{50} Test Results for β-D-2'-C-methyl-cytidine (Compound G)

	CC_{50}	CC_{50}	CC_{50}	EC_{50}	EC_{50}	EC_{50}	EC_{50}	EC_{50}	EC_{50}
Compound	MT-4	Vero 76	BHK	Sb-1	CVB-2	CVB-3	CVB-4	CVA-9	REO-1
G	34	>100	>100	6	11	9	13	26	13

Note: Cell lines utilized include MT-4 for HIV; Vero 76, African green monkey kidney cells for SARS; BHK for Bovine Viral Diarrhea Virus; Sb-1 for poliovirus Sabin type-1; CVB-2, CVB-3, CVB-4, and CVA-9 for Coxsackieviruses B-2, B-3, B-4 and A-9; and REO-1 for double-stranded RNA viruses.

The overall antiviral potency of mCyd was determined against different strains of BVDV and both cytopathic (cp) and noncytopathic (ncp) biotypes in cell protection assays as well as in plaque reduction and yield reduction assays. The latter assays measure the output of infectious virus from cells and hence provide a stringent test of

antiviral efficacy. The different data sets from all three assays show agreement as summarized in Table 9. The range of 50% and 90% effective inhibitory concentration (EC_{50} and EC_{90}) values for mCyd was 0.3 to 2.8 μM and 0.87 to 4.8 μM, respectively.

In the BVDV yield reduction assay, subcytotoxic concentrations (circa 20 μM) of mCyd suppressed *de novo* BVDV production by up to 6 log_{10}, to the point where no infectious virus was detected. A 4 log_{10} effective reduction in BVDV production (EC_{4log10} or $EC_{99.99}$) was attained between 6.0 and 13.9 μM mCyd. In contrast, interferon alpha 2b (IFN α2b), although active against BVDV in this assay (EC_{50} 2.6 IU per ml), never gave more than 2 logs of viral reduction, even at 1000 IU per ml. Thus, the antiviral effect of mCyd against BVDV was much greater than that of IFNα2b or RBV.

EXAMPLE 6: *IN VITRO* ANTIVIRAL ACTIVITY AGAINST OTHER POSITIVE-STRAND RNA VIRUSES

mCyd has been tested for efficacy against positive-strand RNA viruses other than BVDV. Data obtained are summarized in Table 9 and 10. Against flaviviruses, mCyd showed modest activity. The composite EC_{50} ranges (in μM) determined from both sites were: West Nile virus (46-97); Yellow Fever virus (9-80); and Dengue virus (59-95). For mCyd against the alpha virus, Venezuelan equine encephalitis virus, EC_{50} values were 1.3 – 45 μM. mCyd was broadly active against picornaviruses, such as polio virus (EC_{50} = 6 μM), coxsackie virus (EC_{50} = 15 μM), rhinovirus types 5 and 14 (EC_{50}s = <0.1 and 0.6 μg/ml) and rhinovirus type 2 (EC_{50} 2 - 10 μM). mCyd was generally inactive against all RNA and DNA viruses tested except for the positive-strand RNA viruses. mCyd was also found to have no activity against HIV in MT-4 human T lymphocyte cells or HBV in HepG2.2.15 cells.

Table 9: *In Vitro* Antiviral Activity of mCyd Against Plus-Strand RNA Viruses

Method of Assay	Virus Type	Cell Type	n	Antiviral Efficacy (μM)		
				EC_{50}	EC_{90}	$EC_{4\ log}$
Cell Protection Assay	BVDV NADL cp	MDBK	11	0.67 ± 0.22		
Yield Reduction Assay	BVDV NADL cp	MDBK	3	2.77 ± 1.16	4.8 ± 1.55	13.9 ± 3.07
	BVDV	MDBK	6	0.30 ± 0.07	0.87 ± 0.18	6.03 ± 1.41

	New York-1 ncp					
	BVDV I-NADL cp	MDBK	1	0.68	1.73	8.22
	BVDV I-N-dIns ncp	MDBK	1	0.59	1.49	7.14
Plaque Reduction Assay	BVDV NADL cp	MDBK	3	2.57 ± 0.35	4.63 ± 0.72	
Cell Protection Assay	West Nile Virus	BHK	3	63-97		
Cell Protection Assay	Yellow Fever Virus 17D	BHK	1	60-80		
	DENV-2	BHK	2	95		
Cell Protection Assay	DENV-4	BHK	1	59		
	Polio Virus					
Plaque Reduction Assay	Sb-1	VERO	1	6		
Plaque Reduction Assay	Coxsackie Virus B2	VERO	1	15		

cp, cytopathic virus; ncp noncytopathic virus

1-NADL cp and I-N-dIns ncp represent recombinant BVDV viruses

Table 10 *In Vitro* Antiviral Activity, Selectivity, and Cytotoxicity of mCyd

Virus (Cell line)[a]	**EC_{50}**[b] **(μM)**	**CC_{50}**[c] **(μM)**
WNV (Vero)	46	114-124
YFV (Vero)	9-30	150->200
VEE (Vero)	1.3-45	>200
HSV-1 (HFF)[d]	>100	>100
HSV-2 (HFF)[d]	>100	>100
VZV (HFF)[d]	>20	67.8
EBV (Daudi)[d]	25.5	>50
HCMV (HFF)[d]	9.9-15.6	67-73
MCMV (MEF)	>0.8	2.4
Influenza A/H1N1 (MDCK)	>200	>200
Influenza A/H3N2 (MDCK)	>20	45-65
Influenza B (MDCK)	>200	55-140
Adenovirus type 1 (A549)	>200	>200

Parainfluenza type 3 (MA-104)	>200	>200
Rhinovirus type 2 (KB)	2-10	>200
Rhinovirus type 5 (KB)[d]	0.6	20-30
Rhinovirus type 14 (HeLa-Ohio)[d]	<0.1	20->100
RSV type A (MA-104)	>200	200
Punta Toro A (LLC-MK2)	>200	>200

a. HFF, human foreskin fibroblast; Daudi, Burkitt's B-cell lymphoma; MDCK, canine kidney cells; CV-1, African green monkey kidney cells; KB, human nasopharyngeal carcinoma; MA-104, Rhesus monkey kidney cells; LLC-MK2, Rhesus monkey kidney cells; A549, Human lung carcinoma cells; MEF, mouse embryo fibroblast; Vero, African green monkey kidney cells; HeLa, human cervical adenocarcinoma cells.

b. EC_{50} = 50% effective concentration.

c. CC_{50} = 50% cytotoxic concentration.

d. Result presented in μg/mL rather than μM.

EXAMPLE 7: MULTIPLICITY OF INFECTION (MOI) AND ANTIVIRAL EFFICACY

The cell protection assay format was used to test the effect of increasing the amount of BVDV virus on the EC_{50} of mCyd. Increasing the multiplicity of infection (MOI) of BVDV in this assay from 0.04 to 0.16, caused the EC_{50} of mCyd to increase linearly from 0.5 μM to approximately 2.2 μM.

EXAMPLE 8: VIRAL REBOUND IN MCYD TREATED CELLS

The effect of discontinuing treatment with mCyd was tested in MDBK cells persistently infected with a noncytopathic strain (strain I-N-dIns) of BVDV. Upon passaging in cell culture, these cells continuously produce anywhere from 10^6 to $>10^7$ infectious virus particles per ml of media. This virus can be measured by adding culture supernatants from treated MDBK (BVDV) cells to uninfected MDBK cells and counting the number of resultant viral foci after disclosure by immunostaining with a BVDV-specific antibody. Treatment of a persistently infected cell line with 4 μM mCyd for one cell passage (3 days) reduced the BVDV titer by approximately 3 $\log_{10}$ from pretreatment and control cell levels of just under 10^7 infectious units per ml. At this point, mCyd treatment was discontinued. Within a single passage, BVDV titers rebounded to untreated control levels of just over 10^7 infectious units per ml.

EXAMPLE 9: MECHANISM OF ACTION

In standard BVDV CPA assays, mCyd treatment results in a marked increase in total cellular RNA content as cells grow, protected from the cytopathic effects of BVDV. This is coupled with a marked decrease in the production of BVDV RNA due to mCyd. Conversely, in the absence of mCyd, total cellular RNA actually decreases as BVDV RNA rises due to the destruction of the cells by the cytopathic virus. To further test the effect of mCyd on viral and cellular RNAs, the accumulation of intracellular BVDV RNA was monitored in MDBK cells 18-hours post infection (after approximately one cycle of virus replication) using Real Time RT-PCR. In parallel, a cellular housekeeping ribosomal protein mRNA (rig S15 mRNA) was also quantitated by RT-PCR using specific primers. The results showed that mCyd dramatically reduced BVDV RNA levels in *de novo*-infected MDBK cells with an EC_{50} of 1.7 μM and an EC_{90} of 2.3 μM. The maximum viral RNA reduction was 4 $\log_{10}$ at the highest inhibitor concentration tested (125 μM). No effect on the level of the rig S15 cellular mRNA control was observed. Together, the preceding findings suggest that mCyd inhibited BVDV by specifically interfering with viral genome RNA synthesis without impacting cellular RNA content. This idea is further supported by the observation (Table 4a) that inhibition of RNA synthesis as measured by [^{3}H]-uridine uptake in HepG2 cells requires high concentrations of mCyd (EC_{50} = 186 μM).

In *in vitro* studies using purified BVDV NS5B RNA-dependent RNA polymerase (Kao, C. C., A. M. Del Vecchio, et al. (1999). "De novo initiation of RNA synthesis by a recombinant flaviviridae RNA- dependent RNA polymerase." *Virology* 253(1): 1-7) and synthetic RNA templates, mCyd-TP inhibited RNA synthesis with an IC_{50} of 0.74 μM and was a competitive inhibitor of BVDV NS5B RNA-dependent RNA polymerase with respect to the natural CTP substrate. The inhibition constant (K_i) for mCyd-TP was 0.16 μM and the Michaelis-Menten constant (K_m) for CTP was 0.03 μM. Inhibition of RNA synthesis by mCyd-TP required the presence of a cognate G residue in the RNA template. The effect of mCyd-TP on RNA synthesis in the absence of CTP was investigated in more detail using a series of short (21mer) synthetic RNA templates containing a single G residue, which was moved progressively along the template. Analysis of the newly synthesized transcripts generated from these templates in the presence of mCyd-TP revealed that RNA

elongation continued only as far as the G residue, then stopped (Figure 2). In templates containing more than one G residue, RNA synthesis stopped at the first G residue encountered by the polymerase. These data strongly suggest that m-Cyd-TP is acting as a non-obligate chain terminator. The mechanism of this apparent chain termination is under further investigation.

EXAMPLE 10: ERADICATION OF A PERSISTENT BVDV INFECTION

The ability of mCyd to eradicate a viral infection was tested in MDBK cells persistently infected with a noncytopathic strain of BVDV (strain I-N-dIns). (Vassilev, V. B. and R. O. Donis *Virus Res* **2000** 69(2): 95-107.) Compared to untreated cells, treatment of persistently infected cells with 16 μM mCyd reduced virus production from more than 6 logs of virus per ml to undetectable levels within two cell passages (3 to 4 days per passage). No further virus production was seen upon continued treatment with mCyd through passage 12. At passages 8, 9 and 10 (arrows, Figure 3), a portion of cells was cultured for two further passages in the absence of drug to give enough time for mCyd-TP to decay and virus replication to resume. The culture media from the cells were repeatedly tested for the re-emergence of virus by adding culture supernatants from treated MDBK (BVDV) cells to uninfected MDBK cells and counting the resultant viral foci after disclosure by immunostaining with a BVDV-specific antibody. Although this assay can detect a single virus particle, no virus emerged from the cells post drug treatment. Thus, treatment with mCyd for 8 or more passages was sufficient to eliminate virus from the persistently infected cells.

