New Neplanocin Analogues. IX. A Practical Preparation of (6′*R*)-6′-*C*-Methylneplanocin A (RMNPA), a Potent Antiviral Agent, and the Determination of Its 6′-Configuration. Diastereoselective Deamination by Adenosine Deaminase[1)]

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We previously synthesized (6′*R*)- and (6′*S*)-6′-*C*-methylneplanocin A's (2a and 2b, respectively), and found that one of them has a potent antiviral activity, though its 6′-configuration has not been confirmed. This report describes the determination of the 6′-configuration and practical preparation of the antivirally active diastereomer. The 6′-configuration of the active diastereomer was determined as *R* by the modified Mosher's method as well as by synthesizing 2b from the known cyclopentenone derivative 10. A practical method for preparing the 6′*R*-diastereomer was developed by using diastereoselective deamination with Ado deaminase as the key step. Treatment of the diastereomeric mixture of 2a and 2b, which was prepared *via* an addition reaction of Me_3Al with the 6′-formyl derivative 3, with Ado deaminase from calf intestine, deaminated 2b selectively to give the corresponding (6′*S*)-inosine congener 5, and left the desired 2a not deaminated. After silica gel column chromatography, 2a was obtained in a pure form.

Key words *S*-adenosylhomocysteine hydrolase; neplanocin A; antiviral agent; adenosine deaminase; modified Mosher's method

Although RNA viruses such as influenza, parainfluenza, respiratory syncytial, and measles viruses often cause serious diseases, efficient vaccines for these viruses have not been developed. Consequently, antiviral drugs effective against these pathogenic viruses are required.

In recent years, much attention has been focused on the broad-spectrum anti-RNA-viral activity of *S*-adenosylhomocysteine (AdoHcy) hydrolase inhibitors.[2-4)] AdoHcy hydrolase is responsible for the hydrolysis of AdoHcy to adenosine (Ado) and L-homocysteine (Hcy),[2,3)] and is a key enzyme in transmethylation reactions using *S*-adenosyl-L-methionine (AdoMet) as a methyl donor.[2)] Because such transmethylation reactions are involved in the maturation of viral mRNAs and are critical in the virus replicative cycle, inhibitors of AdoHcy hydrolase are assumed to achieve their broad-spectrum antiviral activity due to the inhibition of transmethylation reactions.[2-4)] In fact, a close correlation has been found between the antiviral activity of a series of Ado analogues and their inhibitory effects on AdoHcy hydrolase.[5)]

Neplanocin A (NPA, **1**, Chart 1),[6)] a carbocyclic nucleoside antibiotic, which is one of the most potent AdoHcy hydrolase inhibitors, has a notable anti-RNA-viral effect *in vitro*[7)]; however, it also has a toxic effect on the host cells.[8)] The mechanism of action of NPA has been extensively explored[8,9)]; the cytotoxic effect could be attributed mainly to phosphorylation of the primary hydroxyl group at the 6′-position (the 6′-position of NPA corresponds to the 5′-position of Ado) by Ado kinase and subsequent metabolism by cellular enzymes,[8)] while the antiviral effect would be due to the inhibition of AdoHcy hydrolase *via* suppression of virus mRNA maturation.[9)] NPA is also known to be rapidly deaminated by Ado deaminase to the chemotherapeutically inactive inosine congener,[10,11a)] which would reduce the therapeutic potency of NPA. Based on these results, extensive chemical modifications of NPA have been done to develop efficient antiviral agents.[11,12)] We have chosen the 6′-moiety of NPA as the target site for modifications because of its important role in interactions with these enzymes, namely AdoHcy hydrolase, Ado deaminase, and Ado kinase, and we have prepared various 6′-modified derivatives of NPA.[11a,c,e)] We had synthesized a diastereomeric mixture of (6′*R*)- and (6′*S*)-6′-*C*-methyl-NPA (**2a** and **2b**, respectively), which was obtained by an addition reaction of Me_3Al with the 6′-formyl derivative of NPA (**3**) and subsequent removal of the protecting groups.[11a)] The two individual diastereomers were separated, and it was found that the major diastereomer, which has the 6′*R*-configuration as described below, has significant antiviral activity while the minor one (6′*S*-diastereomer) is inactive.[11a)] However, only a small quantity of the active diastereomer was obtained, because it was purified by reverse-phase HPLC. Accordingly, a better method to obtain the active diastereomer is needed for further evaluation of this antiviral agent.

