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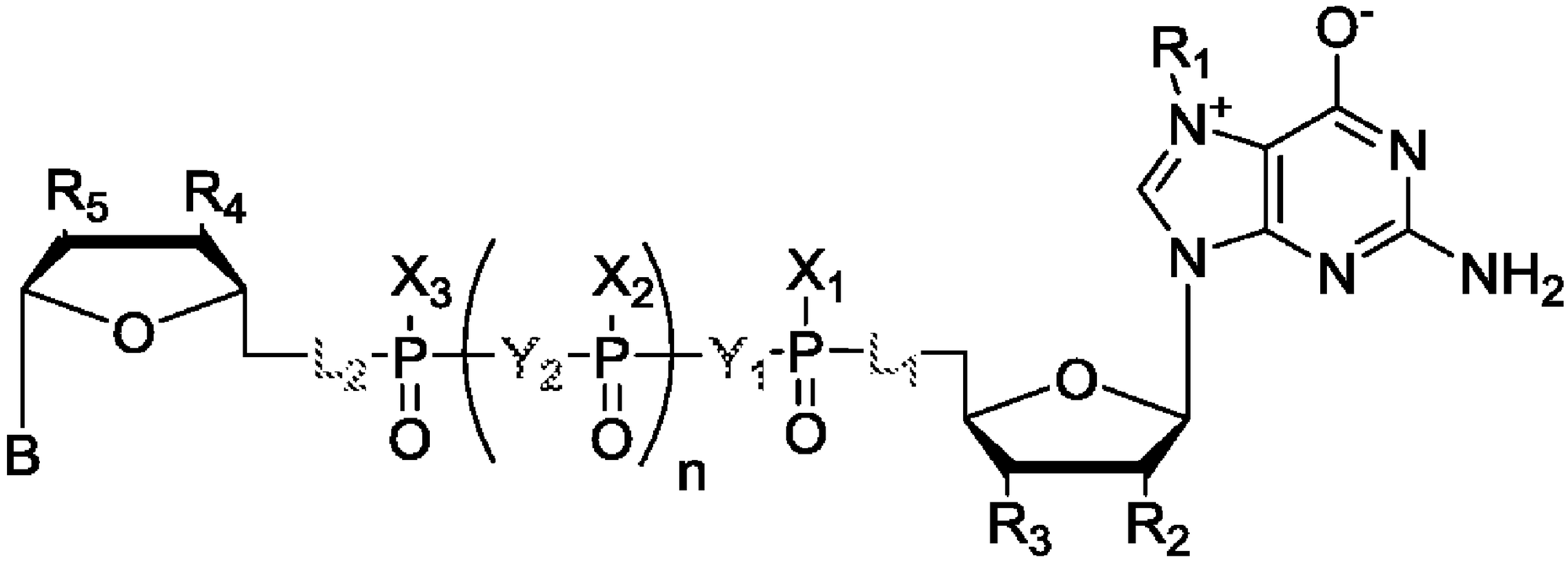
(54) **Titre : ANALOGUES D'EXTREMITE 5' (COIFFE) D'ARNM 5'-PHOSPHOROTHIOLATE , ARNM LES COMPRENANT, LEUR PROCEDE D'OBTENTION ET UTILISATIONS**
(54) **Title: 5'-PHOSPHOROTHIOLATE MRNA 5'-END (CAP) ANALOGS, MRNA COMPRISING THE SAME, METHOD OF OBTAINING AND USES THEREOF**



Formula 1

(57) **Abrégé/Abstract:**
The present invention relates to nucleotides, analogs of mRNA 5'-end (cap) containing sulfur atom at the position 5' of 7-methylguanosine nucleoside. The disclosed compounds are recognized (bound and non-hydrolyzed) by DcpS enzyme (Decapping Scavenger), and thus may find therapeutic use as inhibitors thereof. DcpS is cap-specific enzyme with pyrophosphatase activity, which was identified as a therapeutic target in the treatment of spinal muscular atrophy (SMA). Some of the compounds disclosed have additional modifications in the phosphate chain, wh ich modulate their affinity for DcpS enzyme. The present invention also relates to mRNAs modified at the 5' end with mRNA 5'-end (cap) analogs containing 5'-phosphorothiolate moiety, which mRNAs have an increased stability and translational activity in cellular conditions, to a method of their preparation, their uses, and to a pharmaceutical formulation containing them, wherein L^1 and L^2 are independently selected from the group comprising O and S, wherein at least one of L^1 and L^2 is not O.

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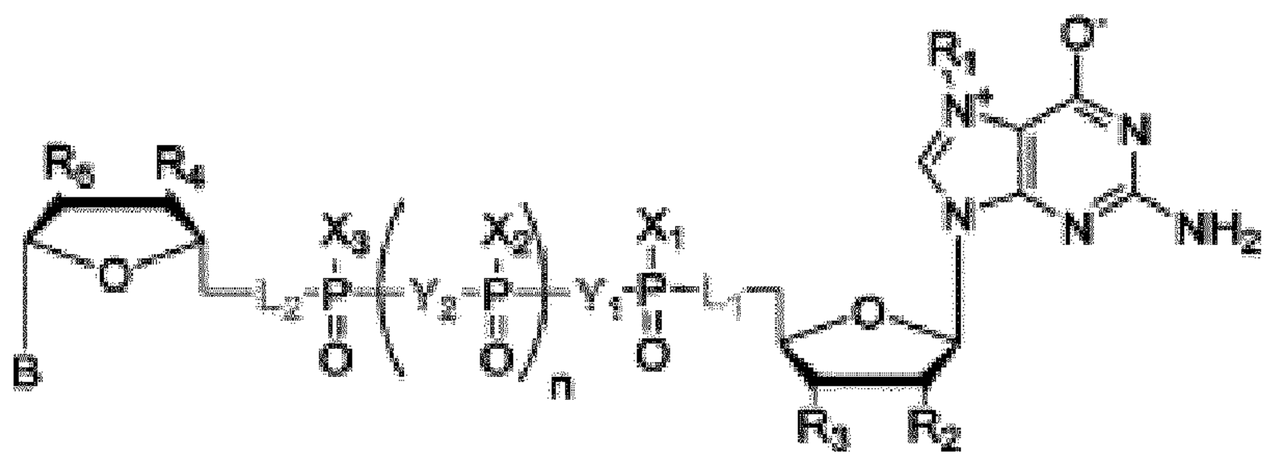
(54) Title: 5'-PHOSPHOROTHIOLATE MRNA 5'-END (CAP) ANALOGS, MRNA COMPRISING THE SAME, METHOD OF OBTAINING AND USES THEREOF



Formula 1

(57) **Abstract**: The present invention relates to nucleotides, analogs of mRNA 5'-end (cap) containing sulfur atom at the position 5' of 7-methylguanosine nucleoside. The disclosed compounds are recognized (bound and non-hydrolyzed) by DcpS enzyme (Decapping Scavenger), and thus may find therapeutic use as inhibitors thereof. DcpS is cap-specific enzyme with pyrophosphatase activity, which was identified as a therapeutic target in the treatment of spinal muscular atrophy (SMA). Some of the compounds disclosed have additional modifications in the phosphate chain, wh ich modulate their affinity for DcpS enzyme. The present invention also relates to mRNAs modified at the 5' end with mRNA 5'-end (cap) analogs containing 5'- phosphorothiolate moiety, which mRNAs have an increased stability and translational activity in cellular conditions, to a method of their preparation, their uses, and to a pharmaceutical formulation containing them, wherein L^1 and L^2 are independently selected from the group comprising O and S, wherein at least one of L^1 and L^2 is not O.

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5′-phosphorothiolate mRNA 5′-end (cap) analogs, mRNA comprising the same, method of obtaining and uses thereof

DESCRIPTION

TECHNICAL FIELD

The present invention relates to analogs of mRNA 5′-end (cap) containing 5′-phosphorothiolate moiety, a method of their preparation, intermediates and uses thereof.

5′-phosphorothiolate cap analogs are used as DcpS enzyme inhibitors which enables their application as a medicine, especially for spinal muscular atrophy (SMA) treatment. The present invention also relates to mRNA modified at the 5′ end with mRNA 5′-end (cap) analogs containing 5′- phosphorothiolate moiety according to the invention, wherein the modification aims at obtaining of mRNA transcripts with an increased stability and translational activity under cellular conditions. Transcripts with such properties are applicable in novel gene therapies based on mRNA.

BACKGROUND ART

Chemically derived mRNA 5′-end analogs have a variety of uses, and modifications implemented within this structure may significantly modify the biological properties of these compounds (Ziemniak, Strenkowska et al., 2013). Among the various applications of cap analogs, the most frequent involve their use as low-molecular inhibitors of cap-dependent processes for therapeutic purposes (e.g., inhibition of DcpS enzyme – spinal muscular atrophy therapy). On the other hand, suitably modified dinucleotide cap analogs are used to modify messenger mRNA by co-transcription *in vitro*, in order to obtain transcripts with improved stability and translational activity under cellular conditions. Transcripts with such properties are being increasingly studied in the context of novel gene therapies based on mRNA. In the latter case, cap structure resistance to another decapping enzyme, Dcp2, is a key issue.

DcpS enzyme (Decapping Scavenger) is an enzyme involved in mRNA degradation process in eukaryotes. There are two main pathways of mRNA degradation in eukaryotic cells, 5′→3′ degradation and 3′→5′ degradation (Rydzik, Lukaszewicz et al., 2009). Both degradation pathways are initiated by deadenylation. The degradation in direction 5′ → 3′ is followed by mRNA decapping as a result of cutting of the bond between α and β phosphates, and degradation by 5′-exonuclease. 3′→5′ degradation involves mRNA degradation by exosome starting from the 3′-end. Such degradation results in a release of dinucleotide cap residues or cap-ended short oligonucleotides, which are then degraded by DcpS enzyme. DcpS belongs to HIT family pyrophosphatases and hydrolyzes the cap between γ and β phosphates releasing 7-

methylguanosine 5′-monophosphate (m^7GMP) and a second product, which is accordingly a nucleoside 5′-diphosphate or a short oligonucleotide. Longer cap-ended mRNA are not substrates for DcpS. Also 7-methylguanosine 5′-diphosphate (m^7GDP), which is a product of 5′→3′ mRNA degradation, is not a substrate for DcpS. An activity of DcpS enzyme is considered vital for cell homeostasis, since unnecessary cap residues released from mRNA during 3′→5′ degradation could adversely affect other cap-dependent cellular processes. DcpS is located both in the cytoplasm and the nucleus, where it may be involved in splicing regulation (Shen, Liu et al., 2008). Therefore, it was suggested that DcpS role in the cell goes beyond its well characterized functions in 3′→5′ mRNA degradation (Bail and Kiledjian 2008).

It was reported in 2008 that DcpS inhibition can provide a therapeutic effect in spinal muscular atrophy. SMA is a common neurodegenerative disease occurring on average once every 6000 births (Akagi and Campbell 1962). It is caused by low levels of SMN protein (Survival Motor Neuron), which is encoded by *SMN* genes. Two SMN genes, i.e., *SMN1* and *SMN2*, are present in humans. The main difference between them is a sequence change in exon 7, which affects pre-mRNA splicing. As a result, an expression of *SMN1* gene leads to a stable and functional protein, while the protein expressed from *SMN2* is shortened. Mutations in both copies of *SMN1* gene, including deletions, conversions to *SMN2*-like gene and point mutations, result in SMA disease. People who have only one defective *SMN1* copy are SMA carriers, but do not show any symptoms of the disease.

Homologous SMN2 gene cannot provide sufficient amounts of functional SMN protein, but it was observed that higher number of SMN2 gene copies is accompanied by a more benign course of the disease. Therefore, it is believed that compounds which increase an amount of protein encoded by the SMN2 gene in a cell can be therapeutics against SMA. It was found that some 5-substituted quinazolines may increase SMN2 gene expression even twofold (Akagi and Campbell, 1962). Trying to unravel the molecular mechanism underlying this activation, in another study using radioactive labeling, authors identified DcpS as the protein binding 5-substituted quinazoline.

These experiments allowed to identify DcpS as a therapeutic target in SMA treatment.

Further studies indicated that various C5-substituted quinazolines are potent inhibitors of the DcpS enzyme (already at nanomolar concentrations), and that the inhibitor potential is correlated with the level of *SMN2* gene promoter activation. The therapeutic potential of these compounds was then demonstrated *in vivo* in a mouse model (Butchbach, Singh et al., 2010). It was reported recently that one of the DcpS inhibitors, RG3039 compound, improves motor function in mice with SMA (Van Meerbeke, Gibbs et al,).

Despite ongoing preclinical and clinical trials, there is still no effective treatment of SMA, therefore, there is a continuing need for new compounds with therapeutic potential.

Dinucleotide cap analogs with modifications in triphosphate bridge and 7-methylguanosine ribose may be used for the synthesis of capped RNA molecules in vitro. The method is useful

since it allows to obtain RNA molecules with improved biological properties, in particular, an increased translational activity and prolonged half-life in cells (Grudzien, Kalek et al., 2006). These both features cause, that a significantly higher amount of protein is obtained while utilizing the same amount of mRNA. This may find a wide range of applications both in research, and for commercial production of peptides and proteins, including therapeutic applications, e.g. in cancer immunotherapy (Sahin, Kariko et al., 2014).

The most common method used to obtain capped mRNA in vitro, is the synthesis of mRNA on DNA template using bacterial or bacteriophage RNA polymerase in the presence of all four ribonucleoside triphosphates and a cap dinucleotide such as (m^7GpppG). Polymerase initiates the transcription by nucleophilic attack of 3′-OH of Guo moiety in m^7GpppG on alpha-phosphate of the next transcribed nucleoside triphosphate, resulting in m^7GpppGpN as an initial product (Contreras and Fiers 1981, Konarska, Padgett et al., 1984).

The amount of protein produced by a synthetic mRNA introduced to a culture of mammalian cells is limited by mRNA degradation in cellular conditions. *In vivo* mRNA degradation is mainly initiated by cap removal from the 5′-end of mRNA by a specific pyrophosphatase Dcp1/Dcp2 which cleaves the bond between the alpha and beta phosphates (Mildvan, Xia et al., 2005). Dcp2 enzyme, which forms a complex with a regulatory protein Dcp1, is responsible for cleaving off the cap structure from the full length transcripts or from at least 20 nucleotide fragments thereof (Lykke-Andersen 2002). The Dcp1/Dcp2 complex plays a key role in gene expression regulation. Making the mRNA transcripts within the cap resistant to this enzyme activity leads to an increased expression of the protein encoded by such modified mRNA (Ziemniak, Strenkowska et al., 2013). When the modification does not simultaneously impair interactions with a translation initiating factor, then this leads to an increased mRNA translational activity. mRNAs having such properties are desirable for therapeutic applications including cancer immunotherapy (Kuhn, Diken et al., 2010), stem cells reprogramming (Warren, Manos et al., 2010) or supplementation of proteins formed in the cells in a defected form or in insufficient quantities. Modifications in a triphosphate bridge of a cap structure are known in literature, increasing the resistance to Dcp2 enzyme. These include, inter alia, analogs where oxygen atoms at alpha-beta bridge position were substituted with a methylene group, analogs, where the non-bridge oxygen at beta position was replaced by a sulfur atom or a boranophosphate group. In the case of the methylene analog, an increased mRNA stability did not result in an increase in the efficiency of protein synthesis in cells, which was probably due to decreased affinity to eIF4E protein (Grudzien, Kalek et al., 2006). In the case of non-bridge modifications in beta position, an increased resistance to Dcp2 and increased affinity for eIF4E resulted in an increased translational activity of such modified mRNA in the cells (Grudzien-Nogalska, Jemielity et al., 2007) (Kowalska, Wypijewska del Nogal et al., 2014). A common feature of all cap analogs that upon incorporation into mRNA demonstrated reduced susceptibility to degradation by Dcp2 was

the localization of the modification near the site of cap cleavage by enzyme, i.e., alpha-beta position in triphosphate bridge.

DISCLOSURE OF INVENTION

Taking into account the described state of the art, the aim of the present invention is to overcome the indicated disadvantages and to provide a new class of nucleotide mRNA 5′-end analogs affecting DcpS activity, their uses, including in SMA treatment, as well as methods for their synthesis.

Another aim of the invention is to provide mRNA modified at the 5′ end with mRNA 5′-end (cap) analogs containing 5′-phosphorothiolate moiety, thereby increasing mRNA stability and biosynthesis efficiency of protein encoded by that mRNA in the cells. Another aim of the invention is to provide mRNA modified at the 5′ end with mRNA 5′-end (cap) analogs containing 5′-phosphorothiolate moiety, which transcripts are intended for use as a medicine, including for use in novel gene therapies based on mRNA.

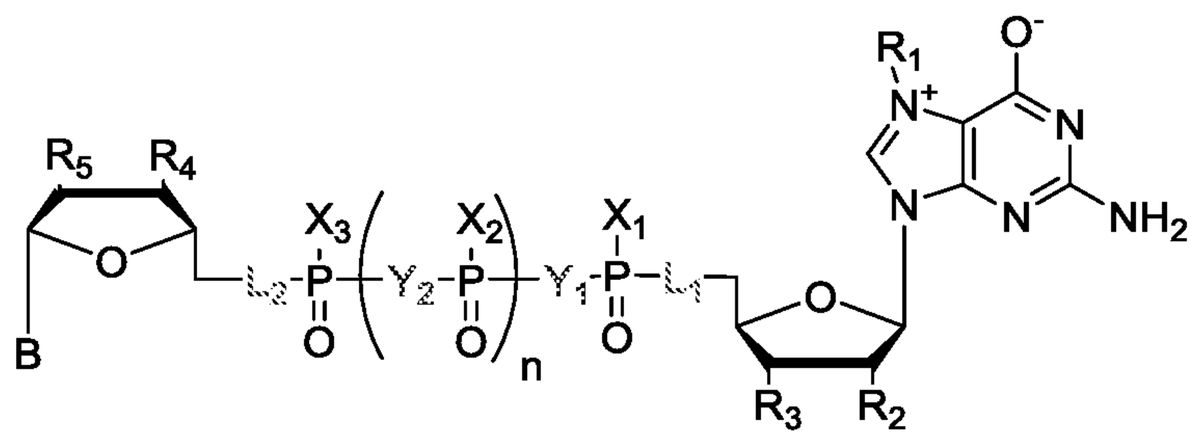
The present invention relates to a novel class of nucleotide mRNA 5′-end analogs. The new analogs contain sulfur atom at the position of 5′-nucleoside, i.e., at least one of oxygen atoms in position 5′ was replaced by a sulfur atom. We surprisingly discovered that the new analogs containing the modification with sulfur atom in position 5′ from the side of 7-methylguanosine are resistant to hydrolytic activity of DcpS enzyme, and are inhibitors of DcpS enzyme, thus affecting the expression of SMN proteins, which is of therapeutic relevance in SMA treatment. Such compounds being stable against the activity of DcpS and/or affecting DcpS activity will also be used in the regulation of mRNA degradation as well as splicing modulation and regulation. The following analogs were found to be particularly preferred from the viewpoint of inhibitory properties: m^7G**S**pppG (no. 24), m^7G**S**ppp**S**G (no. 32), m^7G**S**pp$_s$pG D1 (no. 30), m^7G**S**pp$_s$pG D2 (no. 31), m^7G**S**pp$_s$p**S**G D1 (no. 33), m^7G**S**pp$_s$p**S**G D2 (no. 34), and the most preferred was m^7G**S**pp$_s$p**S**G D2 (no. 34). Equally beneficial were analogs m^7G**S**pp (no. 12), m^7G**S**ppG (no. 23), m^7G**S**pp***CH$_2$***pG (no. 25), $m^{7,2'O}G$**S**pppG (no. 26), m^7Gp***CH$_2$***pp**S**G (no. 37).

The present invention also relates to mRNA modified at the 5′ end with mRNA 5′-end (cap) analogs containing 5′-phosphorothiolate moiety, thereby increasing mRNA stability and biosynthesis efficiency of protein encoded by that mRNA in the cells. The present invention also relates to mRNA modified at the 5′ end with mRNA 5′-end (cap) analogs containing 5′-phosphorothiolate moiety, which modified mRNA are intended for use as a medicine, including for the use in novel gene therapies based on mRNA.

Surprisingly, the inventors found that the new analogs according to the present invention containing the modifications with sulfur atom in position 5′ from the side of 7-methylguanosine after incorporation into mRNA by an *in vitro* transcription method become resistant to the

hydrolytic activity of enzyme Dcp1/2, and thus they affect the stability of mRNA and the efficiency of biosynthesis of protein encoded by this mRNA in a cell, including HeLa cell line. This is the first time when a modification located away from the site of triphosphate bridge cleavage in the cap by Dcp1/2 makes the cap structure resistant to the process of its removal, leading to an increased half-life of mRNA. This unexpected finding is of significant therapeutic importance in gene therapies involving an expression of the desired protein on the basis of the supplied synthetic mRNA, as is the case of specific activation of the immune system in cancer immunotherapy. Thus modified mRNA transcripts, for example encoding a protein characteristic for a given cancer type, may be used to activate the immune system against cancer cells containing this specific antigen. The following analogs were found to be particularly preferred from the viewpoint of translational properties of the modified mRNA: m^7G**S**pppG (no. 24), $m^{7,2'O}G$**S**pppG (no. 26), m^7G**S**ppp**S**G (no. 32), m^7G**S**pp$_s$pG D1 (no. 30), m^7G**S**pp$_s$pG D2 (no. 31), m^7G**S**pp$_s$p**S**G D1 (no. 33), m^7G**S**pp$_s$p**S**G D2 (no. 34),, and the most preferred was $m^{7,2'O}G$**S**pppG (no 26).

The present invention relates a 5'-phosphorothiolate cap analog according to formula 1



Formula 1

wherein

L^1 and L^2 are independently selected from the group comprising O and S, wherein at least one of L_1 and L_2 is not O;

n = 0, 1, or 2;

X_1, X_2, X_3 are independently selected from the group comprising O, S;

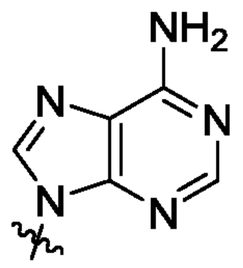
R^1 is selected from the group comprising CH_3, C_2H_5, CH_2Ph, alkyl or substituted alkyl;

R^2 and R^3 are independently selected from the group comprising H, OH, OCH_3, OC_2H_5, -COOH, CH_2COOH, N_3, CH_2N_3, alkyl, alkenyl, or alkynyl;

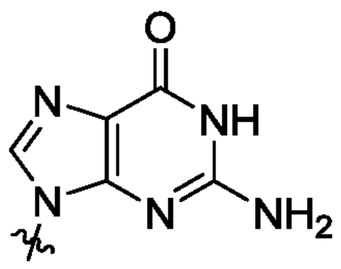
R^4 and R^5 are independently selected from the group comprising H, OH, OCH_3, OC_2H_5, -COOH, CH_2COOH, N_3, CH_2N_3, alkyl, alkenyl, or alkynyl;

Y_1, Y_2 are independently selected from the group comprising CH_2, CHCl, CCl_2, CF_2, CHF, NH, O;

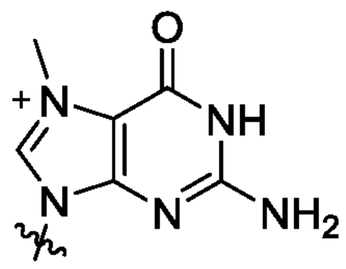
and B is a group according to formula 3, 4, 5, 6, or 7



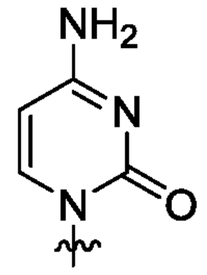
formula 3



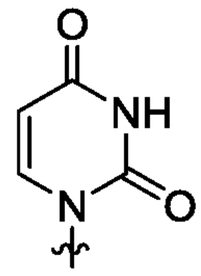
formula 4



formula 5

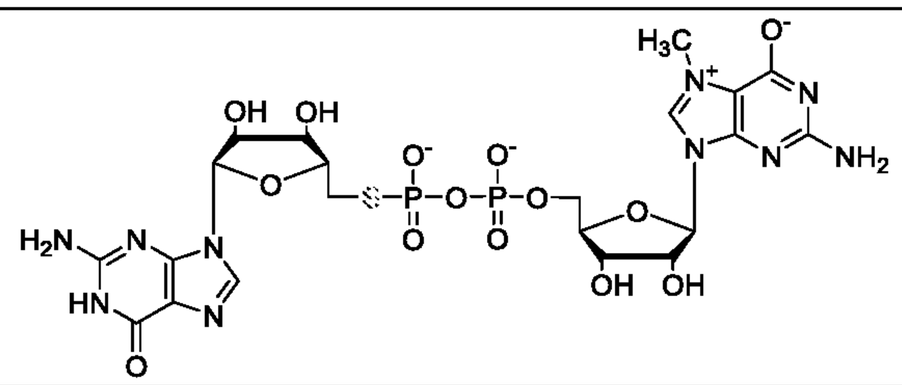
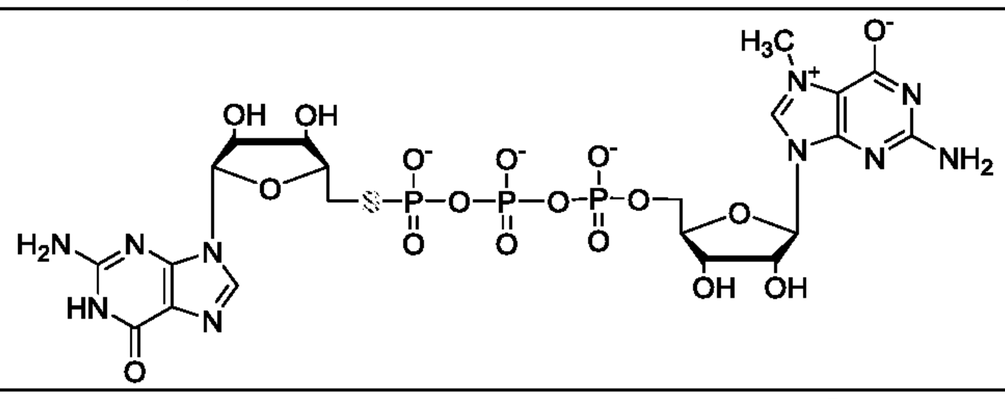
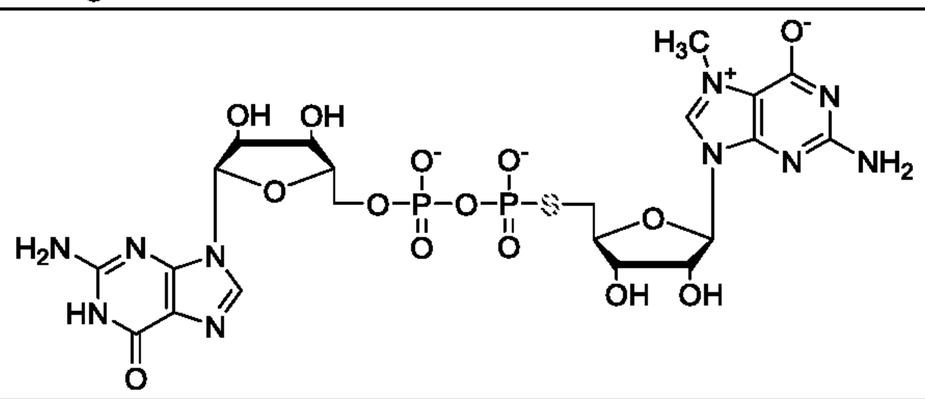
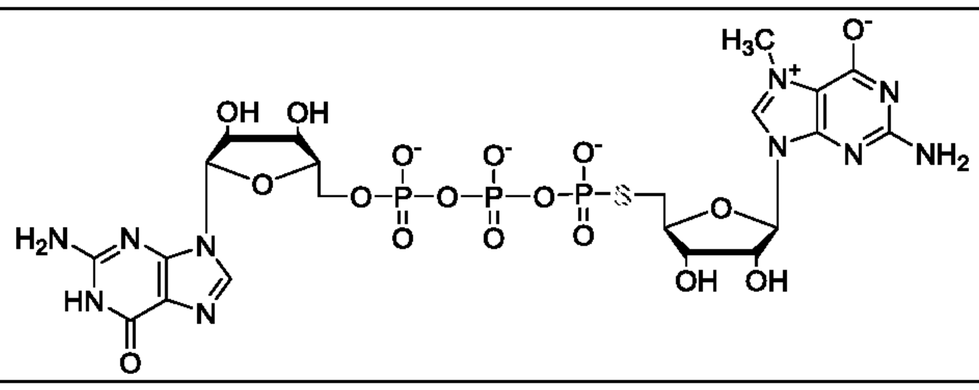
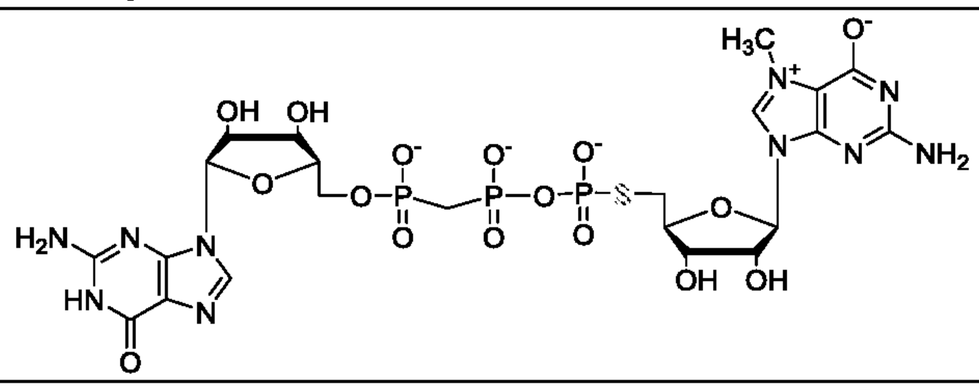
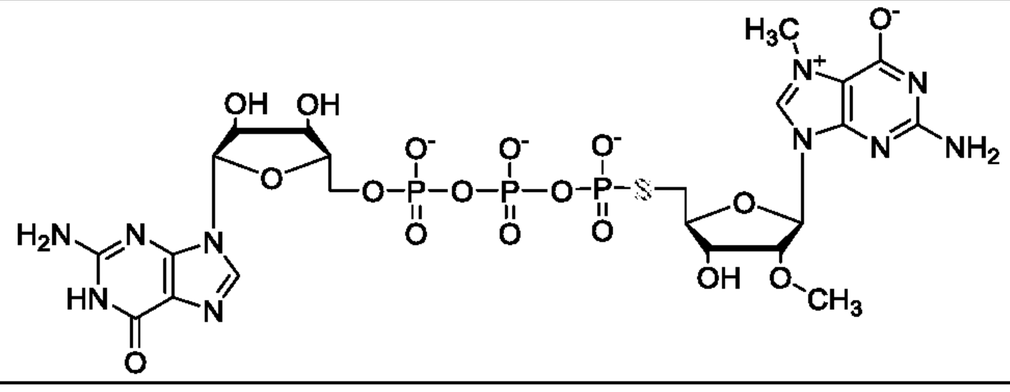


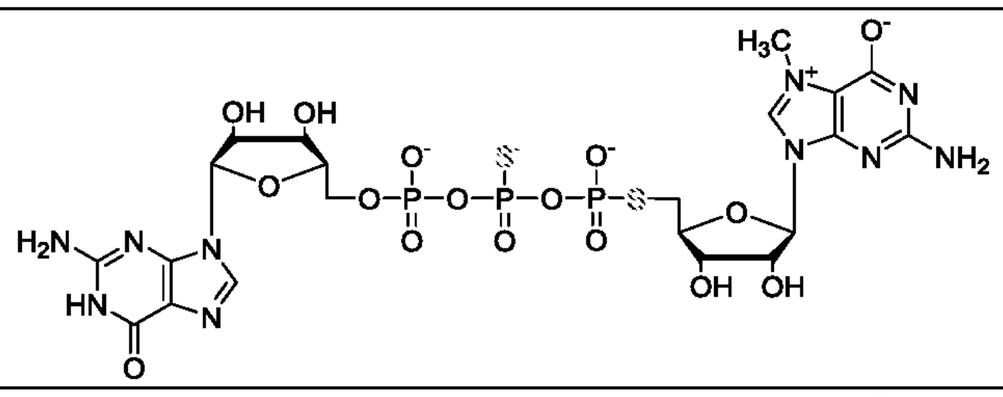
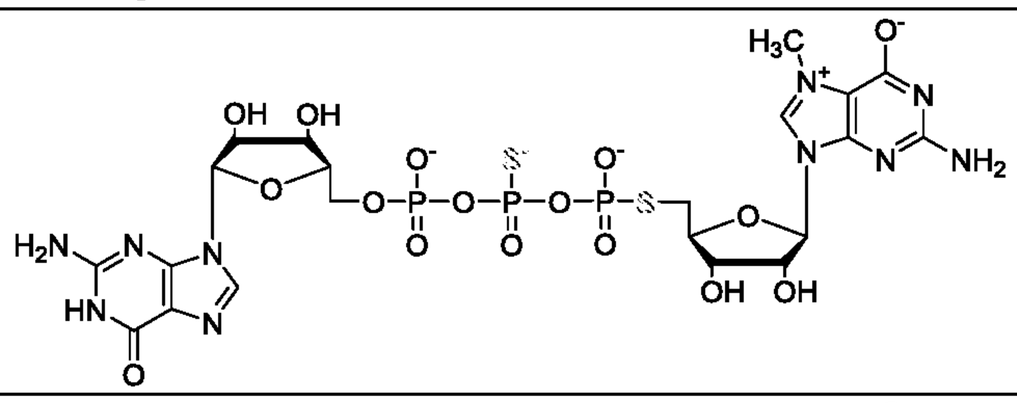
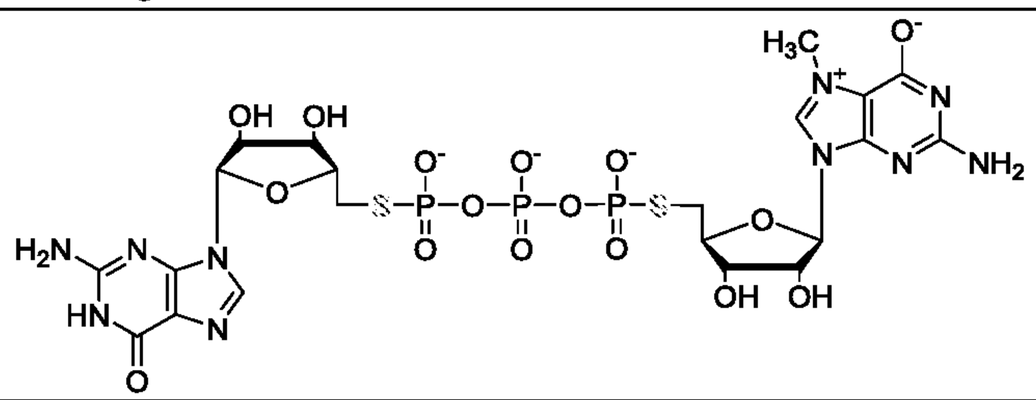
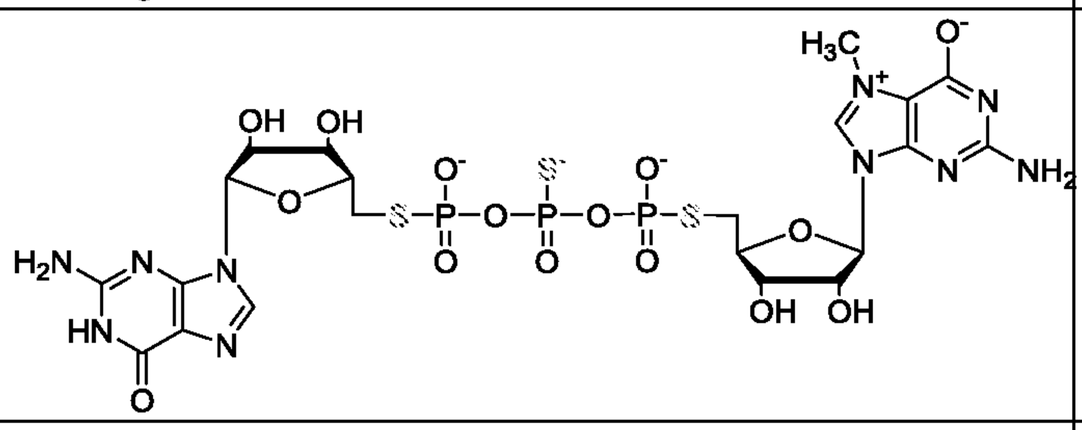
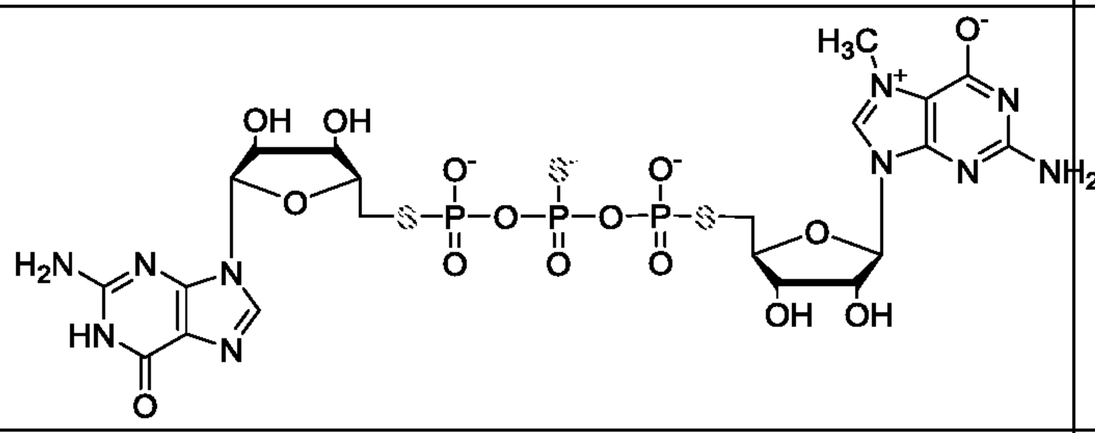
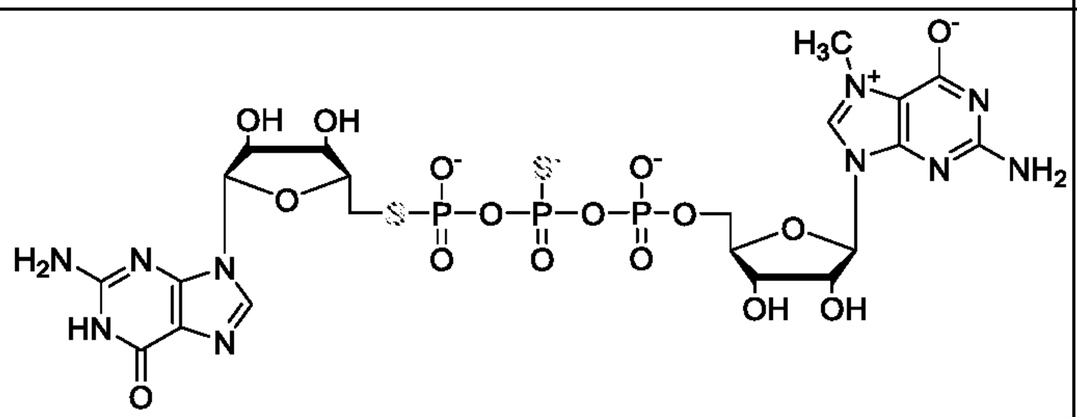
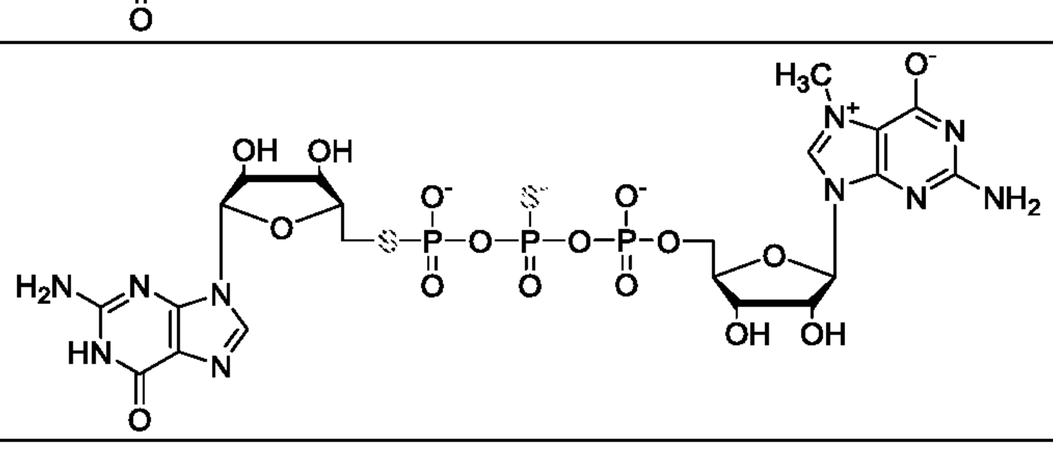
formula 6