EXAMPLE 11: COMBINATION STUDIES WITH INTERFERON ALPHA 2B

The first study, performed in MDBK cells persistently infected with the New York-1 (NY-1) strain of BVDV, compared the effect of monotherapy with either mCyd (8 μM) or interferon alpha 2b (200 IU/ml), or the two drugs in combination (Figure 4A). In this experiment, 8 μM mCyd alone reduced viral titers by approximately 3.5 $\log_{10}$ after one passage to a level that was maintained for two more passages. Interferon alpha 2b alone was essentially inactive against persistent BVDV infection (approximately 0.1 $\log_{10}$ reduction in virus titer) despite being active against *de novo* BVDV infection. However, the combination of mCyd plus interferon alpha

2b reduced virus to undetectable levels by the second passage and clearly showed better efficacy to either monotherapy.

In a follow up study (Figure 4B) of MDBK cells persistently infected with the I-N-dIns noncytopathic strain of BVDV, mCyd was supplied at fixed doses of 0, 2, 4 and 8 μM, while interferon alpha 2b was titrated from 0 to 2,000 IU per ml. Again, interferon alpha 2b was essentially inactive (0.1 log reduction in viral titer), while mCyd alone inhibited BVDV (strain I-N-dIns) propagation in a dose-dependent manner. mCyd at 8 μM reduced virus production by 6.2 $\log_{10}$, to almost background levels.

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EXAMPLE 12: RESISTANCE DEVELOPMENT

In early cell culture studies, repeated passaging of a cytopathic strain of BVDV in MDBK cells in the presence of mCyd failed to generate resistant mutants, suggesting that the isolation of mCyd-resistant BVDV mutants is difficult. However, studies in cell lines persistently infected with noncytopathic forms of BVDV led to the selection of resistant virus upon relatively prolonged treatment with mCyd at suboptimal therapeutic concentrations of drug (2 to 8 μM, depending on the experiment). In the representative experiment shown in Figure 5A, the virus was no longer detectable after two passages in the presence of 8 μM mCyd, but re-emerged
20 by passage 6. The lower titer of the re-emergent virus is apparent from the data: resistant virus typically has a 10 fold or more lower titer than the wild-type virus and is easily suppressed by co-therapy with IntronA (Figure 5A). The phenotype of the virus that re-emerged was remarkably different from the initial wild-type virus: as shown in Figure 5B, it yielded much smaller foci (typically, 3 to 10 times smaller in diameter then those of the wild-type virus). This phenotype did not change after prolonged passaging in culture in the presence of the inhibitor (at least 72 days), however, it quickly reverted to the wild-type phenotype (large foci) after the discontinuation of the treatment.

RT-PCR sequencing of the resistant mutant was used to identify the mutation
30 responsible for resistance. Sequencing efforts were focused on the NS5B RNA-dependent RNA polymerase region of BVDV, which was assumed to be the likely target for a nucleoside inhibitor. A specific S405T amino-acid substitution was identified at the start of the highly conserved B domain motif of the polymerase. The

B domain is part of the polymerase active site and is thought to be involved in nucleoside binding (Lesburg, C. A., M. B. Cable, et al. *Nature Structural Biology* **1999** 6(10): 937-43). Resistance to nucleosides has been mapped to this domain for other viruses such as HBV (Ono et al, *J Clin Invest.* **2001** Feb;107(4):449-55). To confirm that this mutation was responsible for the observed resistance, the mutation was reintroduced into the backbone of a recombinant molecular clone of BVDV. The resulting clone was indistinguishable in phenotypic properties from the isolated mutant virus, confirming that the S405T mutation is responsible for resistance and that the NS5B RNA-dependent RNA polymerase is the molecular target for mCyd. The highly conserved nature of this motif at the nucleotide sequence (Lai, V. C., C. C. Kao, et al. *J Virol* **1999** 73(12): 10129-36) and structural level among positive-strand RNA viruses (including HCV) allows a prediction that the equivalent mutation in the HCV NS5B RNA-dependent RNA polymerase would likely be S282T.

S405T mutant BVDV was refractory to mCyd up to the highest concentrations that could be tested (EC_{50}>32 μM), but was also significantly impaired in viability compared to wild-type virus. As noted above, the S405T mutant exhibited a 1-2 $\log_{10}$ lower titer than wild-type BVDV and produced much smaller viral plaques. In addition, the mutant virus showed a marked reduction in the rate of a single cycle of replication (>1000-fold lower virus titer at 12h), and accumulated to about 100 fold lower levels than the wild-type virus even after 36 h of replication (Figure 5C). The virus also quickly reverted to wild-type virus upon drug withdrawal. Finally, the mutant was also more sensitive (~40 fold) to treatment with IFN alpha 2b than wild-type as shown in Figure 5D.

A second, additional mutation, C446S, was observed upon further passaging of the S405T mutant virus in the presence of drug. This mutation occurs immediately prior to the essential GDD motif in the C domain of BVDV NS5B RNA-dependent RNA polymerase. Preliminary studies suggest that a virus bearing both mutations does not replicate significantly better than the S405T mutant, hence the contribution of this mutation to viral fitness remains unclear.

EXAMPLE 13: *IN VIVO* ANTIVIRAL ACTIVITY OF VAL-MCYD IN AN ANIMAL EFFICACY MODEL

Chimpanzees chronically infected with HCV are the most widely accepted animal model of HCV infection in human patients (Lanford, R. E., C. Bigger, et al. *Ilar J* **2001** 42(2): 117-26; Grakoui, A., H. L. Hanson, et al. *Hepatology* **2001** 33(3): 489-95). A single *in vivo* study of the oral administration of val-mCyd in the chimpanzee model of chronic hepatitis C virus infection has been conducted.

HCV genotyping on the five chimpanzees was performed by the Southwest Foundation Primate Center as part of their mandated internal Health and Maintenance Program, designed to ascertain the disease status of all animals in the facility to identify potential safety hazards to employees. The five chimpanzees used in this study exhibited a high HCV titer in a genotyping RT PCR assay that distinguishes genotype 1 HCV from all other genotypes, but does not distinguish genotype 1a from 1b. This indicated that the chimpanzees used in this study were infected with genotype 1 HCV (HCV-1).

Table 11: Summary of Val-mCyd *In Vivo* Activity Study in the Chimpanzee Model of Chronic HCV Infection

Study Description	Species (N)	Val-mCyd Doses (mg/kg) (n)	Frequency/Route of Administration	Study Endpoints
One-week antiviral activity of mCyd in chronically hepatitis C virus (genotype 1)-infected chimpanzees	Chimpanzee (5)	10 and 20 (2 each) [equivalent to 8.3 and 16.6 mpk of free base], and vehicle control (1)	QD x 7 days (PO)	Serum HCV RNA, serum chemistries, CBCs, general well being, and clinical observations

Seven-Day Antiviral Activity Study in the Chimpanzee Model of Chronic Hepatitis C Virus Infection

Four chimpanzees (2 animals per dose group at 10 mg/kg/day or 20 mg/kg/day) received val-mCyd dihydrochloride, freshly dissolved in a flavorful fruit drink vehicle. These doses were equivalent to 8.3 and 16.6 mg/kg/day of the val-mCyd free base, respectively. A fifth animal dosed with vehicle alone provided a placebo control. The study design included three pretreatment bleeds to establish the baseline fluctuation of viral load and three bleeds during the one week of treatment (on days 2, 5 and 7 of therapy) to evaluate antiviral efficacy. The analysis was completed at the end of the one-week dosing period, with no further follow up.

HCV RNA Determination

Serum levels of HCV RNA throughout the study were determined independently by two clinical hospital laboratories. HCV RNA was assayed using a quantitative RT-PCR nucleic acid amplification test (Roche Amplicor HCV Monitor Test, version 2.0). This assay has a lower limit of detection (LLOD) of 600 IU/mL and a linear range of 600-850,000 IU/mL.

To aid in interpretation of the viral load declines seen during therapy, emphasis was placed on determining (i) the extent of fluctuations in baseline HCV viral load in individual animals, and (ii) the inherent variability and reproducibility of the HCV viral load assay. To address these issues, full viral load data sets obtained from the two laboratories were compared. The results from both sites were found to be closely comparable and affirmed both the stability of the pretreatment HCV viral loads as well as the reliability of the HCV Roche Amplicor assay. To present the most balanced view of the study, the mean values derived by combining both data sets were used to generate the results presented in Figures 6 and 7. Figure 6 presents the averaged data for dose cohorts, while Figure 7 presents the individual animal data. The changes in viral load from baseline seen during therapy for each animal at each site are also summarized in Table 12.

The HCV viral load analysis from the two sites revealed that pretreatment HCV viral loads were (i) very similar among all five animals and all 3 dose groups, and (ii) very stable over the 3-week pretreatment period. The mean pretreatment $\log_{10}$ viral load and standard deviations among the five individual animals were 5.8 ± 0.1 (site 1) and 5.6 ± 0.1(site 2). These data indicated that the c.v. (coefficient of variance) of the assay is only around 2% at both sites. The largest fluctuation in HCV viral load seen in any animal during pretreatment was approximately 0.3 $\log_{10}$.

As seen in Figures 6 and 7, once a day oral delivery of val-mCyd produced a rapid antiviral effect that was not seen for the placebo animal, nor during the pretreatment period. Viral titers were substantially reduced from baseline after two days of therapy for all animals receiving val-mCyd, and tended to fall further under continued therapy in the two treatment arms. By the end of treatment (day 7), the mean reductions from baseline HCV viral load were 0.83 $\log_{10}$ and 1.05 $\log_{10}$ for the 8.3 and 16.6 mg/kg/day dose groups, respectively. The titer of the placebo animal remained essentially unchanged from baseline during the therapy period.

An analysis of the data from the two quantification sites on the changes in baseline HCV viral load in response to therapy is presented in Table 12. Overall, the two data sets agree well, confirming the reliability of the assay. With the exception of animal 501, the difference in viral load between the two sites was generally 0.3 $\log_{10}$ or less, similar to the fluctuation observed during the pretreatment period. For animal 501, the discrepancy was closer to 0.5 $\log_{10}$. The viral load drop seen in response to therapy varied from 0.436 (animal 501, site 1) to 1.514 $\log_{10}$ (animal 497, site 2). The latter corresponds to a change in HCV viral load from 535,000 (pretreatment) to 16,500 (day 7) genomes per ml.

Table 12: Summary of Changes in Baseline Log_{10} HCV RNA Viral Load During Therapy

Dose (mpk)	Animal ID	Site	Day 2	Day 5	Day 7
0	499	1	-0.00041	-0.11518	0.14085
		2	-0.06604	0.10612	-0.16273
8.3	500	1	-1.15634	-0.40385	-0.80507
		2	-1.07902	-0.55027	-1.06259
8.3	501	1	-0.25180	-0.36179	-0.43610
		2	-0.45201	-0.71254	-0.90034
16.6	497	1	-0.72148	-0.90704	-1.27723
		2	-0.85561	-1.01993	-1.51351
16.6	498	1	-0.29472	-0.28139	-0.60304
		2	-0.65846	-0.55966	-0.69138

Exposure of Chimpanzees to mCyd

Limited HPLC analyses were perfomed to determine the concentration of mCyd attained in the sera of chimpanzees following dosing with val-mCyd. In sera drawn 1 to 2 hours post dose on days 2 and 5 of dosing, mCyd levels were typically between 2.9 and 12.1 μM (750 and 3100 ng/mL, respectively) in treated animals. No mCyd was detected in pretreatment sera or in the placebo control sera. Within 24 hours of the final dose, serum levels of mCyd had fallen to 0.2 to 0.4 μM (50 and 100 ng/mL, respectively). No mUrd was detected in any sera samples although the methodology used has a lower limit of quantification of 0.4 μM (100 ng/mL) for mUrd.