Here, we describe a practical method for preparing the active diastereomer by using diastereoselective enzymatic deamination as a key step, and the determination of its 6′-configuration.

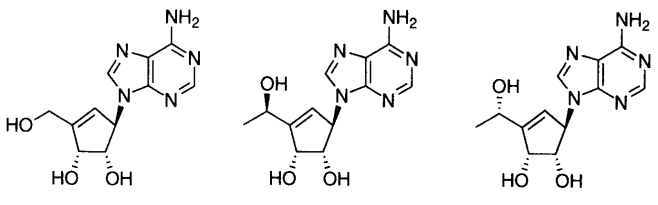

Chart 1

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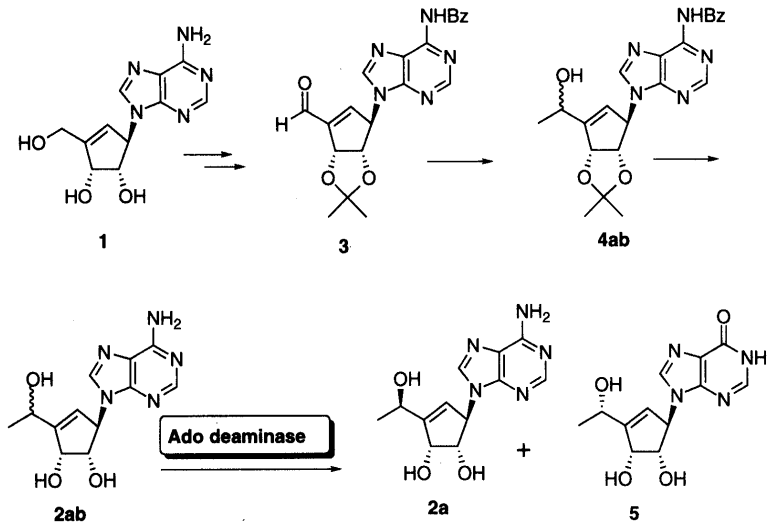
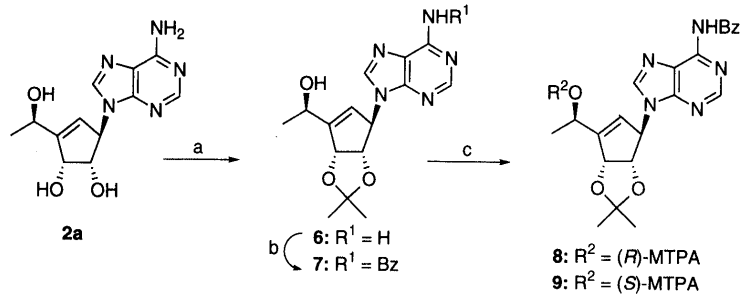


Chart 2



Reagents: a) $HClO_4$, acetone; b) i) TMSCl, py, then BzCl, ii) NH_4OH, aq. py; c) (*R*)- or (*S*)-MTPACl, DMAP, MeCN

Chart 3

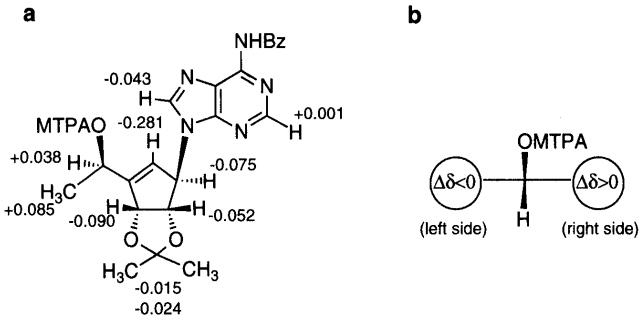


Fig. 1.

a) $\Delta\delta$ Value (ppm) obtained for the MPTA esters **8** and **9**. b) The model to determine the absolute configurations of secondary alcohols (presented by Ohtani *et al.*).[13]