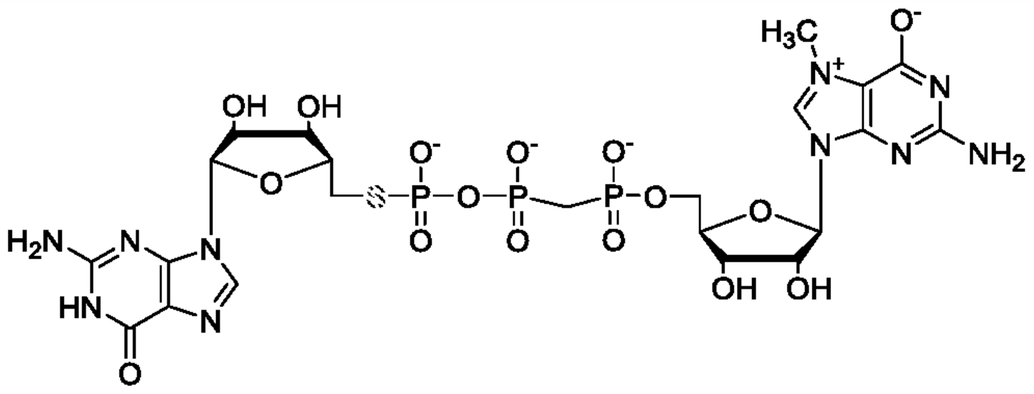
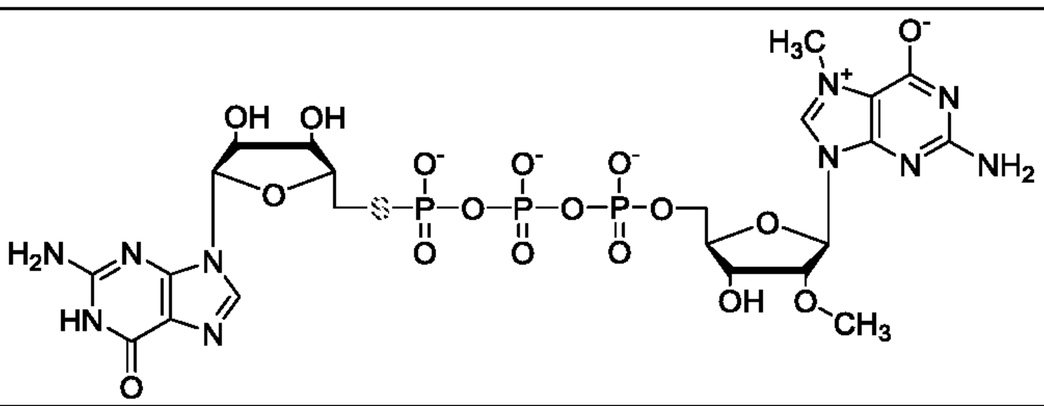


formula 7

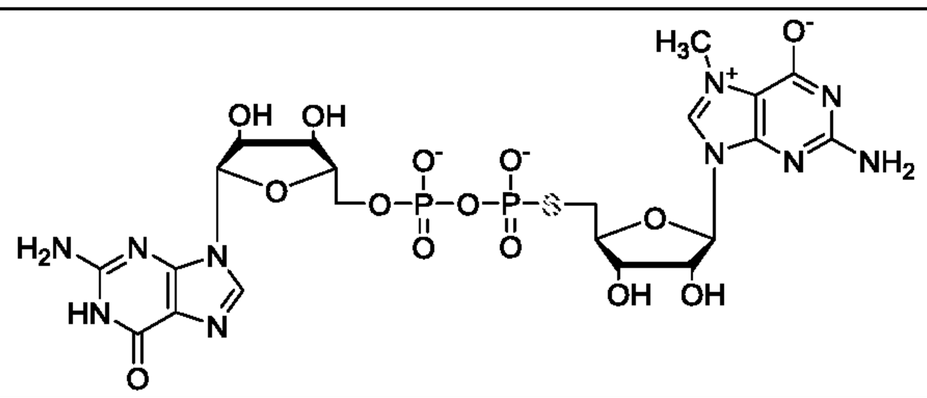
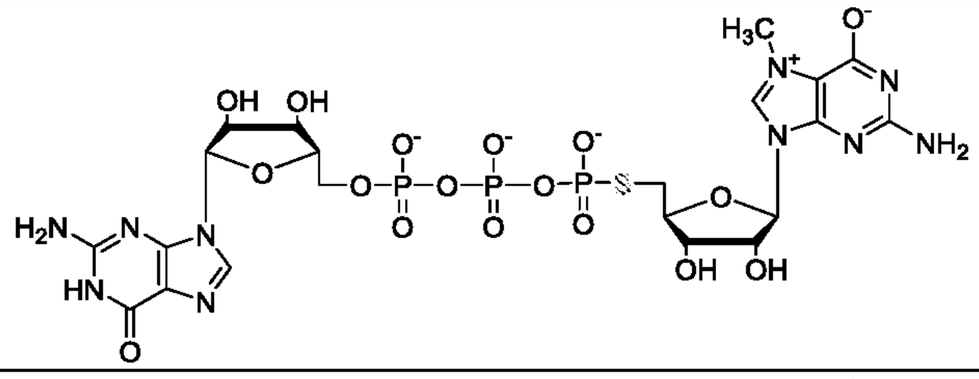
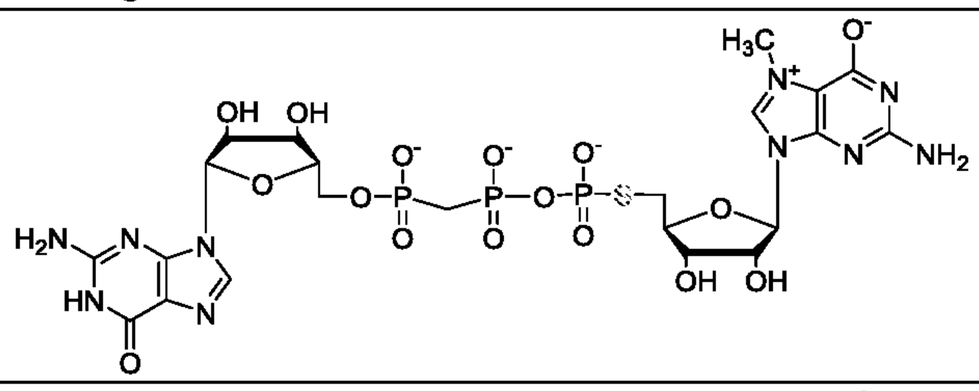
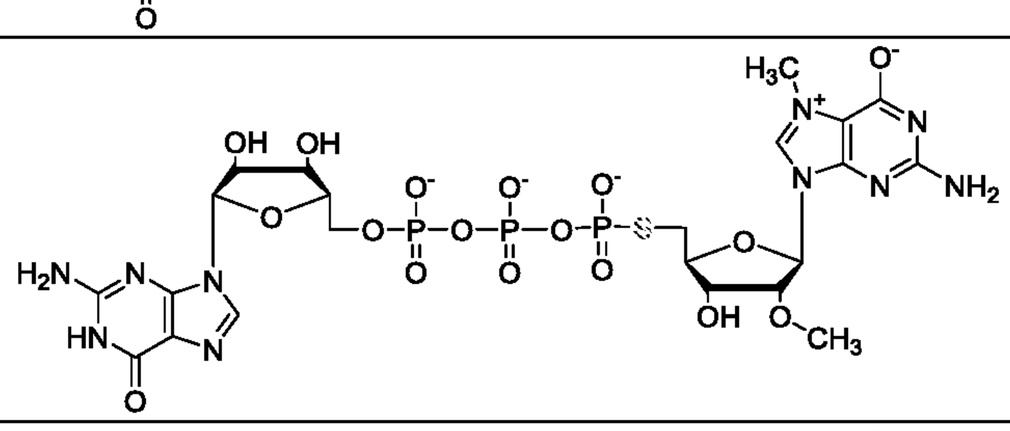
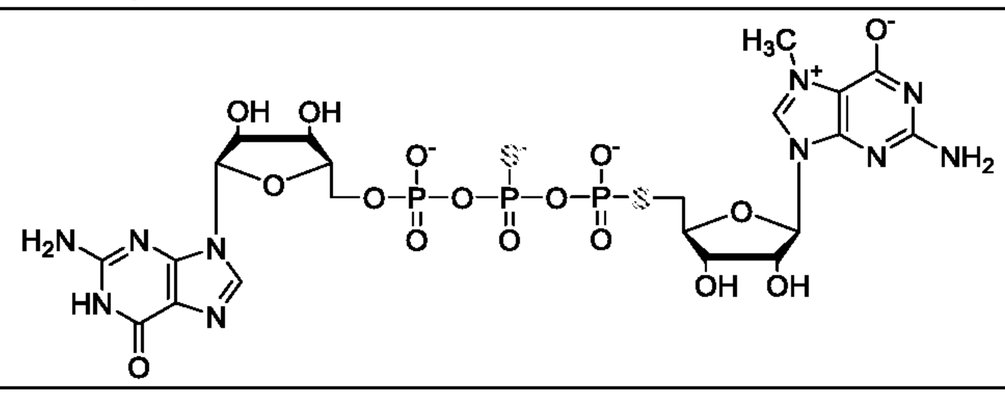
A preferred 5'-phosphorothiolate cap analog is selected from the group consisting of:

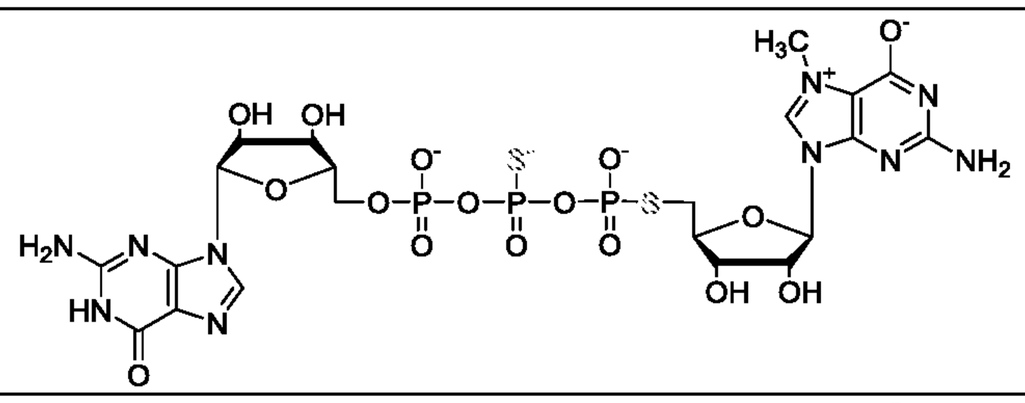
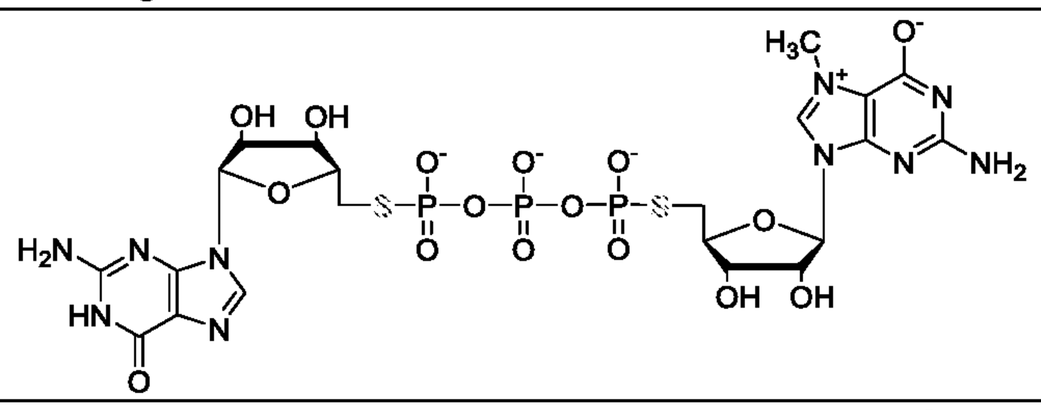
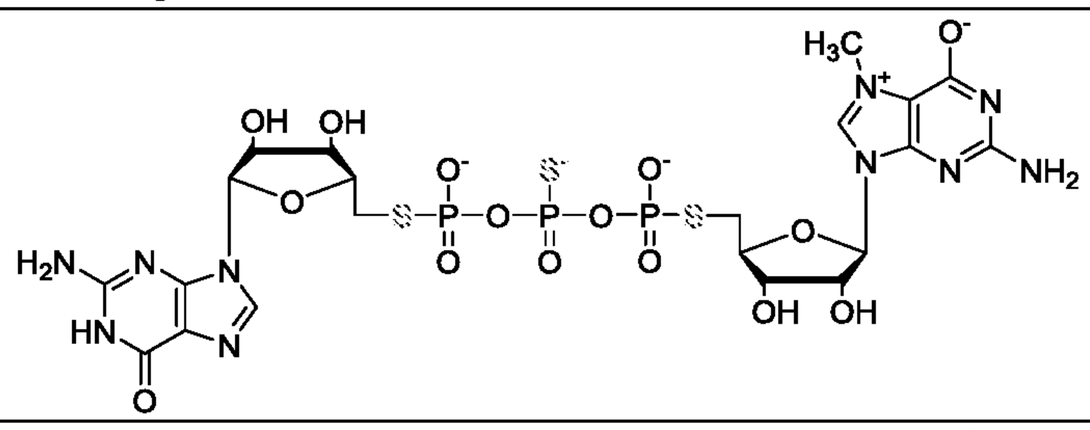
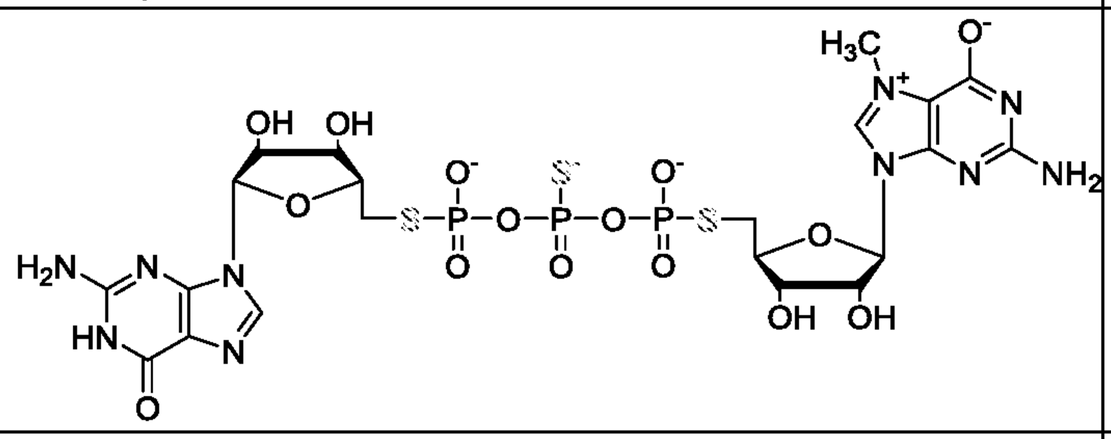
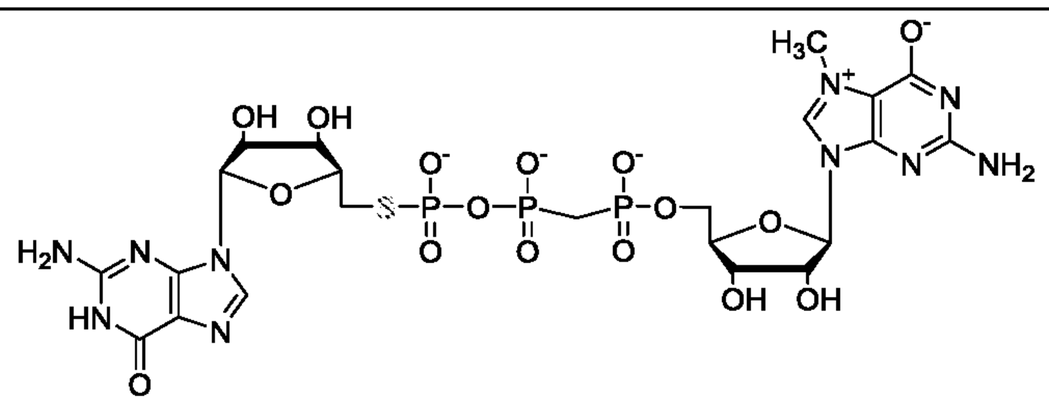
No	Compound	Structural formula	Chemical name
21	m^7GppSG		**P1-(7-methyl-guanosin-5'-yl)-P2-(5'-deoxy-5'-thioguanosin-5'-yl) diphosphate**
22	m^7GpppSG		**P1-(7-methyl-guanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) triphosphate**
23	m^7GSppG		**P1-(7-methyl-5'-deoxy-5'-thioguanosin-5'-yl)-P2-guanosin-5'-yl diphosphate**
24	m^7GSpppG		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl triphosphate**
25	m^7GSpp***CH*$_2$**pG		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl 2,3-methylenotriphosphate**
26	$m^{7,2'O}$GSpppG		**P1-(2'-O-methyl-7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl triphosphate**

30	m^7GSpp_spG *D1*		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl-thiotriphosphate D1**
31	m^7GSpp_spG *D2*		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl 2-thiotriphosphate D2**
32	$m^7GSpppSG$		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) triphosphate**
33	m^7GSpp_spSG *D1*		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) 2-tiotriphosphate D1**
34	m^7GSpp_spSG *D2*		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) 2-thiotriphosphate D2**
35	m^7Gpp_spSG *D1*		**P1-(7-methyl-guanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) 2-tiotriphosphate D1**
36	m^7Gpp_spSG *D2*		**P1-(7-methyl-guanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) 2-thiotrifphosphate D2**

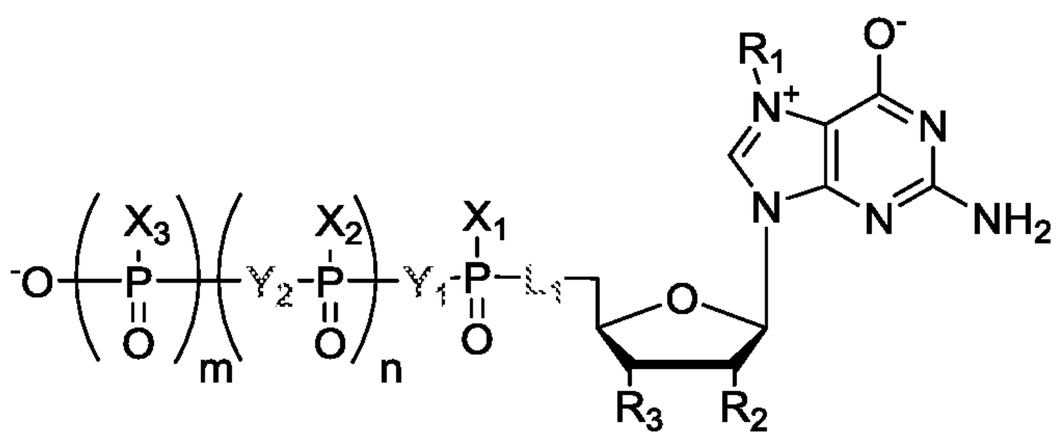
37	m^7GpCH_2ppSG		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl 1,2-methylenotriphosphate**
38	$m^{7,2'O}GpppSG$		**P1-(2'-O-methyl-7-methyl-guanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) triphosphate**

Even more preferred 5'-phosphorothiolate cap analog compound is selected from the group consisting of:

No	Compound	Structural formula	Chemical name
23	m^7GSppG		**P1-(7-methyl-5'-deoxy-5'-thioguanosin-5'-yl)-P2-guanosin-5'-yl diphosphate**
24	$m^7GSpppG$		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl triphosphate**
25	$m^7GSppCH_2pG$		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl 2,3-methylenotriphosphate**
26	$m^{7,2'O}GSpppG$		**P1-(2'-O-methyl-7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl triphosphate**
30	m^7GSpp_spG *D1*		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl 2-triphosphate D1**

31	m^7GSpp_spG *D2*		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl 2-thiotriphosphate D2**
32	$m^7GSpppSG$		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) triphosphate**
33	m^7GSpp_spSG *D1*		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) 2-thiotriphosphate D1**
34	m^7GSpp_spSG *D2*		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) 2-thiotriphosphate D2**
37	$m^7Gp\boldsymbol{CH_2}ppS$ G		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl 1,2-methylenethiotriphosphate**

The invention also relates to a 5'-phosphorothiolate analog according to formula 2



Formula 2

wherein

m=0, 1

n = 0, 1, or 2;

L^1 is S

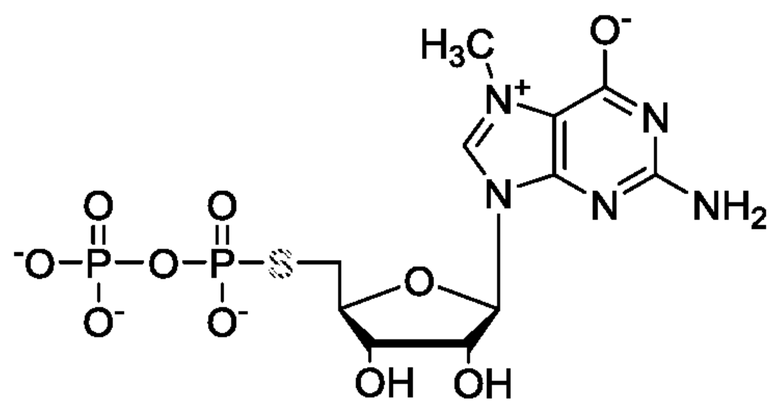
X_1, X_2, X_3 are independently selected from the group comprising O, S;

R^1 is selected from the group comprising CH_3, C_2H_5, CH_2Ph, alkyl, or substituted alkyl;

R^2 and R^3 are independently selected from the group comprising H, OH, OCH_3, OC_2H_5, -COOH, N_3, alkyl, or substituted alkyl;

Y_1, Y_2 are independently selected from the group comprising CH_2, CHCl, CCl_2, CHF, CF_2, NH and O;

A preferred 5'-phosphorothiolate analog is 7-methylguanosine 5'-deoxy-5'-thioguanosine 5'-diphosphorothiolate of formula 13 below



Formula 13.

The invention also relates to the 5'-phosphorothiolate cap analog according to the invention for use as a medicament.

The invention also relates to the 5'-phosphorothiolate cap analog according to the invention for use as a medicament for treatment of spinal muscular atrophy (SMA) and/or alleviation of symptoms of SMA.

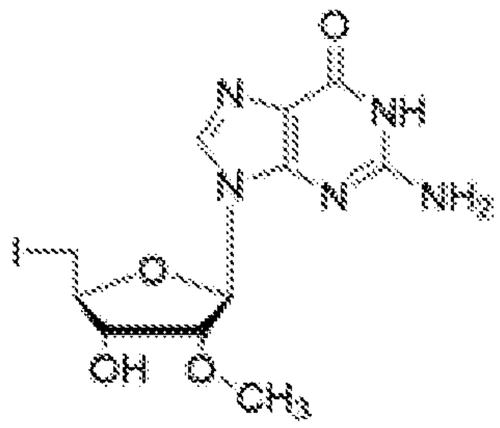
The invention also relates to a use of the 5'-phosphorothiolate cap analog according to the invention in preparation of a medicament.

The invention also relates to a use of the 5'-phosphorothiolate cap analog according to the invention in preparation of a medicament for treatment of spinal muscular atrophy (SMA) and/or alleviation of symptoms of SMA.

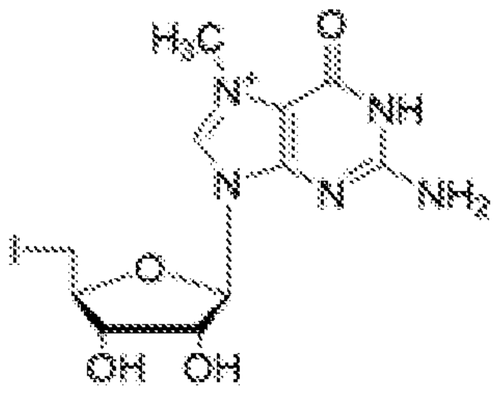
The present invention also relates to a use of the 5'-phosphorothiolate cap analog according to the invention as a regulator of DcpS activity, preferably as an inhibitor of DcpS enzyme activity, more preferably hDcpS.

The invention also relates to a use of the 5'-phosphorothiolate cap analog according to the invention in regulation of mRNA degradation and/or in regulation of mRNA splicing.

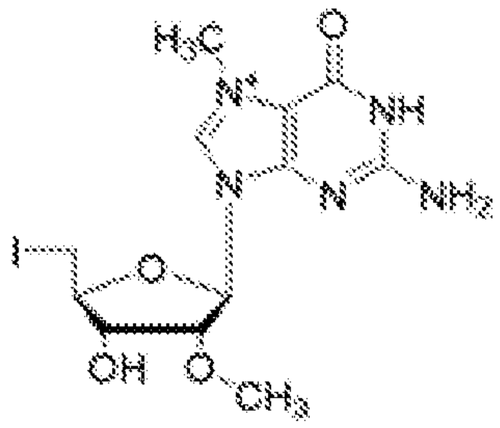
The invention additionally relates to analogs of 5'-deoxy-5'-iodoguanosine having structures according to formulas 10, 11, and 12 shown below.



formula 10

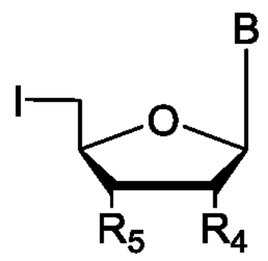


formula 11



formula 12

The present invention additionally relates to a method of preparation of compound according to formula 1, said method comprising: steps wherein a 5'-iodonucleoside according to formula 8

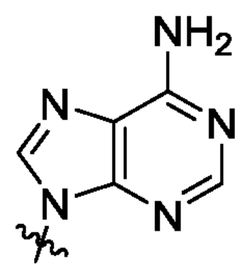


Formula 8

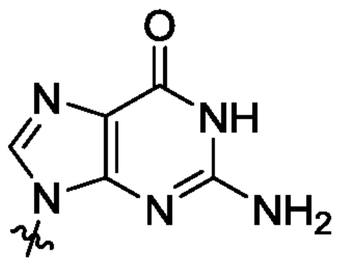
wherein

R^4 and R^5 are independently selected from the group comprising H, OH, OCH_3, OC_2H_5, -COOH, N_3, alkyl, or substituted alkyl;

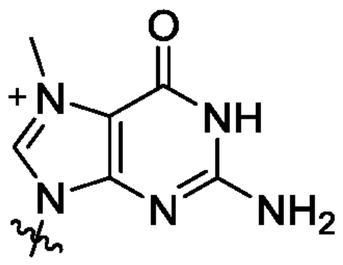
and B is a group according to formula 3, 4, 5, 6, or 7



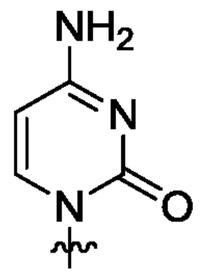
formula 3



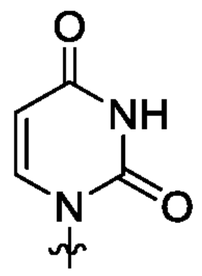
formula 4



formula 5

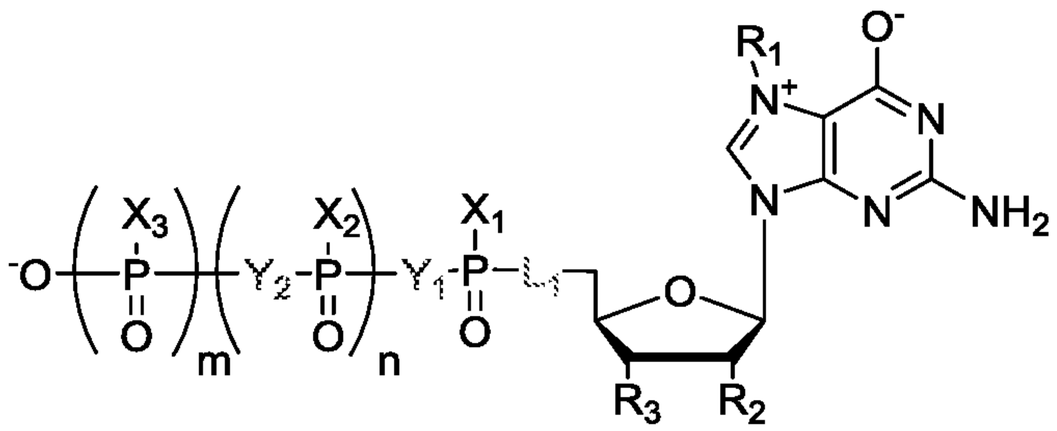


formula 6



formula 7

is reacted with a 5'-phosphorothiolate analog according to formula 2 comprising a terminal thiophosphate moiety



Formula 2

wherein

m=0, 1

n = 0, 1, or 2;

L^1 is O or S;

X_1, X_2, X_3 are independently selected from the group comprising O, S;

R^1 is selected from the group comprising CH_3, C_2H_5, CH_2Ph, alkyl, or substituted alkyl

R^2 and R^3 are independently selected from the group comprising H, OH, OCH_3, OC_2H_5, -COOH, N_3, alkyl, or substituted alkyl;

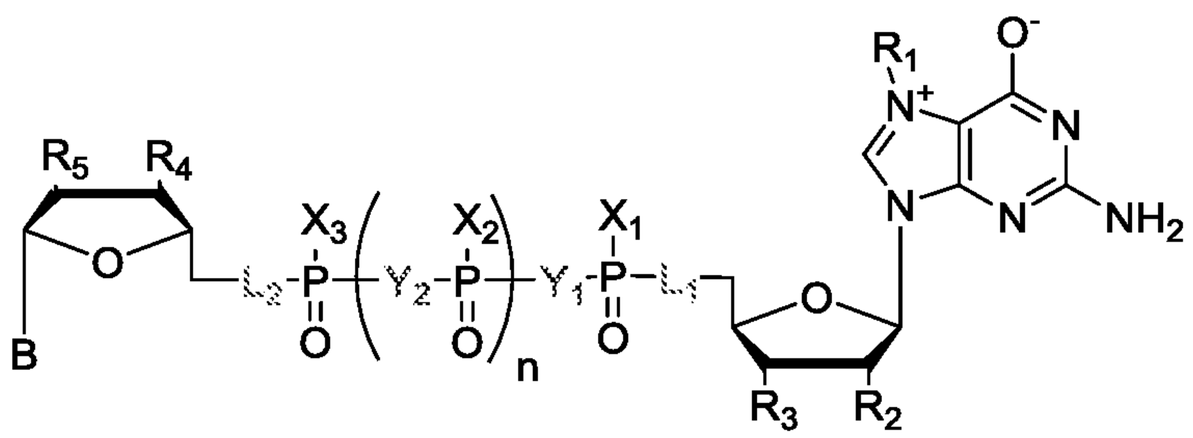
Y_1 and Y_2 are independently selected from the group comprising CH_2, CHCl, CCl_2, CHF, CF_2, NH, and O;

wherein if n = 0 and m = 1 then X_3 is S, and X_1 is O;

if n = 1 and m = 0 then X_2 is S; and X_1 is O;

if n = 1 and m = 1 then X_3 is S; and X_1, X_2 are O

to form a 5'-phosphorothiolate cap analog according to formula 1



Formula 1

wherein

L^1 and L^2 are independently selected from the group comprising O and S, wherein at least one of L_1 and L_2 is not O;

n = 0, 1, or 2;

X_1, X_2, X_3 are independently selected from the group comprising O, S;

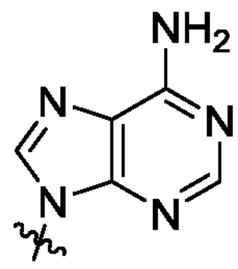
R^1 is selected from the group comprising CH_3, C_2H_5, CH_2Ph, alkyl or substituted alkyl;

R^2 and R^3 are independently selected from the group comprising H, OH, OCH_3, OC_2H_5, -COOH, CH_2COOH, N_3, CH_2N_3, alkyl, alkenyl, or alkynyl;

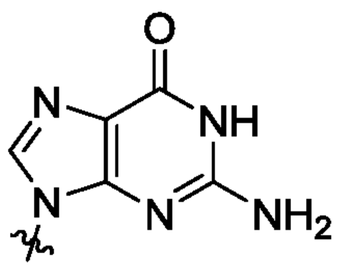
R^4 and R^5 are independently selected from the group comprising H, OH, OCH_3, OC_2H_5, -COOH, CH_2COOH, N_3, CH_2N_3, alkyl, alkenyl, or alkynyl;

Y_1, Y_2 are independently selected from the group comprising CH_2, CHCl, CCl_2, CF_2, CHF, NH, O;

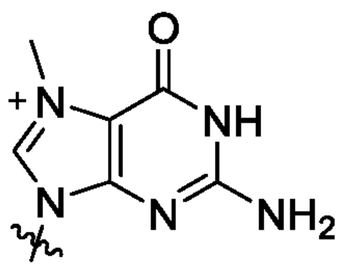
and B is is a group according to formula 3, 4, 5, 6 or 7



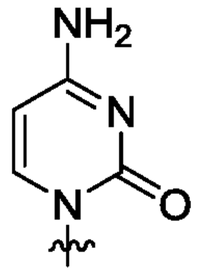
formula 3



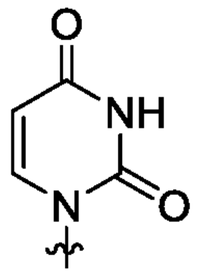
formula 4



formula 5



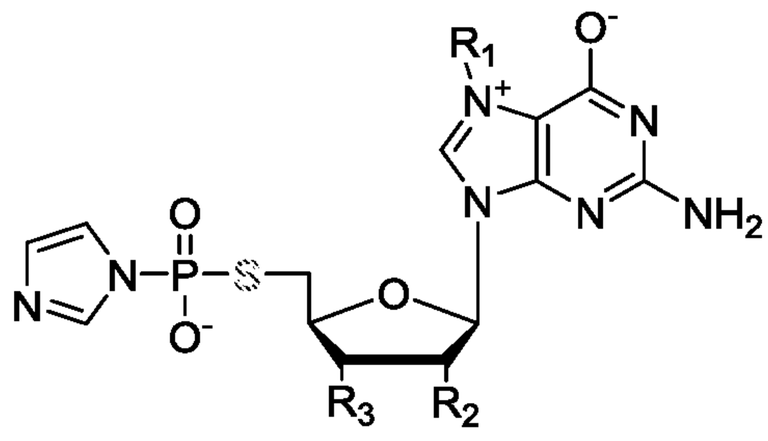
formula 6



formula 7

Preferably, the above mentioned synthesis method comprises using equimolar amounts of the compound according to formula 2, the compound according to formula 8 and DBU (1,8-diazabicyclo(5.4.0)undec-7-ene) as a base.

The invention also relates to a method of preparation of 5'-phosphorothiolate analog according to formula 2a, wherein an imidazolide derivative according to formula 9.



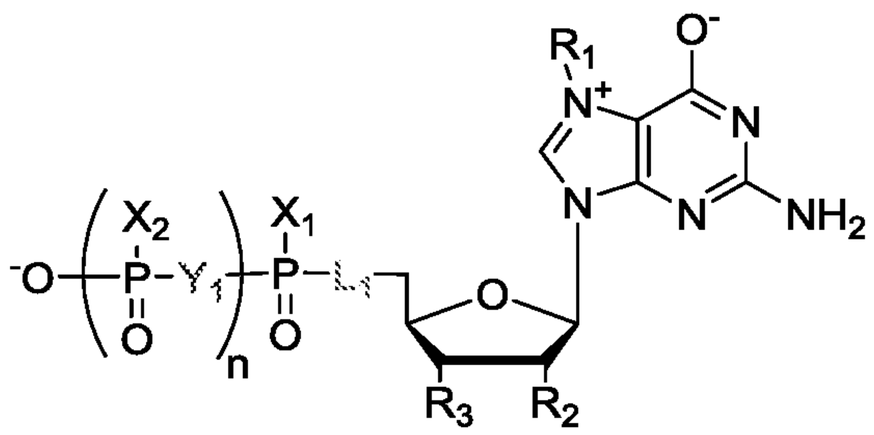
Formula 9

wherein

R^1 is selected from the group comprising CH_3, C_2H_5, CH_2Ph, alkyl, or substituted alkyl;

R^2 i R^3 are independently selected from the group comprising H, OH, OCH_3, $OC_2H_{5'}$ - COOH, N_3, alkyl, or substituted alkyl;

is reacted with a triethylammonium phosphate salt or sodium thiophosphate to form a 5'-phosphorothiolate analog according to formula 2a



Formula 2a

wherein

n = 0, 1, or 2;

L^1 is O or S;

X_1 and X_2 are independently selected from a group comprising O, S;

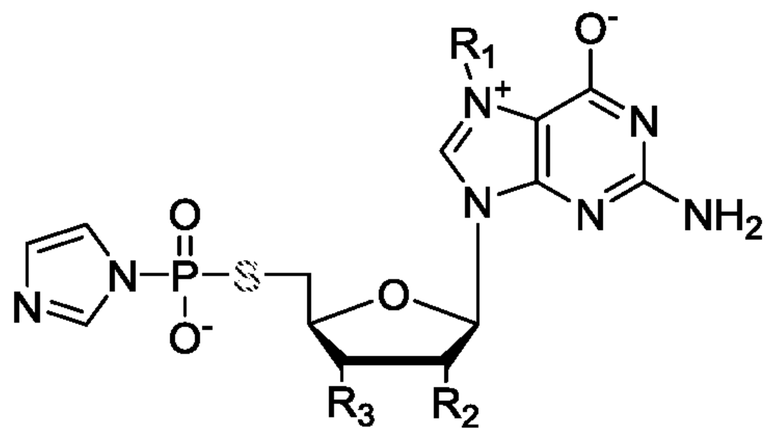
R^1 is selected from a group comprising CH_3, C_2H_5, CH_2Ph, alkyl, or substituted alkyl;

R^2 and R^3 are independently selected from a group comprising H, OH, OCH_3, OC_2H_5, -COOH, N_3, alkyl, or substituted alkyl;

Y^1 is independently selected from a group comprising CH_2, CHCl, CCl_2, CHF, CF_2, NH, or O.