Safety of mCyd in the Chimpanzee Model of Chronic HCV Infection

Chimpanzees were monitored by trained veterinarians throughout the study for weight loss, temperature, appetite, and general well being, as well as for blood chemistry profile and CBCs. No adverse events due to drug were noted. The drug appeared to be well tolerated by all four treated animals. All five animals lost some weight during the study and showed some aspartate aminotransferase (AST) elevations, but these are normal occurrences related to sedation procedures used, rather than study drug. A single animal experienced an alanine aminotransferase (ALT) flare in the pretreatment period prior to the start of dosing, but the ALT levels diminished during treatment. Thus, this isolated ALT event was not attributable to drug.

EXAMPLE 14: *IN VITRO* METABOLISM

Studies were conducted to determine the stability of val-mCyd and mCyd in human plasma. Val-mCyd was incubated in human plasma at 0, 21 or 37°C and samples analyzed at various time points up to 10 hours (Figure 8). At 37°C, val-mCyd was effectively converted to mCyd, with only 2% of the input val-mCyd remaining after 10 hours. The *in vitro* half-life of val-mCyd in human plasma at 37°C was 1.81 hours. In studies of the *in vitro* stability of mCyd in human plasma, or upon treatment with a crude preparation enriched in human cytidine/deoxycytidine deaminase enzymes, mCyd remained essentially unchanged and no deamination to the uridine derivative of mCyd (mUrd) occurred after incubation at 37°C. Only in rhesus and cynomologus monkey plasma was limited deamination observed. Incubation of mCyd at 37°C in cynomologus monkey plasma yielded 6.7 and 13.0% of mUrd deamination product after 24 and 48 hours, respectively, under conditions where control cytidine analogs were extensively deaminated.

In addition to the TP derivatives of mCyd and mUrd, minor amounts of mCyd-5'-diphosphate, mCyd-DP, roughly 10% the amount of the corresponding TP, were seen in all three cell types. Lesser amounts of mUrd-DP were detected only in two cell types, primary human hepatocytes and MDBK cells. No monophosphate (MP) metabolites were detected in any cell type. There was no trace of any intracellular mUrd and no evidence for the formation of liponucleotide metabolites such as the 5'-diphosphocholine species seen upon the cellular metabolism of other cytidine analogs.

Figure 9 shows the decay profile of mCyd-TP determined following exposure of HepG2 cells to 10 μM [^{3}H]-mCyd for 24 hours. The apparent intracellular half-life of the mCyd-TP was 13.9 ± 2.2 hours in HepG2 cells and 7.6 ± 0.6 hours in MDBK cells: the data were not suitable for calculating the half life of mUrd-TP. The long half life of mCyd-TP in human hepatoma cells supported the notion of once-a-day dosing for val-mCyd in clinical trials for HCV therapy. Phosphorylation of mCyd occurred in a dose-dependent manner up to 50 μM drug in all three cell types, as shown for HepG2 cells in Figure 9C. Other than the specific differences noted above, the phosphorylation pattern detected in primary human hepatocytes was qualitatively similar to that obtained using HepG2 or MDBK cells.

Contribution of mUrd

In addition to the intracellular active moiety, mCyd-TP, cells from different species have been shown to produce variable and lesser amounts of a second triphosphate, mUrd-TP, via deamination of intracellular mCyd species. The activity of mUrd-TP against BVDV NS5B RNA-dependent RNA polymerase has not been tested to date but is planned. To date, data from exploratory cell culture studies on the antiviral efficacy and cytotoxicity of mUrd suggest that mUrd (a) is about 10-fold less potent than mCyd against BVDV; (b) has essentially no antiviral activity against a wide spectrum of other viruses; and (c) is negative when tested at high concentrations in a variety of cytotoxicity tests (including bone marrow assays, mitochondrial function assays and incorporation into cellular nucleic acid). Based on these results, it appeared that the contribution of mUrd to the overall antiviral activity or cytotoxicity profile of mCyd is likely to be minor. Extensive toxicology coverage for the mUrd metabolite of mCyd exists from subchronic studies conducted with val-mCyd in the monkey.

EXAMPLE 15: CELLULAR PATHWAYS FOR METABOLIC ACTIVATION

The nature of the enzyme responsible for the phosphorylation of mCyd was investigated in substrate competition experiments. Cytidine (Cyd) is a natural substrate of cytosolic uridine-cytidine kinase (UCK), the pyrimidine salvage enzyme responsible for conversion of Cyd to Cyd-5'-monophosphate (CMP). The intracellular phosphorylation of mCyd to mCyd-TP was reduced in the presence of cytidine or uridine in a dose-dependent fashion with EC_{50} values of 19.17 ± 4.67 μM

for cytidine and 20.92 ± 7.10 μM for uridine. In contrast, deoxycytidine, a substrate for the enzyme deoxycytidine kinase (dCK), had little effect on the formation of mCyd-TP with an EC_{50} > 100 μM. The inhibition of mCyd phosphorylation by both cytidine and uridine, but not deoxycytidine, suggests that mCyd is phosphorylated by the pyrimidine salvage enzyme, uridine-cytidine kinase (Van Rompay, A. R., A. Norda, et al. *Mol Pharmacol* **2001** 59(5): 1181-6). Further studies are required to confirm the proposed role of this kinase in the activation of mCyd.

EXAMPLE 16: PATHWAYS FOR THE CELLULAR BIOSYNTHESIS OF mURD-TP

As outlined above, mUrd-TP is a minor metabolite arising to varying extents in cells from different species. mUrd does not originate via extracellular deamination of mCyd since mUrd was not seen in the cell medium which also lacks any deamination activities. The cellular metabolism data are consistent with the idea that mUrd-TP arises via the biotransformation of intracellular mCyd species. Consideration of the known ribonucleoside metabolic pathways suggests that the most likely routes involve deamination of one of two mCyd species by two distinct deamination enzymes: either mCyd-MP by a cytidylate deaminase (such as deoxycytidylate deaminase, dCMPD), or of mCyd by cytidine deaminase (CD). Further phosphorylation steps lead to mUrd-TP. These possibilities are under further investigation.

EXAMPLE 17: CLINICAL EVALUATION OF VAL-MCYD

Patients who met eligibility criteria were randomized into the study at Baseline (Day 1), the first day of study drug administration. Each dosing cohort was 12 patients, randomized in a 10:2 ratio to treatment with drug or matching placebo. Patients visited the study center for protocol evaluations on Days 1, 2, 4, 8, 11, and 15. After Day 15, study drug was stopped. Thereafter, patients attended follow-up visits on Days 16, 17, 22, and 29. Pharmacokinetic sampling was performed on the first and last days of treatment (Day 1 and Day 15) on all patients, under fasting conditions.

The antiviral effect of val-mCyd was assessed by (i) the proportion of patients with a ≥ 1.0 $\log_{10}$ decrease from baseline in HCV RNA level at Day 15, (ii) the time

to a ≥ 1.0 log_{10} decrease in serum HCV RNA level, (iii) the change in HCV RNA level from Day 1 to Day 15, (iv) the change in HCV RNA level from Day 1 to Day 29, (v) the proportion of patients who experience return to baseline in serum HCV RNA level by Day 29, and (vi) the relationship of val-mCyd dose to HCV RNA change from Day 1 to Day 15.

Clinical Pharmacokinetics of mCyd after Oral Administration of Escalating Doses of Val-mCyd

Pharmacokinetics were evaluated over a period of 8 h after the first dose on day 1 and after the last dose on day 15, with 24-h trough levels monitored on days 2, 4, 8, 11 and 16, and a 48-h trough on day 17. Plasma concentrations of mCyd, mUrd and Val-mCyd were measured by a HPLC/MS/MS methodology with a lower limit of quantitation (LOQ) at 20 ng/ml.

The pharmacokinetics of mCyd was analyzed using a non-compartmental approach. As presented in the tables below, the principal pharmacokinetic parameters were comparable on day 1 and day 15, indicative of no plasma drug accumulation after repeated dosing. The plasma exposure also appeared to be a linear function of dose. As shown in the tables below, principal pharmacokinetic parameters of drug exposure (Cmax and AUC) doubled as doses escalated from 50 to 100 mg.

Table 13: Pharmacokinetic parameters of mCyd at 50 mg

Parameters	C_{max}	T_{max}	$AUC_{0\text{-}inf}$	$t_{1/2}$
	(ng/ml)	(h)	(ng/ml×h)	(h)
Day 1				
Mean	428.1	2.5	3118.7	4.1
SD	175.5	1.1	1246.4	0.6
CV %	41.0	43.2	40.0	13.8
Day 15				
Mean	362.7	2.2	3168.4	4.6
SD	165.7	1.0	1714.8	1.3
CV %	45.7	46.9	54.1	28.6

Table 14: Pharmacokinetic parameters of mCyd at 100 mg

Parameters	C_{max}	T_{max}	$AUC_{0\text{-}inf}$	$t_{1/2}$
	(ng/ml)	(h)	(ng/ml×h)	(h)
Day 1				
Mean	982.1	2.6	6901.7	4.4
SD	453.2	1.0	2445.7	1.1
CV %	46.1	36.2	35.4	25.2
Day 15				
Mean	1054.7	2.0	7667.5	4.2
SD	181.0	0.0	1391.5	0.5
CV %	17.2	0.0	18.1	11.7

The mean day 1 and day 15 plasma kinetic profiles of mCyd at 50 and 100 mg are depicted in the Figure 10.

In summary, following oral administration of val-mCyd, the parent compound mCyd was detectable in the plasma of HCV-infected subjects. mCyd exhibited linear plasma pharmacokinetics in these subjects across the two dose levels thus far examined. There was no apparent accumulation of mCyd in subjects' plasma following 15 days of daily dosing at the doses thus far examined.

Antiviral Activity of mCyd after Oral Administration of Escalating Doses of Val-mCyd Starting at 50 mg/day for 15 Days in HCV-Infected Patients

Serum HCV RNA levels were determined with the use of the Amplicor HCV Monitor™ assay v2.0 (Roche Molecular Systems, Branchburg, NJ, USA), which utilizes polymerase chain reaction (PCR) methods. The lower limit of quantification (LLOQ) with this assay was estimated to be approximately 600 IU/mL and the upper limit of quantification (ULOQ) with this assay was estimated to be approximately 500,000 IU/mL.

Serum samples for HCV RNA were obtained at screening (Day –42 to –7) to determine eligibility for the study. The Screening serum HCV RNA values must be ≥ 5 $\log_{10}$ IU/mL by the Amplicor HBV Monitor™ assay at the central study laboratory.

During the study period, serum samples for HCV RNA were obtained at Baseline (Day 1), and at every protocol-stipulated post-Baseline study visit (Days 2, 4, 8, 11, 15, 16, 17, 22, and 29). Serum samples for HCV RNA were also collected during protocol-stipulated follow-up visits for patients prematurely discontinued from the study.