Determination of the 6′-Configuration of 6′-*C*-Methylneplanocin A's Determination of the 6′-configuration was investigated by the modified Mosher's method, which is very effective for determining the absolute configuration of secondary hydroxyl groups of organic compounds.[13] Treatment of the major diastereomer **2a** with $HClO_4$/acetone system gave the 2′,3′-*O*-isopropylidene derivative **6**, the N^6-amino function of which was protected with a benzoyl group by the usual method to give **7**. Treatments of **7** with (*R*)- and (*S*)-α-methoxy-α-(trifluoromethyl)-phenylacetyl chloride (MTPACl) in the presence of 4-dimethylaminopyridine (DMAP) in MeCN afforded the corresponding (*R*)- and (*S*)-MTPA esters, **8** and **9**, respectively (Chart 3). The $\Delta\delta$ ($\delta_S - \delta_R$) values obtained from the ^{1}H-NMR spectra are shown in Fig. 1a; all of the protons of the cyclopentene ring moiety have $\Delta\delta < 0$ values and the 6′-*C*-methyl protons have the $\Delta\delta > 0$ value of $+0.085$ ppm.[14] This result was applied to the model to determine the absolute configurations of the secondary alcohols shown in Fig. 1b, in which the protons with $\Delta\delta < 0$ must be located on the left side of the MTPA plane and the protons with $\Delta\delta >$ on the right side.[13] Thus, the 6′-configuration of the major diastereomer was suggested to be *R*.

The result from the modified Mosher's method was confirmed by synthesizing the 6′*S*-diastereomer **2b** (SMNPA) from a tosyloxycyclopentene derivative **11** (Chart 4). Compound **11** was prepared from the known cyclopentenone derivative **10**, and its stereochemistry was previously confirmed based on X-ray crystallographic analysis of the 3-deazaadenine derivative **13**, which was derived from **11**.[11c] The tosyloxycyclopentene derivative **11** was treated with adenine in the presence of NaH and 15-crown-5 in DMF at 80 °C to give the desired (6′*S*)-6′-*C*-methylneplanocin A derivative **12** in 64% yield. Removal of the protecting groups was done by treating **12** with HCl/MeOH to furnish (6′*S*)-6′-*C*-methylneplanocin A (**2b**, SMNPA), which gave spectral data in accord with those of the minor diastereomer previously obtained by HPLC

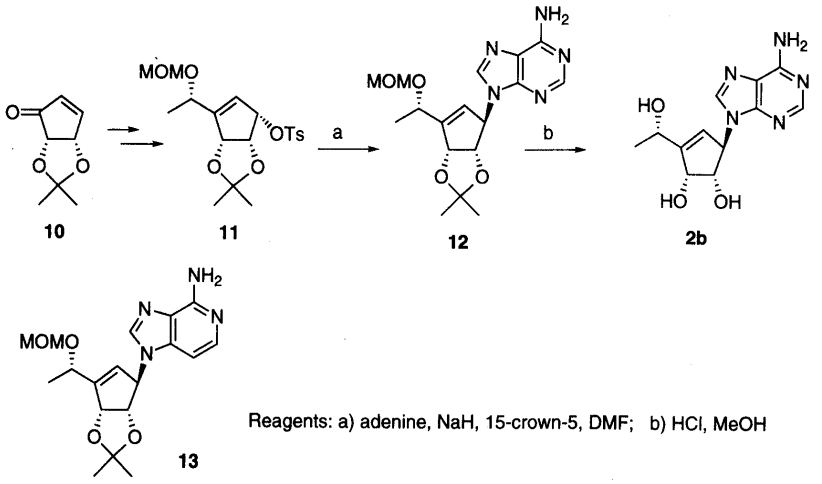


Chart 4

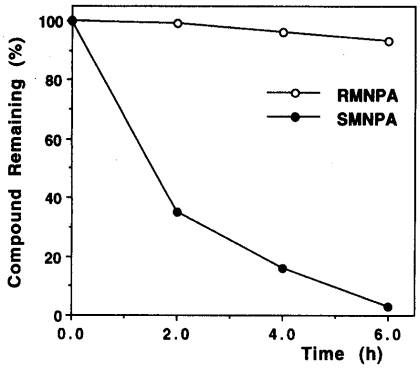


Fig. 2. Enzymatic Deamination of **2a** and **2b** by Ado Deaminase from Calf Intestine

separation.[11a)]

Therefore, it was demonstrated that the diastereomer with significant antiviral activity has the 6′*R*-configuration. The determination of the configuration by the modified Mosher's method has been done based on the $\Delta\delta$ values of several nonequivalent protons on each side of the MTPA plane. Although, in this case, only the 7′-methyl protons were located on the right side on the MTPA plane, the modified Mosher's method indicated the correct 6′-configuration.

Practical Method for Preparing RMNPA Because we previously recognized that the biologically inactive diastereomer was deaminated by Ado deaminase but the active one was resistant to deamination,[11a)] development of a practical method for preparing RMNPA, the biologically active diastereomer, was planned based on this different susceptibility.