The invention also relates to a method of preparation of the compound according to formula 1, said method comprising steps wherein:

an imidazolide derivative according to formula 9



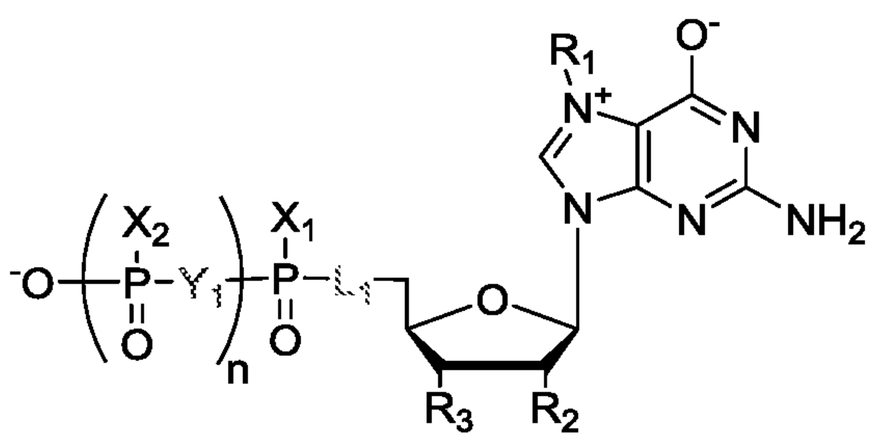
Formula 9

wherein

R^1 is selected from a group comprising CH_3, C_2H_5, CH_2Ph, alkyl, or substituted alkyl;

R^2 and R^3 are independently selected from a group comprising H, OH, OCH_3, OC_2H_5, -COOH, N_3, alkyl, or substituted alkyl;

is reacted with a 5'-phosphorothiolate analog according to formula 2a comprising a terminal thiophosphate moiety



Formula 2a

wherein

n = 1

L^1 is O or S;

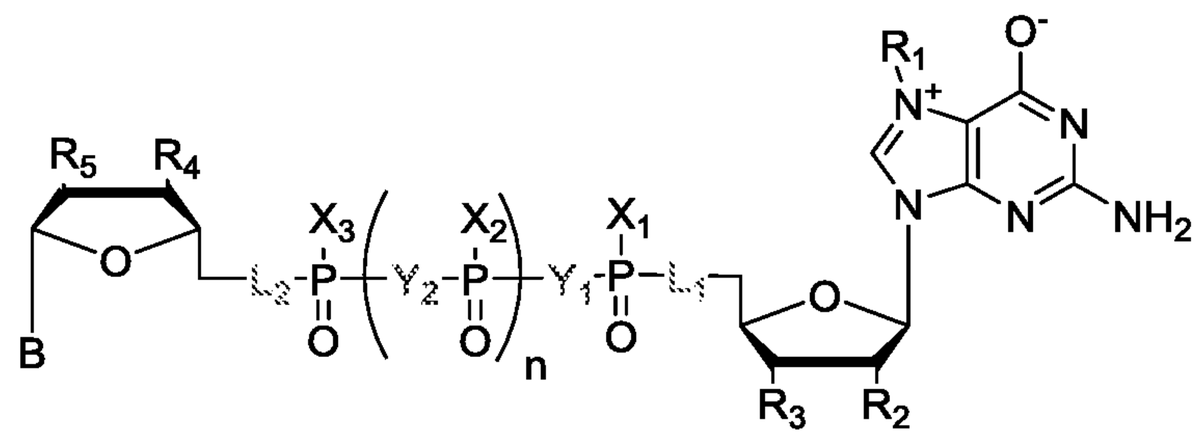
X_1 and X_2 are independently selected from a group comprising O, S;

R^1 is selected from a group comprising CH_3, C_2H_5, CH_2Ph, alkyl, or substituted alkyl;

R^2 and R^3 are independently selected from a group comprising H, OH, OCH_3, OC_2H_5, -COOH, N_3, alkyl, or substituted alkyl;

Y_1 is independently selected from a group comprising CH_2, CHCl, CCl_2, CHF, CF_2, NH, or O.

to form a 5'-phosphorothiolate cap analog according to formula 1



Formula 1

wherein

L^1 and L^2 are independently selected from the group comprising O and S, wherein at least one of L_1 and L_2 is not O;

n = 0, 1, or 2;

X_1, X_2, X_3 are independently selected from the group comprising O, S;

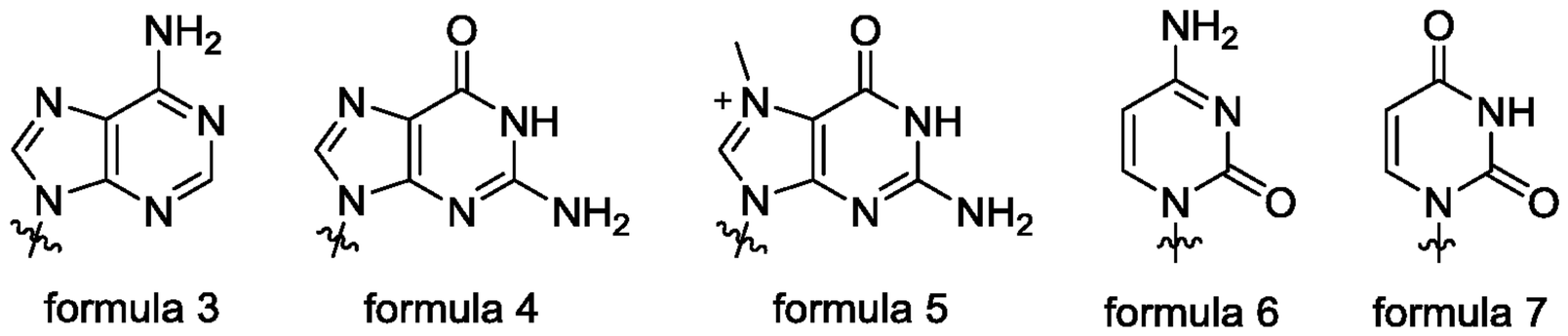
R^1 is selected from the group comprising CH_3, C_2H_5, CH_2Ph, alkyl or substituted alkyl;

R^2 and R^3 are independently selected from the group comprising H, OH, OCH_3, OC_2H_5, -COOH, CH_2COOH, N_3, CH_2N_3, alkyl, alkenyl, or alkynyl;

R^4 and R^5 are independently selected from the group comprising H, OH, OCH_3, OC_2H_5, -COOH, CH_2COOH, N_3, CH_2N_3, alkyl, alkenyl, or alkynyl;

Y_1, Y_2 are independently selected from the group comprising CH_2, CHCl, CCl_2, CF_2, CHF, NH, O;

and B is is a group according to formula 3, 4, 5, 6 or 7



formula 3 formula 4 formula 5 formula 6 formula 7

In the method of synthesis with the imidazolide derivative, preferably the reaction is

carried out in the presence of divalent metal chloride, wherein the preferred divalent metal chloride is zinc chloride $ZnCl_2$.

In the method of synthesis with the imidazolide derivative, preferably a 1,5-fold excess of imidazolide according to formula 9 over phosphate group, thiophosphate group, or the compound according to formula 2a is utilized, in the presence of 8-fold excess of divalent metal chloride.

The present invention also relates to a pharmaceutical formulation comprising the 5'-phosphorothiolate cap analog according to the invention and a pharmaceutically acceptable carrier.

The pharmaceutical formulation according to the invention comprising the 5'-phosphorothiolate cap analog according to the invention and a pharmaceutically acceptable carrier has properties of inhibiting DcpS activity, preferably inhibiting hDcpS activity, and is intended for use in SMA treatment.

The selection of a pharmaceutically acceptable carrier will be dependent on the method of administering the pharmaceutical formulation and on the necessity of protecting the 5'-phosphorothiolate analog according to the invention from inactivation of degradation, before delivering into cells, tissues, or an organism. The pharmaceutically acceptable carriers include solvents, dispersing media and auxiliary agents (coating materials, surfactants, aromas and flavors, antioxidants and others). The pharmaceutical formulation according to the invention can be administered by different routes, including injection, oral, topical and rectal administration. A dose of a pharmaceutical formulation is established accounting for the route of administration, the condition requiring treatment or prophylactics, and other relevant circumstances.

The invention also relates to an mRNA comprising at the 5' end the novel 5'-phosphorothiolate cap analog according to the invention.

The preferred mRNA is characterized by the 5'-phosphorothiolate cap analog being selected from a group comprising m^7G**S**pppG (no. 24), $m^{7,2'O}G$**S**pppG (no. 26), m^7G**S**ppp**S**G (no. 32), m^7G**S**pp$_s$pG D1 (no. 30), m^7G**S**pp$_s$pG D2 (no. 31), m^7G**S**pp$_s$p**S**G D1 (no. 33), m^7G**S**pp$_s$p**S**G D2 (no. 34), more preferably it is $m^{7,2'O}G$**S**pppG (no. 26).

The present invention also relates to a method of preparation of mRNA comprising a 5'-phosphorothiolate cap analog at the 5'-end of the molecule, said method comprising: incorporation of the 5'-phosphorothiolate cap analog according to the invention into the mRNA molecule during synthesis.

In a preferred method of preparation of mRNA the 5'-phosphorothiolate cap analog is selected from a group comprising m^7GSpppG (no. 24), $m^{7,2'O}$GSpppG (no. 26), m^7GSpppSG (no. 32),

m^7GSpp_spG D1 (no. 30), m^7GSpp_spG D2 (no. 31), m^7GSpp_spSG D1 (no. 33), m^7GSpp_spSG D2 (no. 34), more preferably it is $m^{7,2'O}GSpppG$ (no. 26).

In a preferred method of preparation of mRNA, the synthesis of mRNA proceeds through transcription *in vitro*.

The invention also relates to mRNA prepared by the method of preparation of mRNA comprising the 5'-phosphorothiolate cap analog according to the invention at the 5'-end of the molecule.

The invention also relates to a use of the mRNA comprising the 5'-phosphorothiolate cap analog according to the invention at the 5'-end of the molecule for production of proteins.

The use of mRNA for production of proteins is preferably carried out in a cellular or a non-cellular system.

The invention also relates to the mRNA according to the invention and the one prepared according to the method of preparation of mRNA comprising the 5'-phosphorothiolate cap analog according to the invention at the 5' end of the molecule for use as a medicament.

Such mRNA is preferably used as a medicament for treatment of spinal muscular atrophy (SMA) an/or for alleviation of symptoms of SMA.

Preferably, such mRNA is utilized for use as an anti-cancer medicament, more preferably as a medicament in anti-cancer immunotherapy.

The invention also relates to a use of the mRNA according to the invention and the one prepared according to the method of preparation of mRNA comprising the 5'-phosphorothiolate analog according to the invention at the 5' end of the molecule in production of a medicament.

In a preferred use, mRNA is used for preparation of a medicament for treatment of spinal muscular atrophy (SMA) an/or for alleviation of symptoms of SMA, as an anti-cancer medicament, more preferably as a medicament in anti-cancer immunotherapy.

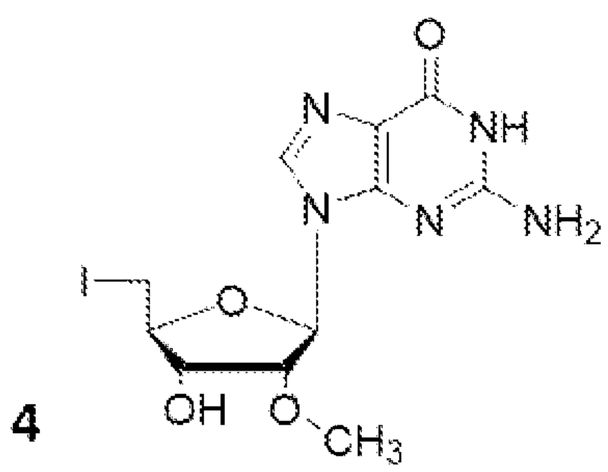
The invention also relates to a pharmaceutical formulation, comprising the mRNA according to the invention and the one prepared by the method of preparation of mRNA comprising the 5'-phosphorothiolate analog according to the invention at the 5' end of the molecule and a pharmaceutically acceptable carrier.

Unmethylated compounds (GppSG and GpppSG) were synthesized as controls for biological studies.

Table 1 lists alkylating agents used for the synthesis of appropriately modified nucleotides which were obtained for the first time by the inventors.Tables 2 and 3 list 5'-phosphorothiolate cap analogs obtained and subsequently characterized by biophysical and biochemical methods.

Among the compounds listed in Table 2 and Table 3, particularly preferred in relation to SMA treatment are the 5'-phosphorothiolate analogs comprising sulfur at the 5'-position from the side of 7-methylguanosine (compounds no. 12, 23, 24, 25, 26, 30, 31, 32, 33, 34 and 37), which are characterized by stability in the presence of DcpS enzyme.

Table 1. 5'-deoxy-5'-iodo-guanosine analogs (compound numbers indicated next to the structures)



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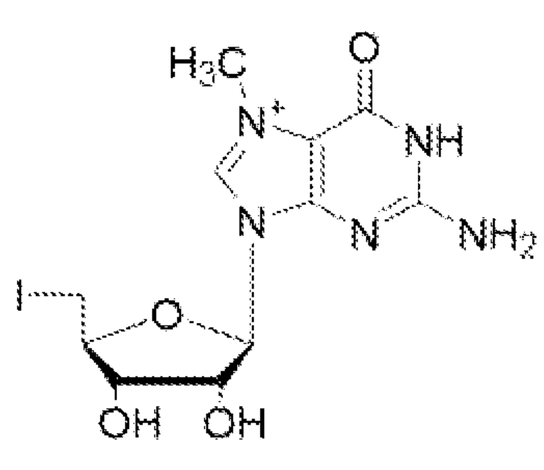
Formula 10



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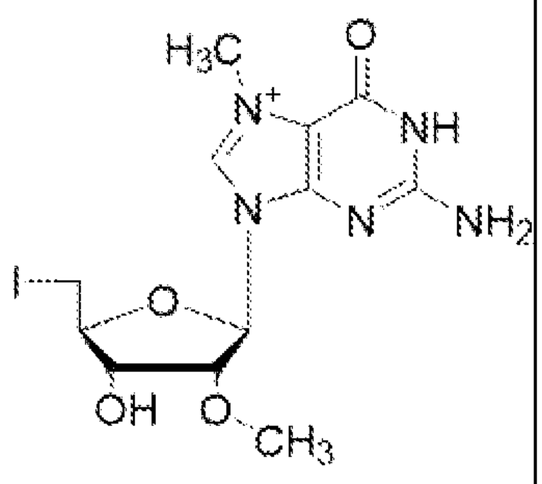
Formula 11



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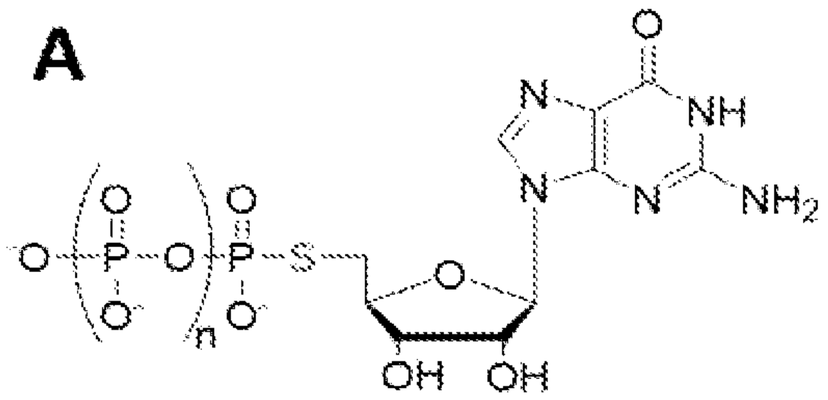
Formula 12

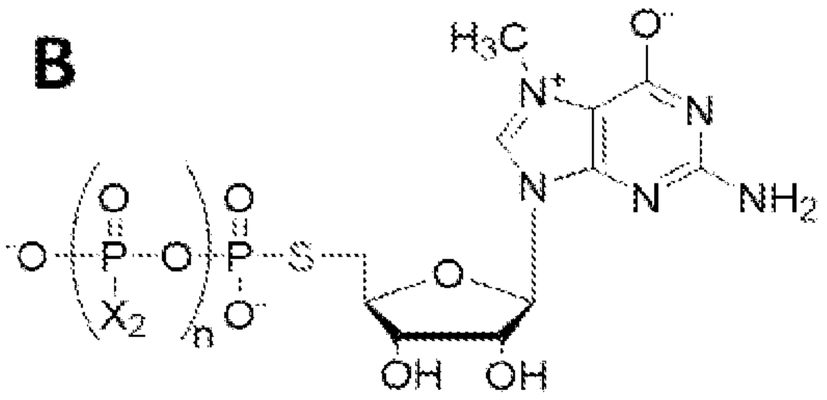
Table 2. Mononucleotide 5'-thiophosphate analogs: panel A – guanosine, panel B – 7-methyloguanosine

A



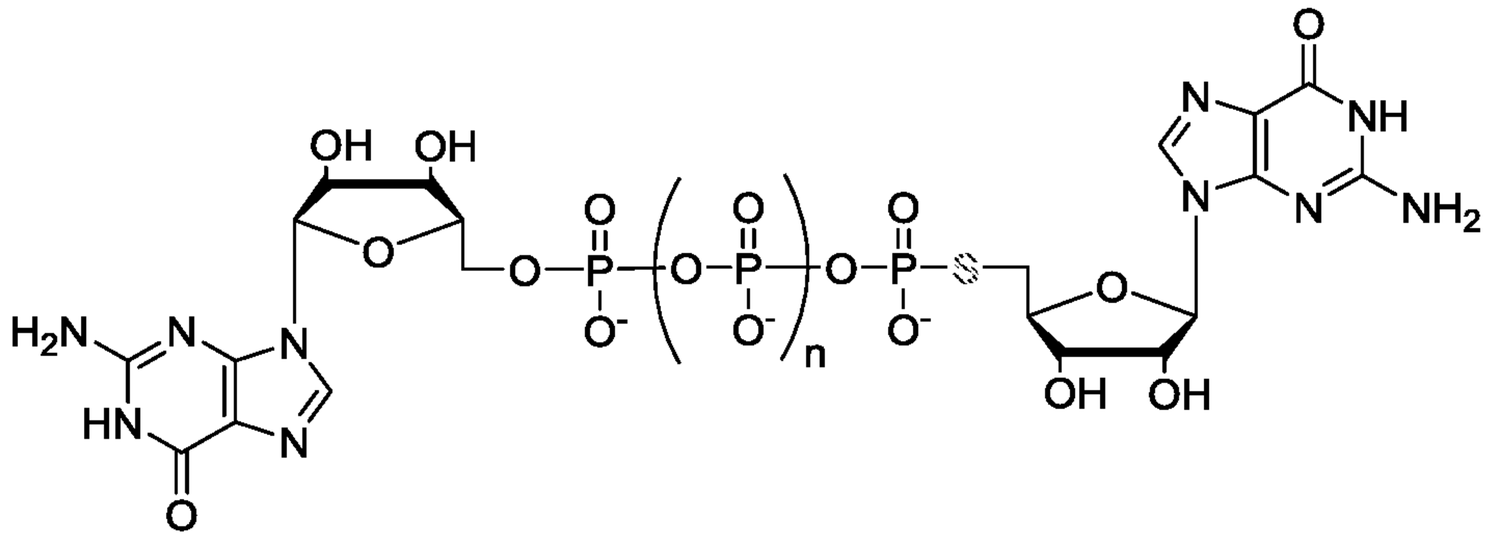
7: n=0
11: n=1

B



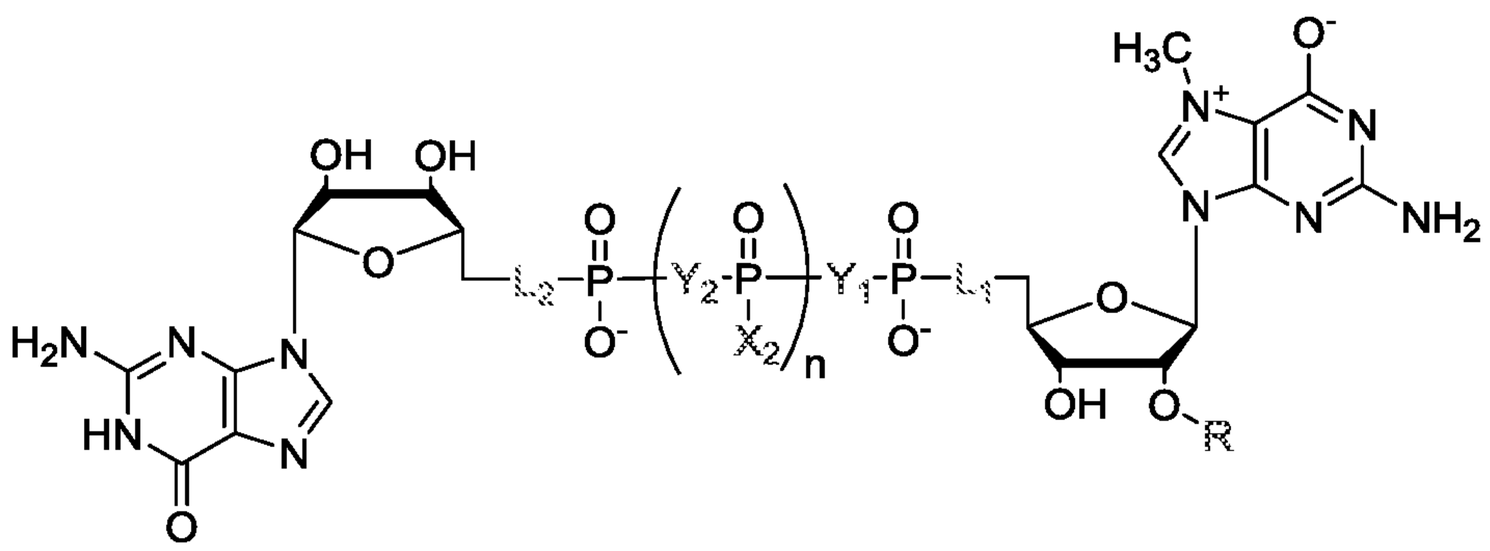
8: n=0 X_2 = O
12: n=1 X_2 = O
13: n=1 X_2 = S

Table 3. 5'-Thiophosphate cap analogs



19: n=0

20: n=1



Compound number	**Compound**	**n**	**R**	**L_1**	**L_2**	**Y_1**	**Y_2**	**X_2**
21	m^7GppSG	0	H	O	S	O	O	O
22	m^7GpppSG	1	H	O	S	O	O	O
23	m^7GSppG	0	H	S	O	O	O	O
24	m^7GSpppG	1	H	S	O	O	O	O
25	m^7GSpp***CH_2***pG	1	H	S	O	O	CH_2	O
38	$m^{7,2'O}$GpppSG	1	CH_3	O	S	O	O	O
26	$m^{7,2'O}$GSpppG	1	CH_3	S	O	O	O	O
32	m^7GSpppSG	1	H	S	S	O	O	O
35	m^7Gpp$_s$pSG *D1*	1	H	O	S	O	O	S
36	m^7Gpp$_s$pSG *D2*	1	H	O	S	O	O	S
30	m^7GSpp$_s$pG *D1*	1	H	S	O	O	O	S
31	m^7GSpp$_s$pG *D2*	1	H	S	O	O	O	S
33	m^7GSpp$_s$pSG *D1*	1	H	S	S	O	O	S
34	m^7GSpp$_s$pSG *D2*	1	H	S	S	O	O	S
37	m^7Gp***CH_2***ppSG	1	H	O	S	CH_2	O	O

The documents cited in the description and documents referenced therein are also hereby incorporated by reference.

BRIEF DESCRIPTION OF DRAWINGS

For better understanding of the invention it was ilustrated with examples and on the attached figures wherein:

Fig.1 Illustrates synthesis of 5'-deoxy-5'-iodo-guanosine analogs

Fig.2 Illustrates synthesis of 5'-deoxy-5'-thioguanosine-5'-thiophosphates. A – synthesis of guanosine derivative; B – synthesis of 7-methyloguanosine derivatives.

Fig.3 Illustrates synthesis of 5'-thiophosphate cap analogs via S-alkylation. A –terminal thiophosphates used in alkylation reaction; B – schemes of alkylation reaction using 5'-deoxy-5'-iodo-guanosine (z Fig. 1) and terminal thiophosphates shown in A.

Fig.4 Illustrates synthesis of 5'-thiophosphate cap analogs via imidazolides. A – compounds used in the method; B – final compounds synthesis using two different activated derivatives no. **9** i **29.**

Fig.5 Illustrates hydrolysis of natural dinucleotide substrate by DcpS and stability studies of 5'-S modified analogs: panel A – stability studies of natural cap analog m^7GpppG against DcpS; panel B – stability studies of cap analog no. **20** against DcpS enzyme (Table 3); panel C – stability studies of cap analog no. **21** against DcpS enzyme (Table 3).

Fig.7. Illustrates a crystal structure of active site of the enzyme ΔN37hDcpS in complex with m^7GSpp_spSG D2.

Fig. 8. Illustrates susceptibility to Dcp1/2 enzyme activity of short 26 nt RNAs capped with various cap analogs (transcripts without cap at their 5' ends are 25 nt long) being incubated with the SpDcp1/2 decapping enzyme. The reactions were conducted for 0, 5, 15, 30 min, after termination thereof reaction mixture was resolved on denaturing 15 % polyacrylamide gel, after the electrophoretic separation was completed the gel was stained with SYBR-Gold (Invitrogen). On each panel the leftmost lane refers to the control, which is uncapped RNA.

Fig. 9. Illustrates relative susceptibility to Dcp1/2 enzyme activity determined from the data on Fig. 8. The relative susceptibility to Dcp1/2 activity was calculated as the ratio of intensity of the band corresponding to the RNA capped at the 5' end to the sum of the intensities of bands corresponding to capped and uncapped RNA. All values were normalized in relation to time 0 min for individual RNAs.

Fig. 10. Illustrates relative translational efficiency obtained from measurements of translation efficiencies of mRNA encoding *Renilla* luciferase capped with various cap analogs on the 5' end in rabbit reticulocyte extract.

Fig. 11. Illustrates relative translational efficiency in HeLa cells determined on the basis of luciferase activity at selected time points. Results are presented as a ratio of luciferase activity measured for lysate of cells transfected with mRNA capped with $m_2^{7,\ 2'\text{-}O}$GSpppG or $m_2^{7,\ 2'\text{-}}$

^{O}GpppSG on the 5' end to luciferase activity measured for lysate of cells transfected with mRNA capped with m^7GpppG. The histograms represent the mean value from three biological repetitions.

Chemical synthesis of 5'-thiophosphate cap analogs is a creative combination of three nucleotide synthesis methods based on chemistry of:

1) Imidazolide nucleotide derivatives (see (Abrams and Schiff 1973); (Barnes, Waldrop et al. 1983); (Kalek, Jemielity et al. 2006) and (Kalek, Jemielity et al. 2005))
2) S-alkylation by halogen containing nucleoside derivatives (see (Arakawa, Shiokawa et al. 2003))
3) Synthesis of terminal nucleoside β-thio-di and γ-thio-triphosphates (see (Zuberek, Jemielity et al. 2003))

In order to synthesize sulfur-containing cap analogs at the 5'-position we developed two complementary approaches that on the whole allow synthesis of a whole variety of 5'-phosphorothioate analogs of mono-, di-, and triphosphates of nucleosides and dinucleotide cap analogs (Fig. 2-4). Approach 1 (FIG. 2 and the first step in Fig. 3) involves the reaction of S-alkylation using a nucleophilic substitution reaction of 5'-deoxy-5'-iodonucleoside by β- or γ-thiophosphates. The second approach (FIG. 4) yielding dinucleotide compounds having sulfur atom at the 5 'position, uses a coupling reaction between the prior activated form of an appropriate imidazolide nucleotide and diphosphate (in both cases, at a chosen stage the reaction of S-alkylation was used) in the presence of $ZnCl_2$ as a catalyst.

The first approach uses the corresponding phosphorothioates (mono-, di-, tri-) bearing at a terminal position a phosphorothioate moiety. The optimum conditions for this reaction is the use of equimolar amounts of phosphorothioate, 5'-iodonucleoside and DBU (1,8-diazabicyclo (5.4.0) undec-7-ene) as a base. To date, using this method, we obtained 9 different dinucleotide cap analogs including two units containing methylene modifications at positions α-β and β-γ of triphosphate bridge (Figure 3).

The second method for the efficient yield required the presence of divalent metal chlorides such as $ZnCl_2$, which also improves the solubility in an organic medium, protects against hydrolysis of imidazolide derivative and accelerates the reaction rate by getting the imidazole derivative and the phosphate of the other molecule closer to one another. The optimum conditions for this reaction was the use of 1.5 equivalents of the imidazole derivative relative to the diphosphate in the presence of 8-fold excess of $ZnCl_2$ in DMF. Using the second method we obtained further nine 5'-phosphorothioate cap analogs containing two sulfurs at the 5 'position and sulfur at the β–nonbridging position in the triphosphate chain (Fig. 4). To date the use of 5'-

phosphorothioate analogs of nucleotides in this type of reaction have not been described. Due to the presence of a stereogenic center located on the phosphorus atom, each analog containing β-S-sulfur atom was obtained as a mixture of diastereomers (called D1 and D2 according to the order of their elution from the RP-HPLC column). The individual diastereomers were separated by RP-HPLC.

The obtained cap analogs were purified by ion exchange chromatography, DEAE Sephadex A-25, and if the purity was not sufficient, by preparative HPLC. Then, the purified compounds were tested for their biochemical and biological properties.

The synthesis routes leading to cap analogs containing sulfur atom at the 5 'position are shown in Figures 1-4.

The obtained cap analogs were then tested as substrates of the human enzyme DcpS (hDcpS). As determined by using reverse phase HPLC (RP HPLC), only four of the analogs: m^7GppSG (no. **21**), m^7GpppSG (no. **22**) $m^{7,2'\text{-}O}$GpppSG (no. **38**) and m^7Gpp_spSG D1/D2 (no. **35** - **36**) are hydrolyzed by DcpS. Other analogs containing sulfur atom at the 5 ' position from the side of the 7-methylated guanosine are resistant to hydrolysis by hDcpS (stability comparison of two different analogs (no. **22**) and (no. **24**) - Fig. 5, Table 4). In contrast to the compounds no. **21, 22, 38** and **35 - 36**, analog **37** (m^7GpCH_2ppSG) was additionally modified with a methylenebisphosphonate moiety, and was also resistant to hydrolysis by the enzyme hDcpS (**Table 5**). Then, the fluorescence method and fluorogenic probe were used for determining the ability of these compounds to inhibit the enzyme hDcpS while determining for the compounds which are resistant to the enzyme activity the parameter IC_{50} (see patent application PL406893). After the studies, it was discovered that the resulting compounds are very good inhibitors of the human enzyme DcpS.

Analog no. **34**, displaying the best inhibitory properties against hDcpS enzyme from all tested cap analogs, was co-crystallized with a shortened version of the enzyme (ΔN37hDcpS; full-length enzyme did not form crystals), and the 2.05 Å resolution structure of the complex was determined by X-Ray crystallography (**Fig. 7**). Conformation of the analog No. **34** observed in the complex structure differs significantly from the conformation of a non-modified cap analog m^7GpppG (compound No. **0**) in complex with a catalytically-inactive H277N hDcpS mutant (Gu, Fabrega et al. 2004). Particularly susbstantial differences between those two ligands were observed in the alignment of the triphosphate bridge, resulting in exclusion of γ phosphate of the analog no. **34** from the catalytic center Additionally, besides the typical cap/DcpS enzyme complex interactions with the C-terminal domain, analog no. **34** interacts through hydrogen bonds with the lysine 142 and tyrosine 143 residues. Those amino acids are located in the so-called hinge region, connecting C- and N-terminal domains, which move relative to each other during the catalytic cycle.

The structure and purity of the obtained compounds were confirmed by mass spectrometry and ^{1}H and ^{31}P NMR.

The observation that $m^{7}GSpppG$ (Compound no. **24**) and its analogs are resistant to hDcpS is unexpected because the hydrolysis of obtained compounds proceeds through a nucleophilic attack on the phosphate group adjacent to 7-methylguanosine, which is consistent with the catalytic mechanism established for the natural substrates.

In summary, the invention describes structures and methods for synthesis of various analogs of the 5' end of the mRNA (cap) containing 5'-phosphorothioate moiety. None of the cap analogs described, their properties against the enzyme DcpS, nor methods of their use, particularly for the treatment of spinal muscular atrophy (SMA) and/or alleviating the symptoms of SMA have been previously described in the literature.

Selected analogs were used for mRNA synthesis using *in v*itro transcription method with RNA SP6 polymerase (New England BioLabs). It was examined which percentage of the pool of transcripts with a length of 35 nucleotides has a cap structure, and then the susceptibility of these transcripts to degradation by a recombinant enzyme Dcp1/2 from *Schizosaccharomyces pombe* was examined (Example 2, Test 4, Fig. 8, Fig. 9, Tab. 6.). Full-length transcripts encoding luciferase (as a reporter gene) were subjected to translation in rabbit reticulocyte lysate (Fig. 10, Example 2, Test 5) and in HeLa cells transfected with modified mRNA (Fig. 11, Example 2, Test 6). In both cases, the efficiency of mRNA translation in both translational systems was determined by examining the activity of the synthesized protein (luciferase) (Tab. 6).

The terms used in the description have the following meanings. Terms not defined herein have the meaning that is presented and understood by a person skilled in the art in light of this disclosure and the context of the description of the patent application. The following conventions, unless stated otherwise, were used in the present description, the terms having the meanings indicated as in the definitions below.

The term "*alkyl*" refers to a saturated, linear or branched hydrocarbonyl substituent having the indicated number of carbon atoms. The examples of an alkyl substituent are -methyl, -ethyl, -*n*-propyl, -*n*-butyl, -*n*-pentyl, -*n*-hexyl, -*n*-heptyl, -*n*-octyl, -*n*-nonyl and -*n*-decyl. Representative branched -(C1-C10)alkyls include -isopropyl, -*sec*-butyl, -isobutyl, -*tert*-butyl, -isopentyl, -neopentyl, -1- -methylbutyl, -2-methylbutyl, -3-methylbutyl, -1,1-dimethylpropyl, -1,2-dimethylpropyl, -1-methylpentyl, -2-methylpentyl, -3-methylpentyl, -4-methylpentyl, -1-ethylbutyl, -2-ethylbutyl, -3-ethylbutyl, -1,1-dimethylbutyl, -1,2-dimethylbutyl, 1,3-dimethylbutyl, -2,2-dimethylbutyl, -2,3-dimethylbutyl, -3,3-dimethyl-butyl, -1-methylhexyl, 2-methylhexyl, -3-methylhexyl, -4-methylhexyl, -5-methylhexyl, -1,2-dimethylpentyl, -1,3-dimethylpentyl, -1,2-

dimethylhexyl, -1,3-dimethylhexyl, -3,3-dimethylhexyl, 1,2-di-methylheptyl, -1,3-dimethylheptyl and -3,3-dimethylheptyl and others.

The term „*alkenyl*" refers to a saturated, linear or branched acyclic hydrocarbyl substituent having the indicated number of carbon atoms and containing at least one carbon-carbon double bonds.The examples of an alkenyl substituent are -vinyl, -allyl, -1-butenyl, -2-butenyl, -isobutylenyl, -1-pentenyl, -2-pentenyl, -3-methyl-1-butenyl, -2-methyl-2-butenyl, -2,3-dimethyl-2-butenyl, -1-hexenyl, -2-hexenyl, -3-hexenyl, -1-heptenyl, -2-heptenyl, -3-heptenyl, -1-octenyl, -2-octenyl, -3-octenyl, -1-nonenyl, -2-nonenyl, -3-nonenyl, -1-decenyl, -2-decenyl, -3-decenyl and others.

The term "*alkynyl*" refers to a saturated, linear or branched acyclic hydrocarbyl substituent having the indicated number of carbon atoms and containing at least one carbon-carbon triple bond. The examples of an alkynyl substituent are acetylenyl, propynyl, -1-butynyl, -2-butynyl, -1-pentynyl, -2-pentynyl, -3-methyl-1-butynyl, 4-pentynyl, -1-hexynyl, -2-hexynyl, -5-hexynyl and others.

The term "*heteroatom*" refers to an atom selected from the group of oxygen, sulfur, nitrogen, phosphorus and others.

The term "*HPLC*" refers to high performance liquid chromatography, and the solvents designated as solvents for "HPLC" mean solvents of suitable purity for HPLC analysis (High Performance Liquid Chromatography).

The term "*NMR*" means nuclear magnetic resonance.

The term "cellular system" refers to cells capable of carrying out a protein biosynthesis process on an RNA template.

The term "non-cellular system" means a biological mixture containing all the ingredients necessary for protein biosynthesis on the basis of an RNA template, usually a lysate of animal or plant cells.

MODES FOR CARRYING OUT THE INVENTION

The following examples are provided merely to illustrate the invention and to explain its various aspects, and not for its limitation, and should not be equated with its all scope, which is defined in the appended claims. The following examples, unless stated otherwise, involved the use of standard materials and methods used in the field or the procedures recommended by the manufacturer for the particular materials and methods.