The antiviral activity associated with the first two cohorts (50 and 100 mg per day) in the ongoing study is summarized in the following tables and graphs. Although the duration of dosing was short (15 days) and the initial dose levels low, there were already apparent effects on the levels of HCV RNA in the plasma of infected patients.

Table 15: Summary Statistics of HCV RNA in Log_{10} Scale

		Day										
		-1	**1**	**2**	**4**	**8**	**11**	**15**	**16**	**17**	**22**	**29**
Treatment												
Placebo	**N**	6	5	5	4	4	4	4	4	3	4	3
	Median	6.45	6.25	6.25	6.52	6.42	6.28	6.58	6.51	6.64	6.35	6.61
	Mean	6.45	6.28	6.40	6.48	6.36	6.34	6.54	6.52	6.50	6.40	6.40
	StdErr	0.25	0.12	0.15	0.18	0.24	0.16	0.11	0.19	0.31	0.23	0.30
50 mg	**N**	10	10	10	10	10	10	10	10	10	10	10
	Median	6.81	6.69	6.58	6.55	6.56	6.46	6.57	6.45	6.54	6.73	6.67
	Mean	6.72	6.72	6.60	6.56	6.62	6.47	6.57	6.57	6.54	6.64	6.71
	StdErr	0.11	0.11	0.12	0.06	0.10	0.09	0.08	0.11	0.08	0.10	0.09
100 mg	**N**	11	10	10	10	9	10	10	9	9	10	4
	Median	6.75	6.93	6.80	6.46	6.59	6.56	6.41	6.40	6.72	6.66	6.71
	Mean	6.60	6.68	6.52	6.43	6.42	6.36	6.30	6.23	6.65	6.53	6.67
	StdErr	0.16	0.24	0.23	0.21	0.24	0.22	0.22	0.23	0.16	0.18	0.17

Table 16: Summary Statistics of Change From Baseline (Day 1) in Log_{10} HCV RNA

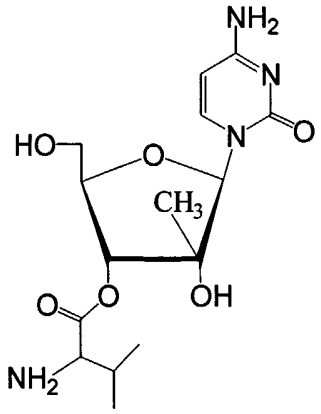
		Day								
		2	**4**	**8**	**11**	**15**	**16**	**17**	**22**	**29**
Treatment										
Placebo	**N**	5	4	4	4	4	4	3	4	3
	Median	0.17	0.21	0.15	0.08	0.31	0.21	0.27	0.17	0.09
	Mean	0.12	0.22	0.10	0.08	0.28	0.25	0.15	0.14	0.09
	StdErr	0.09	0.12	0.16	0.06	0.15	0.10	0.18	0.09	0.16
50 mg	**N**	10	10	10	10	10	10	10	10	10
	Median	-0.07	-0.13	-0.06	-0.26	-0.10	-0.13	-0.21	-0.09	-0.04
	Mean	-0.13	-0.16	-0.11	-0.26	-0.15	-0.15	-0.18	-0.09	-0.01
	StdErr	0.05	0.07	0.05	0.06	0.08	0.05	0.07	0.06	0.10
100 mg	**N**	10	10	9	10	10	9	9	10	4
	Median	-0.12	-0.24	-0.20	-0.28	-0.43	-0.49	-0.24	-0.19	-0.12
	Mean	-0.16	-0.25	-0.21	-0.32	-0.38	-0.39	-0.18	-0.15	0.13
	StdErr	0.07	0.10	0.16	0.13	0.12	0.14	0.15	0.13	0.28

Figure 11 depicts the Median Change From Baseline In Log_{10} HCV RNA By Visit

The present invention is described by way of illustration in the following examples. It will be understood by one of ordinary skill in the art that these examples are in no way limiting and that variations of detail can be made without departing from the spirit and scope of the present invention.

We claim:

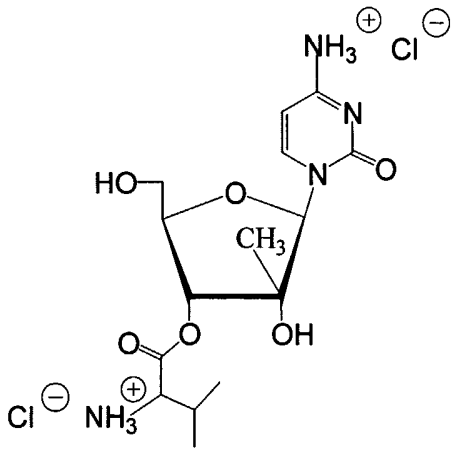
1. A compound of Formula (I) or a pharmaceutically acceptable salt thereof:



Formula (I)

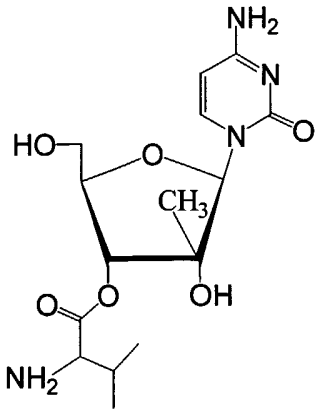
2. The compound of claim 1, wherein the pharmaceutically acceptable salt is a hydrochloride salt.

3. The compound of claim 1, wherein the pharmaceutically acceptable salt is the dihydrochloride salt of Formula (II).



Formula (II)

4. A pharmaceutical composition comprising an effective amount of the compound of Formula (I) or a pharmaceutically acceptable salt thereof to treat a *Flaviviridae* infection, in a pharmaceutically acceptable carrier.



Formula (I)

5. The pharmaceutical composition of claim 4 wherein the pharmaceutically acceptable salt is a hydrochloride salt.

6. The pharmaceutical composition of claim 4 wherein the pharmaceutically acceptable salt is a dihydrochloride salt.

7. The pharmaceutical composition of claim 4, whrein the pharmaceutically acceptable carrier is suitable for oral delivery.

8. The pharmaceutical composition of claim 4, further comprising a second antiviral agent.

9. The pharmaceutical composition of claim 8, wherein the second anti-viral agent is selected from the group consisting of an interferon, ribavirin, interleukin, NS3 protease inhibitor, cysteine protease inhibitor, phenanthrenequinone, thiazolidine derivative, thiazolidine, benzanilide, a helicase inhibitor, a polymerase inhibitor, nucleotide analogue, gliotoxin, cerulenin, antisense phosphorothioate oligodeoxynucleotides, inhibitors of IRES-dependent translation, and a ribozyme.

10. The pharmaceutical composition of claim 8, wherein the second agent is an interferon.

11. The pharmaceutical composition of claim 8, wherein the second agent is selected from the group consisting of pegylated interferon alpha 2a, interferon alphacon-1, natural interferon, albuferon, interferon beta-1a, omega interferon, interferon alpha, interferon gamma, interferon tau, interferon delta and interferon gamma- 1b.

12. The pharmaceutical composition of claim 8, wherein the second agent is interferon alpha 2.

13. The pharmaceutical composition of claim 4, wherein the compound is in the form of a dosage unit.

14. The composition of claim 13, wherein the dosage unit contains .01 to 50 mg of the compound.

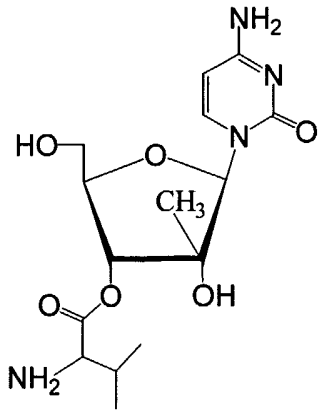
15. The composition of claim 13, wherein said dosage unit is a tablet or capsule.

16. The composition of claim 4, wherein the compound is in substantially pure form.

17. The compound of claims 1-3, wherein the compound is at least 90% by weight of the β-D-isomer.

18. The compoound of claims 1-3, wherein the compound is at least 95% by weight of the β-D-isomer.

19. A method of treating a host infected with a flavivirus or pestivirus, comprising administering to a host in need thereof an effective amount of a compound having the structure of Formula (I) or a pharmaceutically acceptable salt or prodrug thereof optionally in a pharmaceutically acceptable carrier.



Formula (I)

20. The method according to claim 19, wherein the pharmaceutically acceptable salt is a hydrochloride salt.

21. The method according to claim 19, wherein the pharmaceutically acceptable salt is a dihydrochloride salt.

22. The method according to claim 19, further comprising administering the compound in a pharmaceutically acceptable carrier, diluent or excipient.

23. The method according to claim 19, wherein the compound is administered in combination or alternation with a second anti-viral agent.

24. The method according to claim 23, wherein the second antiviral agent is selected from the group consisting of interferon, ribavirin, interleukin, an NS3 protease inhibitor, cysteine protease inhibitor, thiazolidine derivative, thiazolidine, benzanilide, phenan-threnequinone, a helicase inhibitor, a polymerase inhibitor, a nucleotide analogue, gliotoxin, cerulenin, antisense phosphorothioate oligodeoxynucleotides, inhibitor of IRES-dependent translation, and a ribozyme.

25. The method according to claim 23, wherein the second antiviral agent is an interferon.

26. The method according to claim 19, wherein the second antiviral agent is selected from the group consisting of pegylated interferon alpha 2a, interferon alphacon-1, natural interferon, albuferon, interferon beta-1a, omega interferon, interferon alpha, interferon gamma, interferon tau, interferon delta and interferon gamma- 1b.

27. The method of claim 26, wherein the second antiviral agent is interferon alpha 2.

28. The method of claim 19, wherein the host is a human.

29. The method of claim 19, wherein the compound is in the form of a dosage unit.

30. The method of claim 29, wherein the dosage unit contains 10 to 500 mg of the compound.

31. The method of claim 29, wherein said dosage unit is a tablet or capsule.

32. The method of claim 19, wherein the pharmaceutically acceptable carrier is suitable for oral or intravenous delivery.

33. The method of claim 19, wherein the compound is in administered in substantially pure form.

34. The method of claim 19, wherein the compound is at least 90% by weight of the β-D-isomer.

35. The method of claim 19, wherein the compound is at least 95% by weight of the β-D-isomer.

36. The method of claim 19, wherein the virus is HCV.

37. A compound of Formula I or II, wherein the 5'-hydroxyl group is replaced with a 5'-OR, wherein R is phosphate; a stabilized phosphate prodrug; acyl; alkyl; sulfonate ester including alkyl or arylalkyl sulfonyl including methanesulfonyl and benzyl, wherein the phenyl group is optionally substituted; a lipid; an amino acid; a carbohydrate; a peptide; cholesterol; or other pharmaceutically acceptable leaving group which when administered *in vivo* is capable of providing a compound wherein R is independently H or phosphate.

38. A pharmaceutical composition that comprises the compound of Formula I or II in a pharmaceutically acceptable carrier, wherein the 5'-hydroxyl group is replaced with a 5'-OR, wherein R is phosphate; a stabilized phosphate prodrug; acyl; alkyl; sulfonate ester including alkyl or arylalkyl sulfonyl including methanesulfonyl and; benzyl, wherein the phenyl group is optionally substituted; a lipid, an amino acid; a carbohydrate; a peptide; a cholesterol; or other pharmaceutically acceptable leaving group which when administered *in vivo* is capable of providing a compound wherein R is independently H or phosphate.