First the susceptibility of RMNPA and SMNPA to Ado deaminase from calf intestine, which is commercially available, was investigated in detail. The diastereomeric mixture (0.5 μmol) in 50 mM Tris–HCl buffer (pH 7.2, 500 μl) was treated with the Ado deaminase (0.4 units) at 25 °C. The reaction was monitored by HPLC and the result is shown in Fig. 2. Under these conditions, SMNPA was deaminated effectively but RMNPA was significantly resistant to the enzymatic deamination: after 6 h, SMNPA was almost entirely converted to the corresponding inosine congener **5**, while 93% of RMNPA remained without having been deaminated.[15)] Therefore, it was considered that after treatment of the diastereomeric mixture of **2a** and **2b** with the Ado deaminase at 25 °C, RMNPA would be isolated readily in a pure form. A solution of the diastereomeric mixture of RMNPA and SMNPA (4 mmol), which was synthesized from neplanocin A *via* the addition reaction of Me_3Al with **3**,[11a)] and calf intestine Ado deaminase (660 units) in 50 mM Tris–HCl buffer (pH 7.2, 80 ml) was stirred at 25 °C for 17 h. After the usual silica gel flash column chromatography, RMNPA was obtained in a pure form in 73% yield together with the deaminated (6′*S*)-6′-*C*-methylinosine congener **5** in 25% yield.

Our result suggested that the three-dimensional structure around the 6′-moiety of NPA and its analogues is important for the compounds to be recognized as substrates by Ado deaminase.

This method can provide enough RMNPA for further biological evaluation. Thus, the therapeutic potential of RMNPA as an antiviral drug *in vitro* as well as *in vivo* can be further pursued.

Experimental

Melting points were measured on a Yanagimoto MP-3 micromelting point apparatus and are uncorrected. NMR spectra were recorded with a JEOL FX-270, or a GCX-400 spectrometer with tetramethylsilane as an internal standard. Mass spectra were measured on a JEOL SX-102 spectrometer. High-resolution mass spectra were measured on a JMX DX-303 spectrometer. Thin-layer chromatography was done on Merck precoated plates $60F_{254}$. Flash chromatography was conducted with Merck silica gel 9385. NPA was prepared according to a reported method.[6)]

(6′*R*)-2′,3′-*O*-Isopropylidene-6′-*C*-methylneplanocin A (6) A mixture of the major 6′-diastereomer **2a**[11a)] (14 mg, 0.051 mmol) and 70% $HClO_4$ (10 μl) in acetone (3 ml) was stirred at room temperature for 2 h. The reaction mixture was neutralized with 0.8 M $NaHCO_3$ and the insoluble salt was filtered off. The filtrate was evaporated, and the residue was purified by column chromatography (silica gel, $CHCl_3$–MeOH, 20 : 1, followed by 10 : 1) to give **6** (15 mg, 94%) as a white powder. ^{1}H-NMR (DMSO-d_6 + D_2O) δ: 7.33, 7.11 (each s, each 1H, H-2, 8), 4.89 (m, 1H, H-5), 4.69 (d, 1H, J = 1.9 Hz, H-1′), 4.62 (d, 1H, J = 5.5 Hz, H-3′), 3.87 (d, 1H, J = 5.5 Hz, H-2′), 3.68 (q, 1H, J = 6.6 Hz, H-6′), 0.60, 0.47 (each s, each 3H, isopropyl-CH_3 × 2), 0.57 (d, 3H, J = 6.6 Hz, 7′-CH_3). FAB-MS m/z: 422 (MH^+).

(6′*R*)-N^6-Benzoyl-2′,3′-*O*-isopropylidene-6′-*C*-methylneplanocin A (7) Trimethylsilane (TMSCl) (40 μl, 0.31 mmol) was added to a solution of