EXAMPLES

General information related to the synthesis, isolation and characterization of new cap analogs

Nucleotides which were intermediates were purified by ionexchange chromatography on DEAE Sephadex A-25 (HCO_3^- form) using a linear gradient of triethylammonium bicarbonate (TEAB) in deionized water. After evaporation under reduced pressure, during which 96% ethanol was added several times to decompose the TEAB buffer, intermediates were isolated as a triethyalammonium salts. The final products (cap analogs) were purified in the same manner and then purified by semi-preparative HPLC, and subjected to lyophilization several times and were isolated as ammonium salts. Analytical reverse phase HPLC (RP HPLC) was performed on Agilent Technologies Series 1200 apparatus, with Supelcosil LC-18 RP-T column (4.6 x 250 mm, flow 1.3 ml/min) with a linear gradient of 0% -25% methanol (program A) in 0.05 M ammonium acetate (pH 5.9) or 0% -50% methanol (program B) in 0.05 M ammonium acetate (pH 5.9). The eluted compounds were detected using UV-VIS detector (at 260 nm) and fluorescence detector (excitation 260 nm, emission 370 nm). Preparative RP HPLC was carried out on the same apparatus using a Discovery RP Amide C16 column (21.2 mm × 250 mm, flow 5.0 ml/min) using a linear gradient of acetonitrile in 0.05 M ammonium acetate (pH 5.9) as the mobile phase. ^1H NMR and ^{31}P NMR spectra were recorded at 25°C on a Varian UNITY-plus at a frequency of 399.94 MHz and 161.90 MHz respectively. ^1H NMR chemical shifts were reported to TSP (3-trimethylsilyl [2,2,3,3-D4] sodium propionate) in D_2O (internal standard). ^{31}P NMR chemical shifts were reported to 20% phosphoric acid in D_2O (external standard). The high resolution mass spectra in negative [MS ESI (-)] or positive ion mode [MS ESI (+)] were recorded on a Micromass QToF 1 MS. Reading the fluorescence plate reader was performed on a Tecan Infinit 200 ® PRO with excitation at 480 nm and emission at 535 nm. Samples were placed in a black 96-well plate (Greiner). Crystallisations were performed on 96-well plates with 3-lens wells (Swissci), utilizing a pipetting robot Mosquito Crystal (TTp Labtech). Solvents and other reagents were purchased from Sigma-Aldrich and used without further purification, unless stated otherwise below. Commercially available sodium salts of GMP and GDP were converted to triethylammonium salts using ion exchange chromatography on Dowex 50 WX8. Triethylammonium salts and m^7GMP and m^7GDP sodium salts, m^7GMP-Im and m^7GDP-Im were obtained as described in the literature (Kalek, Jemielity et al. 2005), (Jemielity, Fowler et al. 2003). 5'-deoxy-5'-iodo-guanosine, 5'-deoxy-5'-thiogaunosin-5'-monothiophosphate and triethylamine phosphorothioate were obtained as described in the literature ((Arakawa, Shiokawa et al. 2003), (Zuberek, Jemielity et al. 2003))..
m^7GpCH_2p triethylammonium salt was prepared as described in the literature (Kalek, Jemielity et al. 2006). $GpCH_2ppS$ was prepared as described (Kowalska, Ziemniak et al. 2008)

In the examples below, in the brackets for specific compounds the reference to the figure and the number indicating the specified substituents is given, which corresponds to a particular number for the particular cap analog.

Example 1. Synthesis and isolation of new cap analogs

General method of synthesis of 5'-iodo nucloside derivatives (Fig 1, no. 3, 4)

Iodine (3 mmol, M=253.81 g/mol was added over 5 min to a magnetically stirred suspension of the corresponding nucleoside (1 mmol), triphenylphosphine (3 mmol, M=262.29 g/mol) and imidazole (6 mmol, M=68.08 g/mol) in N-methyl-2-pyrrolidinone (to a concentration of nucleoside 0.25 mol/l) at room temperature. The reaction was performed over 3 h, and the progress of the reaction was monitored using RP HPLC. Then, the reaction mixture was poured into a solution of CH_2Cl_2:H_2O (3:1, v/v), diluting the reaction mixture 12-times. A white crystalline precipitate formed during 24 h in 4 ˚C, at the interface of the two layers. The precipitate was filtered off under reduced pressure, washed with methylene chloride and dried in vaccum over P_2O_5.

5'-deoxy-5'-iodo-guanosine *(Fig. 1, no. 3)*

5'-deoxy-5'-iodo-guanosine (**Fig. 1, no. 3**), (10.4 g, 26.5 mmol, 75%) was obtained starting from guanosine (Fig. 1, no. **1**), (10 g, 35.3 mmol) following the general procedure. t_R (B) = 12.36 min;

^{1}H NMR (400 MHz, DMSO-d_6) δ ppm 10.65 (s, 1H, H-1), 7.89 (s, 1H, H-8), 6.47 (bs, 2H, NH2), 5.68 (d, 1H, J = 6.26 Hz, H-1'), 5.51 (d, 1H, J = 6.26 Hz, 2'-OH), 5.35 (d, 1H, J = 4.70 Hz, 3'-OH), 4.59 (q, 1H, J = 5.48 Hz, H-2'), 4.03 (q, 1H, J = 5.09, 3.13 Hz, H-3'), 3.90 (dt, 1H, J = 6.26, 3.13 Hz, H-4'), 3.53 (dd, 1H, J = 6.26, 5.87 Hz, H-5'), 3.39 (dd, 1H, J = 10.17, 6.65 Hz, H-5'); HRMS ESI (-) calcd. *m/z* for $C_{10}H_{11}IN_5O_4^-$, $(M-H)^-$; 391.9861, found 391.98610

5'-deoxy-5'-iodo-2'-*O*-methyl-guanosine *(Fig. 1, no. 4)*

2'-*O*-methyl-5'-deoxy-5'-iodo- guanosine (Fig. 1, no. **4**), (328.8 mg, 0.81 mmol, 80%) was obtained starting from 2'-O-methylguanosine (Fig. 1, no. **2**) (300 mg, 1.0 mmol) following the general procedure. t_R (B) = 14.44 min;

^{1}H NMR (400 MHz, DMSO-d_6) δ ppm 7.95 (s, 1H, H-8), 6.50 (bs, 2H, NH2), 5.81 (d, 1H, J = 6.41 Hz, H-1'), 5.50 (d, 1H, J = 5.34 Hz, 3'-OH), 4.41, 4.40 (2d, 1H, J = 6.26, 6.41 Hz, H-2'), 4.28-4.25 (m, 1H, H-3'), 3.97, 3.96 (2t, 1H, J = 6.56, 3.05 Hz, H-4'), 3.56 (dd, 1H, J = 6.41, 10.38 Hz, H-5'), 3.43 (dd, 1H, J = 10.53, 6.87, 6.71 Hz, H-5'), 3.30 (s, 3H, CH_3);

HRMS ESI (-) calcd. *m/z* for $C_{11}H_{13}IN_5O_4^-$ $[M-H]^-$: 406.0090, found 406.0021.

5'-deoxy-5'-iodo-7-methylguanosine *(Fig. 1, no. 5)*

5'-deoxy-5'-iodo-guanosine (**Fig. 1, no. 3**) (2g, 5.09 mmol) was dissolved in anhydrous DMF (20 mL) and MeI (2.5 mL, 40.7 mmol) was added. Reaction mixture was stirred on magnetic stirrer at room temperature. The reaction progress was monitored by RP HPLC. When no starting material was observed, reaction was stopped by adding water (10 mL), and the excess of methyl iodide was evaporated under vacuum and reaction mixture was concentrated under reduced pressure. Then, to the remaining crude product CH_2Cl_2 (100 mL) was added and yellow precipitate was formed. Precipitate was filtered off, under reduced pressure, washed with CH_2Cl_2 (3 x 20 mL) and dried for 24 h in vaccum over P_4O_{10}. Yield 1.6 g (77.0 %). t_R (B) = 11.94 min;

^{1}H NMR (400 MHz, D_2O) δ ppm 5.98 (d, 1H, J = 3.91 Hz, H-1'), 4.81 (dd, 1H, J = 4.70 Hz, H-2'), 4.31 (t, 1H, J = 5.09, H-3'), 4.15 (q, 1H, J = 5.48, H-4'), 4.07 (s, 3H, CH_3), 3.50-3.62 (m, 2H, J = 4.70, 5.87 Hz, H-5');

HRMS ESI (+) calcd. m/z $C_{11}H_{15}IN_5O_4^+$ $[M+H]^+$: 408.01687, found 408.01163.

5'-deoxy-5'-iodo-2'-O-methyl-7-methylguanosine *(Fig. 1, no. 6)*

5'-deoxy-5'-iodo-2'-O-methylguanosine (**Fig. 1, no. 4**) (200.8 mg, 0.49 mmol) was dissolved in anhydrous DMSO (3.3 mL) and MeI (0.25 mL, 3.9 mmol) was added. Reaction mixture was stirred on magnetic stirrer at room temperature. The reaction progress was monitored by RP HPLC. When no starting material was observed, reaction was quenched with water (10 mL) and pH was adjusted to neutral using $NaHCO_3$, excess of methyl iodode was extracted with diethyl ether and the water phases were polled, followed by concentrating the mixture and purification by preparative HPLC obtaining 45.8 mg of the compound (77 %). t_R (B) = 11.94 min;

^{1}H NMR (400 MHz, DMSO-d_6) δ ppm 9.03 (s, 1H, H-8), 6.39 (bs, 2H, NH_2), 5.95 (d, 1H, J = 4.27 Hz, H-1'), 4.40 (t, 1H, J = 4.58 Hz, H-2'), 4.24 (t, 1H, J = 4.88 Hz, H-3'), 4.08-4.06 (m, 1H, H-4'), 4.02 (s, 3H, CH_3), 3.59 (dd, 1H, J = 5.19, 4.88, 10.68 Hz, H-5'), 3.50 (dd, 1H, J = 7.93, 7.63, 10.68 Hz, H-5'), 3.41 (s, 3H, CH_3);

HRMS ESI (-) calcd. m/z $C_{12}H_{15}IN_5O_4^-$ $[M-H]^-$: 420.01741, found: 420.01758.

guanosine 5'-deoxy-5'-thioguanosine- 5'-monophosphorothiolate (Fig. 2, no. 7)

To a suspension of 5′-deoxy-5′-iodoguanosine (**Fig. 2, nr 3**) (2.0 g, 5.1 mmol) in 100 mL of DMF:H_2O mixture (1:1, v/v) trisodium thiophosphate (4.6 g, 25.5 mmol) was added. The reaction mixture was stirred for 24 h at room temperature. Precipitate was removed by filtration, the filtrate was evaporated under reduced pressure. The residue was dissolved in 50 mL of water and the excess of trisodium thiophosphate was precipitated by addition of 100 mL of methanol. After separation, the crude product was purified by ion exchange chromatography on Sephadex. The product was freeze-dried. Yield 1.9 g, (64 %). t_R (B) = 4.24 min;

^{1}H NMR (400 MHz, D_2O) δ ppm 8.05 (s, 1H, H-8), 5.89 (d, 1H, J = 5.73 Hz, H-1'), 4.85 (dd, 1H, J = 5.48 Hz, H-2'), 4.51 (2d, 1H, J = 4.98, 4.23 Hz, H-3'), 4.33-4.39 (m, 1H, H-4'), 3.16-3.08 (m, 2H, Hz, H-5'); ^{31}P NMR (162 MHz, D_2O) δ ppm 15.42 (s, 1P);

HRMS ESI (-) calcd. m/z $C_{10}H_{13}N_5O_7PS^-$ [M-H]$^-$: 378.02788, found: 378.02828.

guanosine 5'-deoxy-5'-thio-7-methylguanosine- 5'-monophosphorothiolate (Fig. 2, no. 8)

To a suspension of 5′-deoxy-5′-iodo-7-methylguanosine (**Fig. 2, no. 6**) (2.0 g, 4.92 mmol) in 100 mL of DMF trisodium thiophosphate (4.43 g, 24.6 mmol) was added. The reaction mixture was stirred for 48 h at room temperature. Precipitate was removed and the filtrate was evaporated under reduced pressure. The residue was dissolved in 50 mL of water and the excess of trisodium thiophosphate was precipitated by addition of methanol (100 mL). After separation, the crude product was purified by ion exchange chromatography on Sephadex. The product was freeze-dried. Yield 1.55 g, (53%). t_R (B) = 4.64 min;

^{1}H NMR (400 MHz, D_2O) δ ppm 7.85 (s, 1H, H-8), 5.89 (d, 1H, J = 3.74 Hz, H-1'), 4.78-4.75 (m, 1H, H-2'), 4.43-4.39 (m, 2H, H-3', H-4'), 4.09 (s, 3H, CH_3), 3.08-2.94 (m, 2H, Hz, H-5'); ^{31}P NMR (162 MHz, D_2O) δ ppm 14.45 (s, 1P);

HRMS ESI (-) calcd. m/z $C_{11}H_{15}N_5O_7PS^-$ [M-H]$^-$: 392.04353, found: 392.04378.

General procedure of synthesis of guanosine 5'-deoxy-5'-thioguanosine-5'-monophosphorothiolate imidazolides (Fig. 2, no. 9, 10)

An appropriate starting compound (nucleotide TEA salt) (1 mmol), was mixed with imidazole (10 mmol) and 2,2′-dithiodipyridine (3 mmol) in DMF (to the nucleotide concentration of 0.15 M). Next, triethylamine (3 mmol) and triphenylphosphine (3 mmol) were added, and the mixture was stirred for 24 h at room temperature. Addition of an anhydrous solution of $NaClO_4$ (4 mmol for each phosphate moiety) in dry acetone (volume 10 x greater than the DMF added) resulted in precipitation of the product off the reaction mixture. After cooling to 4 °C the precipitate was filtered off, washed with cold, dry acetone and dried in vacuum over P_4O_{10}.

guanosine 5'-deoxy-5'-thioguanosine-5'-monophosphorothiolate imidazolide (Fig. 2, no. 9)

Guanosine 5'-deoxy-5'-thioguanosine-5'-monophosphorothioate imidazolide (**Fig. 2, no. 9**) (352 mg, 0.75 mmol, 89 %) was obtained starting from 5'-deoxy-5'-thioguanosine-5'-monophosphorothioate (**Fig. 2, no. 7**) (500 mg, 0.86 mmol) following the general procedure. t_R (B) = 8.27 min;

^{31}P NMR (162 MHz, D_2O) δ ppm 11.69 (m, 1P);

HRMS ESI (-) calcd. m/z for $C_{13}H_{15}N_7O_6PS^-$ [M-H]$^-$: 428.05476, found 428.05452.

5'-deoxy-5'-thioguanosine-7-methylguanosine-5'-monophosphorothiolate imidazolide (Fig. 2, no. 10)

5'-deoxy-5'-thioguanosine-7-methylguanosine-5'-monophosphorothioate imidazolide (**Fig. 2, no. 10**) (321 mg, 0.69 mmol, 82%) was obtained starting from 5'-deoxy-5'-thio-7-methylguanosine-5'-monophosphorothioate (**Fig. 2, no. 8**) (500 mg, 0.84 mmol) following the general procedure. t_R (B)=8.39 min;

HRMS ESI (-) calcd. m/z for $C_{14}H_{17}N_7O_6PS^-$ $[M-H]^-$: 442.07041, found 442.07070.

Guanosine 5'-deoxy-5'-thioguanosine-5'-diphosphorothiolate (Fig. 2, no. 11)

Guanosine 5'-deoxy-5'-thioguanosine-5'-monophosphorothioate imidazolide (**Fig. 2, no. 9**) (100 mg, 0.22 mmol) was dissolved in anhydrous DMF (2 mL), and tris(triethylammonium) phosphate (100 mg, 0.26 mmol) was added, followed by addition of $ZnCl_2$ (235.84 mg, 1.76 mmol). Reaction progress was controlled with RP-HPLC. The reaction mixture was stirred at room temperature until the disappearance of the starting material. Then, the reaction was stopped by addition of an aqueous solution of EDTA (513.92 mg, 1.76 mmol, 50 mL) and neutralized with 1M $NaHCO_3$. Crude product was purified by ion exchange chromatography on DEAE-Sephadex and isolated as TEA salts. Yield: 108.5 mg (0.14 mmol, 65 %);

HRMS ESI (-) calcd. m/z for $C_{10}H_{14}N_5O_{10}P_2S^-$ $[M-H]^-$: 457.99421, found 457.99481.

5'-deoxy-5'-thioguanosine-7-methylguanosine-diphosphate *(Fig. 2, no. 12)*

5'-deoxy-5'-thioguanosine-7-methylguanosine-5'-monophosphorothioate imidazolide (**Fig. 2, no. 10**) (100 mg, 0.21 mmol) was dissolved in anhydrous DMF (2 mL), and tris(triethylammonium)-phosphate (100 mg, 0.26 mmol) was added, followed by addition of $ZnCl_2$ (224.54 mg, 1.68 mmol). Reaction progress was controlled with RP-HPLC. The reaction mixture was stirred at room temperature until the disappearance of the starting material. Then, the reaction was stopped by addition of an aqueous solution of EDTA (490.56 mg, 1.68 mmol, 50 mL) and neutralized with 1M $NaHCO_3$. Crude product was purified by ion exchange chromatography on DEAE-Sephadex and isolated as TEA salts. Yield: 91 mg (0.12 mmol, 54 %), t_R (B) = 5.07 min,

^{1}H NMR (400 MHz, D_2O) δ ppm 8.11 (s, 1H, H-8 slowly exchangeable), 5.97 (d, 1H, J = 3.91 Hz, H-1'), 4.50, 4.49 (2d, 1H, J = 5.09 Hz, H-2'), 4.41 (q, 1H, J = 5.48, 5.09 Hz, H-3'), 4.07 (s, 3H, CH_3), 3.34-3.13 (m, 3H, H-4', H-5'); ^{31}P NMR (162 MHz, D_2O) δ ppm 6.71 (d, 1P, J = 30.81 Hz), 8.21 (d, 1P, J = 30.81 Hz);

HRMS ESI (-) calcd. m/z for $C_{11}H_{16}N_5O_{10}P_2S$- $[M-H]^-$: 472.00986, found 472.00967.

guanosine 5'-deoxy-5'-thio-7-methylguanosine-2'-diphosphorothiolate (Fig. 2, no. 13)

5'-deoxy-5'-thioguanosine-7-methylguanosine-5'-monophosphorothioate imidazolide (**Fig. 2, no. 10**) (100 mg, 0.21 mmol) was dissolved in anhydrous DMF (2 mL), and sodium thiophosphate (47 mg, 0.26 mmol) was added, followed by addition of $ZnCl_2$ (224.54 mg, 1.68 mmol). Reaction progress was controlled with RP-HPLC. The reaction mixture was stirred at room temperature until the disappearance of the starting material. Then, the reaction was stopped by addition of an aqueous solution of EDTA (490.56 mg, 1.68 mmol, 50 mL) and neutralized with 1M $NaHCO_3$. Crude product was purified by ion exchange chromatography on DEAE-Sephadex and the isolated TEA salt was used immediately in the coupling reaction. Yield: 110 mg (0.13 mmol, 64 %);

HRMS ESI (-) calcd. m/z for $C_{11}H_{16}N_5O_9P_2S_2^-$ $[M-H]^-$: 487.98702, found 487.98724.

Synthesis of 5'-S-cap analogs *via* S-alkylation

General procedure

Nucleoside terminal thiophosphate TEA salt (1 equiv.) was suspended in DMSO (to concentration ca. 0.1 - 0.2 M). Then, DBU (1,8-diazabicyclo(5.4.0)undec-7-ene) (1 equiv.) and a derivative of 5'-iodoguanosine (1 equiv.) was added. The progress of the reaction was monitored by RP HPLC. The reaction was stopped after there was no signal from the terminal thiophosphate by addition of 1% acetic acid to pH=7, the reaction mixture was diluted with water and washed with ethyl acetate. Product was purified by ion exchange chromatography on DEAE-Sephadex and isolated as triethylammonium salt. The product was purified by semi-preparative RP-HPLC.

P1-(guanosin-5'-yl)-P2-(5'-deoxy-5'-thioguanosin-5'-yl) diphosphate - GppSG (Fig. 3, no. 19)

GppSG (207 mOD, 0.009 mmol, 24%) was obtained starting from GDPβS (**Fig. 3, nr 14)**, (506 mOD, 0.042 mmol) following the general procedure. RP-HPLC: t_R (A) = 6.9 min;

^{1}H NMR (400 MHz, D_2O) δ ppm 7.96 (s, 1 H), 7.81 (s, 1 H), 5.77 (d, 1 H, *J* = 5.48 Hz), 5.70 (d, 1 H, *J* = 5.87 Hz), 4.80-4.70 (m, 2H, overlapped with water signal), 4.64 (t, 1 H, *J* = 5.48 Hz), 4.43 (t, 1 H, t, *J* = 3.91 Hz), 4.37 (t, 1 H, *J* = 3.91 Hz), 4.30-4.15 (m, 4H), 3.30-3.13 (m, 2 H);

^{31}P NMR (162 MHz, D_2O) δ ppm 7.63 (d, 1P, J = 32.28, 12.5 Hz), -12.02 (d, 1P, J = 30.81 Hz);

HRMS ESI (-) calcd. m/z for $C_{20}H_{25}N_{10}O_{14}P_2S^-$ $[M-H]^-$: 723.07531, found 723.07546.

P1-(7-methyl-guanosin-5'-yl)-P2-(5'-deoxy-5'-thioguanosin-5'-yl) diphosphate - m^7GppSG (Fig. 3, no. 21)

m^7GppSG (1028 mOD, 0.045 mmol, 9 %) was obtained starting from m^7GDPβS (**Fig. 3, no. 17**, 5830 mOD, 0.51 mmol)) following the general procedure. RP-HPLC: t_R (A) = 5.9 min;
^{1}H NMR (400 MHz, D_2O) δ ppm 8.98 (s, 1 H, H-8 m^7G), 7,87 (s, 1 H, H-8 G), 5.88 (d, 1 H, *J* = 2.0 Hz, H-1' m^7G), 5.73 (d, 1 H, *J* = 5.7 Hz, H-1' G), 4.69 (t, 1 H, *J* = 5.5 Hz, H-2' G), 4.51 (bs., 1 H, H-2' m^7G), 4,32 – 4.44 (m, 5 H, H-3' G, H-3' m^7G, H-4' G, H-4' m^7G, H-5' m^7G), 4.24 (dd, 1 H, *J*=11.3, 5.4 Hz, H5" m^7G), 4.04 (s, 3 H, CH_3), 3.24 – 3.41 (m, 2 H, H5', 5" G);
^{31}P NMR (162 MHz, D_2O) δ ppm 7.38 (dt, 1P, J = 29.0, 11.5 Hz), -12.00 (d, 1P, J = 32.23 Hz);
HRMS ESI (-) calcd. m/z for $C_{21}H_{27}N_{10}O_{14}P_2S^-$ [M-H]$^-$: 737.09096, found 737.09052.

P1-(7-methyl-5'-deoxy-5'-thioguanosin-5'-yl)-P2-guanosin-5'-yl diphosphate - m^7GSppG (Fig. 3, no. 23)

m^7GSppG (1660 mOD, 0.073 mmol, 35%) was obtained starting from GDPβS (**Fig. 3, no. 14**; 2532 mOD, 0.21 mmol) following the general procedure. RP-HPLC: t_R (A) = 7.75 min;
^{1}H NMR (400 MHz, D_2O) δ ppm 7.99 (s, 1 H, H-8 G), 5.83 (d, 1 H, J = 4,2 Hz, H-1' m^7G), 5.80 (d, 1 H, J = 6.0 Hz, H-1' G), 4.65 – 4.70 (2 H, m, H-2' G, H-2' m^7G), 4.45 (t, 1 H, J = 4.1 Hz, H-3' G), 4.19 – 4.41 (5 H, m, H-3' m^7G, H-4' G, H-4' m^7G, H5', 5" G), 4.05 (s, 3 H, CH_3), 3.35 – 3.43 (m, 2 H, H5', 5" m^7G);
^{31}P NMR (162 MHz, D_2O) δ ppm 7.32 (dt, 1P, J = 29.0, 11.0 Hz), -11.84 (d, 1P, J = 29.00 Hz);
HRMS ESI (-) calcd. m/z for $C_{21}H_{27}N_{10}O_{14}P_2S^-$ [M-H]$^-$: 737.09096, found 737.09146.

P1-(guanosin-5'-yl)-P3-(5'-deoxy-5'-thioguanosin-5'-yl) trifphosphate – GpppSG (Fig. 3, no. 20)

GpppSG (1149 mOD, 0.051 mmol, 51 %) was obtained starting from GTP$_\gamma$S (**Fig. 3, no. 15**; 1233 mOD, 0.10 mmol) following the general procedure. RP-HPLC: t_R (A) = 5.50 min;
^{1}H NMR (400 MHz, D_2O) δ ppm 8.02 (s, 1 H, H-8 G), 7.90 (s, 1 H, H-8 G), 5.82 (d, 1 H, J = 6.0 Hz, H-1' G), 5.78 (d, 1 H, J = 6.2 Hz, H-1' G), 4.84 (t, 1 H, J = 5.7 Hz, H-2' G), 4.74 (t, 1 H, J = 5.7 Hz, H-2' G), 4.52 (t, 1 H, J = 4.2 Hz, H-3' G), 4.47 (t, 1 H, J = 4.3 Hz, H-3' G), 4.30 – 4.38 (m, 2 H, H-4', 5' G), 4.27 (m, 2 H, H-4', 5" G), 3.25 – 3.35 (m, 2 H, H5', 5" G);
^{31}P NMR (162 MHz, D_2O) δ ppm 8.21 (dt, 1P, J = 27.00, 13.3 Hz), -11.34 (d, 1P, J = 19.30 Hz), --23.78 (dd, 1P, J = 27.00, 19.30 Hz);
HRMS ESI (-) calcd. m/z for $C_{20}H_{26}N_{10}O_{17}P_3S^-$ [M-H]$^-$: 803.04164, found 803.04135.

P1-(7-methyl-5'-deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl triphosphate - m^7GSpppG (Fig. 3, no. 24)

m^7GSpppG (729 mOD, 0.032 mmol, 13 %) was obtained starting from $GTP_\gamma S$ (**Fig. 3, no. 15**; 3000 mOD, 0.25 mmol) following the general procedure. RP-HPLC: t_R (A) = 5.36 min;

^{1}H NMR (400 MHz, D_2O) δ ppm 8.92 (s, 1 H, H-8 m^7G), 7.96 (s, 1 H, H-8 G), 5.78 (d, 1 H, J = 4.30 Hz, H-1' m^7G), 5,74 (d, 1 H, J = 5.87 Hz, H-1' G), 4.63 (m, 2 H, H-2' G, H2' m^7G), 4,48 (dd, 1 H, J = 4.43, 3.52 Hz, H-3' m^7G), 4.36 – 4.26 (m, 4 H, H-3' G, H-4' G, H-4' m^7G, H-5' G), 4.24 - 4.19 (m, 1H, H-5" G), 4.00 (s, 3 H, CH_3), 3.33 – 3.24 (2 H, m, H-5', 5" m^7G);

^{31}P NMR (162 MHz, D_2O) δ ppm 7.57 (d, 1P, J = 27.88 Hz), -11.68 (d, 1P, J = 20.54 Hz), -24.00 (dd, 1P, J = 29.35, 22.01 Hz);

HRMS ESI (-) calcd. m/z for $C_{21}H_{28}N_{10}O_{17}P_3S^-$ $[M-H]^-$ 817.05729, found 817.05494.

P1-(7-methyl-guanosin-5'-yl)-P3-(5'-deoxy-5'-thioguanosin-5'-yl) triphosphate - m^7GpppSG (Fig. 3, no. 22)

m^7GpppSG (1582 mOD, 0.07 mmol, 32 %) was obtained starting from $m^7GTP_\gamma S$ (**Fig. 3, no. 18**; 2616 mOD, 0.23 mmol) following the general procedure. RP-HPLC: t_R (A) = 6.06 min;

^{1}H NMR (400 MHz, D_2O) δ ppm 9.02 (s, 1 H, H-8 m^7G), 7.87 (s, 1 H, H-8 G), 5.84 (d, 1 H, J = 3.52 Hz, H1' m^7G), 5.70 (d, 1 H, J = 6.65 Hz, H-1' G), 4.80 – 4.67 (m, 1 H, H-2' G), 4.52 (t, 1 H, J = 4.30 Hz, H-2' m^7G), 4.41 (dd, 2 H, J=4.70, 4.30 Hz, H3' G, H3' m^7G), 4.38 – 4.30 (m, 2 H, H-4' G, H-4' m^7G), 4.36-4.31 m, 2H, H5' m^7G), 4.02 (s, 3 H, CH_3), 3.30-3.20 (m, 2 H, J = 12.6, 6.3 Hz, H5', 5" G);

^{31}P NMR (162 MHz, D_2O) δ ppm 7.66 (d, 1P, J = 29.35 Hz), -11.73 (d, 1P, J = 22.01 Hz), -23.95 (dd, 1P, J = 22.01, 27.88 Hz);

HRMS ESI (-) calcd. m/z for $C_{21}H_{28}N_{10}O_{17}P_3S^-$ $[M-H]^-$: 817.05729, found 817.05748.

P1-(2'-O-methyl-7-methyl-5'-deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl triphosphate - $m_2^{7,2'\text{-}O}$GSpppG (Fig. 3, no. 26)

$m_2^{7,2'\text{-}O}$GSpppG (140 mOD, 0.006 mmol, 5%) was obtained starting from $GTP_\gamma S$ (**Fig. 3, no. 15**; 1500 mOD, 0.12 mmol) following the general procedure. RP-HPLC: t_R (A) = 7.89 min;

^{1}H NMR (400 MHz, D_2O) δ ppm 7.93 (s, 1H, G), 5.81 (d, 1H, J = 3.91 Hz, H-1' m^7G), 5.72 (d, 1H, J = 6.26 Hz, H-1' G), 4.65 (t, 1H, J = 5.48 Hz, H-2' m^7G), 4.43-4.40 (m, 1H, H-2', G, H-3' m^7G), 4.32-4.18 (m, 6H, H-3' G, H-4', H-5', G, m^7G), 4.01 (s, 3H, CH_3), 3.52 (s, 3H, OCH_3);

^{31}P NMR (162 MHz, D_2O) δ ppm 7.35 (d, 1P, J = 26.41 Hz), -11.68 (d, 1P, J = 19.07 Hz), -24.02, -24.18 (2d, 1P, J = 26.41, 19.07 Hz);

HRMS ESI (-) calcd. m/z for $C_{22}H_{30}N_{10}O_{17}P_3S^-$ $[M-H]^-$ 831.07294, found 831.07477.

P1-(7-methyl-5'-deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl-2,3-methylenotriphosphate - $m^7GSppCH_2pG$ (Fig. 3, no. 25)

m^7GSpppCH_2pG (353 mOD, 0.016 mmol, 27%) was obtained starting from m^7GpCH_2ppγS (**Fig. 3, no. 16**; 717 mOD, 0.06 mmol) following the general procedure. RP-HPLC: t_R (A) = 6.36 min; ^{1}H NMR (400 MHz, D_2O) δ ppm 9.03 (s, 1H, H-8, m^7G), 8.17 (s, 1H, G), 5.83 (d, 1H, J = 4.30 Hz, H-1' m^7G), 5.78 (d, 1H, J = 4.48 Hz, H-1' G), 4.70-4.66 (m, 2H, H-2' m^7G, H-2', G), 4.46 (d, 1H, J = 3.91, 5.09 Hz, H-3', G), 4.38-4.33 (m, 2H, H-3', m^7G, H-4', G), 4.32-4.28 (m, 1H, H-4', m^7G), 4.26-4.20 (m, 1H, H-5', G), 4.19-4.13 (m, 1H, H-5" G), 4.02 (s, 3H, CH_3), 3.34-3.22 (m, 4H, H-5', G, m^7G); ^{31}P NMR (162 MHz, D_2O) δ ppm

^{31}P NMR (162 MHz, D_2O) δ ppm 17.03 (d, 1P, J = 10.27 Hz), 7.47-6.97 (m, 2P);

HRMS ESI (-) calcd. m/z for $C_{22}H_{30}N_{10}O_{16}P_3S^-$ $[M-H]^-$ 815.07803, found 815.07923.

Synthesis of 5'-S- cap analogs *via* imidazolides

General procedure

5'S-GMP-Im, (**Fig. 2, no. 9**) (Na salt, 50 mg, 0.11 mmol) and appropriate diphosphate (1 mmol): $m_2^{7,2'-O}$GDP (**Fig. 4, no. 28**), m^7GpCH_2p (**Fig. 4, no. 27**), m^7-5'S GDP (**Fig. 2, no. 12**), m^7GSppβS (**Fig. 2, no. 13**) or m^7GDPβS (**Fig. 3, no. 17**) were suspended in anhydrous DMF (1.0 mL) followed by addition of anhydrous $ZnCl_2$ (95 mg, 10 eq, 0.7 mmol). The reaction mixture was vigorously shaken until the reagents dissolved. The reaction progress was monitored by RP-HPLC. After completion (24 h), appropriate amount of EDTA solution (Na_2EDTA, 237 mg, 0.7 mmol) was added,pH was adjusted to 6 with solid $NaHCO_3$, followed by purification of the crude product by ion exchange chromatography by DEAE-Sephadex and isolated as TEA salts (or directly purified by preparative HPLC). The products were then additionally purified by RP-HPLC.

P1-(2'-O-methyl-7-methyl-guanosin-5'-yl)-P3-(5'-deoxy-5'-thioguanosin-5'-yl) triphosphate - $m_2^{7,2'-O}$GpppSG (Fig. 4, no. 38)

$m_2^{7,2'-O}$GpppSG (122 mOD, 0.005 mmol, 6%) was obtained starting from *$m_2^{7,2'-O}$G*DP (**Fig. 4, no. 28**; 912 mOD, 0.08 mmol) following the general procedure. RP-HPLC: t_R (A)=6.29 min; ^{1}H NMR (400 MHz, D_2O) δ ppm 9.00 (s, 1H, H-8 m^7G), 7.88 (s, 1H, G), 5.87 (d, 1H, J = 2.74 Hz, H-1' m^7G), 5.69 (d, 1H, J = 6.65 Hz, H-1' G), 4.64 (t, 1H, J = 5.48 Hz, H-2' m^7G), 4.48 (dd, 1H, J = 4.48 Hz, H-2', G), 4.43-4.38 (m, 2H, H-3',G, H-3', m7G), 4.36-4.32 (m, 1H, H-4', G), 4.30-4.26 (m, 1H, H-4', m^7G), 4.25-4.16 (m, 2H, H-5', G), 4.03 (s, 3H, CH3), 3.53 (s, 3H, OCH_3), 3.30-3.22 (m, 2H, H-5', m^7G);

^{31}P NMR (162 MHz, D_2O) δ ppm 7.68(d, 1P, J = 27.88 Hz), -11.68 (d, 1P, J = 20.54 Hz), -23.78, -23.94 (2d, 1P, J = 27.88, 19.07Hz);

HRMS ESI (-) calcd. m/z for $C_{22}H_{30}N_{10}O_{17}P_3S^-$ $[M-H]^-$ 831.07294, found 831.07350.

P1-(7-methyl-5'-deoxy-5'-tioguanozyn-5'-yl)-P3-guanosin-5'-yl 1,2-methylenetriphosphate - m^7GpCH_2ppSG (Fig. 4, no. 37)

m^7GpCH_2ppSG (1002 mOD, 0.044 mmol, 25 %) was obtained starting from m^7GpCH_2p (**Fig. 4, no. 27**; 2052 mOD, 0.18 mmol) and 5'-S-GMP-Im (122 mg, 0.27 mmol) following the general procedure. RP-HPLC: t_R (A) = 6.26 min,

^{1}H NMR (400 MHz, D_2O) δ ppm 9.31 (s, 1H, H-8, m^7G), 8.02 (s, 1H, G), 5.90 (d, 1H, J = 3.13 Hz, H-1' m^7G), 5.75 (d, 1H, J = 5.87 Hz, H-1' G), 4.80-4.70 (m, 2H, overlapped with solvent signal, H-2' m^7G, H-2', G), 4.58 (dd, 1H, J = 3.91, 3.48 Hz, H-3', G),4.48 (t, 1H, H-3', m^7G), 4.40 (dd, 1H, J = 3.91, 4.06, H-4', G), 4.37-4.29 (m, 3H, H-4', m^7G, H-5', G), 4.19-4.13 (m, 2H, H-5', G), 4.03 (s, 3H, CH_3), 3.30-3.19 (m, 2H, H-5', G, m^7G), 2.40 (t, 2H, J = 20.35 Hz, CH_2);

^{31}P NMR (162 MHz, D_2O) δ ppm 17.11 (d, 1P, J = 8.80 Hz), 7.64-6.76 (m, 2P);

HRMS ESI (-) calcd. m/z for $C_{22}H_{30}N_{10}O_{16}P_3S^-$ $[M-H]^-$ 815.07803, found 815.07906.

P1-(7-methyl-5'-deoxy-5'-thioguanozy-5'-yl)-P3-(5'-deoxy-5'-thioguanosin-5'-yl) triphosphate - $m^7GSpppSG$ (Fig. 4, no. 32)

$m^7GSpppSG$ (768 mOD, 32 mg, 0.028 mmol, 40 %) was obtained starting from m^7-5'S-GDP (57 mg, 0.07 mmol) and 5'S-GMP-Im (50 mg, 0.11 mmol) following the general procedure. RP-HPLC: t_R (A) = 6.80 min;

^{1}H NMR (400 MHz, D_2O) δ ppm 8.38 (s, 1H, H-8 m^7G slowly exchangeable), 7.84 (s, 1H, G), 5.78 (d, 1H, J = 4.70 Hz, H-1' m^7G), 5.69 (d, 1H, J = 6.65 Hz, H-1' G), 4.64 (t, 1H, J = 4.70 Hz, H-2' m^7G), 4.40, 4.39 (2d, 1H, J = 2.74, 3.52, 4.40 Hz, H-3', G), 4.36-4.29 (m, 3H, H-4' G, H-5', G), 3.99 (s, 3H, CH_3), 4.37-4.28 (m, 3H, H-4', H-5', m^7G);

^{31}P NMR (162 MHz, D_2O) δ ppm 7.74 (t, 2P, J = 27.88), -24.61 (t, 1P, J = 29.35 Hz);

HRMS ESI (-) calcd. m/z for $C_{21}H_{28}N_{10}O_{16}P_3S_2^-$ $[M-H]^-$ 833.03445, found 833.03550.

P1-(7-methyl-5'-deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl 2-thiotriphosphate - m^7GSpp_spG D1/D2 (Fig. 4, no. 30, 31, respectively)

m^7GSpp_spG (1080 mOD, 45 mg, 0.039 mmol, 56 %) was obtained as a mixture of diastareoisomers D1/D2 starting from $m^7GSppβS$ (56 mg, 0.07 mmol) and 5'S-GMP-Im (50 mg, 0.11 mmol) following the general procedure. Diastereoisomers were separated using RP-HPLC and isolated as ammonium salts. **D1** (**Fig. 4, no. 30**): (438 mOD, 18 mg, 0.016 mmol, 23%) RP-HPLC: t_R (A) = 6.56 min;

^{1}H NMR (400 MHz, D_2O) δ ppm 8.98 (s, 1H, H-8, m^7G), 8.08 (s, 1H, G), 5.82 (d, 1H, J = 4.27 Hz, H-1' m^7G), 5.77 (d, 1H, J = 5.80 Hz, H-1' G), 4.67-4.65 (m, 2H, H-2' m^7G, H-2', G), 4.49-4.47 (m,

1H, H-3', G), 4.39-4.35 (m, 1H, H-3', m^7G, H-4', G), 4.33-4.23 (m, 3H, H-4', m^7G, H-5', G), 4.02 (s, 3H, CH_3), 3.38-3.25 (m, 2H, H-5', m^7G);

^{31}P NMR (162 MHz, D_2O) δ ppm 29.18 (dd, 1P, J = 34.83, 27.37 Hz), 6.96 (dt, 1P, J = 34.83, 12.44 Hz), -12.37 (d, 1P, J = 27.37 Hz);

HRMS ESI (-) calcd. m/z for $C_{21}H_{28}N_{10}O_{16}P_3S_2^-$ $[M-H]^-$: 833.03445, found 833.03549;

D2 (**Fig. 4, no. 31**): m^7GSpp_spG *D2* (380 mOD, 16 mg, 0.014 mmol, 20%) RP-HPLC: t_R (A) = 6.71 min;

^1H NMR (400 MHz, D_2O) δ ppm 8.98 (s, 1H, H-8, m^7G), 8.14 (s, 1H, G), 5.82 (d, 1H, J = 4.27 Hz, H-1' m^7G), 5.77 (d, 1H, J = 5.49 Hz, H-1' G), 4.69-4.65 (m, 2H, H-2' m^7G, H-2', G), 4.49-4.45 (m, 1H, H-3', G), 4.40-4.35 (m, 1H, H-3', m^7G, H-4', G), 4.34-4.21 (m, 3H, H-4', m^7G, H-5', G), 4.03 (s, 3H, CH_3), 3.39-3.24 (m, 2H, H-5', m^7G);

^{31}P NMR (162 MHz, D_2O) δ ppm 29.44-28.67 (m, 1P), 7.17-6.54 (m, 1P), -12.09-(-12.72) (m, 1P);

HRMS ESI (-) calcd. m/z for $C_{21}H_{28}N_{10}O_{16}P_3S_2^-$ $[M-H]^-$: 833.03445, found 833.03606.