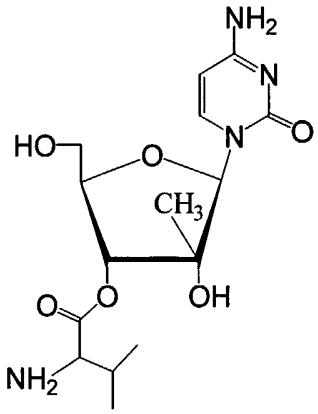
39. A method for treating a host infected with an RNA-dependant RNA polymerase virus, comprising administering an effective amount of the compound of Formula I or II in a pharmaceutically acceptable carrier, wherein the 5'-hydroxyl group is replaced with a 5'-OR, wherein R is hydrogen, phosphate; a stabilized phosphate prodrug; acyl; alkyl; sulfonate ester including alkyl or arylalkyl sulfonyl including methanesulfonyl and; benzyl, wherein the phenyl group is optionally substituted; a lipid, an amino acid; a carbohydrate; a peptide; a cholesterol; or other pharmaceutically acceptable leaving group which when administered *in vivo* is capable of providing a compound wherein R is independently H or phosphate.

40. The method of claim 39 wherein the virus is a *Flaviviridae* virus.

41. The method of claim 39 or 40 wherein the *Flaviviridae* virus is hepatitis C.

42. The method of Claims 39, 40 or 41 wherein the host is human.

43. Use of a compound having the structure of Formula (I) or a pharmaceutically acceptable salt or prodrug thereof optionally in the manufacture of a medicant for the treatment of a host infected with a flavivirus or pestivirus:



Formula (I)

44. The use according to claim 43, wherein the pharmaceutically acceptable salt is a hydrochloride salt.

45. The use according to claim 43, wherein the pharmaceutically acceptable salt is a dihydrochloride salt.

46. The use according to claim 43, further comprising administering the compound in a pharmaceutically acceptable carrier, diluent or excipient.

47. The use according to claim 43, wherein the compound is manufactured in combination with a second anti-viral agent.

48. The use according to claim 47, wherein the second antiviral agent is selected from the group consisting of interferon, ribavirin, interleukin, an NS3 protease inhibitor, cysteine protease inhibitor, thiazolidine derivative, thiazolidine, benzanilide, phenan-threnequinone, a helicase inhibitor, a polymerase inhibitor, a nucleotide analogue, gliotoxin, cerulenin, antisense phosphorothioate oligodeoxynucleotides, inhibitor of IRES-dependent translation, and a ribozyme.

49. The use according to claim 47, wherein the second antiviral agent is an interferon.

50. The use according to claim 47, wherein the second antiviral agent is selected from the group consisting of pegylated interferon alpha 2a, interferon alphacon-1, natural interferon, albuferon, interferon beta-1a, omega interferon, interferon alpha, interferon gamma, interferon tau, interferon delta and interferon gamma- 1b.

51. The use of claim 47, wherein the second antiviral agent is interferon 2alpha.

52. The use of claim 47, wherein the host is a human.

53. The use of claim 47, wherein the compound is in the form of a dosage unit.

54. The use of claim 43, wherein the dosage unit contains 10 to 500 mg of the compound.

55. The use of claim 43, wherein said dosage unit is a tablet or capsule.

56. The use of claim 43, wherein the pharmaceutically acceptable carrier is suitable for oral delivery.

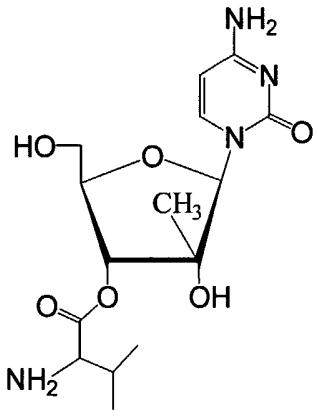
57. The use of claim 43, wherein the compound is in administered in substantially pure form.

58. The use of claim 43, wherein the compound is at least 90% by weight of the β-D-isomer.

59. The use of claim 43, wherein the compound is at least 95% by weight of the β-D-isomer.

60. The use of claim 43, wherein the virus is HCV.

61. A compound having the structure of Formula (I) or a pharmaceutically acceptable salt or prodrug thereof optionally in a pharmaceutically acceptable carrier for use in the treatment of a host infected with a flavivirus or pestivirus:



Formula (I)

62. The compound according to claim 61, wherein the pharmaceutically acceptable salt is a hydrochloride salt.

63. The compound according to claim 61, wherein the pharmaceutically acceptable salt is a dihydrochloride salt.

64. The compound according to claim 61, further comprising a pharmaceutically acceptable carrier, diluent or excipient.

65. The compound according to claim 61, further comprising a second anti-viral agent.

66. The compound according to claim 65, wherein the second antiviral agent is selected from the group consisting of interferon, ribavirin, interleukin, an NS3 protease inhibitor, cysteine protease inhibitor, thiazolidine derivative, thiazolidine, benzanilide, phenan-threnequinone, a helicase inhibitor, a polymerase inhibitor, a nucleotide analogue, gliotoxin, cerulenin, antisense phosphorothioate oligodeoxynucleotides, inhibitor of IRES-dependent translation, and a ribozyme.

67. The compound according to claim 65, wherein the second antiviral agent is an interferon.

68. The compound according to claim 65, wherein the second antiviral agent is selected from the group consisting of pegylated interferon alpha 2a, interferon alphacon-1, natural interferon, albuferon, interferon beta-1a, omega interferon, interferon alpha, interferon gamma, interferon tau, interferon delta and interferon gamma- 1b.

69. The compound of claim 65, wherein the second antiviral agent is interferon 2alpha.

70. The compound of claim 65, wherein the host is a human.

71. The compound of claim 65, wherein the compound is in the form of a dosage unit.

72. The compound of claim 61, wherein the dosage unit contains 10 to 500 mg of the compound.

73. The compound of claim 72, wherein said dosage unit is a tablet or capsule.

74. The compound of claim 61, wherein the pharmaceutically acceptable carrier is suitable for oral delivery.

75. The compound of claim 61, wherein the compound is in administered in substantially pure form.

76. The compound of claim 61, wherein the compound is at least 90% by weight of the β-D-isomer.

77. The compound of claim 61, wherein the compound is at least 95% by weight of the β-D-isomer.

78. The compound of claim 61, wherein the virus is HCV.

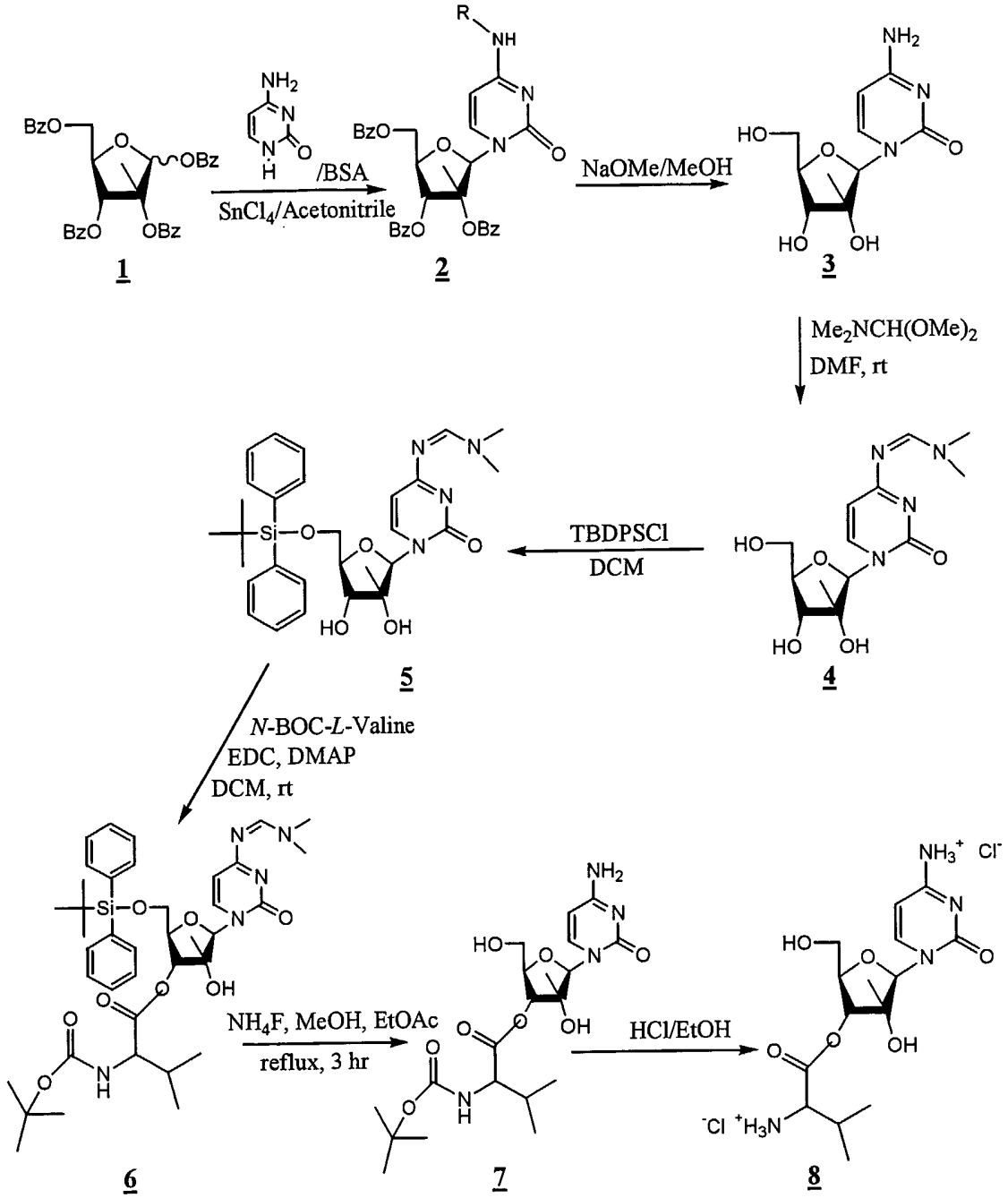
79. The compound of claim 1 or 61, wherein the pharmaceutically acceptable salt is selected from tosylate, methanesulfonate, acetate, citrate, malonate, tartarate, succinate, benzoate, ascorbate, α-ketoglutarate, and α-glycerophosphate, formate, fumarate, propionate, glycolate, lactate, pyruvate, oxalate, maleate, salicyate, sulfate, sulfonate, nitrate, bicarbonate, hydrobromate, hydrobromide, hydroiodide, carbonate, and phosphoric acid salts.

80. The composition of claim 4, wherein the pharmaceutically acceptable salt is selected from tosylate, methanesulfonate, acetate, citrate, malonate, tartarate, succinate, benzoate, ascorbate, α-ketoglutarate, and α-glycerophosphate, formate, fumarate, propionate, glycolate, lactate, pyruvate, oxalate, maleate, salicyate, sulfate, sulfonate, nitrate, bicarbonate, hydrobromate, hydrobromide, hydroiodide, carbonate, and phosphoric acid salts.