6 (16 mg, 0.050 mmol) in pyridine (1 ml), and the mixture was stirred at room temperature for 30 min, then BzCl (14 μl, 1.5 mmol) was added, and the whole was further stirred at room temperature for 1.5 h. To this mixture, H_2O (200 μl) was added at 0 °C, and the whole was stirred. After 5 min, 28% NH_4OH (200 μl) was added, and the mixture was stirred at room temperature for 40 min. The resulting mixture was evaporated, and the residue was partitioned between $CHCl_3$ and brine. The organic phase was dried (Na_2SO_4), evaporated, and purified by column chromatography (silica gel; $CHCl_3$–MeOH, 20 : 1) to give **7** as an oil (17 mg, 80%). ^{1}H-NMR ($CDCl_3$) δ: 9.46 (br s, 1H, N^6-H), 8.80, 7.93 (each s, each 1H, H-2, 8), 8.07—7.42 (m, 5H, Ph), 6.17 (br s, 1H, OH), 5.79 (m, 1H, H-5′), 5.64 (d, 1H, J=1.5 Hz, H-1′), 5.50 (d, 1H, J=5.9 Hz, H-3′), 4.78 (d, 1H, J=5.9 Hz, H-2′), 4.70 (q, 1H, J=6.6 Hz, H-6′), 1.51, 1.38 (each s, each 3H, isopropyl-CH_3 × 2), 1.49 (d, 3H, J=6.6 Hz, 7′-CH_3). FAB-MS m/z: 422.1847 (Calcd for $C_{22}H_{24}N_5O_4$: 422.1828).

(*R*)- and (*S*)-MTPA Esters (8 and 9) (+)-(*R*)- or (−)-(*S*)-MTPACl (6 μl, 0.017 mmol) was added to a solution of **7** (4.0 mg, 0.0095 mmol) and DMAP (9.0 mg, 0.074 mmol) in MeCN (0.5 ml), and the resulting mixture was stirred at room temperature for 2 h. After addition of MeOH (100 μl), the mixture was evaporated, and the residue was partitioned between $CHCl_3$ and 0.5 N HCl. The organic phase was washed (brine), dried (Na_2SO_4), and evaporated. The residue was purified by column chromatography (silica gel; $CHCl_3$ followed by $CHCl_3$–MeOH, 120 : 1) to give the corresponding (*R*)-MTPA ester **8** or (*S*)-MTPA ester **9** as an oil. The (*R*)-MTPA ester **8** (yield 50%): ^{1}H-NMR ($CDCl_3$, 400 MHz) δ: 9.01 (br s, 1H, N^6-H), 8.772 (s, 1H, H-2), 7.868 (s, 1H, H-8), 8.04—7.37 (m, 10H, Ph), 5.897 (m, 1H, H-6′), 5.715 (br s, 1H, H-5′), 5.599 (br s, 1H, H-1′), 5.473 (d, 1H, J=5.4 Hz, H-3′), 4.792 (d, 1H, J=5.4 Hz, H-2′), 3.546 (d, 3H, J=1.0 Hz, OMe), 1.585 (d, 3H, J=6.5 Hz, 7′-CH_3), 1.508, 1.397 (each s, each 3H, isopropylidene-CH_3 × 2). FAB-MS m/z: 638. 2229 (Calcd for $C_{32}H_{31}F_3N_5O_6$: 638.2226). The (*S*)-MTPA ester **9** (yield 66%): ^{1}H-NMR ($CDCl_3$, 400 MHz) δ: 9.05 (br s, 1H, N^6-H), 8.773 (s, 1H, H-2), 7.825 (s, 1H, H-8), 8.04—7.37 (m, 10H, Ph), 5.935 (m, 1H, H-6′), 5.524 (br s, 1H, H-5′), 5.524 (br s, 1H, H-1′), 5.383 (d, 1H, J=5.4 Hz, H-3′), 4.740 (d, 1H, J=5.4 Hz, H-2′), 3.587 (d, 3H, J=1.0 Hz, OMe), 1.632 (d, 3H, J=6.6 Hz, 7′-CH_3), 1.493, 1.355 (each s, each 3H, isopropylidene-CH_3 × 2). FAB-MS m/z: 638.2203 (Calcd for $C_{32}H_{31}F_3N_5O_6$: 638.2226).