P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-(5'-deoxy-5'-thioguanosin-5'-yl) 2-tiotriphosphate - m^7GSpp_spSG D1/D2 (Fig. 4, no. 33, 34, respectively)

m^7GSpp_spSG (942 mOD, 39 mg, 0.003 mmol, 48 %) was obtained as a mixture of diastareoisomers **D1**/**D2** starting from $m^7GSppβS$ (56 mg, 0.07 mmol) and 5'S-GMP-Im (50 mg, 0.11 mmol) following the general procedure. Diastereoisomers were separated using RP-HPLC and isolated as ammonium salts. **D1** (**Fig. 4, no. 33**) (510 mOD, 21 mg, 0.018 mmol, 26 %) RP-HPLC: t_R (A) = 7.53 min;

^1H NMR (400 MHz, D_2O) δ ppm 9.00 (s, 1H, H-8, m^7G), 7.99 (s, 1H, G), 5.83 (d, 1H, J = 4.27 Hz, H-1' m^7G), 5.75 (d, 1H, J = 6.10 Hz, H-1' G), 4.79-4.68 (m, 2H, overlapped with solvent signal, H-2' m^7G, H-2', G), 4.44 (dd, 1H, J = 4.58 Hz, H-3', G), 4.41-4.33 (m, 3H, H-3', m^7G, H-4', G, m^7G), 4.03 (s, 3H, CH_3), 3.39-3.26 (m, 4H, H-5', G, m^7G);

^{31}P NMR (162 MHz, D_2O) δ ppm 28.25 (t, 1P, J = 34.83 Hz), 7.31-6.74 (m, 2P);

HRMS ESI (-) calcd. m/z for $C_{21}H_{28}N_{10}O_{15}P_3S_3^-$ $[M-H]^-$: 849.01161, found 849.01213.

D2 (**Fig. 4, no. 34**) (274 mOD, 11 mg, 0.0098 mmol, 14 %), RP-HPLC: t_R (A) = 7.62 min;

^1H NMR (400 MHz, D_2O) δ ppm 8.99 (s, 1H, H-8, m^7G), 8.04 (s, 1H, G), 5.83 (d, 1H, J = 4.58 Hz, H-1' m^7G), 5.75 (d, 1H, J = 6.10 Hz, H-1' G), 4.78-4.66 (m, 2H, overlapped with solvent signal, H-2' m^7G, H-2', G), 4.46-4.42 (m, 1H, H-3', G), 4.41-4.34 (m, 3H, H-3', m^7G, H-4', G, m^7G), 4.04 (s, 3H, CH_3), 3.39-3.24 (m, 4H, H-5', G, m^7G);

^{31}P NMR (162 MHz, D_2O) δ ppm 28.29 (t, 1P, J = 34.83 Hz), 7.32-6.68 (m, 2P);

HRMS ESI (-) calcd. m/z for $C_{21}H_{28}N_{10}O_{15}P_3S_3^-$ $[M-H]^-$: 849.01161, found 849.01217.

P1-(7-methyl-guanosin-5'-yl)-P3-(5'-deoxy-5'-thioguanosin-5'-yl) 2-thiotriphosphate - m^7Gpp_spSG D1/D2 (Fig. 4, no. 35, 36, respectively)

m^7GppspSG (1941 mOD, 0.086 mmol, 28 %) was obtained as a mixture of diastareoisomers D1/D2 starting from m^7GDPβS (3492 mOD, 0.31 mmol) and 5'S-GMP-Im (5550 mOD, 0.46 mmol) following the general procedure. Diastereoisomers were separated using RP-HPLC and isolated as ammonium salts. **D1** (**Fig. 4, no. 35**): (888 mOD, 0.039 mmol, 13%) RP-HPLC: t_R (A) = 7.12 min;

^{1}H NMR (400 MHz, D_2O) δ ppm 9.07 (s, 1H, H-8, m^7G), 7.95 (s, 1H, G), 5.88 (d, 1H, J = 3.52 Hz, H-1' m^7G), 5.74 (d, 1H, J = 6.26 Hz, H-1' G), 4.80-4.70 (m, 2H, H-2' m^7G, H-2', G overlapped with D_2O signal), 4.56 (dd, 1H, J = 4.70, 3.52 Hz, H-3', G), 4.47-4.40 (m, 2H, H-3', m^7G, H-4', G), 4.39-4.33 (m, 3H, H-4', m^7G, H-5', G), 4.03 (s, 3H, CH_3), 3.35-3.20 (m, 2H, H-5', m^7G);

^{31}P NMR (162 MHz, D_2O) δ ppm 29.00 (dd, 1P, J = 33.75, 26.41Hz), 6.98 (d, 1P, J = 33.75, Hz), -12.56 (d, 1P, J = 24.94 Hz);

HRMS ESI (-) calcd. m/z for $C_{21}H_{28}N_{10}O_{16}P_3S_2^-$ $[M-H]^-$: 833.03445, found 833.03514.;

D2 (**Fig. 4, no. 36**): m^7GppspG D2 (1053 mOD, 0.046 mmol, 15%) RP-HPLC: t_R (A) = 7.42 min;

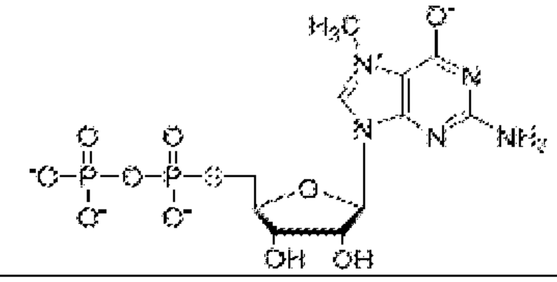
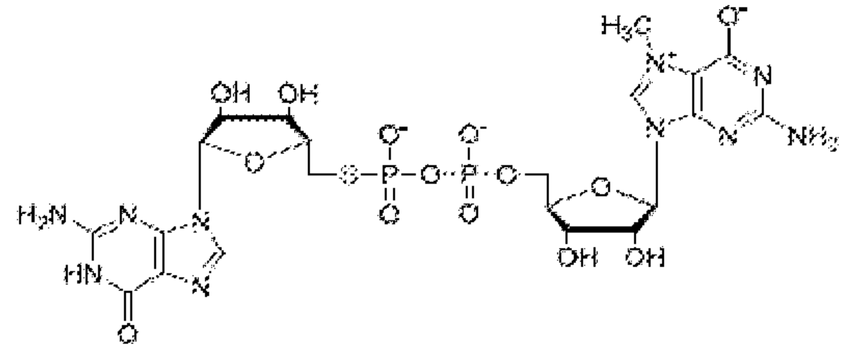
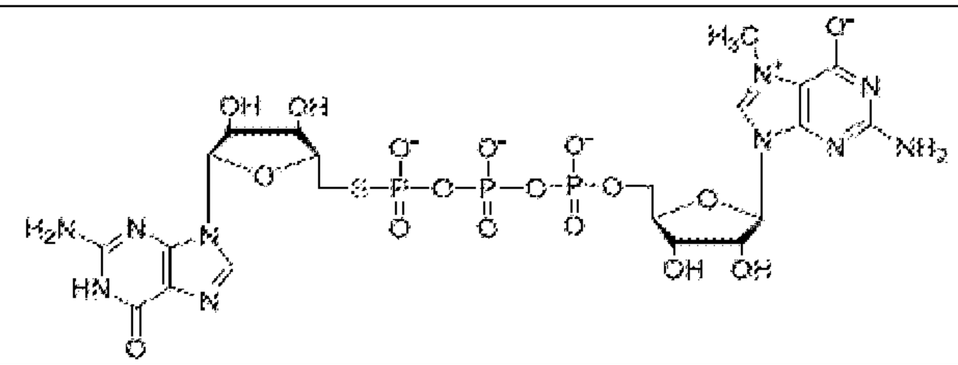
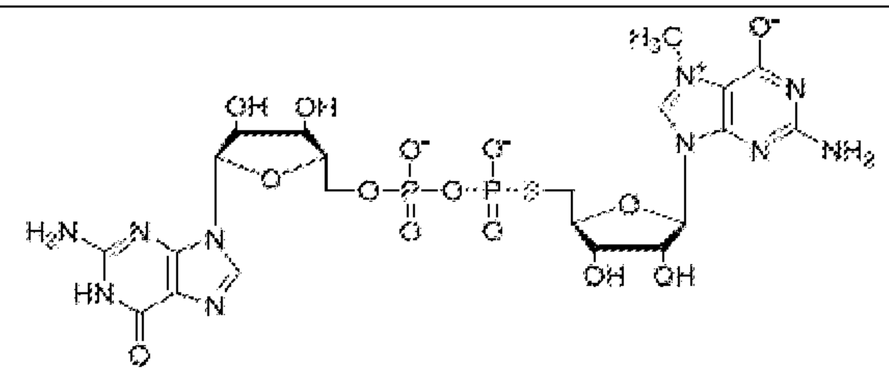
^{1}H NMR (400 MHz, D_2O) δ ppm 9.04 (s, 1H, H-8, m^7G), 7.95 (s, 1H, G), 5.85 (d, 1H, J = 3.52 Hz, H-1' m^7G), 5.73 (d, 1H, J = 6.26 Hz, H-1' G), 4.80-4.70 (m, 2H, H-2' m^7G, H-2', G overlapped with D_2O signal), 4.54 (dd, 1H, J = 4.30, 3.91 Hz, H-3', G), 4.45 (t, 1H, J = 5.09 Hz, H-3', m^7G), 4.43-4.40 (m, 1H, H-4', G), 4.39-4.32 (m, 3H, H-4', m^7G, H-5', G), 4.03 (s, 3H, CH_3), 3.37-3.21 (m, 2H, H-5', m^7G);

^{31}P NMR (162 MHz, D_2O) δ ppm 28.99 (dd, 1P, J = 33.75, 26. 41, 24.94Hz), 6.94 (d, 1P, J = 35.21, Hz), -12.48 (d, 1P, J = 24.94 Hz);

HRMS ESI (-) calcd. m/z for $C_{21}H_{28}N_{10}O_{16}P_3S_2^-$ $[M-H]^-$: 833.03445, found 833.03494.

CA 03011663 2018-07-17

Table 4. Synthesised and studied new cap analogs are presented.

Number	Compound	Structural formula	Chemical name
12	m^7G**S**pp		5'-deoxy-5'-thioguanosin-5'-7-methyloguanosine diphosphate
21	m^7Gpp**S**G		P1-(7-methyl-guanosin-5'-yl)-P2-(5'-deoxy-5'-thioguanosin-5'-yl) diphosphate
22	m^7Gppp**S**G		P1-(7-methyl-guanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) triphosphate
23	m^7G**S**ppG		P1-(7-methyl-5'-deoxy-5'-thioguanosin-5'-yl)-P2-guanosin-5'-yl diphosphate

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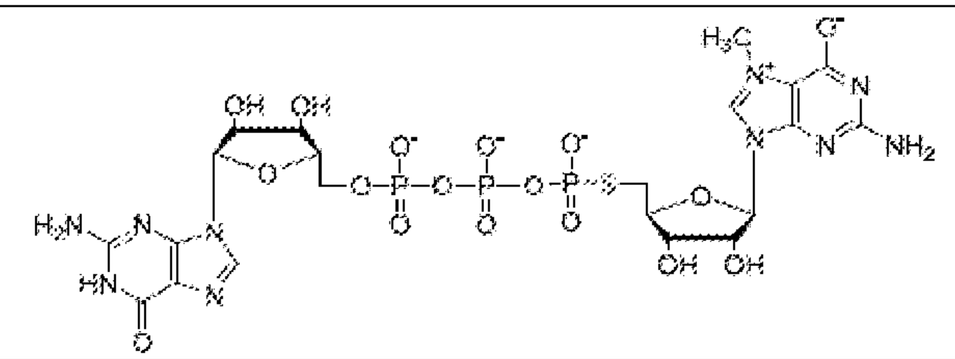
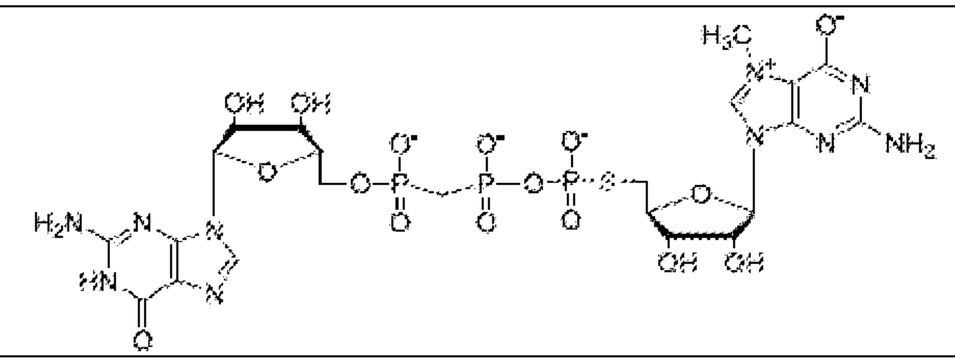
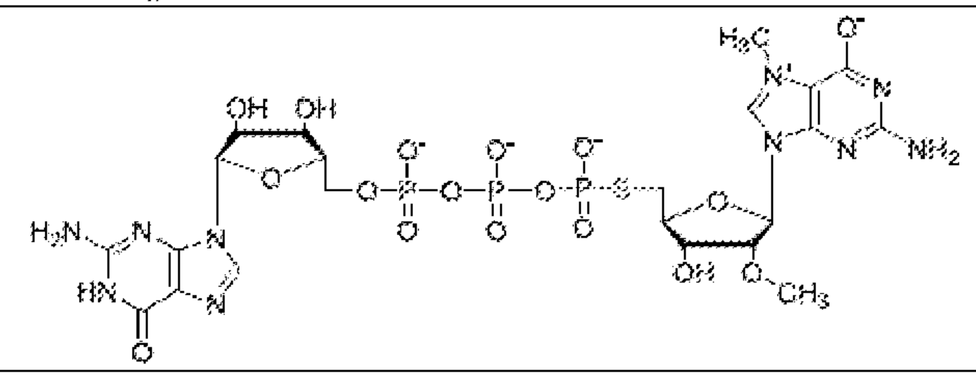
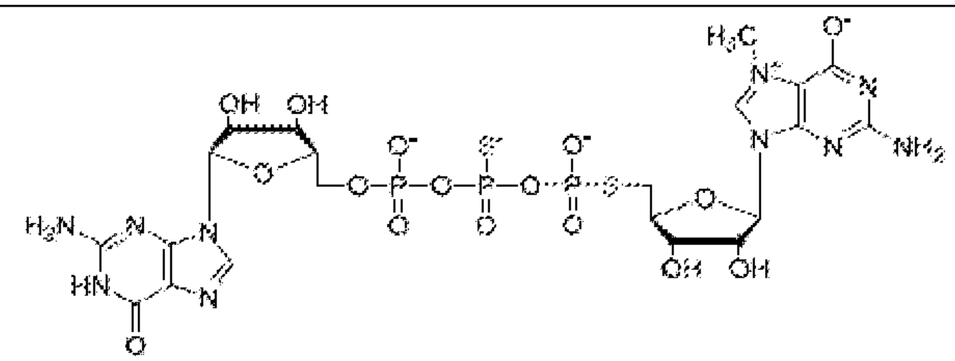
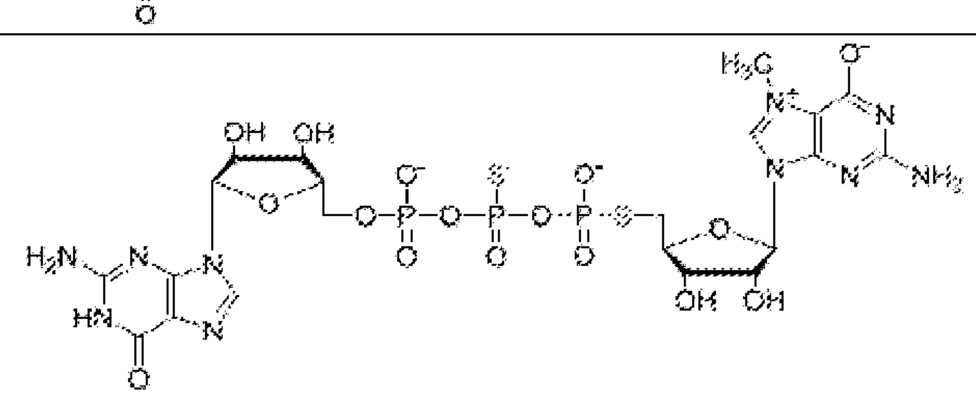
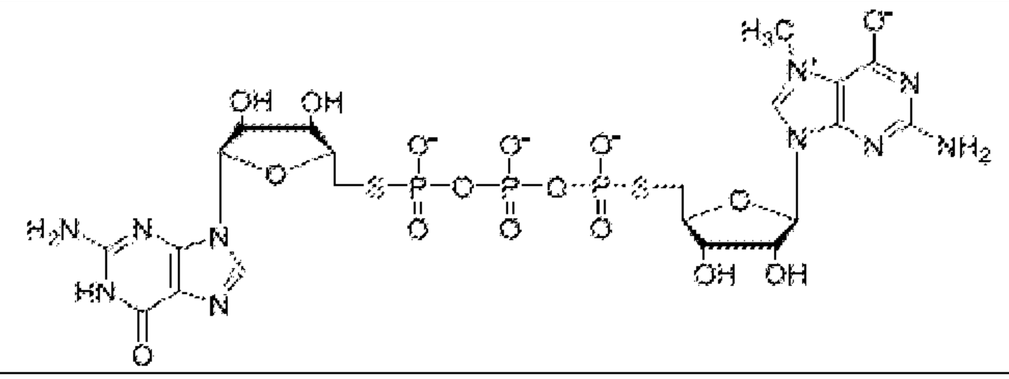
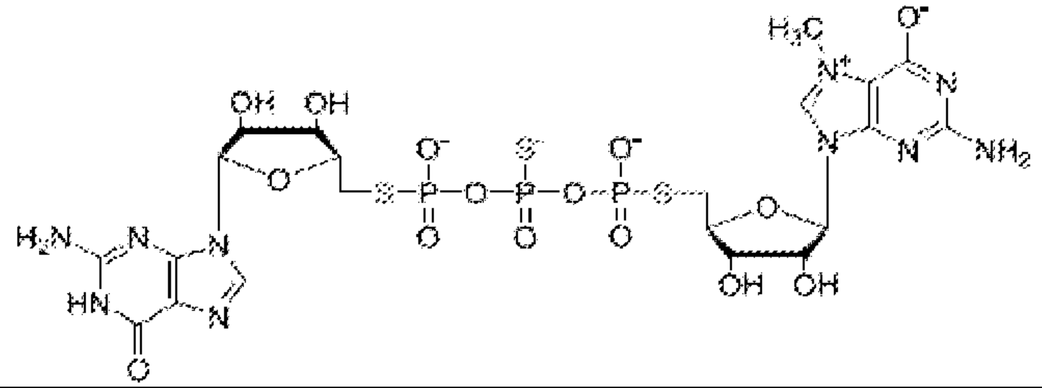
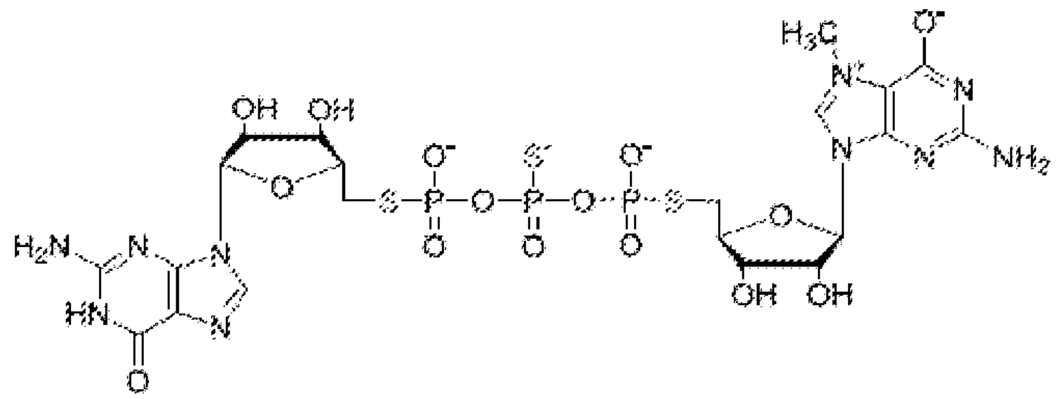
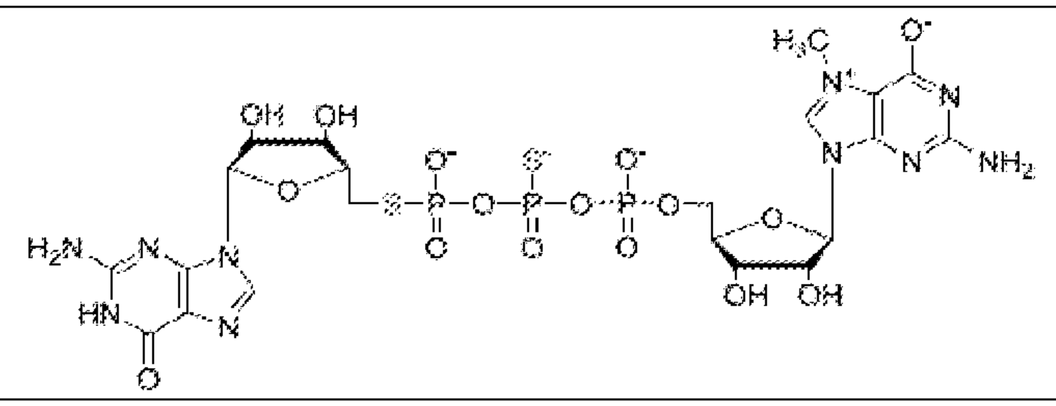
24	m^7GSpppG		P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl triphosphate
25	m^7GSpp***CH$_2$***pG		P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl 2,3-metylenetriphosphate
26	$m^{7,2'O}$GSpppG		P1-(2'-O-methyl-7-methylo-5'- deoxy-5'-thioguanosin-5'-ylo)-P3-guanosin-5'-yl triphosphate
30	m^7GSpp$_s$pG *D1*		P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl 2-triphosphate D1
31	m^7GSpp$_s$pG *D2*		P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl 2-triphosphate D2

32	m^7G**S**ppp**S**G		P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) triphosphate
33	m^7G**S**pp$_s$p**S**G *D1*		P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) 2-triphosphate D1
34	m^7G**S**pp$_s$p**S**G *D2*		P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) 2-triphosphate D2
35	m^7Gpp$_s$p**S**G *D1*		P1-(7-methyl-guanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) 2-triphosphate D1

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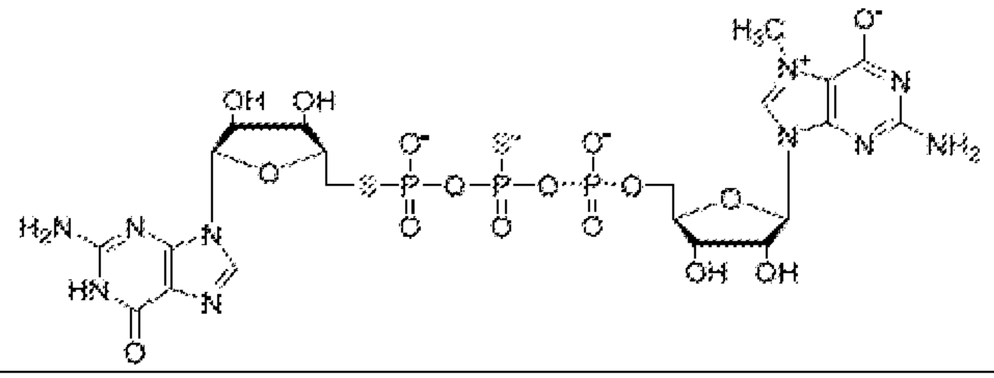
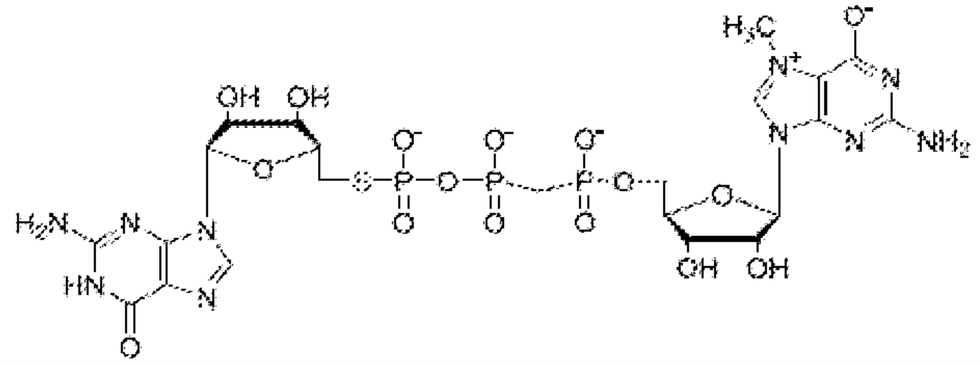
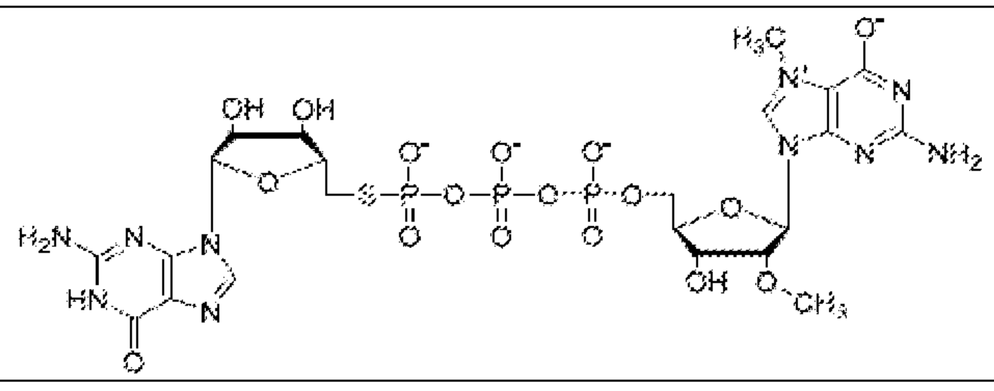
36	m^7Gpp_sp**S**G *D2*		**P1-(7-methyl-guanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) 2-triphosphate D2**
37	m^7Gp***CH*$_2$**pp**S**G		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl 1,2-metylenetriphosphate**
38	$m^{7,2'O}$GpppSG		**P1-(2'-O-methyl-7-methyl-guanosin-5'-yl)-P3-(5'- deoxy-5'-htioguanosin-5'-yl) triphosphate**

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Example 2. New cap analogs characteristics

Test 1. The susceptibility study of analogs to degradation by DcpS enzyme.

The aim of the test was to check if new 5'-thiophosphate cap analogs are hydrolyzed by human DcpS enzyme (hDcpS). Recombinant human protein encoding DcpS enzyme was expressed as described previously (Kowalska, Lewdorowicz et al. 2008). The susceptibility of new analogs to hDcpS hydrolysis is tested in 50 mM Tris-HCl buffer containing 200 mM KCl and 0.5 mM EDTA. Reaction mixture includes the tested cap analog (20 µM) and hDcpS enzyme (100 nM) in 400 µl of buffer. At the appropriate intervals 100 µl sample is collected from the reaction mixture. Sample is incubated at 98 ºC for 2.5 min, and then cooled to 0ºC and analyzed on RP-HPLC under conditions described in general informations. In tests also commercially available inhibitor of DcpS was tested, the compound RG3039 (no. **000**) (https://www.mda.org/quest/fda-approves-phase-1-clinical-trial-rg3039-sma), GppSG (no. **19**), GpppSG (no. **20**), as well m^7GpppG (no. **0**) and m^7Gpp (no. **00**) as controls. Exemplary results obtained are shown on Fig.5 and Table 5.

Test 2. IC_{50} determination for selected inhibitors

The purpose of the test was to determine the the concentration, wherein the given inhibitor inhibits DcpS activity to 50% of the maximal value in the particular conditions. The buffer in this test and in the test 1 is the same. Ten mixture reactions were prepared at the same time and each of them contained a m^7GMPF (60 µM), hDcpS enzyme (50 nM) and the tested compound in concentration range between 0-50 µM in 200 µl of buffer. After appropriate time, when 30% of substrate were converted into product without inhibitor, the reaction was stopped by mixing with 100 µl of ACN. Samples of 25 µl were taken for analysis, followed by mixing with 90 µl of TBDS-fluorescein solution of concentration 2.5 µM in DMSO and incubated for 60 min. Next, 100 µl of 200 mM HEPES buffer pH = 7.0 was added to the samples and the fluorescence was measured as described in general information. Based on the results, dependence of inhibitor concentration vs. fluorescence were plotted and the IC_{50} values were determined by fitting theoretical curve to data. Obtained results are presented in Table 5 and Fig 5.

Table 5. IC_{50} values and susceptibility for degradation by DcpS enzyme for selected compounds.

No.	Compound	DcpS susceptibility	IC_{50} [µM]
0	m^7GpppG	hydrolyzable	nd
00	m^7Gpp	***resistant/inhibitor***	4.30 ± 0.78
000	RG3039	***resistant/inhibitor***	0.041 ± 0.012
12	m^7G**S**pp	***resistant/inhibitor***	1.93 ± 0.38
19	Gpp**S**G	hydrolyzable	above 100
20	Gppp**S**G	hydrolyzable	above 100
21	m^7Gpp**S**G	hydrolyzable	nd
22	m^7Gppp**S**G	hydrolyzable	nd
23	m^7G**S**ppG	***resistant/inhibitor***	2.81 ± 0.51
24	m^7G**S**pppG	***resistant/inhibitor***	0.84 ± 0.07
25	m^7G**S**pp***CH$_2$***pG	***resistant/inhibitor***	6.25 ± 1.22
26	$m^{7,2'O}$G**S**pppG	***resistant/inhibitor***	12.57 ± 5.22
30	m^7G**S**pp$_s$pG *D1*	***resistant/inhibitor***	0.23 ± 0.04
31	m^7G**S**pp$_s$pG *D2*	***resistant/inhibitor***	0.17 ± 0.02
32	m^7G**S**ppp**S**G	***resistant/inhibitor***	0.33 ± 0.09
33	m^7G**S**pp$_s$p**S**G *D1*	***resistant/inhibitor***	0.26 ± 0.04
34	m^7G**S**pp$_s$p**S**G *D2*	***resistant/inhibitor***	**0.051 ± 0.008**
35	m^7Gpp$_s$p**S**G *D1*	hydrolyzable	nd
36	m^7Gpp$_s$p**S**G *D2*	hydrolyzable	nd
37	m^7Gp***CH$_2$***pp**S**G	***resistant/inhibitor***	5.67 ± 1.01
38	$m^{7,2'O}$Gppp**S**G	hydrolyzable	72 ± 17

Test 3. Structure determination of human DcpS enzyme (ΔN37hDcpS) in complex with analog no. 34 (m^7GSpp$_s$pSG *D2*)

The aim of this test was to study the mechanism of interactions of analog no. **34** with human DcpS enzyme. Recombinant human DcpS enzyme truncated at the N-terminus (ΔN37 - residues Ala38 to Ser337) was obtained as described earlier (Singh et al. 2008). Crystallization by sitting drop vapor diffusion was performed using 0.2 uL of sample containing 0.1 M analog 34 and 7.3 mg/mL DcpS enzyme (incubated on ice for 15 min prior to crystallization setup) and 0.2 uL of reservoir solution. Complex crystals appeared in a mixture containing 29% PEG 4000 and 0.1M Tris·HCl pH 7.6 after about a week. To the drop containing crystal a mixture of reservoir solution and glycerol (1:1 v/v) was added and then the crystals were harvested and flash frozen in liquid nitrogen. The diffraction data were collected at 100K at synchrotron source (Beamline 14.1, Bessy II, Helmholtz-Zentrum Berlin, Germany) using a Dectris PILATUS 6M detector and then data were processed using XDS software (Kabsch 2010). The structure was solved by Molecular Replacement using Phaser software (McCoy, Grosse-Kunstleve et al.2007) with a structure of DcpS bound to DG157493 inhibitor (pdb: 3BL9) (Singh, Salcius et al. 2008) as a search model. Ligand model and dictionary were generated using ProDRG (Schuttelkopf and van Aalten 2004). The model building and ligand fitting was performed in Coot software (Emsley & Cowtan 2004). The structure was refined using phenix.refine (Adams, Afonine et al. 2010).

Test 4. Susceptibility study of short RNA molecules comprising cap analogs at the 5' end to degradation with the Dcp1/2 enzyme.

The aim of this study was to check whether incorporation of selected 5'- phosphothioate cap analogs to 5' end of RNA could influence susceptibility of thus prepared transcripts towards Dcp1/2 decapping enzyme activity. *Schizosaccharomyces pombe* recombinant protein in the form of a heterodimer Dcp1/2 was obtained as described previously (Floor, Jones et al. 2010). The trancripts utilized in this assay were obtained by transcription *in vitro* using RNA SP6 polymerase (New England BioLabs). Annealed oligonucleotides: ATACGATTTAGGTGACACTATAGAAGAAGCGGGCATGCGGCCAGCCATAGCCGATCA (SEQ ID NO.: 1), and TGATCGGCTATGGCTGGCCGCATGCCCGCTTCTTCTATAGTGTCACCTAAATCGTAT (SEQ ID NO: 2) were used as a template in *in vitro* transcription, the oligonucleotides comprising the promoter sequence for SP6 polymerase (ATTTAGGTGACACTATAGA (SEQ ID NO: 3)) allow to obtain 35 nt long RNAs having a sequence of GAAGAAGCGGGCAUGCGGCCAGCCAUAGCCGAUCA (SEQ ID NO: 4), however 5' end capped RNAs are 36 nt long. Typical *in vitro* transcription reaction was perforemed in volume 20 µl and was incubated in 40°C for 2 hours and contained the following: 1U SP6 polymerase, 1 U RiboLock RNase Inhibitor (ThermoFisher Scientific), 0.5 mM ATP/CTP/UTP, 0.125 mM GTP, 1.25 mM dinucleotide cap analog and 0.1 µM template. Following 2 hours incubation, 1U DNase I (Ambion) was added to the reaction mixture and incubation was continued for 30 min in 37°C, after that EDTA was added to 25 mM final concentration. Obtained RNAs were purified using RNA Clean & Concentrator-25 (Zymo Research). Then the quality of the synthesized RNA was determined on a denaturating 15% polyacrylamide gel. The concentration of the RNA was in turn evaluated spectrophotometrically. The thus obtained RNA is characterized by substantial heterogeneity of the 3' end, hence to eliminate the problem, the obtained RNAs were incubated with DNAzyme 10-23 (TGATCGGCTAGGCTAGCTACAACGAGGCTGGCCGC (SEQ ID NO: 5)) which lead to obtaining RNA 25 nt long. RNA having a cap at the 5' end was 26 nt long. The reaction of cleaving the 3' ends was as follows: 1 µM of RNA was incubated with 1 µM of DNazyme 10-23 in a mixture containing 50 mM $MgCl_2$ and 50 mM Tris-HCl pH 8.0 for 1 hour in 37°C (Coleman et al., 2004).

For enzymatic tests 20 ng of each RNA was used, which were incubated with 3.5 nM Dcp1/2 enzyme in buffer containing 50 mM Tris-HCl pH 8.0, 50 mM NH_4Cl, 0.01 % NP-40, 1 mM DTT, and 5 mM $MgCl_2$. Reactions were performed at 37°C in the final volume of 25 µl. The reaction was stopped after 0, 5, 15 and 30 min by adding an equal amount of a mixture of 5 M urea, 44 % formamide, 20 mM EDTA, 0.03 % bromophenol blue, 0.03 % xylene cyanol. Reaction products were resolved on denaturing 15 % polyacrylamide gels, after the electrophoretic separation was completed, the gel was stained with SYBR Gold (Invitrogen) and visualized using a Storm 860 PhosphorImager (GE Healthcare). Quantification of the obtained results was

performed with ImageQuant software (Molecular Dynamics). Representative results of this assay were presented on Fig. 8, Fig. 9 and also in Table 6.

Table6. Biological properties of mRNAs comprising selected cap analogs at the 5' end

	capping efficiency[a]	Dcp1/2 susceptibility[b]	relative translation efficiency[c]
GpppG	0.91	0	0.05 ± 0.01
m^7GpppG	0.93	0.69	1.00
$m_2^{7,2'-O}$GpppG	0.84	0.52	1.56 ± 0.14
$m_2^{7,2'-O}$Gpp$_S$pG D2	0.82	0.43	3.45 ± 0.42
$m_2^{7,2'-O}$GSpppG	0.70	0.07	1.73 ± 0.24
$m_2^{7,2'-O}$GpppSG	0.76	0.52	2.23 ± 0.31

[a] The data of Fig. 8 (time point 0') were used to calculate capping efficiency.
[b] The data of Fig. 8 were used to calculate susceptibility to Dcp1/2 activity, given as ratio of capped RNAs to a sum of uncapped and capped RNA at one time point 15 min and after normalization to 0' time for individual RNAs.
[c] Relative translational efficiency shows the average translation efficiency of *Renilla* luciferase mRNAs in biological triplicates after normalization to the values obtained for mRNA capped with m^7GpppG at the 5' end.

Test 5. Study on the effect of the presence of novel cap analogs on translational efficiency of mRNAs in rabbit reticulocyte lysate.