81. The method of claim 19, wherein the pharmaceutically acceptable salt is selected from tosylate, methanesulfonate, acetate, citrate, malonate, tartarate, succinate, benzoate, ascorbate, α-ketoglutarate, and α-glycerophosphate, formate, fumarate, propionate, glycolate, lactate, pyruvate, oxalate, maleate, salicyate, sulfate, sulfonate, nitrate, bicarbonate, hydrobromate, hydrobromide, hydroiodide, carbonate, and phosphoric acid salts.

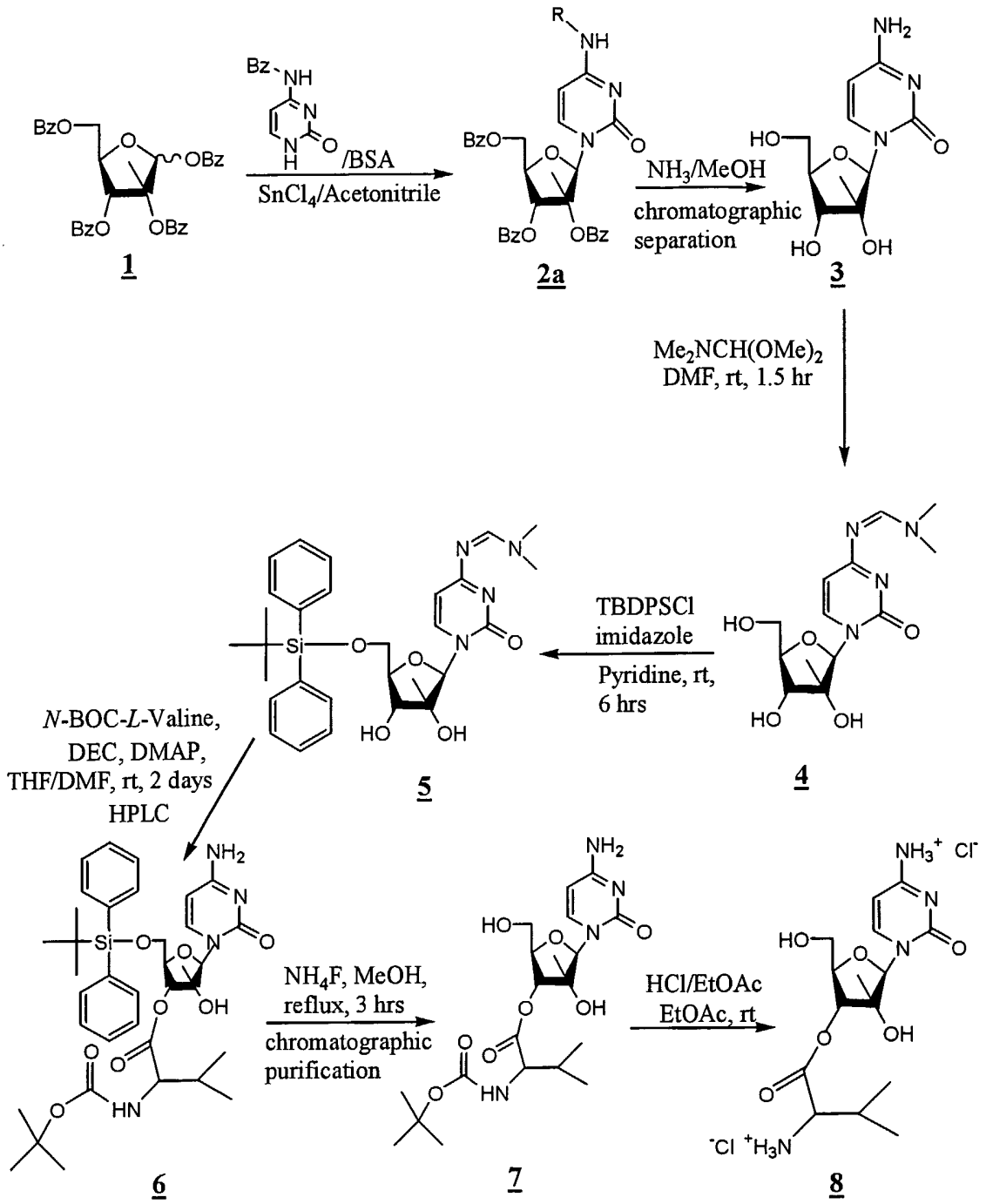
82. The use of claim 42, wherein the pharmaceutically acceptable salt is selected from tosylate, methanesulfonate, acetate, citrate, malonate, tartarate, succinate, benzoate, ascorbate, α-ketoglutarate, and α-glycerophosphate, formate, fumarate, propionate, glycolate, lactate, pyruvate, oxalate, maleate, salicyate, sulfate, sulfonate, nitrate, bicarbonate, hydrobromate, hydrobromide, hydroiodide, carbonate, and phosphoric acid salts.

Figure 1a



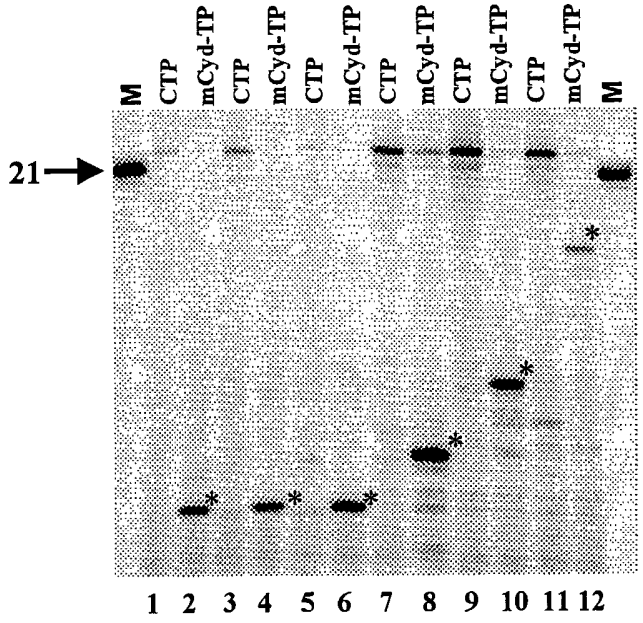
where: R = H

Figure 1b



where R = Bz

Figure 2



Lane #	template	→
1-2	(-21)	3' CAUAU**G**CUCUUAAUCUUUUCC
3-4	(-21)-7G	3' CAUAU**GG**UCUUAAUCUUUUCC
5-6	(-21)-9G	3' CAUAU**G**CU**G**UUAAUCUUUUCC
7-8	(-21)-6C/7G	3' CAUAUC**G**UCUUAAUCUUUUCC
9-10	(-21)-6C/9G	3' CAUAUCCU**G**UUAAUCUUUUCC
11-12	(-21)-6C/15G	3' CAUAUCCUCUUAAU**G**UUUUCC

Figure 3

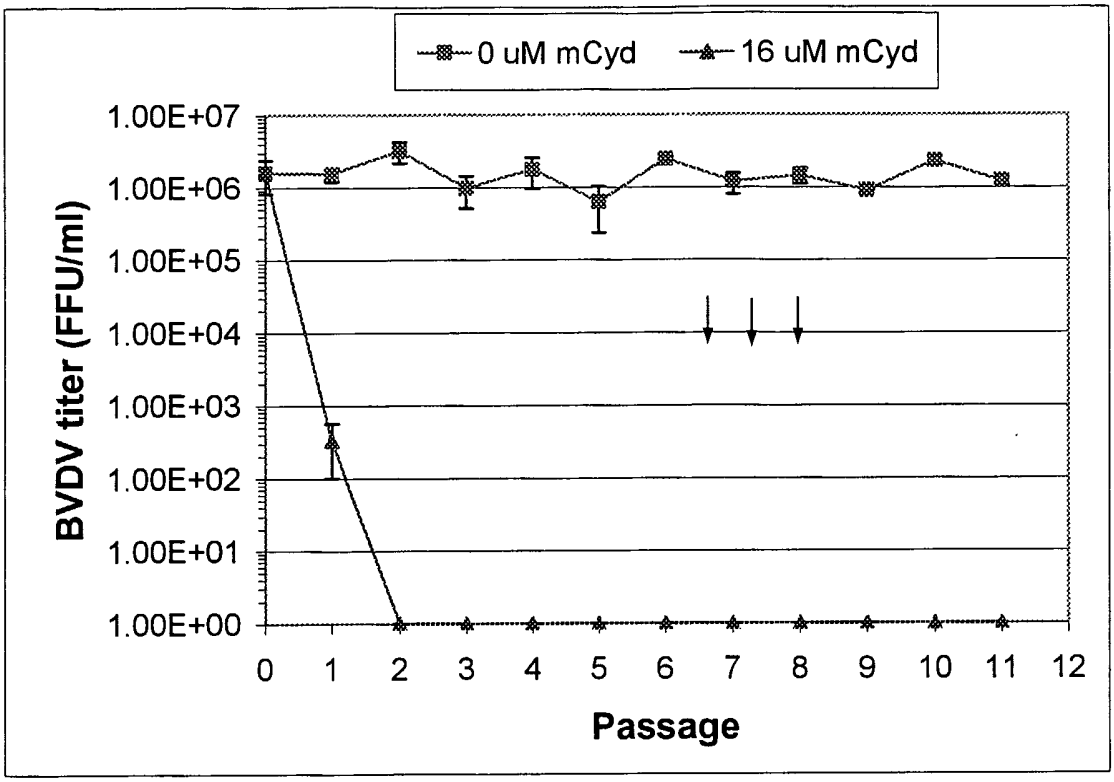
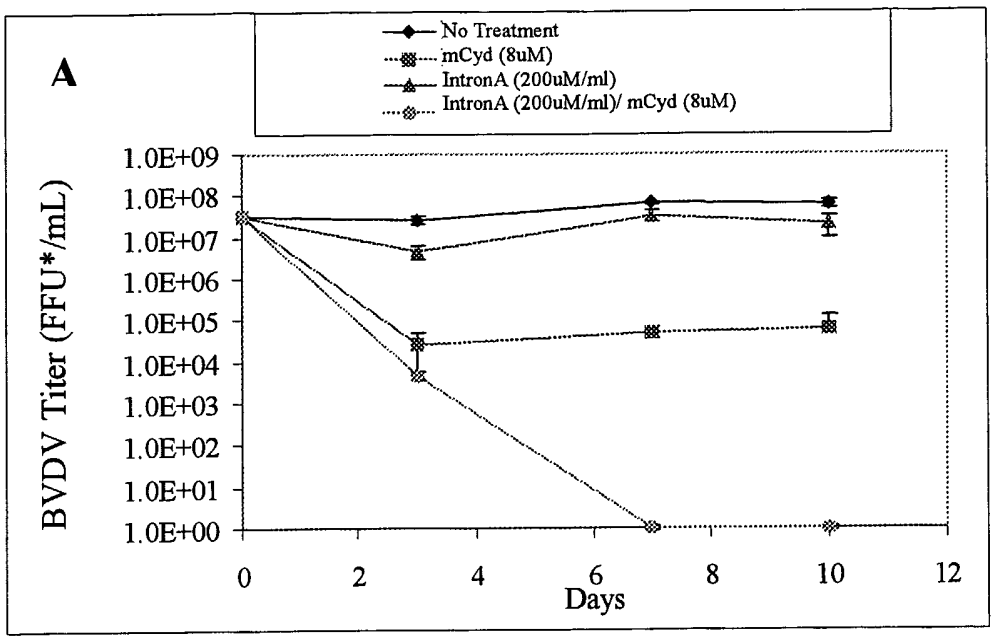