(6′*S*)-2′,3′-*O*-Isopropylidene-6′-*O*-methoxymethyl-6′-*C*-methylneplanocin A (12) A suspension of adenine (68 mg, 0.50 mmol), 15-crown-5 (50 μl, 0.25 mmol) and NaH (50% in oil, 24 mg, 0.50 mmol) in dimethyl formamide (DMF) (2.5 ml) was stirred at room temperature under an argon atmosphere for 1 h. Then, a solution of **11** (94 mg, 0.24 mmol) in DMF (0.5 ml) was added, and the mixture was stirred at 80 °C for 2 h. The resulting mixture was cooled to room temperature, and the solvent was removed. The residue was taken up in EtOAc (50 ml), and the insoluble material was filtered off. The filtrate was washed with brine (10 ml), filtered through Whatman 1PS filter paper, and evaporated. The residue was purified by flash chromatography (silica gel, $CHCl_3$–MeOH–25% NH_4OH = 30 : 1 : 0.1) to give **12** (55 mg, 64%) as a solid. ^{1}H NMR ($CDCl_3$) δ: 8.38, 7.86 (each s, each 1H, H-2, 8), 5.78 (br s, 1H, H-5′), 5.32 (m, 3H, NH_2 and H-1′), 5.46 (d, 1H, J=5.6 Hz, H-3′), 4.77—4.66 (m, 3H, OCH_2 and H-2′), 4.45 (q, 1H, J=6.6 Hz, H-6′), 3.41 (s, 3H, CH_3O), 1.49 (d, 3H, J=6.6 Hz, 6′-CH_3), 1.48, 1.36 (each s, each 3H, isopropyl-CH_3 × 2). FAB-MS m/z: 362 (MH^+).

SMNPA (2b) A solution of **12** (5 mg, 0.01 mmol) in HCl/MeOH (5 N, 2 ml) was stirred at room temperature for 15 h. The solvent was evaporated and the residue was dissolved in EtOH (1 ml). The pH of the mixture was adjusted to about 10 with 25% NH_4OH, and then the solvent was evaporated. The residue was purified by flash chromatography (silica gel, $CHCl_3$–MeOH–25% NH_4OH = 65 : 25 : 2) to give SMNPA (**2b**, 3.5 mg, 91%) as a solid having spectral data in accord with those reported previously.[11a)]

HPLC Monitoring of Enzymatic Deamination of RMNPA and SMNPA The Ado deaminase solution (20 units/ml) was prepared from commercially available calf intestine Ado deaminase (Boehringer Mannheim 102091, 200 units/ml) by diluting it 10-fold with Tris–HCl buffer (50 mM, pH 7.2). The Ado deaminase solution prepared (10 μl, 0.4 units) was added to a solution of the compound (0.5 mM) in Tris–HCl buffer (50 mM, pH 7.2, 0.5 μl), and the resulting solution was incubated at 25 °C. After 2, 4, and 6 h, the reaction mixture (5 μl) was sampled and analyzed by HPLC (column, Merck Superspher RP-18-4, 0.4 × 15 cm; eluate, 10% MeOH; temperature, 50 °C; detector, UV 260 nm).

(6′*R*)-6′-*C*-Methylneplanocin A (RMNPA, 2a) A solution of a diastereomeric mixture of RMNPA and SMNPA (1.11 g, 4 mmol), which was prepared according to the previously reported method,[11a)] and calf intestine Ado deaminase (Boehringer Mannheim 102091, 660 units) in 50 mM Tris–HCl buffer (pH 7.2, 80 ml) was stirred at 25 °C for 17 h. The solvent was removed *in vacuo*, and the residue was purified by flash chromatography (silica gel, $CHCl_3$/MeOH, 7 : 1, followed by 4 : 1) to give RMNPA (**2a**, 808 mg, 73%), having spectral data in accord with those reported previously,[11a)] and **5** (277 mg, 25%). Physical data of **5**: mp >256 °C (dec.). ^{1}H-NMR (400 MHz, CD_3OD) δ: 8.06, 8.05 (each s, each 1H, H-2, 8), 5.89 (m, 1H, H-5′), 5.54 (m, 1H, H-1′), 4.67 (d, 1H, J=5.6 Hz, H-3′), 4.48 (br q, 1H, J=6.6 Hz, H-6′), 4.34 (dd, 1H, H-2′, J=5.6, 3.9 Hz), 1.42 (d, 3H, J=6.6 Hz, 6′-C-Me). *Anal.* Calcd for $C_{12}H_{14}N_4O_4 \cdot 1/3\ H_2O$: C, 50.70; H, 5.20; N, 19.71. Found: C, 50.85; H, 5.24; N, 19.85.

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14) Although H-2 had a $\Delta\delta$ value of $+0.001$ ppm, the value was very small and may be an observational error. The small $\Delta\delta$ value of H-2 suggests that these MTPA esters would be in an *anti*-conformation around the glycosyl linkage, because $\Delta\delta$ values are proportional to the distance between the protons and the MTPA moiety (ref. 13).
15) When the enzymatic reaction was done at 35 °C, considerable deamination of RMNPA was observed.