The aim of this study was to check the effect of introducing novel cap analogs at the 5' end of mRNAs on translation efficiency. For this purpose series of *Renilla* luciferase encoding mRNAs, and differing in the cap structure at the 5' end were prepared. The transcripts used fot this test were obtained by *in vitro* transcription reaction using SP6 RNA polymerase. As the template for the *in vitro* transcription a PCR product was used, prepared using primers ATTTAGGTGACACTATAGAACAGATCTCGAGCTCAAGCTT (SEQ ID NO: 6) and GTTTAAACATTTAAATGCAATGA (SEQ ID NO: 7) and the hRLuc-pRNA2(A)128 plasmid (Williams et al. 2010). PCR reaction thus conducted allowed to introduce promoter sequence for SP6 polymerase upstream of the sequence encoding *Renilla* luciferase. The transcription reaction itself was similar to the short RNA synthesis described above (Test 4). The reaction was conducted for 2 hours in 20µl in 40°C and contained the following: 1U SP6 polymerase, 1 U RiboLock RNase Inhibitor (ThermoFisher Scientific), 0.5 mM ATP/CTP/UTP, 0.125 mM GTP, 1.25 mM dinucleotide cap analog and 100 µg of a template. Following 2 hours incubation, 1U DNase I (Ambion) was added and incubation was continued for 30 min in 37°C, after that EDTA was added to 25 mM final concentration. Obtained mRNAs were purified using NucleoSpin RNA Clean-up XS (Macherey-Nagel). Quality of the synthetized RNA was checked on a denaturing 15% polyacrylamide gel. The RNA concentrations were determined spectrophotometrically.

An *in vitro* translation reaction was performed in rabbit reticulocyte lysate (RRL, Promega) in conditions determined for cap-dependent translation (Rydzik et al., 2009). A typical reaction mixture (10µl) contained: 40% RRL lysate, 0.01 mM mixture of amino acids (Promega), 1.2 mM $MgCl_2$, 170 mM potassium acetate and a *Renilla* luciferase encoding mRNA with an appropriate cap analog at the 5' end, the mixture being incubated in 37°C for 1 hour. Four different concentrations of mRNAs: 0.1 ng/µl, 0.25 ng/µl, 0.5 ng/µl, 0.75 ng/µl were used in the experiment. Activity of synthesized luciferase was measured using Dual-Luciferase Reporter Assay System (Promega) in a microplate reader Synergy H1 (BioTek). Obtained results were analyzed in Origin (Gambit) software, and theoretical curve was fitted to experimental data, wherein the slope of obtained curve represents translation efficiency. Representative data were presented on Fig. 10, whereas average translation efficiency obtained for biological triplicates is presented in Table 6.

Test 6. Study on the effect of the presence of novel cap analogs on translational efficiency of mRNAs in HeLa cells.

Human cervical carcinoma HeLa cells were grown in DMEM (Gibco) supplemented with 10% FBS (Sigma-Aldrich), 1% penicillin/streptomycin (Gibco) and L-glutamine with a final concentration of 2 mM at 5% CO_2 and 37°C. A day before the planned experiment, 10^4 cells suspended in 100 µl medium without antibiotics were seeded per each well of a 96-well plate. The cell transfection was as follows, 0.3 µl Lipofectamine MessengerMAX Transfection Reagent (Invitrogen), 0.1 µg mRNA and 10 µl Opti-MEM (Gibco) were added to each well. The transfections were conducted for 1 hour in an incubator. After transfection, cells were washed three times with PBS and supplemented with fresh medium without antibiotics. After 2, 3, 4.5, 6.5, 10.5 and 24 hours since the beginning of transfection, the cells were washed three times with PBS, lysed and luciferase activity was measured using Luciferase Reporter Assay System (Promega) employing Synergy H1 microplate reader (. Exemplary data are shown on Fig. 11.

mRNA encoding firefly luciferase and having two repeats of β-globin 3'UTR and poly(A) tail of 128 adenines at the 3' end was used for transfection. This mRNA, comprising differen cap analogs at the 5' end was obtained by *in vitro* transcription. pJET_luc_128A plasmid digested with AarI (ThermoFisher Scientifics) was used as a template for the synthesis. Typical *in vitro* transcription reaction) was conducted for 2 hours in a volume of 20 µl in 40°C and contained the following: 1 U SP6 polymerase, 1 U RiboLock RNase Inhibitor (ThermoFisher Scientific), 0.5 mM ATP/CTP/UTP, 0.125 mM GTP, 1.25 mM dinucleotide cap analog and 0.1 µg of the template. The following steps of mRNA preparation as described above in the case of Renilla luciferase encoding mRNA (Test 5). Additionally, after purification of the mRNA using NucleoSpin RNA Clean-up XS column the transcripts were ethanol precipitated in presence of 2 µg glycogen and sodium acetate, then dissolved in deionized water.

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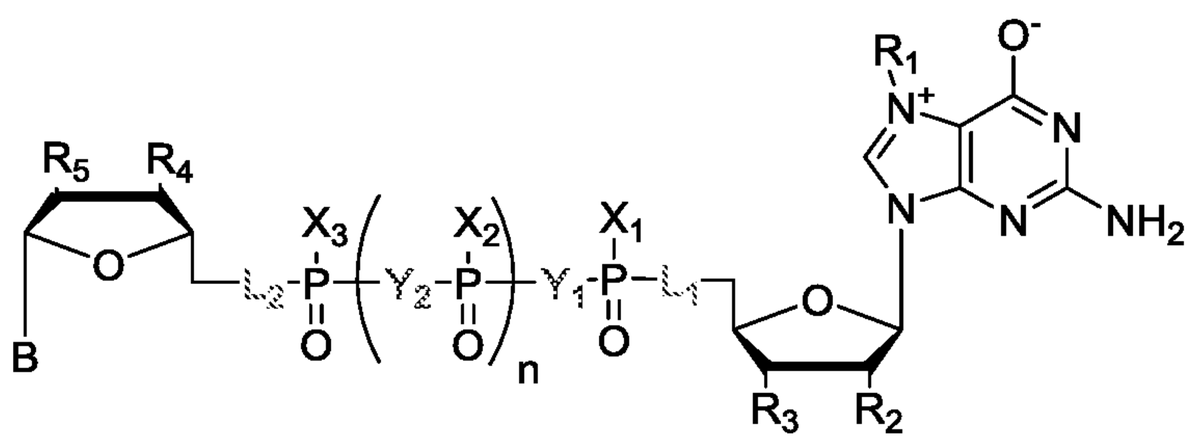
CLAIMS

1. A 5'-phosphorothiolate cap analog according to formula 1



Formula 1

wherein

L^1 and L^2 are independently selected from the group comprising O and S, wherein at least one of L_1 and L_2 is not O;

n = 0, 1, lub 2;

X_1, X_2, X_3 are independently selected from the group comprising O, S;

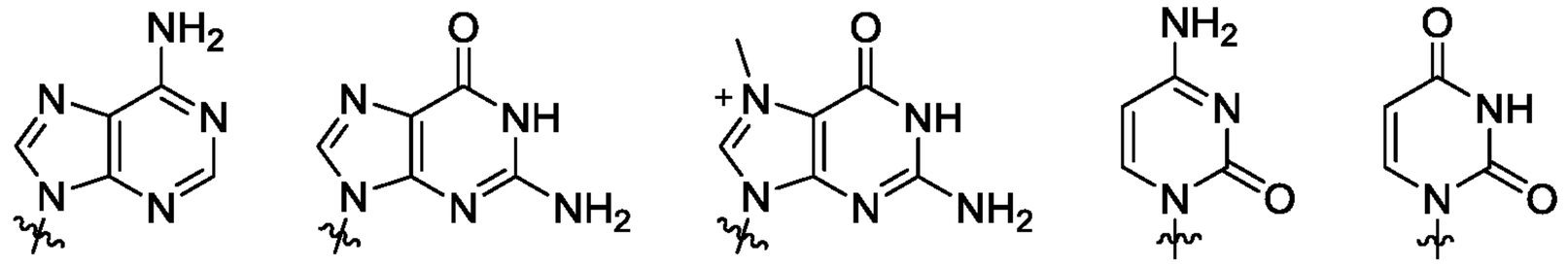
R^1 is selected from the group comprising CH_3, C_2H_5, CH_2Ph, alkyl, or substituted alkyl;

R^2 and R^3 are independently selected from the group comprising H, OH, OCH_3, OC_2H_5, -COOH, N_3, alkyl, alkenyl or alkynyl;

R^4 and R^5 are independently selected from the group comprising H, OH, OCH_3, OC_2H_5, -COOH, CH_2COOH, N_3, CH_2N_3, alkyl, alkenyl, or alkynyl;

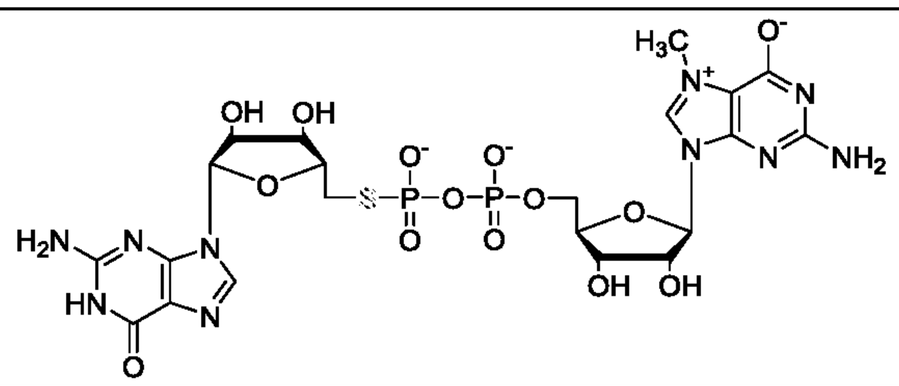
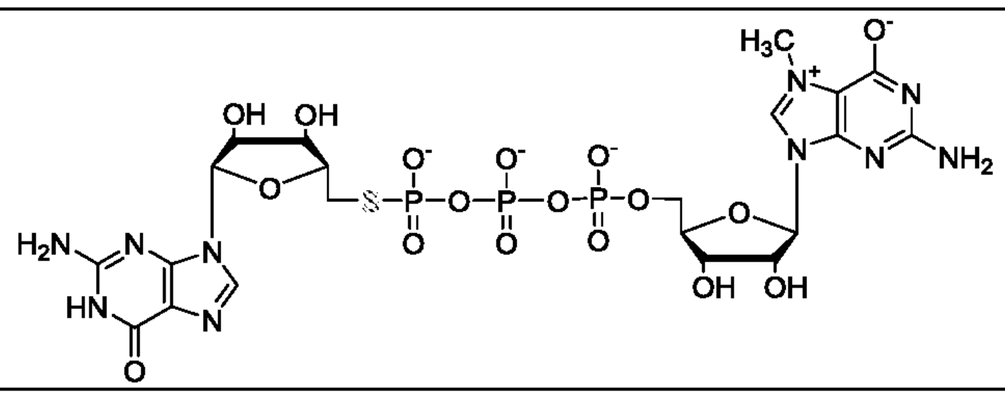
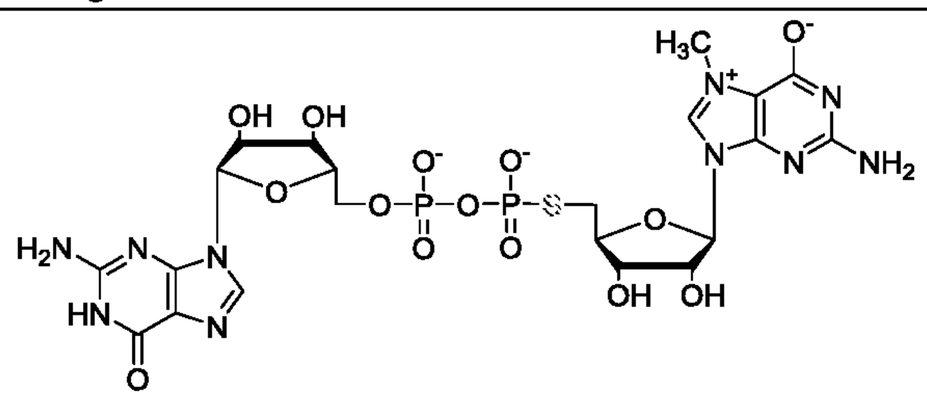
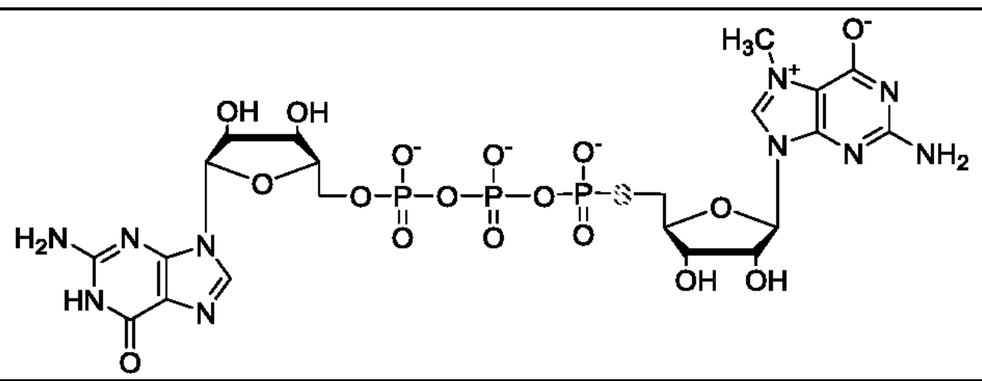
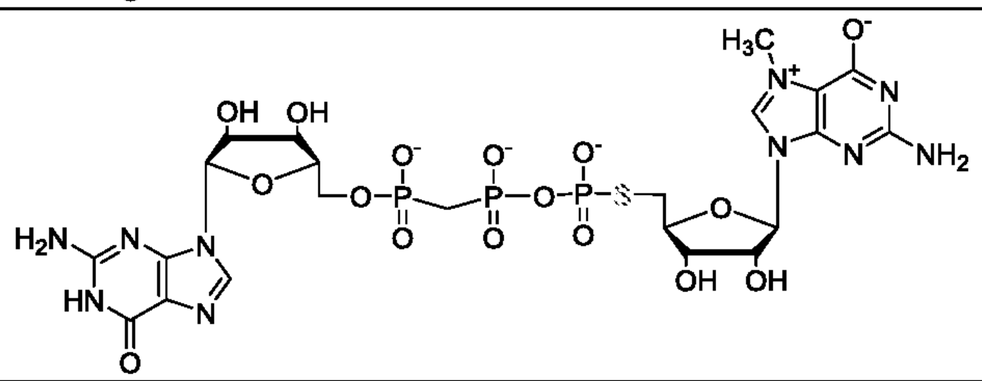
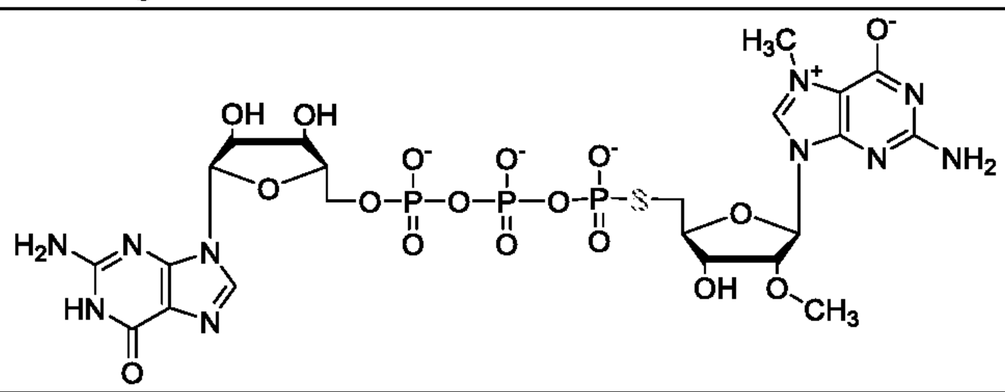
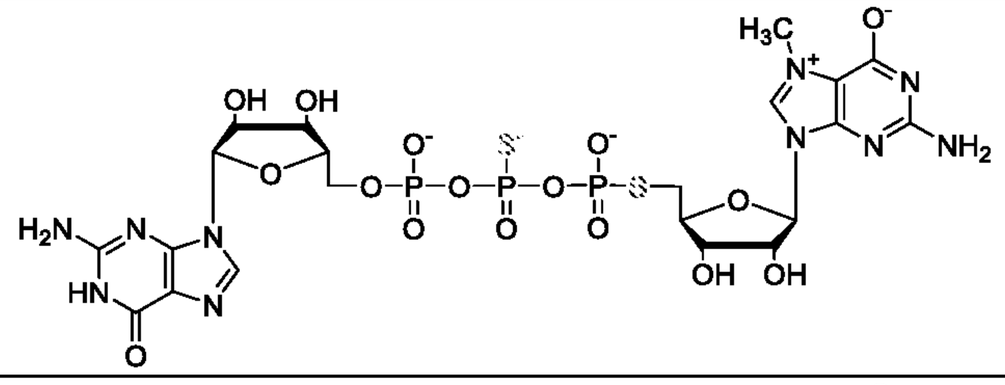
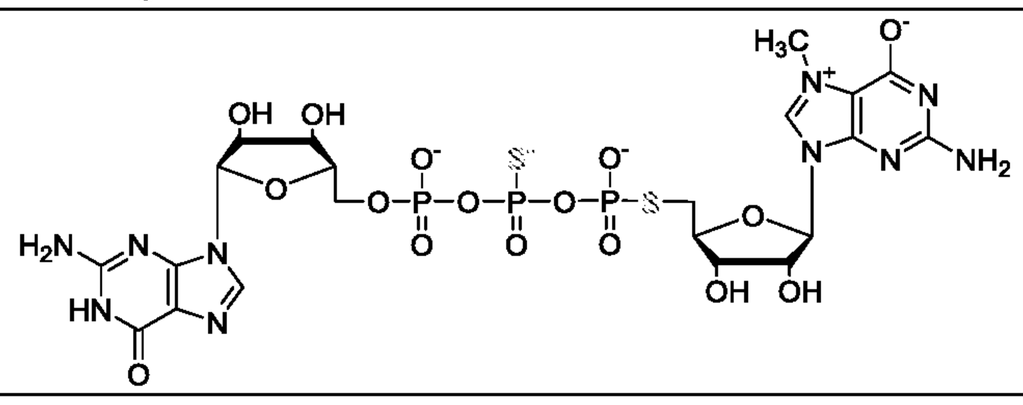
Y_1, Y_2 are independently selected from the group comprising CH_2, CHCl, CCl_2, CF_2, CHF, NH, O;

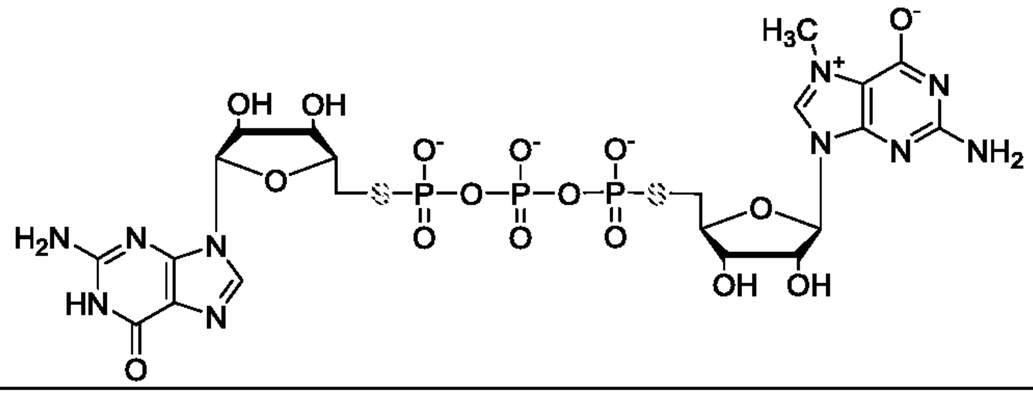
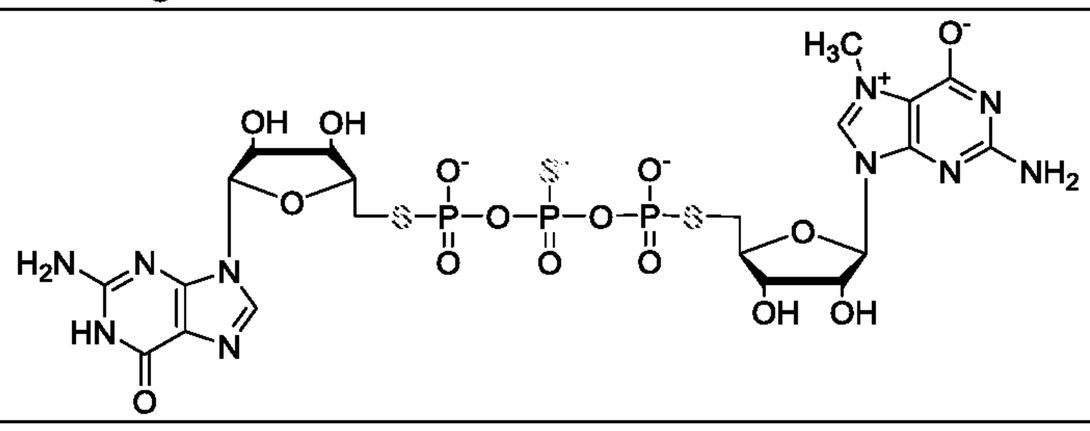
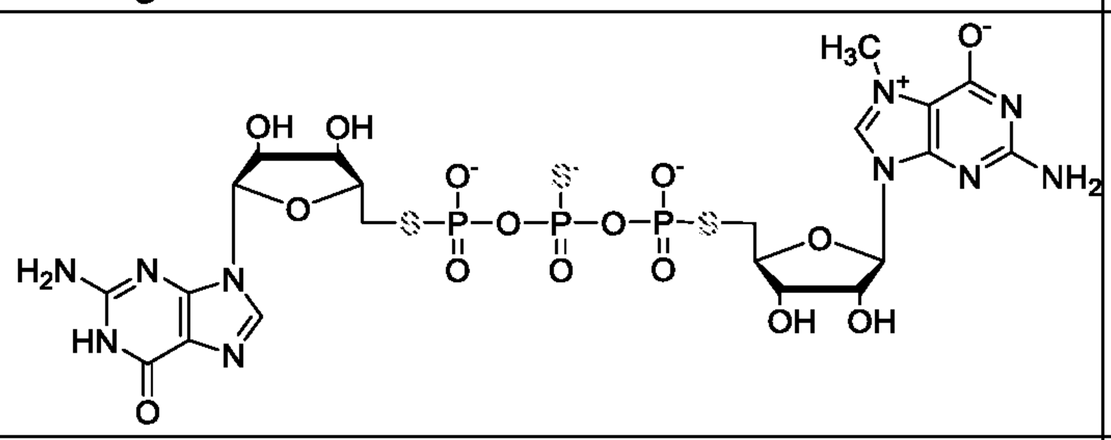
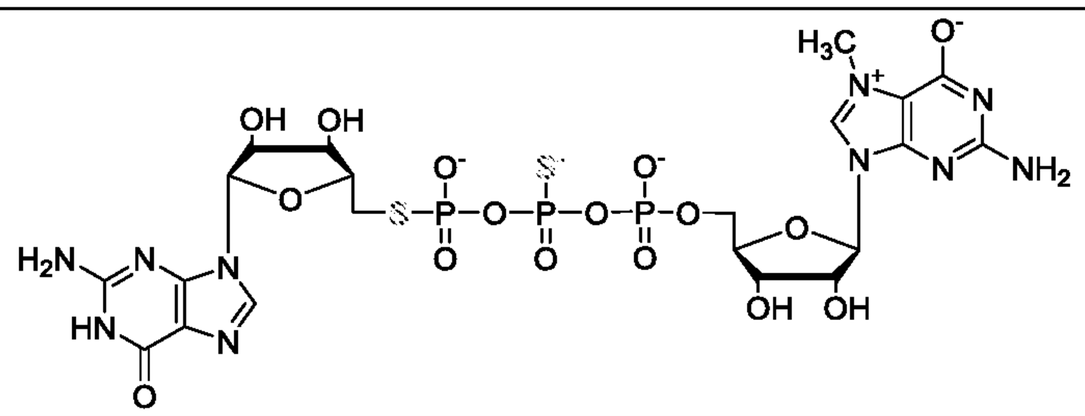
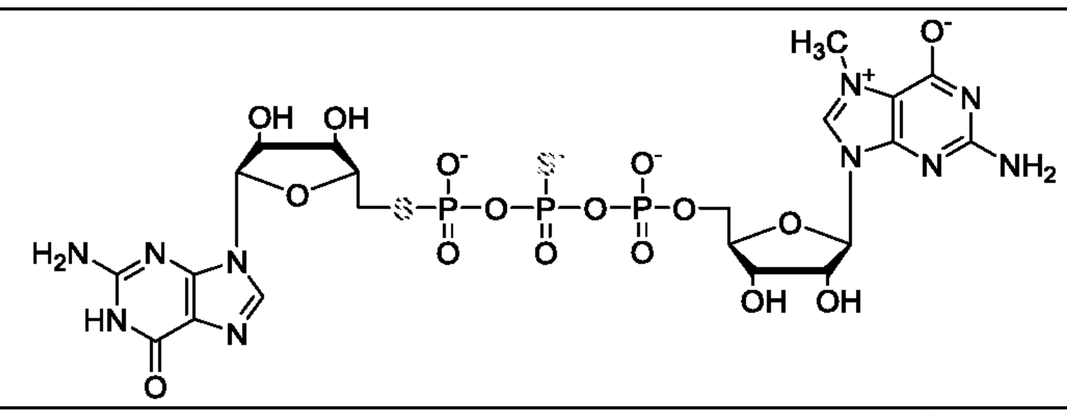
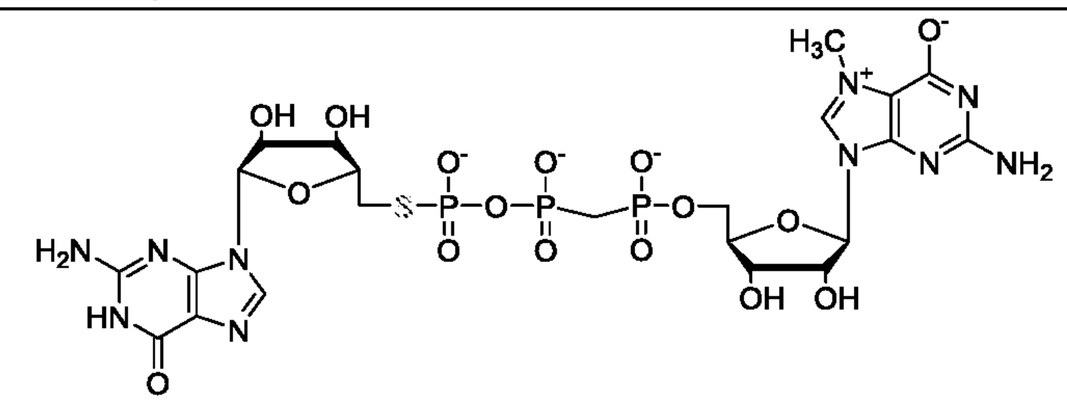
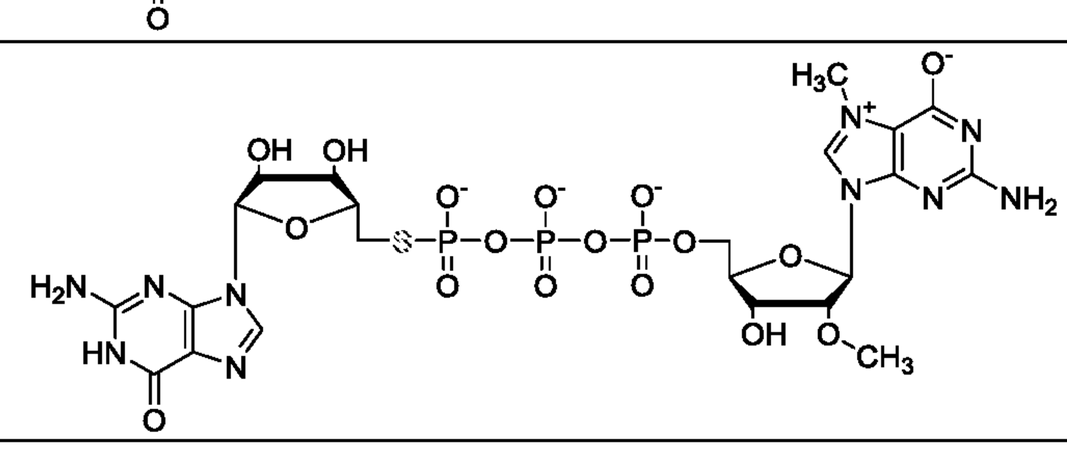
and B is a group according to formula 3, 4, 5, 6 or 7



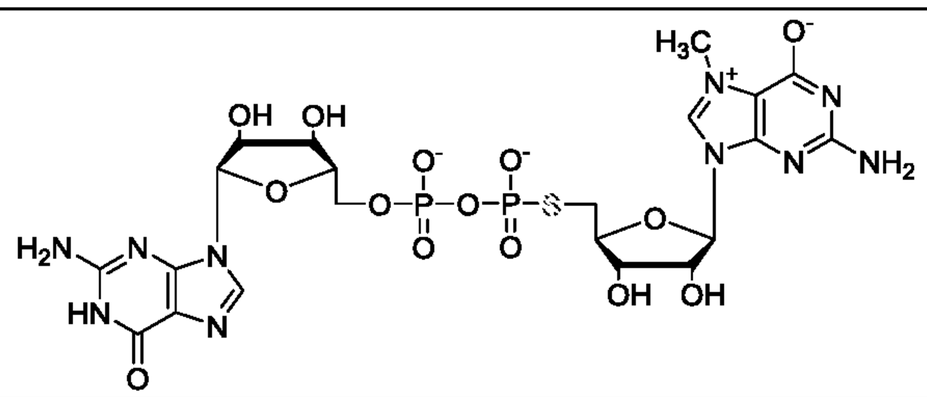
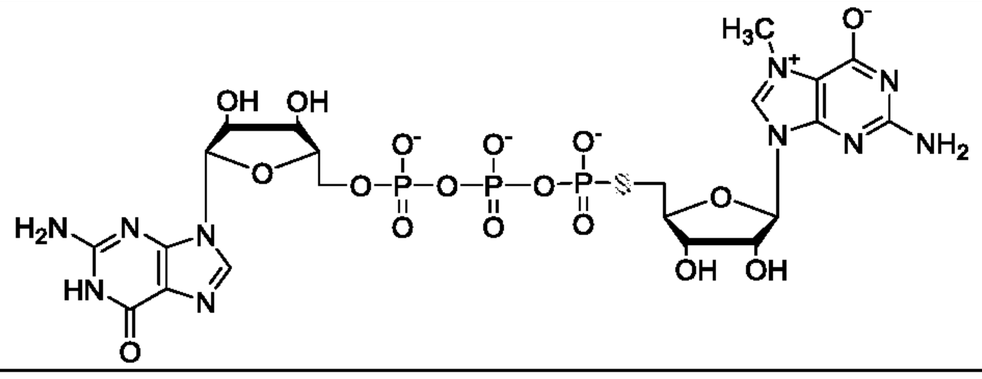
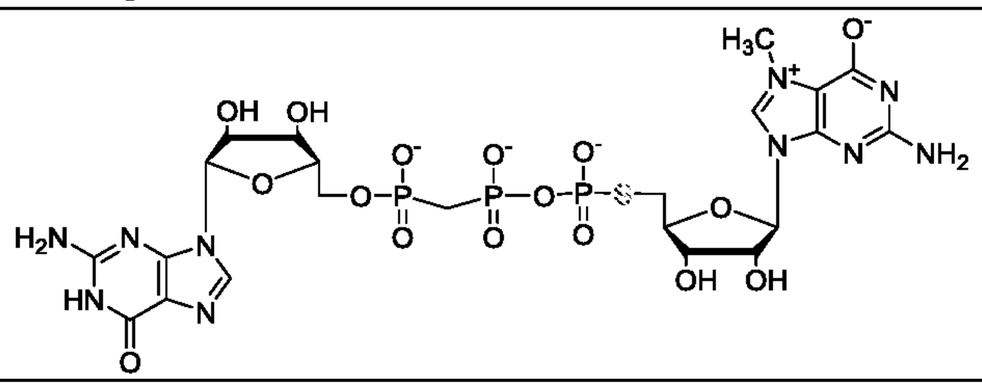
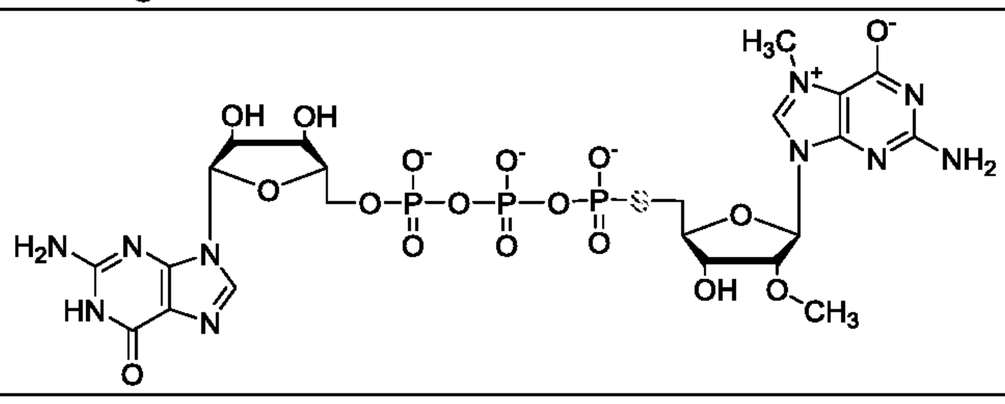
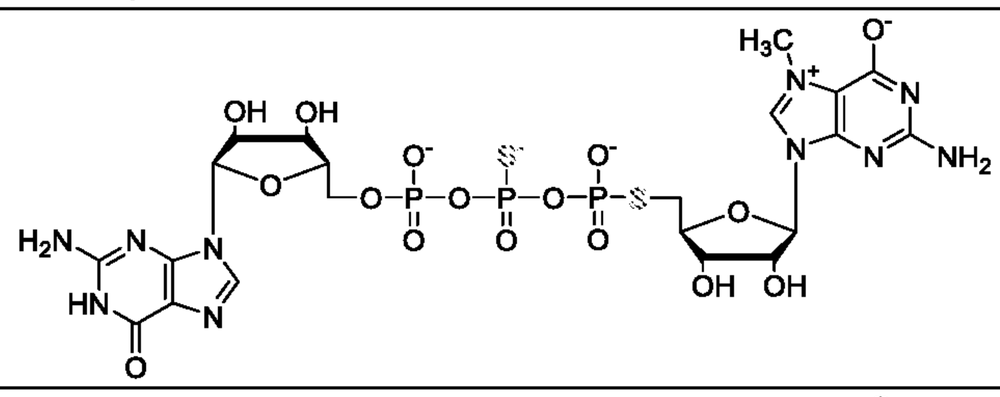
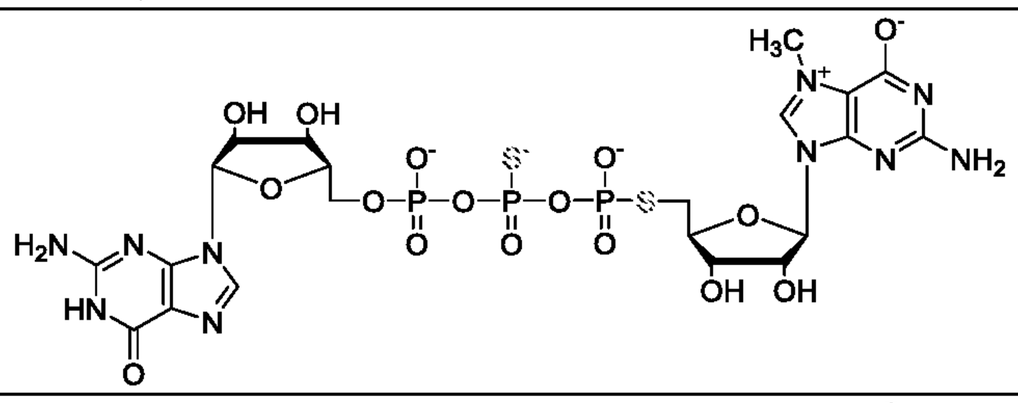
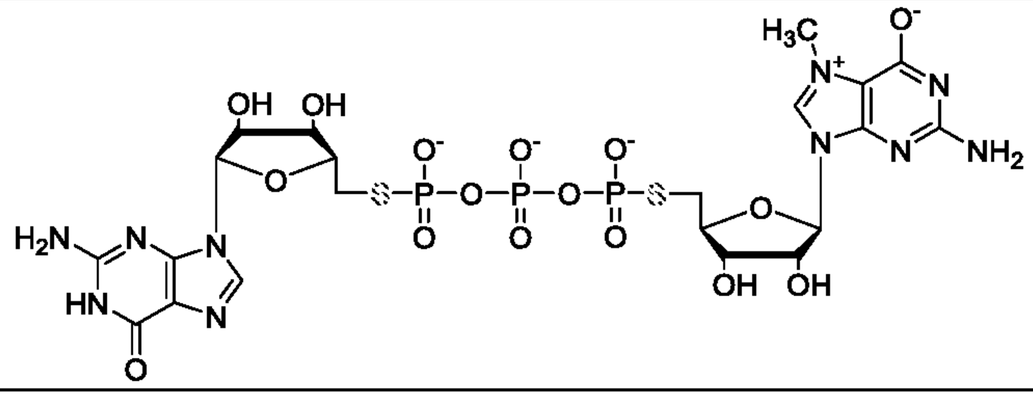
formula 3 formula 4 formula 5 formula 6 formula 7