0 uM mCyd
16 uM mCyd
BVDV titer (FFU/ml)
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
0
1
2
3
4
5
6
7
8
9
10
11
12
Passage

Figure 4


A
No Treatment
mCyd (8uM)
IntronA (200uM/ml)
IntronA (200uM/ml)/ mCyd (8uM)
BVDV Titer (FFU*/mL)
1.0E+09
1.0E+08
1.0E+07
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E+02
1.0E+01
1.0E+00
0
2
4
6
8
10
12
Days

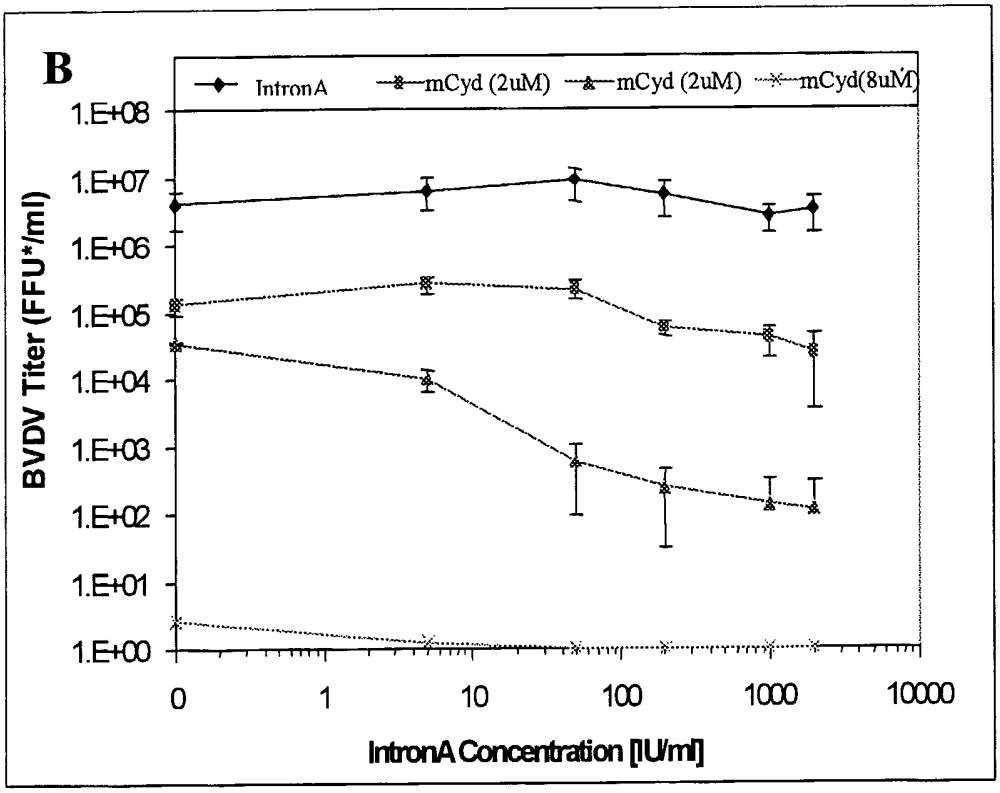

B
IntronA
mCyd (2uM)
mCyd (2uM)
mCyd(8uM)
BVDV Titer (FFU*/ml)
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
0
1
10
100
1000
10000
IntronA Concentration [IU/ml]

Figure 5

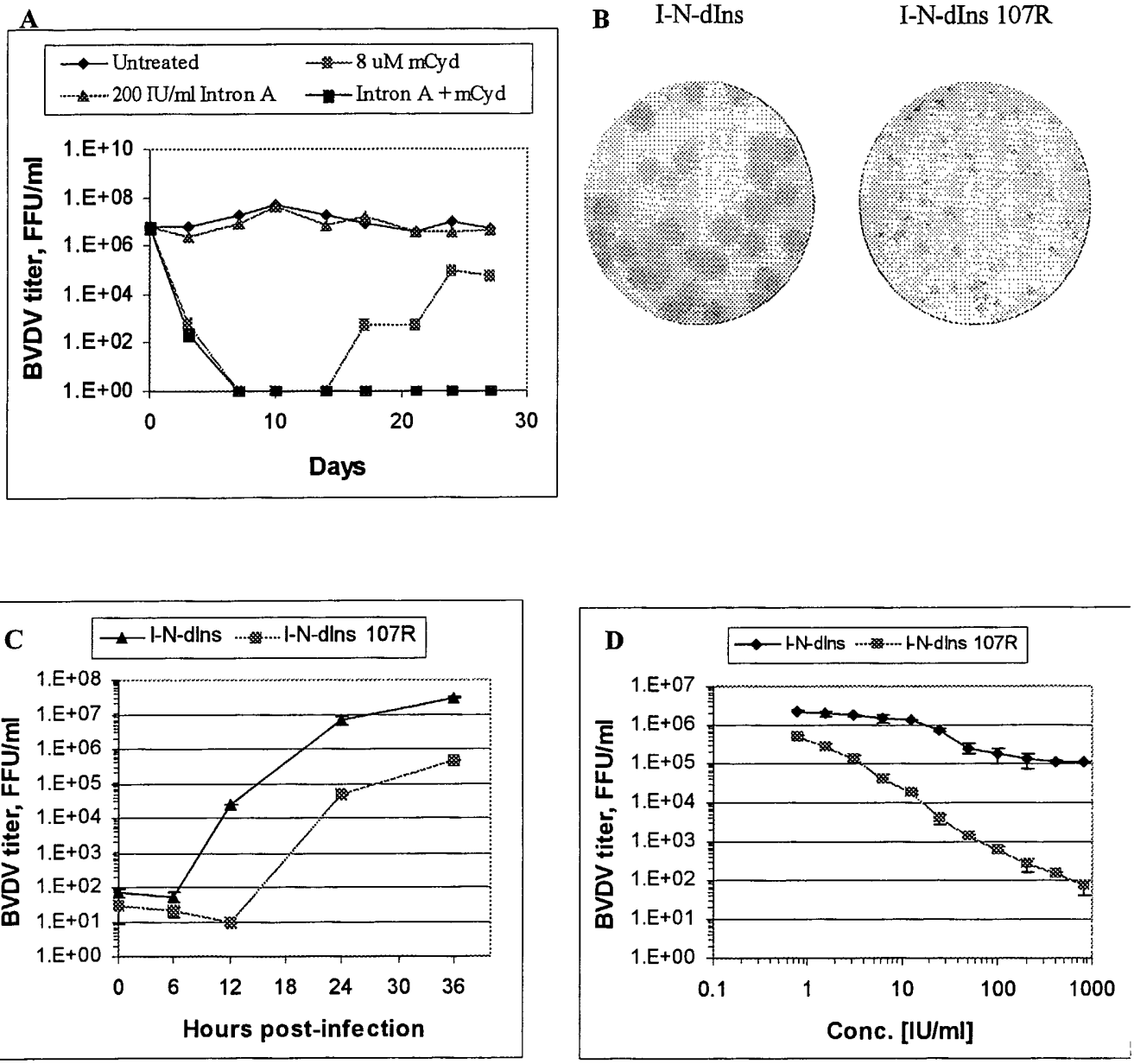

A
Untreated
8 uM mCyd
200 IU/ml Intron A
Intron A + mCyd
BVDV titer, FFU/ml
1.E+10
1.E+08
1.E+06
1.E+04
1.E+02
1.E+00
0
10
20
30
Days
B
I-N-dIns
I-N-dIns 107R
C
I-N-dIns
I-N-dIns 107R
BVDV titer, FFU/ml
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
0
6
12
18
24
30
36
Hours post-infection
D
I-N-dIns
I-N-dIns 107R
BVDV titer, FFU/ml
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
0.1
1
10
100
1000
Conc. [IU/ml]

Figure 6

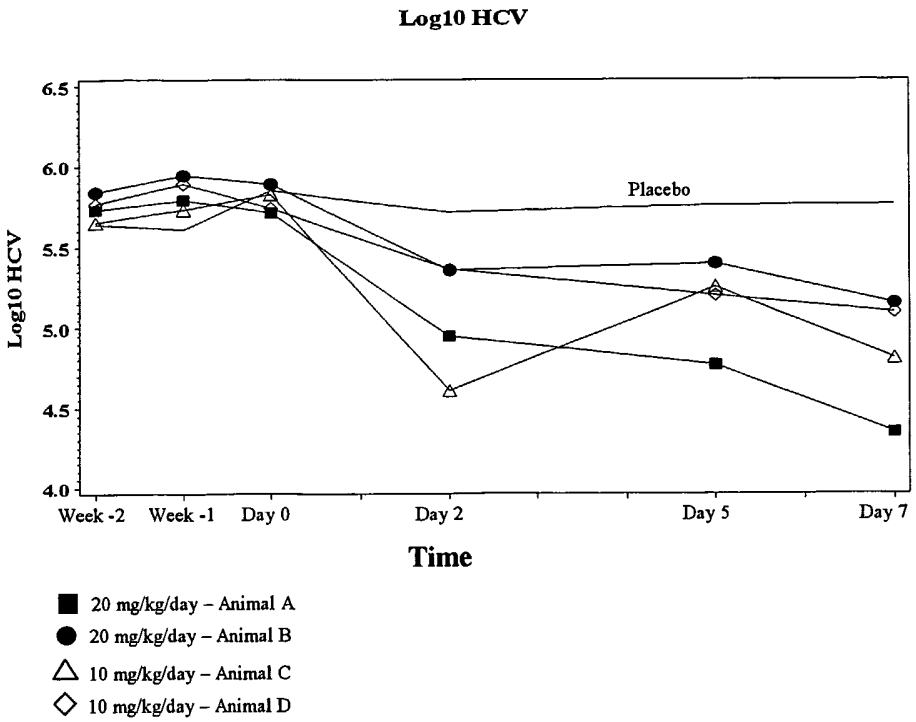

Log10 HCV
6.5
6.0
5.5
5.0
4.5
4.0
Log10 HCV
Placebo
Week -2
Week -1
Day 0
Day 2
Day 5
Day 7
Time
20 mg/kg/day – Animal A
20 mg/kg/day – Animal B
10 mg/kg/day – Animal C
10 mg/kg/day – Animal D

Figure 7

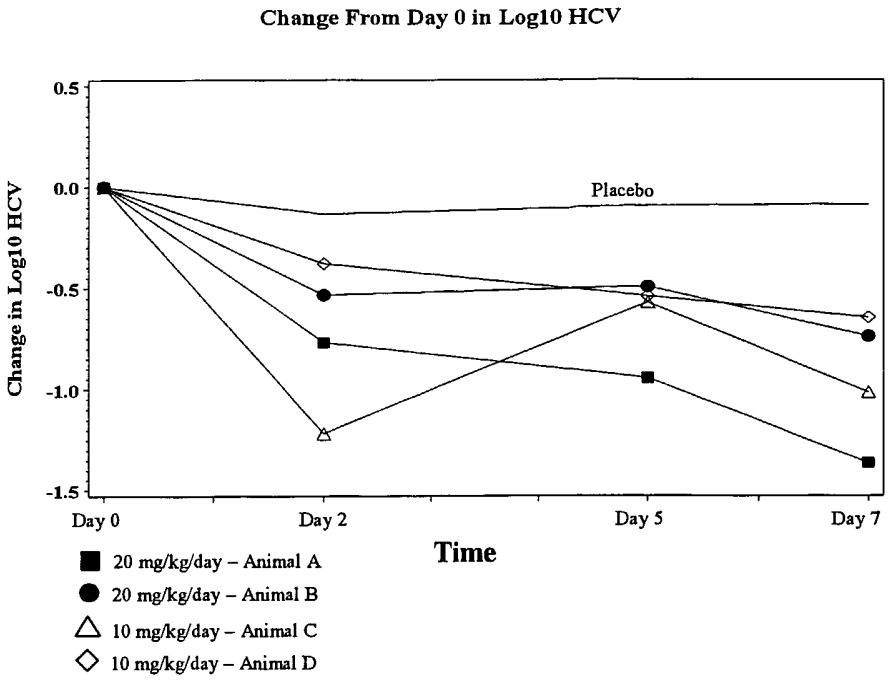

Change From Day 0 in Log10 HCV
Change in Log10 HCV
0.5
0.0
-0.5
-1.0
-1.5
Placebo
Day 0
Day 2
Day 5
Day 7
Time
20 mg/kg/day – Animal A
20 mg/kg/day – Animal B
10 mg/kg/day – Animal C
10 mg/kg/day – Animal D

Figure 8

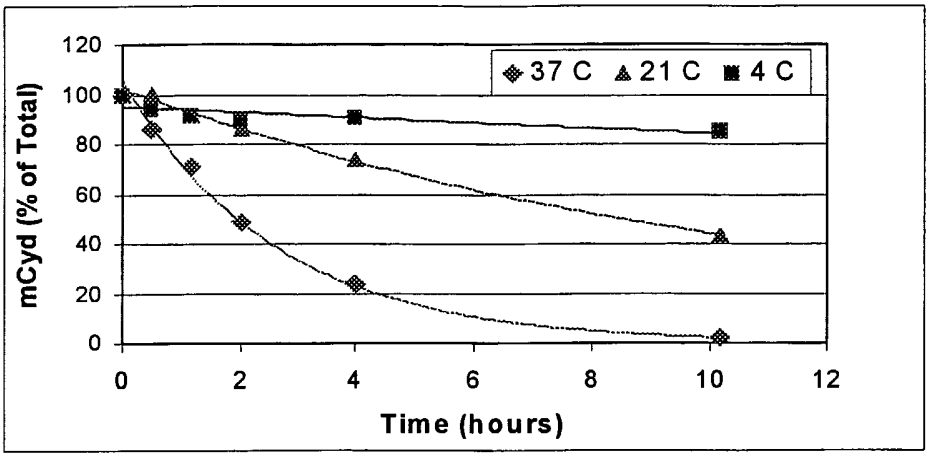

37 C
21 C
4 C
mCyd (% of Total)
120
100
80
60
40
20
0
0
2
4
6
8
10
12
Time (hours)

Figure 9

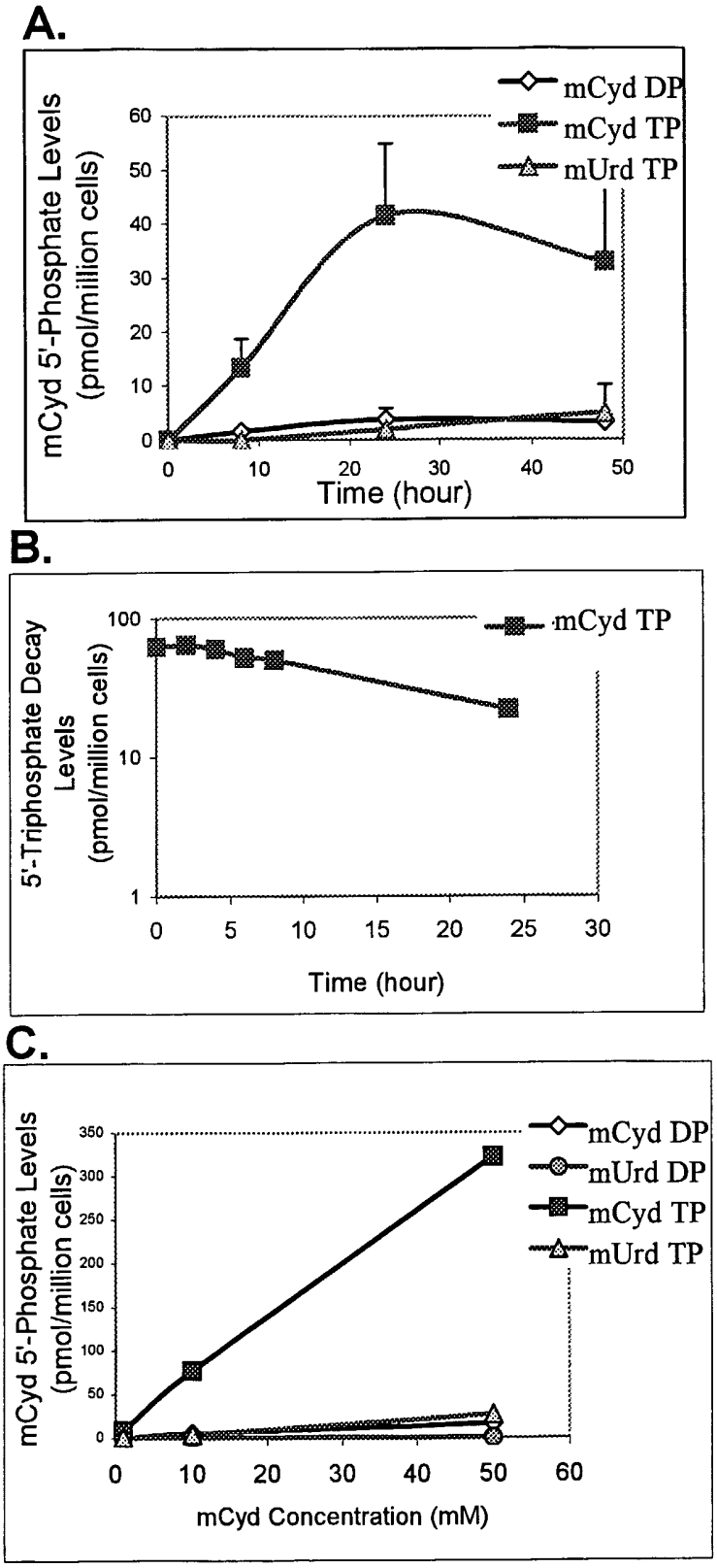

A.
mCyd 5'-Phosphate Levels (pmol/million cells)
mCyd DP
mCyd TP
mUrd TP
Time (hour)
B.
5'-Triphosphate Decay Levels (pmol/million cells)
mCyd TP
Time (hour)
C.
mCyd 5'-Phosphate Levels (pmol/million cells)
mCyd DP
mUrd DP
mCyd TP
mUrd TP
mCyd Concentration (mM)

Figure 10

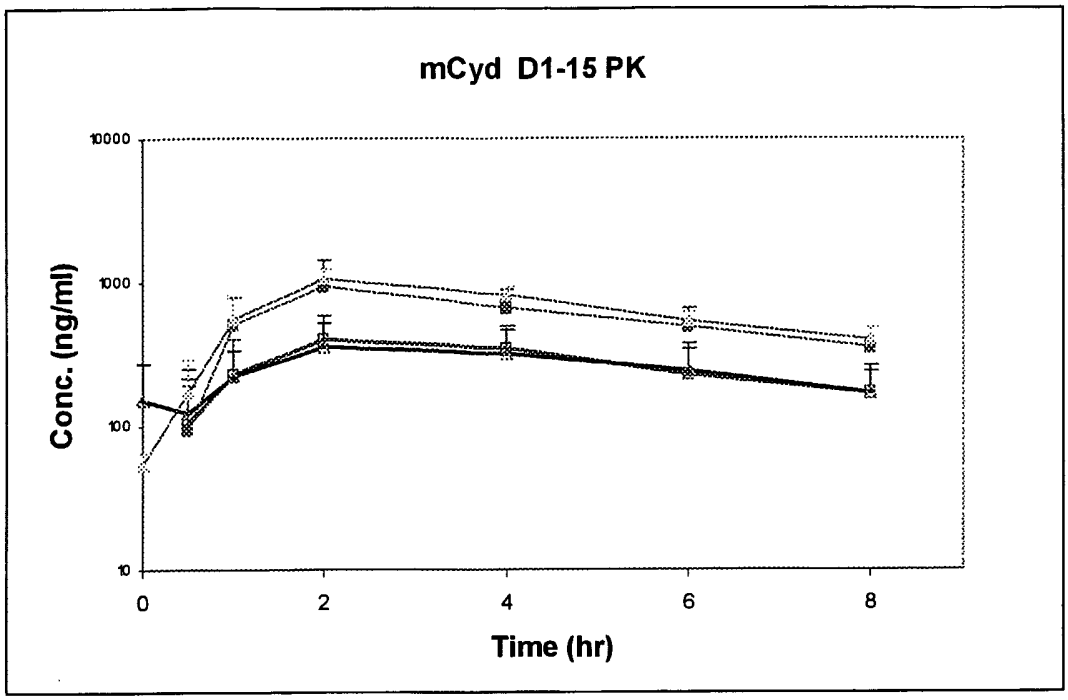
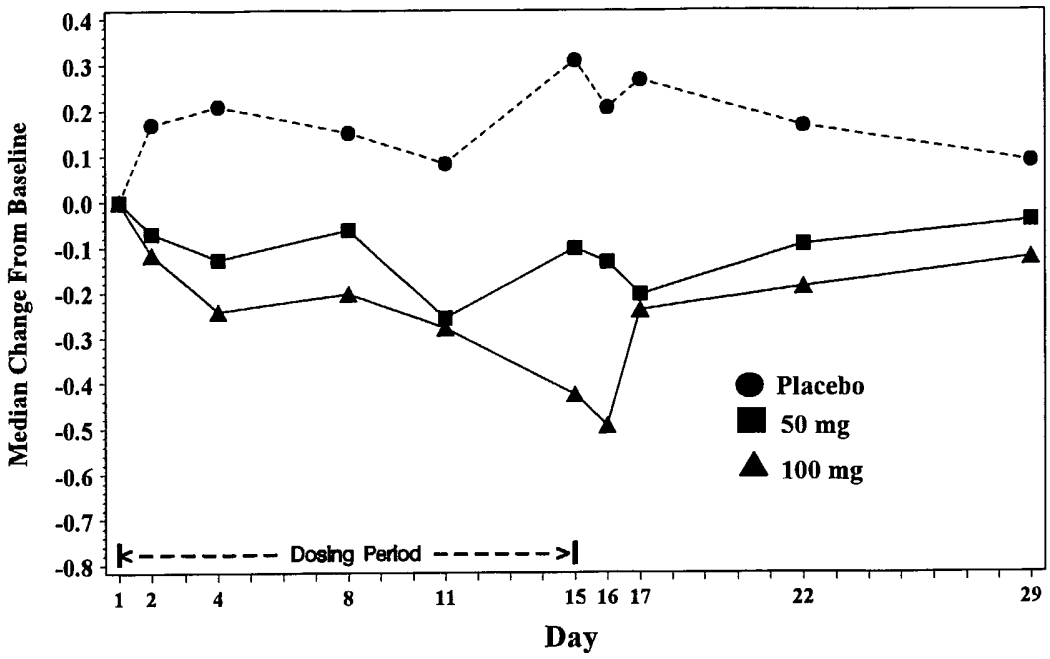


Figure 11


Median Change From Baseline
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
Dosing Period
1 2 4 8 11 15 16 17 22 29
Day
Placebo
50 mg
100 mg