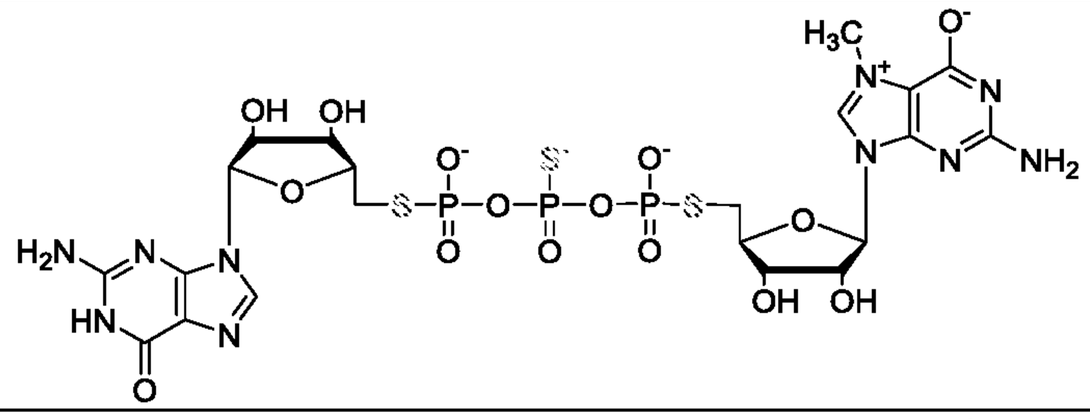
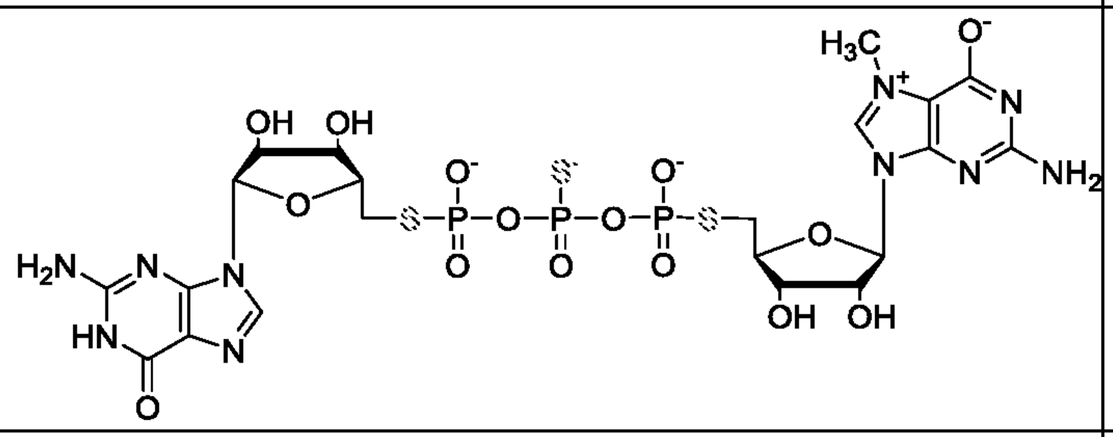
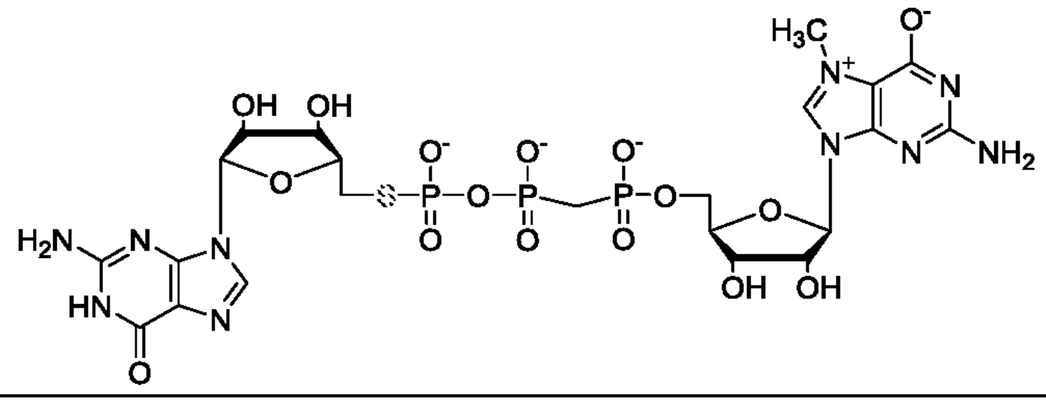
2. The compound according to claim 1, selected from a group consisting of:

No.	Compound	Structural formula	Chemical name
21	m^{7}GppSG		**P1-(7-methyl-guanosin-5'-yl)-P2-(5'-deoxy-5'-thioguanosin-5'-yl) diphosphate**
22	m^{7}GpppSG		**P1-(7-methyl-guanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) triphosphate**
23	m^{7}GSppG		**P1-(7-methyl-5'-deoxy-5'-thioguanosin-5'-yl)-P2-guanosin-5'-yl diphosphate**
24	m^{7}GSpppG		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl triphosphate**
25	m^{7}GSpp***CH$_2$***pG		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl 2,3-methylenotriphosphate**
26	m$^{7,2'O}$GSpppG		**P1-(2'-O-methyl-7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl triphosphate**
30	m^{7}GSpp$_s$pG *D1*		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl-thiotriphosphate D1**
31	m^{7}GSpp$_s$pG *D2*		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl 2-thiotriphosphate D2**

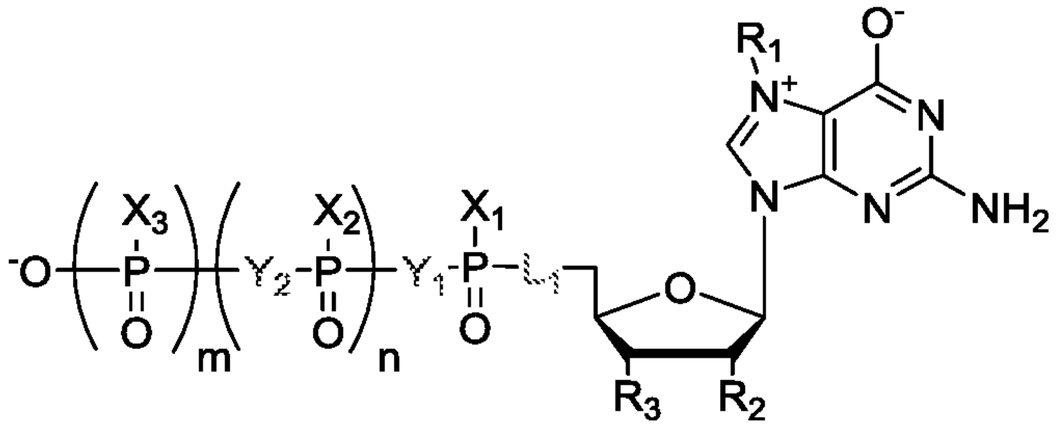
32	$m^7GSpppSG$		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) triphosphate**
33	m^7GSpp_spSG *D1*		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) 2-tiotriphosphate D1**
34	m^7GSpp_spSG *D2*		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) 2-thiotriphosphate D2**
35	m^7Gpp_spSG *D1*		**P1-(7-methyl-guanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) 2-tiotriphosphate D1**
36	m^7Gpp_spSG *D2*		**P1-(7-methyl-guanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) 2-thiotrifphosphate D2**
37	$m^7Gp\boldsymbol{CH_2}ppSG$		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl 1,2-methylenotriphosphate**
38	$m^{7,2'O}GpppSG$		**P1-(2'-O-methyl-7-methyl-guanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) triphosphate**

3.The compound according to claims 1-2, selected from a group consisting of:

No.	Compound	Structural formula	Chemical name
23	m^7G**S**ppG		**P1-(7-methyl-5'-deoxy-5'-thioguanosin-5'-yl)-P2-guanosin-5'-yl diphosphate**
24	m^7G**S**pppG		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl triphosphate**
25	m^7G**S**pp***CH₂***pG		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl 2,3-methylenotriphosphate**
26	$m^{7,2'O}$G**S**ppp G		**P1-(2'-O-methyl-7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl triphosphate**
30	m^7G**S**pp$_s$pG *D1*		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl 2-triphosphate D1**
31	m^7G**S**pp$_s$pG *D2*		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl 2-thiotriphosphate D2**
32	m^7G**S**ppp**S** G		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) triphosphate**

33	m^7GSpp_spS G *D1*		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) 2-thiotriphosphate D1**
34	m^7GSpp_spS G *D2*		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-(5'- deoxy-5'-thioguanosin-5'-yl) 2-thiotriphosphate D2**
37	m^7GpCH_2pp **S**G		**P1-(7-methyl-5'- deoxy-5'-thioguanosin-5'-yl)-P3-guanosin-5'-yl 1,2-methylenethiotriphosphate**

4. 5'-phosphorothiolate analog according to formula 2



Formula 2

wherein

m = 0, 1

n = 0, 1, or 2;

L^1 is S

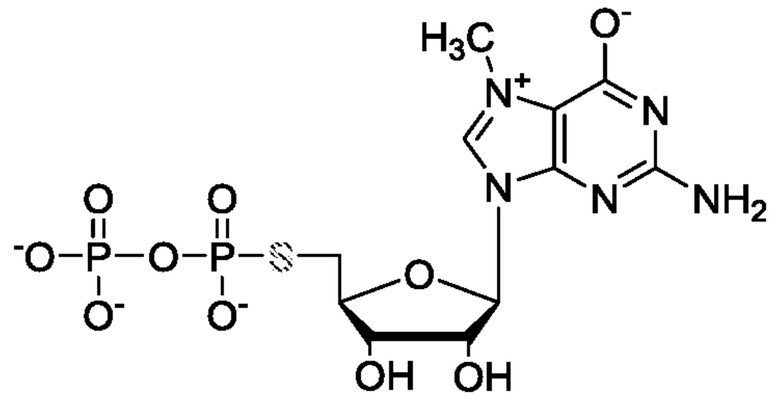
X_1, X_2, X_3 are independently selected from the group comprising O, S;

R^1 is selected from the group comprising CH_3, C_2H_5, CH_2Ph, alkyl, or substituted alkyl;

R^2 and R^3 are independently selected from the group comprising H, OH, OCH_3, OC_2H_5, -COOH, N_3, alkyl, or substituted alkyl;

Y_1, Y_2 are independently selected from the group comprising CH_2, CHCl, CCl_2, CHF, CF_2, NH and O.

5. The compound according to claim 4, which is 5'-deoxy-5'-thioguanosine-7-metylguanosine 5'-diphosphorothiolate according to formula 13



Formula 13.

6. The compound according to claims 1-5 for use as a medicament.

7. The compound according to claims 1-5 for use as a medicament in treatment of spinal muscular atrophy (SMA) and/or in alleviating symptoms of SMA.

8. Use of the compound according to claims 1-5 in preparation of a medicament.

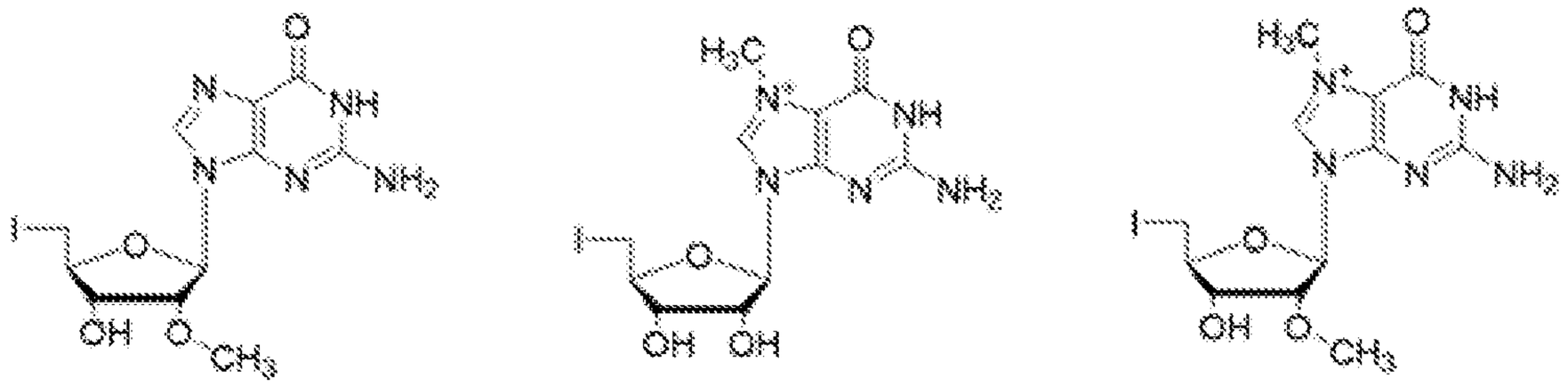
9. The use according to claim 6, characterized in that the compound is used in preparation of a medicament for treatment of spinal muscular atrophy (SMA) and/or alleviation of symptoms of SMA.

10. Use of the compound according to claims 1-5 as a regulator of DcpS activity, preferably as an inhibitor of DcpS enzyme activity, more preferably hDcpS.

11. Use of the compound according to claims 1-5 in regulation of mRNA degradation and/or in regulation of mRNA splicing.

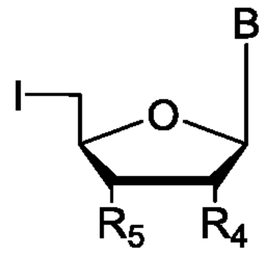
12. A pharmaceutical formulation comprising the compound according to claims 1-5 and a pharmaceutically acceptable carrier.

13. Analogs of 5'-deoxy-5'-iodoguanosine having structures according to formulas 10, 11, and 12 shown below



formula **10** formula **11** formula **12**

14. A method of preparation of compound according to formula 1, said method comprising: steps wherein a 5'-iodonucleoside according to formula 8

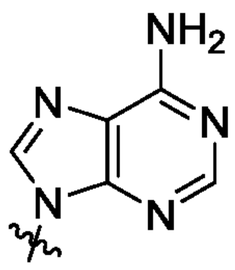


Formula 8

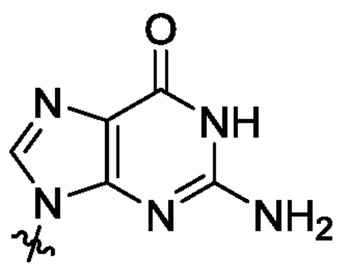
wherein

R^4 and R^5 are independently selected from the group comprising H, OH, OCH_3, OC_2H_5, -COOH, N_3, alkyl, or substituted alkyl;

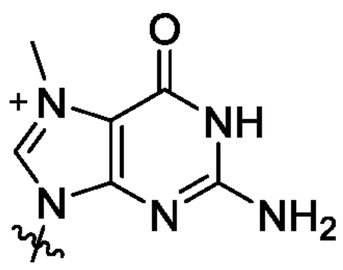
and B is a group according to formula 3, 4, 5, 6, or 7



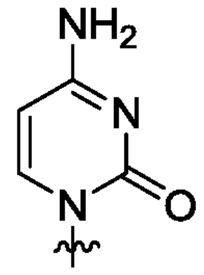
formula 3



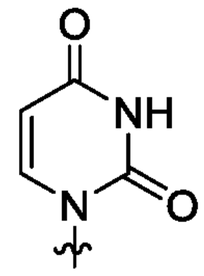
formula 4



formula 5

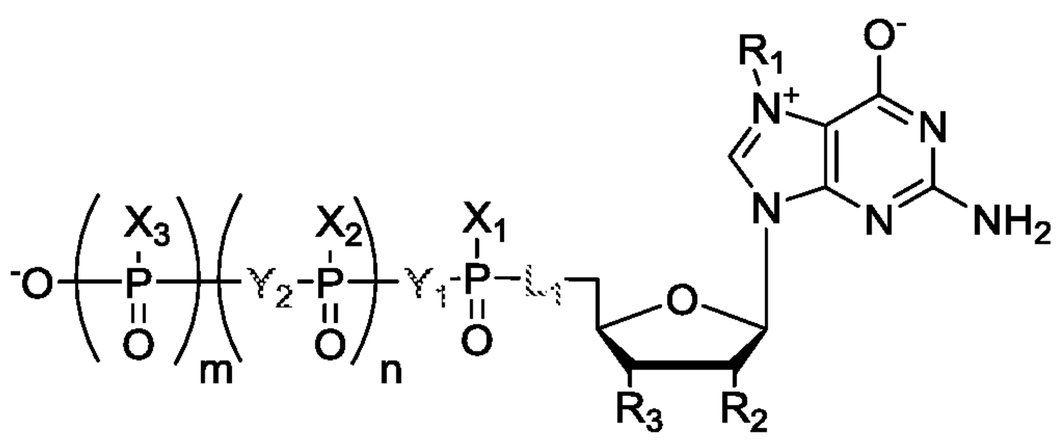


formula 6



formula 7

is reacted with 5'-phosphorothiolate analog according to formula 2 comprising a terminal thiophosphate moiety



Formula 2

wherein

m=0, 1

n = 0, 1, or 2;

L^1 is O or S;

X_1, X_2, X_3 are independently selected from the group comprising O, S;

R^1 is selected from the group comprising CH_3, C_2H_5, CH_2Ph, alkyl, or substituted alkyl

R^2 and R^3 are independently selected from the group comprising H, OH, OCH_3, OC_2H_5, -COOH, N_3, alkyl, or substituted alkyl;

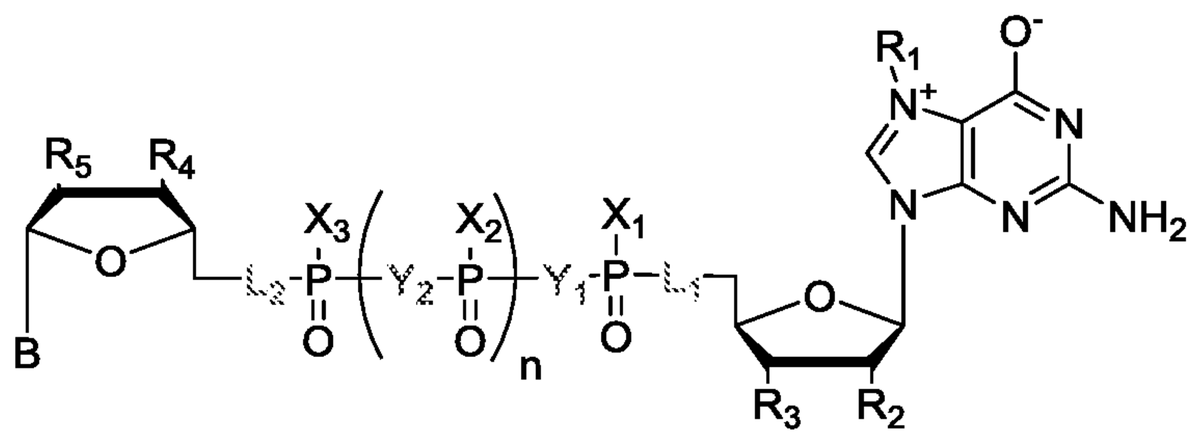
Y_1 and Y_2 are independently selected from the group comprising CH_2, CHCl, CCl_2, CHF, CF_2, NH, and O;

wherein if n = 0 and m = 1 then X_3 is S, and X_1 is O;

if n = 1 and m = 0 then X_2 is S; and X_1 is O;

if n = 1 and m = 1 then X_3 is S; and X_1, X_2 are O

to form a 5'-phosphorothiolate cap analog according to formula 1



Formula 1

wherein

L^1 and L^2 are independently selected from the group comprising O and S, wherein at least one of L_1 and L_2 is not O;

n = 0, 1, or 2;

X_1, X_2, X_3 are independently selected from the group comprising O, S;

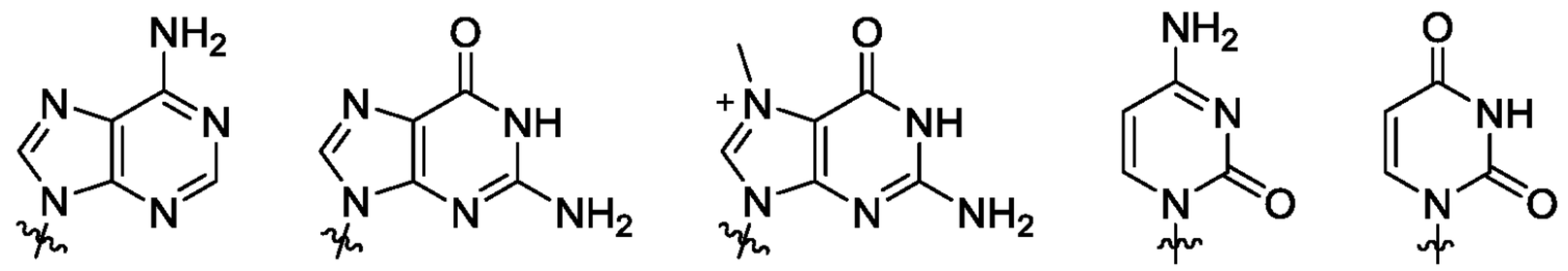
R^1 is selected from the group comprising CH_3, C_2H_5, CH_2Ph, alkyl or substituted alkyl;;

R^2 and R^3 are independently selected from the group comprising H, OH, OCH_3, OC_2H_5, -COOH, CH_2COOH, N_3, CH_2N_3, alkyl, alkenyl, or alkynyl;

R^4 and R^5 are independently selected from the group comprising H, OH, OCH_3, OC_2H_5, -COOH, CH_2COOH, N_3, CH_2N_3, alkyl, alkenyl, or alkynyl;

Y_1, Y_2 are independently selected from the group comprising CH_2, CHCl, CCl_2, CF_2, CHF, NH, O;

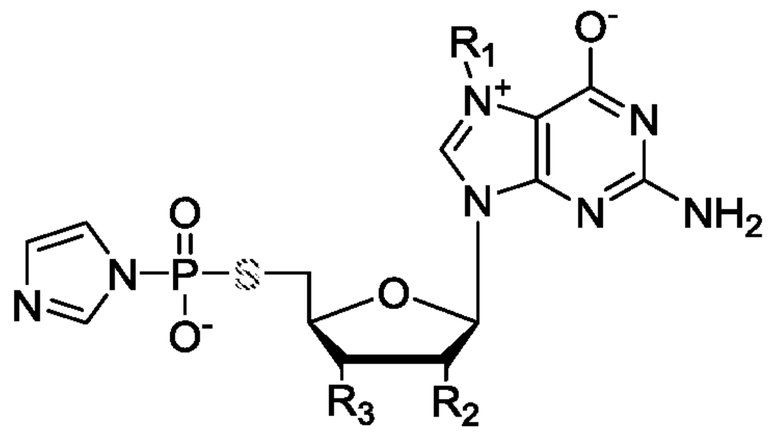
and B is is a group according to formula 3, 4, 5, 6 or 7



formula 3 formula 4 formula 5 formula 6 formula 7

15 The method according to claim 14, characteized in that equimolar amounts are used of the compound according to formula 2 and the compound according to formula 8 and DBU (1,8-diazabicyclo(5.4.0)undec-7-ene) as a base.

16. The method of preparation of 5'-phosphorothiolate analog according to formula 2a, wherein an imidazolide derivative according to formula 9



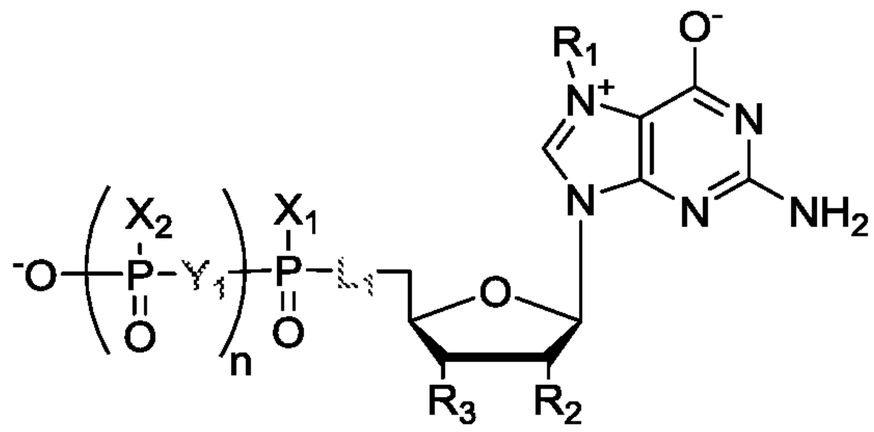
Formula 9

wherein

R^1 is selected from the group comprising CH_3, C_2H_5, CH_2Ph, alkyl, or substituted alkyl;

R^2 i R^3 are independently selected from the group comprising H, OH, OCH_3, OC_2H_5, -COOH, N_3, alkyl, or substituted alkyl;

is reacted with a triethylammonium phosphate salt or sodium thiophosphate to form a 5'-phosphorothiolate analog according to formula 2a



Formula 2a

wherein

n = 0, 1, or 2;

L^1 is O or S;

X_1 and X_2 are independently selected from a group comprising O, S;

R^1 is selected from a group comprising CH_3, C_2H_5, CH_2Ph, alkyl, or substituted alkyl;

R^2 and R^3 are independently selected from a group comprising H, OH, OCH_3, OC_2H_5, -COOH, N_3, alkyl, or substituted alkyl;

Y^1 is selected from a group comprising CH_2, CHCl, CCl_2, CHF, CF_2, NH, and O.

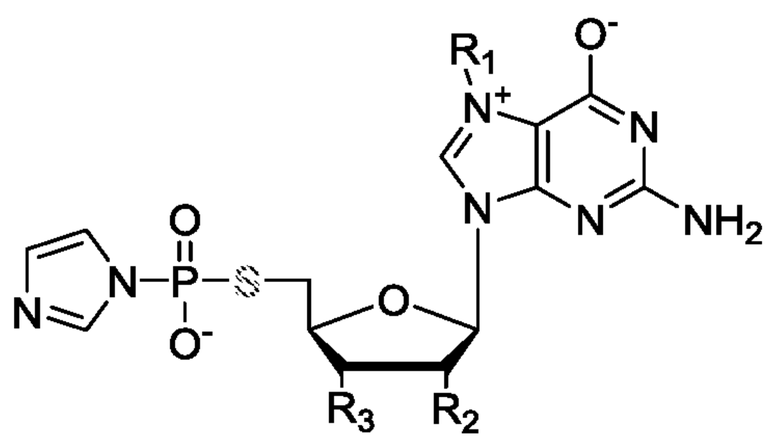
17. The method according to claim 16, characterized in that the reaction is conducted in the presence of a divalent metal chloride.

18. The method according to claim 17, wherein said divalent metal chloride is zinc chloride $ZnCl_2$.

19. The method according to claims 17 or 18, characterized in that a 1,5-fold excess of imidazolide derivative according to formula 9 over the phosphate or the thiophosphate group is used in the presence of 8-fold excess of the divalent metal chloride.

20. A method of preparation of a compound according to formula 1, comprising steps wherein:

an imidazolide derivative according to formula 9



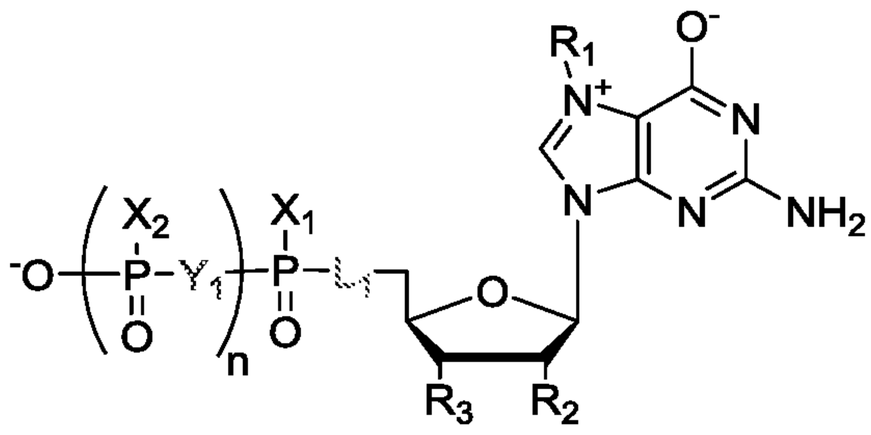
Formula 9

wherein

R^1 is selected from a group comprising CH_3, C_2H_5, CH_2Ph, alkyl, or substituted alkyl;

R^2 and R^3 are independently selected from a group comprising H, OH, OCH_3, OC_2H_5, -COOH, N_3, alkyl, or substituted alkyl;

is reacted with a 5'-phosphorothiolate analog according to formula 2a comprising a terminal thiophosphate moiety



Formula 2a

wherein

n = 1

L^1 is O or S;

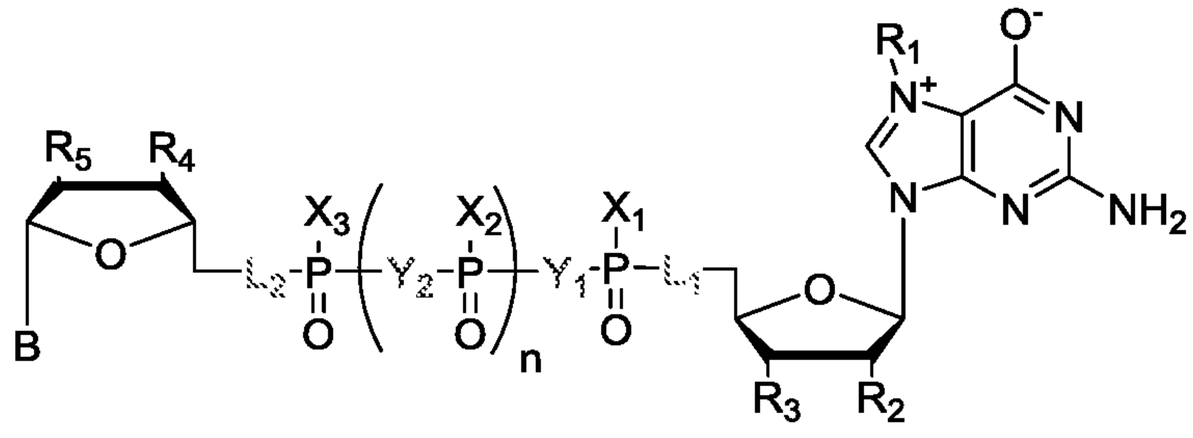
X_1 and X_2 are independently selected from a group comprising O, S;

R^1 is selected from a group comprising CH_3, C_2H_5, CH_2Ph, alkyl, or substituted alkyl;

R^2 and R^3 are independently selected from a group comprising H, OH, OCH_3, OC_2H_5, -COOH, N_3, alkyl, or substituted alkyl;

Y_1 is independently selected from a group comprising CH_2, CHCl, CCl_2, CHF, CF_2, NH, and O,

to form a 5'-phosphorothiolate cap analog according to formula 1



Formula 1

wherein

L^1 and L^2 are independently selected from the group comprising O and S, wherein at least one of L_1 and L_2 is not O;

n = 0, 1, or 2;

X_1, X_2, X_3 are independently selected from the group comprising O, S;

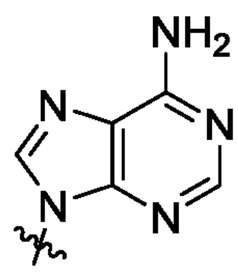
R^1 is selected from the group comprising CH_3, C_2H_5, CH_2Ph, alkyl or substituted alkyl;

R^2 and R^3 are independently selected from the group comprising H, OH, OCH_3, OC_2H_5, -COOH, CH_2COOH, N_3, CH_2N_3, alkyl, alkenyl, or alkynyl;

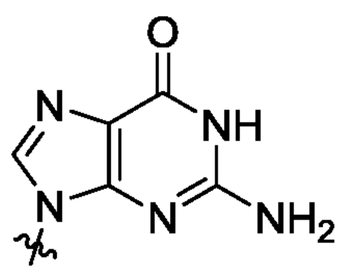
R^4 and R^5 are independently selected from the group comprising H, OH, OCH_3, OC_2H_5, -COOH, CH_2COOH, N_3, CH_2N_3, alkyl, alkenyl, or alkynyl;

Y_1, Y_2 are independently selected from the group comprising CH_2, $CHCl$, CCl_2, CF_2, CHF, NH, O;

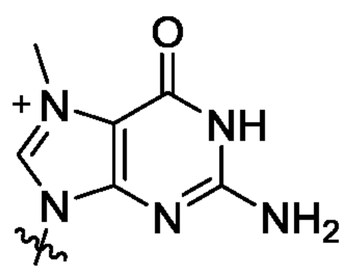
and B is is a group according to formula 3, 4, 5, 6 or 7



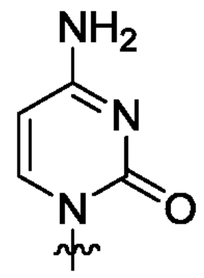
formula 3



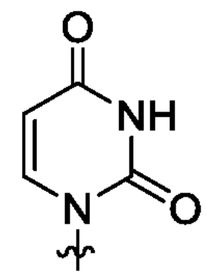
formula 4



formula 5



formula 6



formula 7

21. The method according to claim 20, characterized in that the reaction is carried out in the presence of a divalent metal chloride.

22. The method according to claim 21, characterized in that said divalent metal chloride is zinc chloride $ZnCl_2$.

23. The method according to claim 21 or 22, characterized in that a 1,5-fold excess of imidazolide derivative according to formula 9 over a compound according to formula 2a is used, in the presence of an 8-fold excess of the divalent metal chloride.

24. An mRNA comprising at the 5' end the 5'-phosphorothiolate cap analog according to claim 1-3.

25. The mRNA according to claim 24, wherein said 5'-phosphorothiolate cap analog is selected from a group comprising m^7G**S**pppG (no. 24), $m^{7,2'O}G$**S**pppG (no. 26), m^7G**S**ppp**S**G (no. 32), m^7G**S**pp_spG D1 (no. 30), m^7G**S**pp_spG D2 (no. 31), m^7G**S**pp_sp**S**G D1 (no. 33), m^7G**S**pp_sp**S**G D2 (no. 34), more preferably it is $m^{7,2'O}G$**S**pppG (no. 26).

26. A method of preparation of mRNA comprising at the 5' end of the mRNA molecule a 5'-phosphorothiolate cap analog, characterized in that the 5'-phosphorothiolate cap analog according to claim 1-3 is incorporated during synthesis of the mRNA molecule.

27. The method of preparation of mRNA according to claim 26, characterized in that the 5'-phosphorothiolate cap analog is selected from a group comprising m^7G**S**pppG (no. 24), $m^{7,2'O}G$**S**pppG (no. 26), m^7G**S**ppp**S**G (no. 32), m^7G**S**pp_spG D1 (no. 30), m^7G**S**pp_spG D2 (no. 31), m^7G**S**pp_spSG D1 (no. 33), m^7G**S**pp_sp**S**G D2 (no. 34), more preferably it is $m^{7,2'O}G$**S**pppG (no. 26).

28. The method of preparation of mRNA according to claims 26-27characterized in that the synthesis of mRNA proceeds through transcription *in vitro*.

29. mRNA prepared with the method according to claim 26-28.

30. Use of the mRNA comprising the 5'-phosphorothiolate cap analog according to claims 24-25 and 29 at the 5'-end for production of proteins

31 The use of mRNA according to claim 30, characterized in that the production of proteins carried out in a cellular or a non-cellular system.

32. mRNA according to claims 24-25 and 29 for use as a medicament.

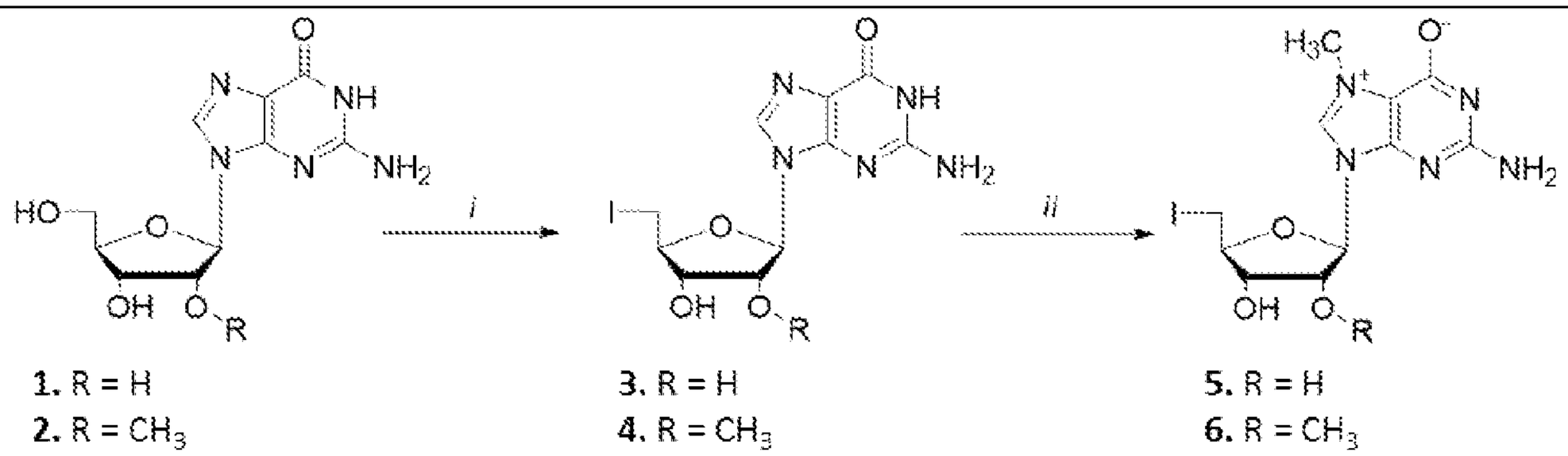
33. mRNA according to claims 24-25 and 29 for use as a medicament for treatment of spinal muscular atrophy (SMA) an/or for alleviation of symptoms of SMA

34. mRNA according to claims 24-25 and 29 for use as an anti-cancer medicament, more preferably as a medicament in anti-cancer immunotherapy.

35. Use of the mRNA according to claims 24-25 and 29 for production of a medicament.

36. The use according to claim 33, characterized in that the mRNA is used in preparation of a medicament for treatment of spinal muscular atrophy (SMA) an/or for alleviation of symptoms of SMA, as an anti-cancer medicament, more preferably as a medicament in anti-cancer immunotherapy.

37. A pharmaceutical formulation comprising the mRNA according to claims 24-25 and 29 and a pharmaceutically acceptable carrier.



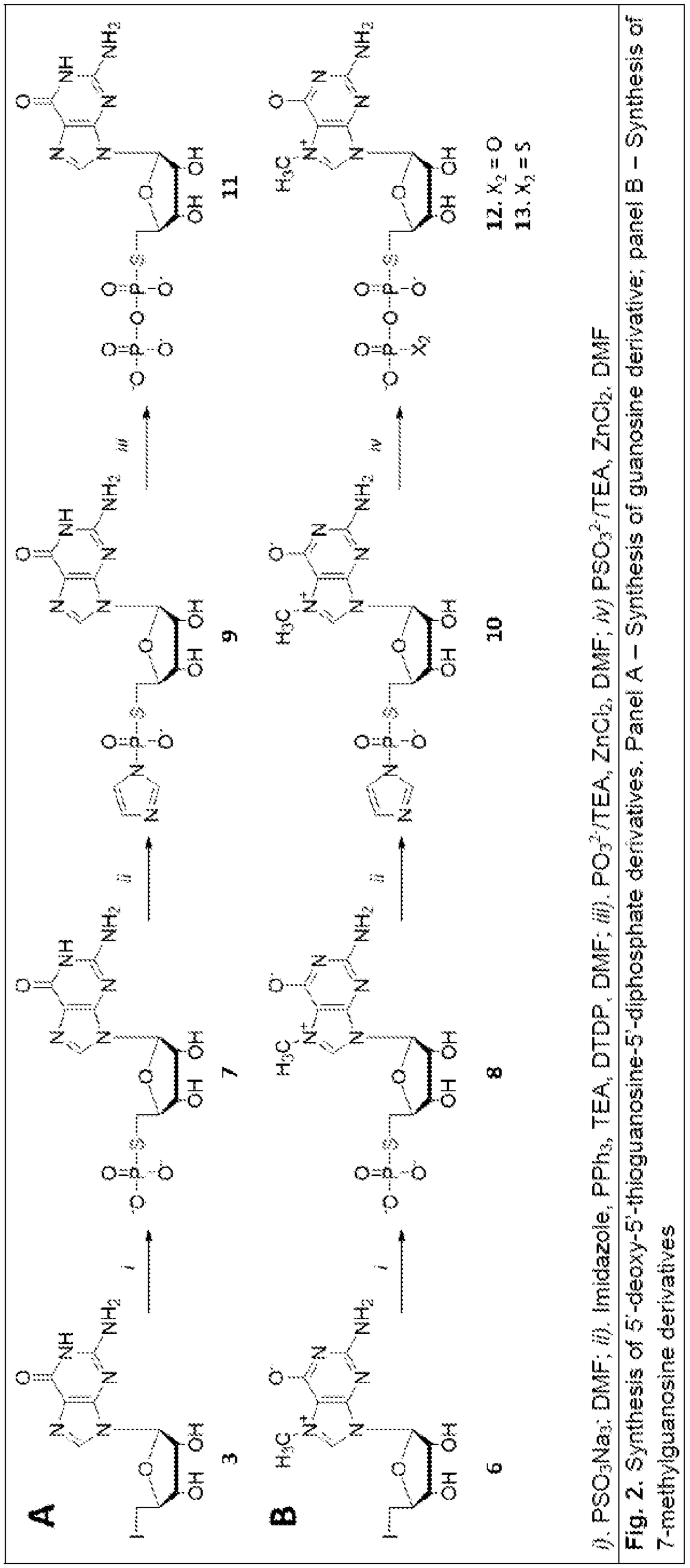
1. R = H
2. R = CH_3

3. R = H
4. R = CH_3

5. R = H
6. R = CH_3

i). I_2, imidazole, PPh_3, NMP; *ii)*. MeI, DMSO

Fig. 1. Synthesis of 5'-deoxy-5'-iodo-guanosine analogs



i). PSO_3Na_3; DMF; *ii*). Imidazole, PPh_3, TEA, DTDP, DMF; *iii*). PO_3^{2-}/TEA, $ZnCl_2$, DMF; *iv*) PSO_3^{2-}/TEA, $ZnCl_2$, DMF

Fig. 2. Synthesis of 5'-deoxy-5'-thioguanosine-5'-diphosphate derivatives. Panel A – Synthesis of 7-methylguanosine derivatives

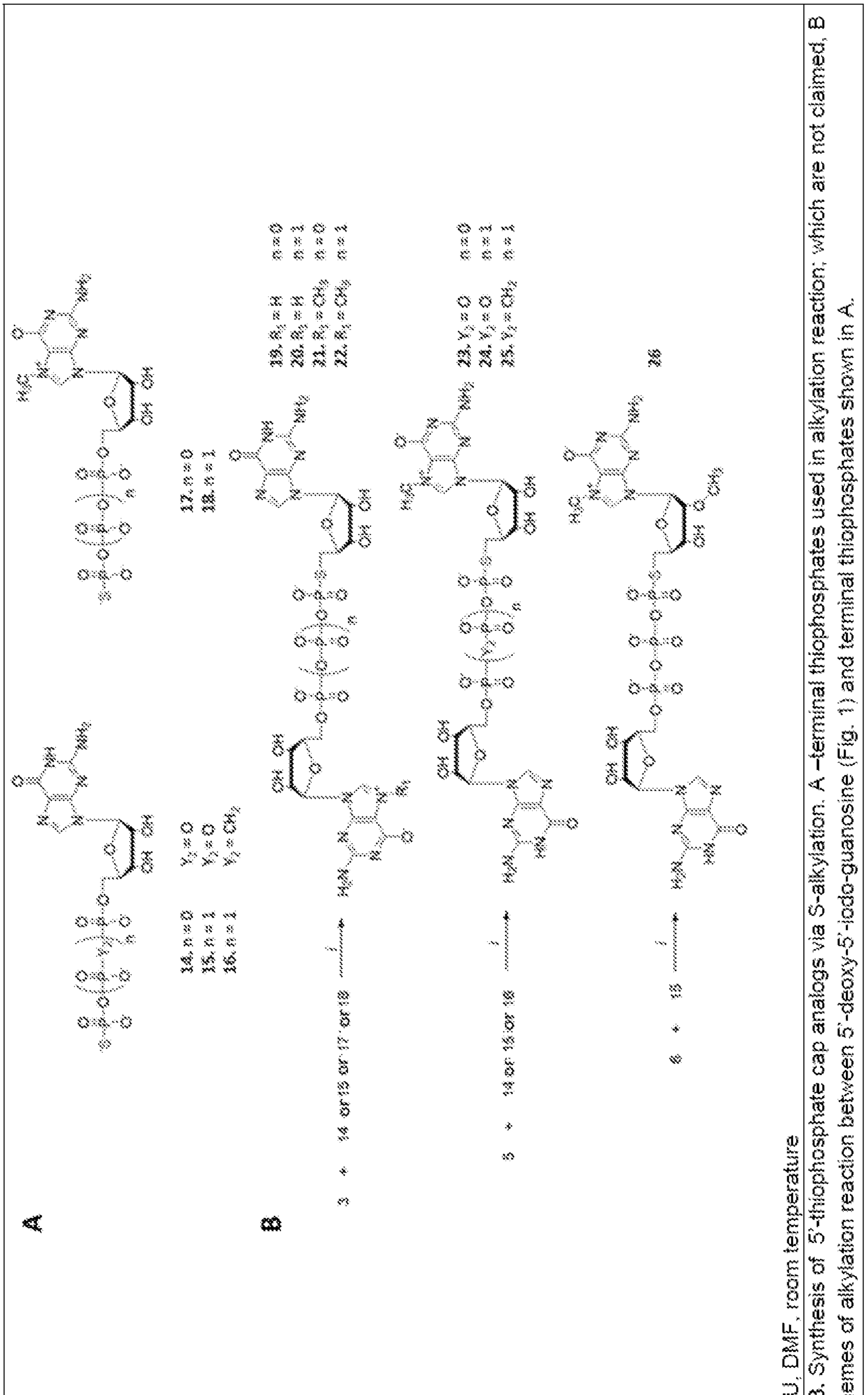


Fig. 3. Synthesis of 5'-thiophosphate cap analogs via S-alkylation. A –terminal thiophosphates used in alkylation reaction; which are not claimed, B – schemes of alkylation reaction between 5'-deoxy-5'-iodo-guanosine (Fig. 1) and terminal thiophosphates shown in A.

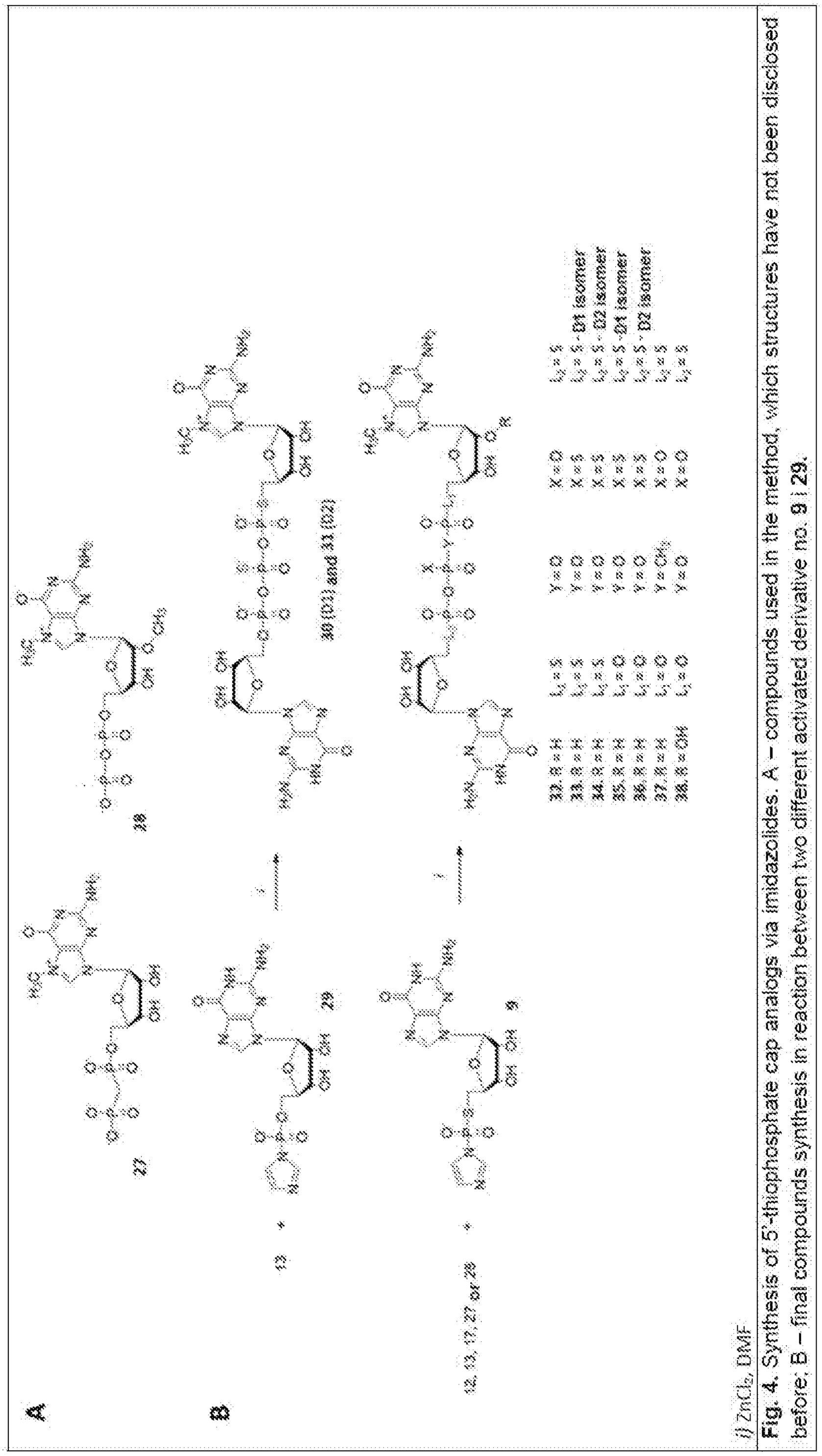


Fig. 4. Synthesis of 5'-thiophosphate cap analogs via imidazolides. A – compounds used in the method, which structures have not been disclosed before; B – final compounds synthesis in reaction between two different activated derivative no. **9** i **29**.

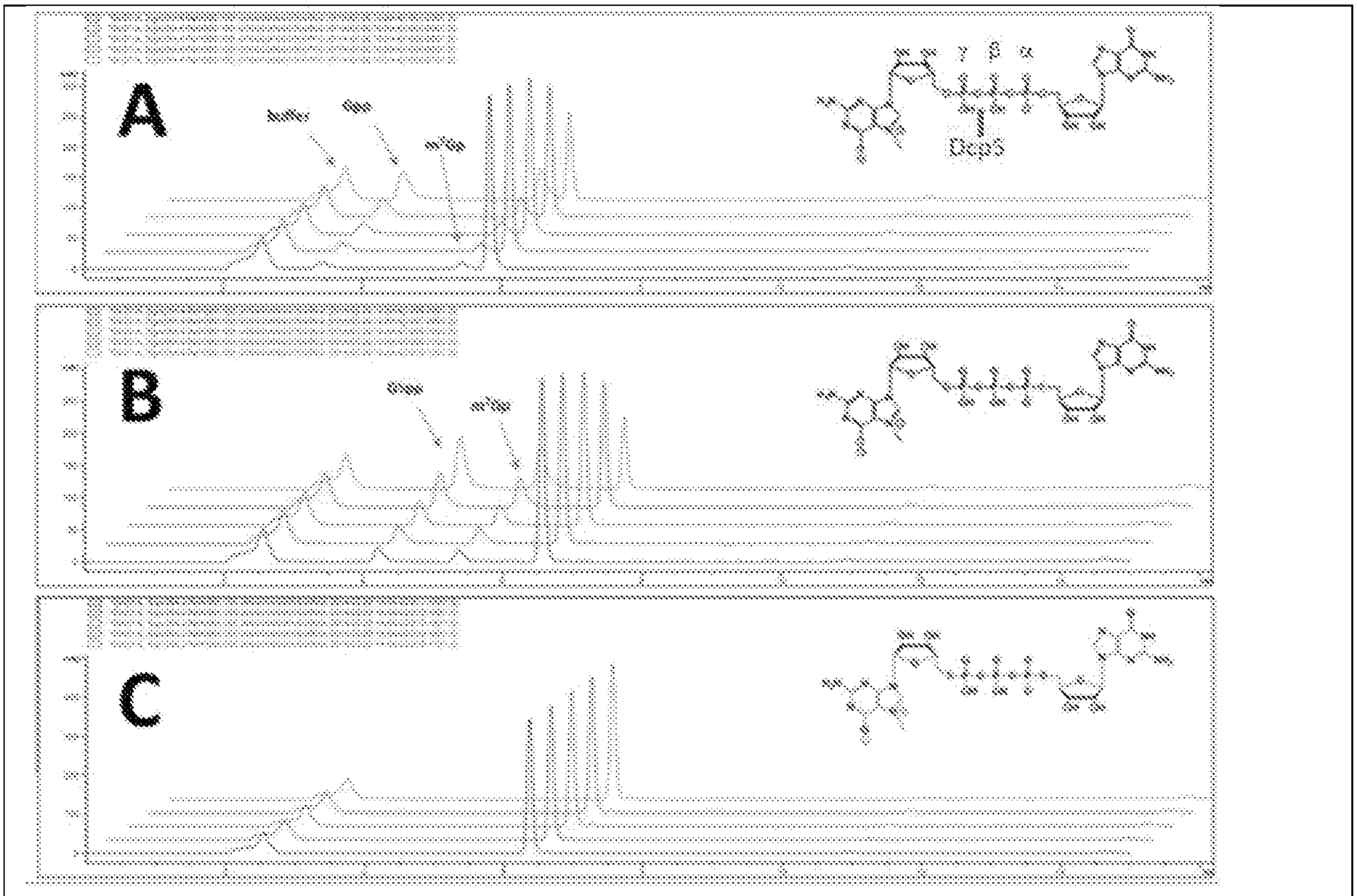


Fig. 5. Susceptibility studies of a dinucleotide substrate (m7GpppG) and 5'-S modified cap analogs to hydrolysis mediated by the DcpS enzyme. Phosphate terminology is indicated on the structure of the natural DcpS enzyme substrate.

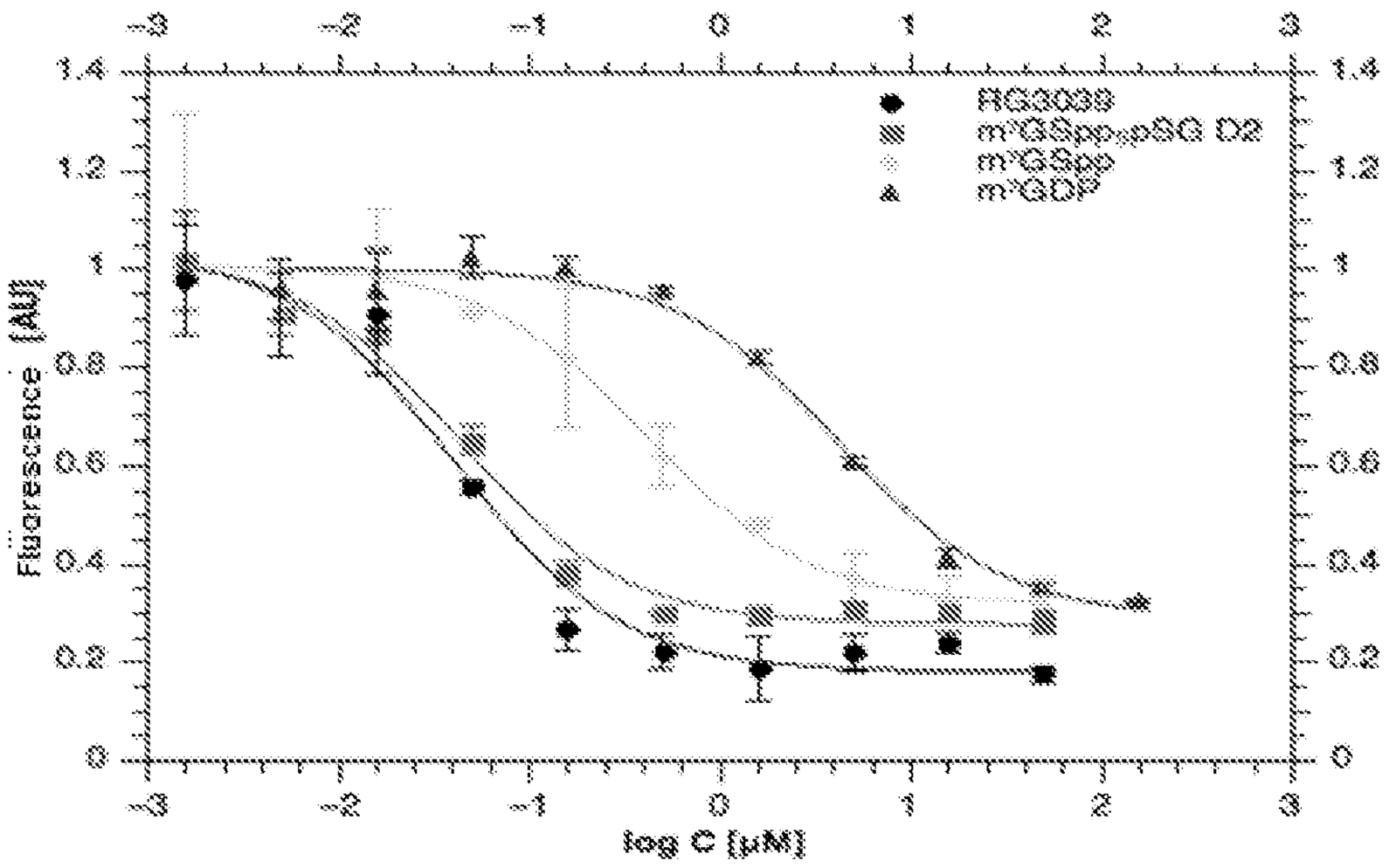


Fig. 6. The result of IC_{50} determination for compounds: m^7GSpp_spSG D2, m^7GSpp, m^7GDP and RG3039.

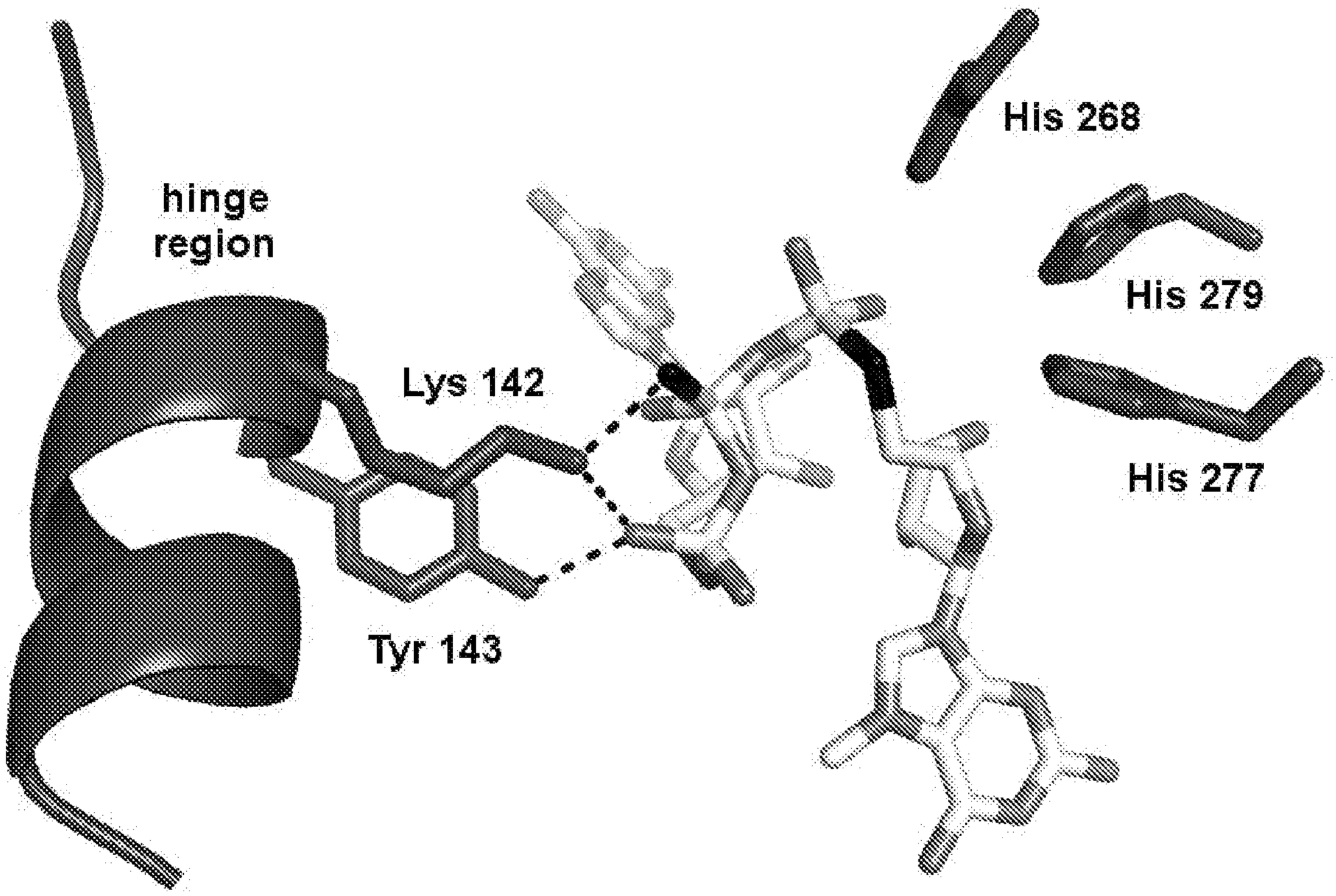


Fig.7.

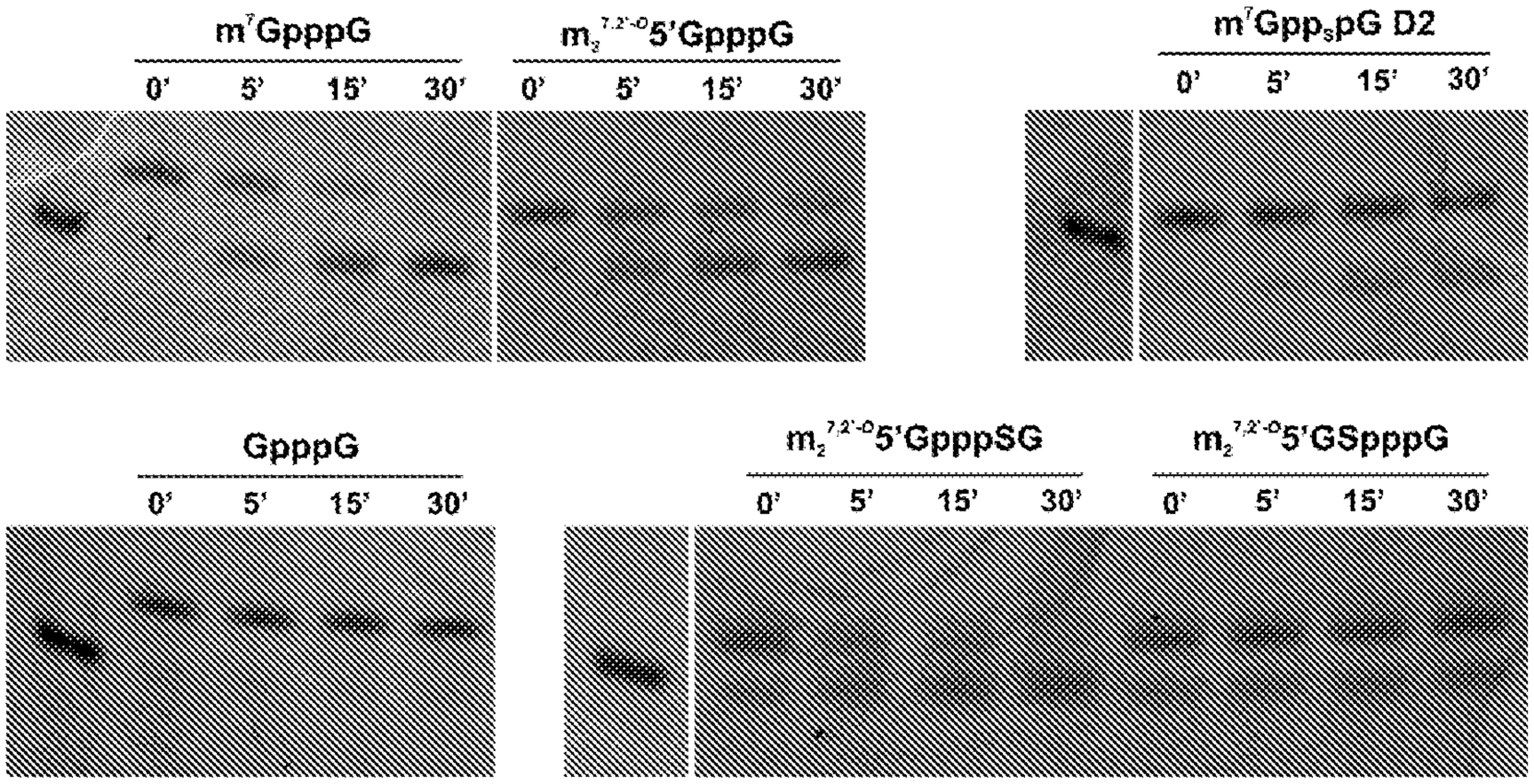


Fig. 8. Susceptibility to Dcp1/2 enzyme activity.

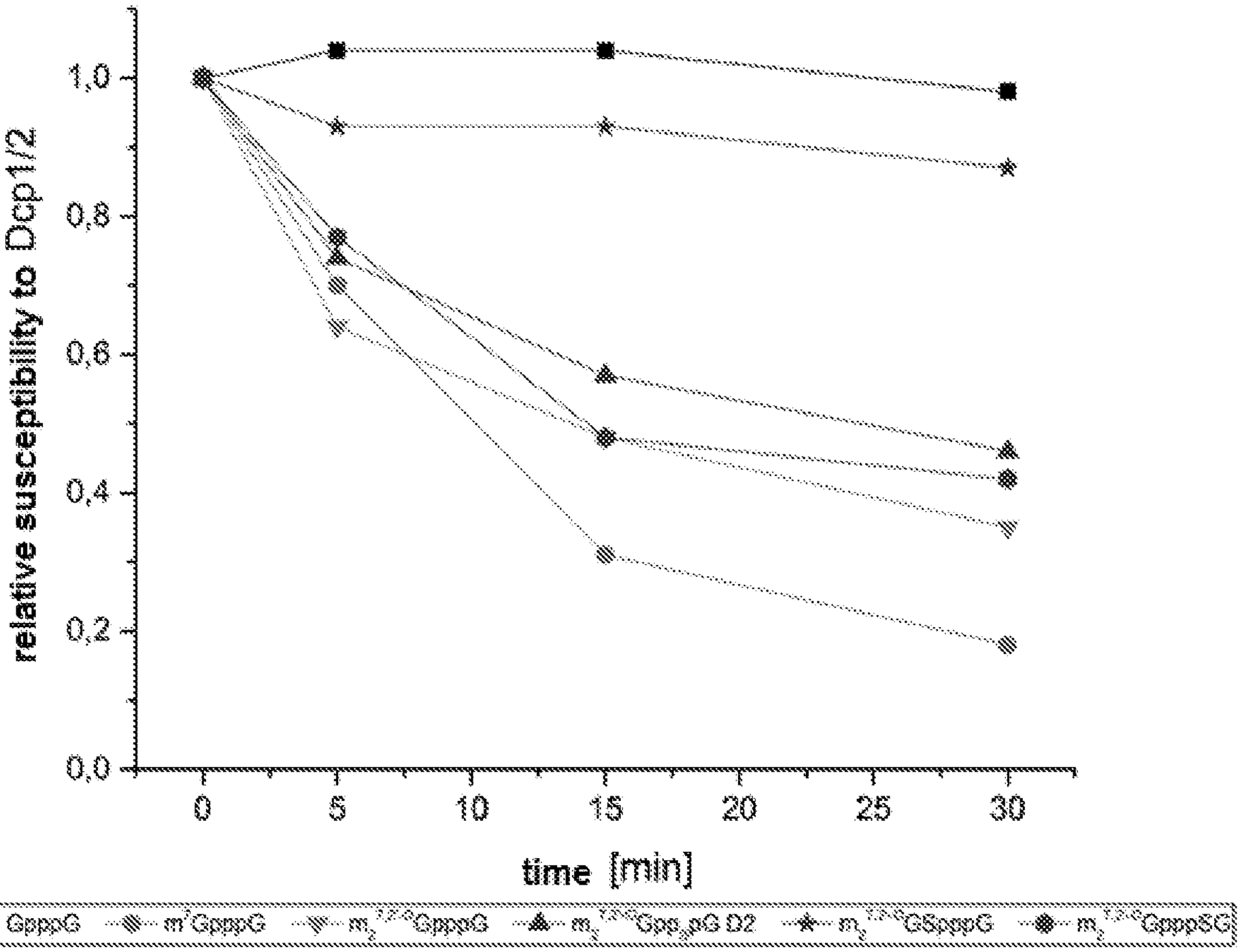


Fig. 9. Relative susceptibility to Dcp1/2 enzyme activity

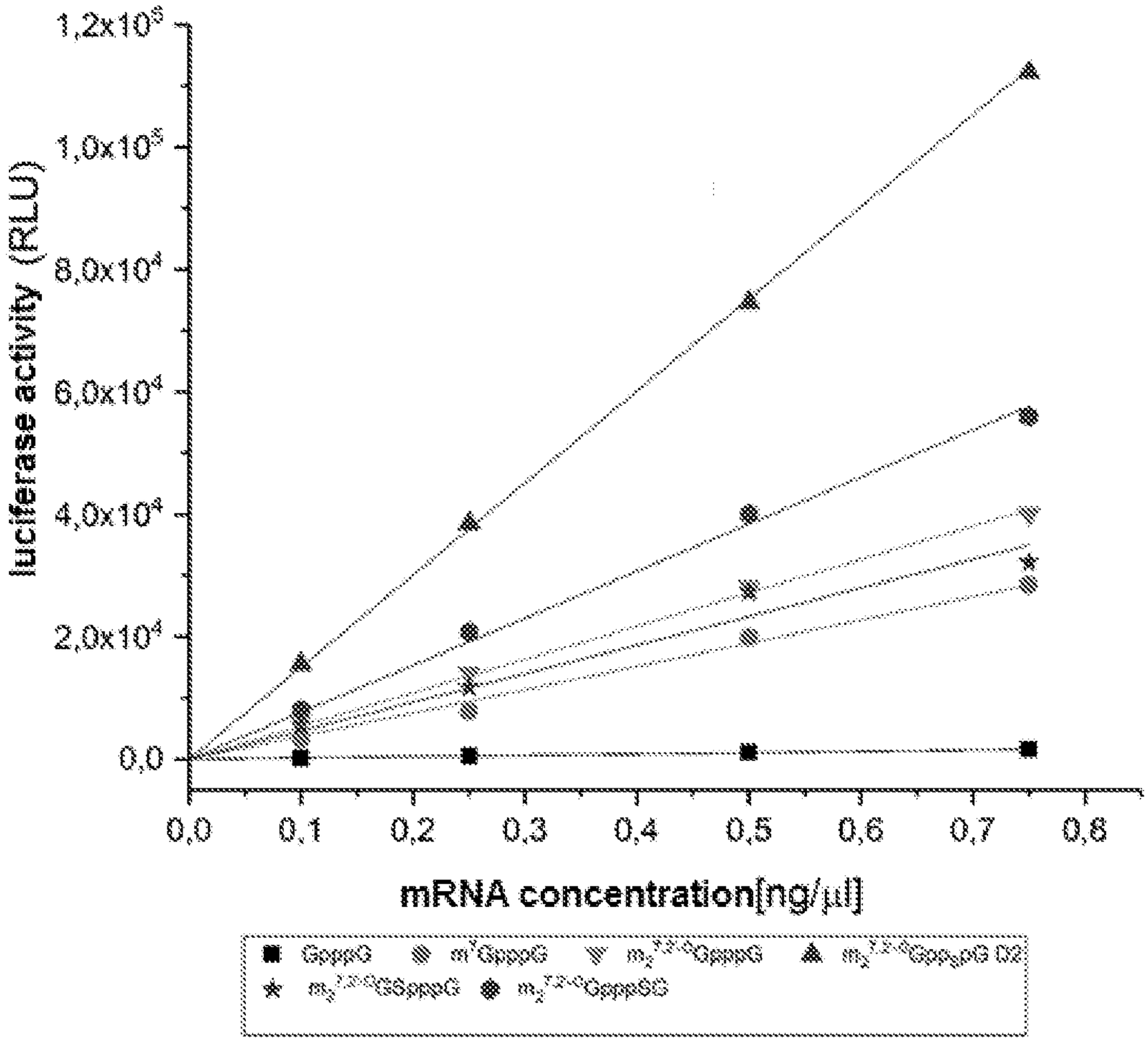


Fig. 10. Relative translational efficiency.

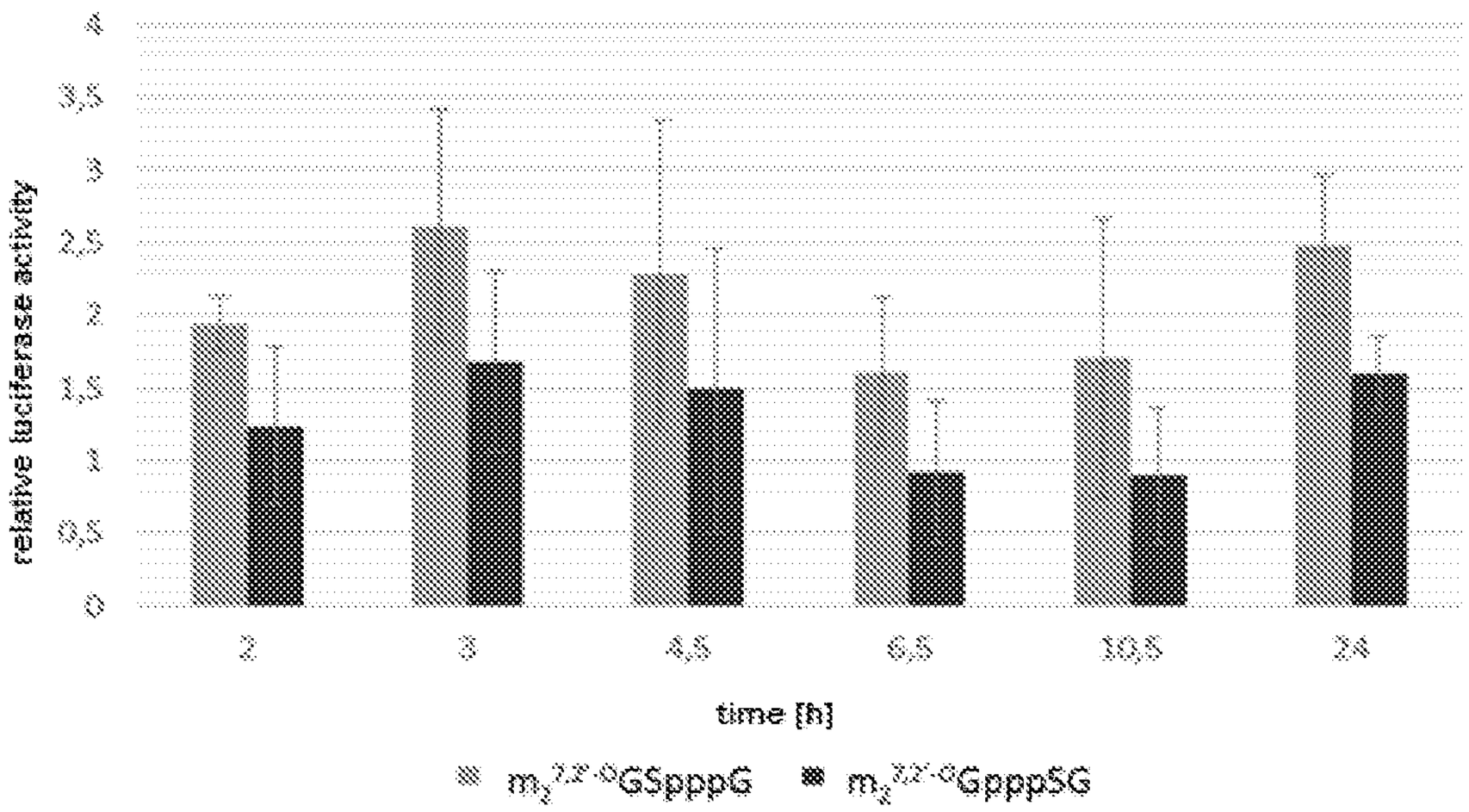
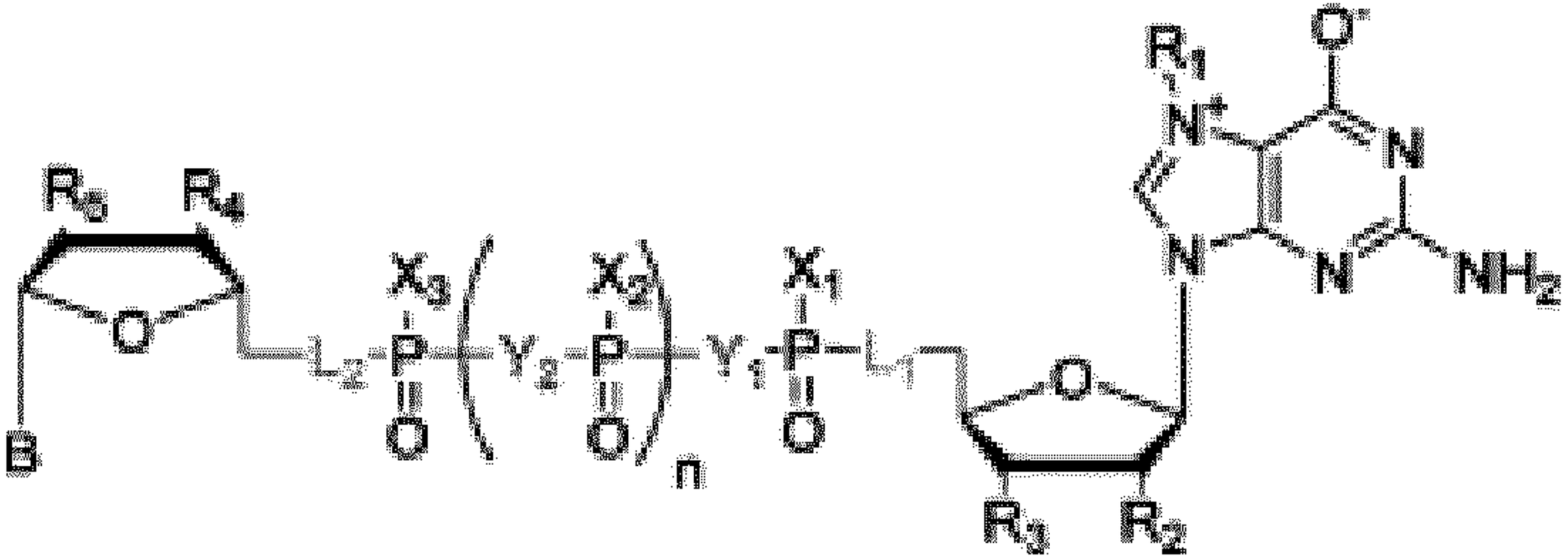


Fig. 11. Relative translational efficiency in HeLa cells



Formula 1