Available online at www.sciencedirect.com
SCIENCE DIRECT®
Tetrahedron: Asymmetry
Tetrahedron: *Asymmetry* 15 (2004) 283–287

First synthesis of a dihydroorotidine analogue via a diastereoselective [2+2] photocycloaddition

Attila Agócs,[a] Gyula Batta,[a] József Jekő[b] and Pál Herczegh[a,*]

[a]*Research Group for Antibiotics of the Hungarian Academy of Sciences and Department of Pharmaceutical Chemistry, University of Debrecen, PO Box 70, H-4010 Debrecen, Hungary*
[b]*ICN Hungary, Tiszavasvári, H-4440, Hungary*

Received 30 September 2003; accepted 18 November 2003

Dedicated to Professor Sándor Antus, on the occasion of his 60th birthday

Abstract—The first synthesis of a dihydroorotidine analogue via [2+2] photocycloaddition is described. The product is a potential inhibitor of the orotidine-5′-phosphate decarboxylase enzyme.

1. Introduction

One of the key intermediates of the biosynthesis of pyrimidine nucleotides is orotidine-5′-phosphate **1**.[1] With the aid of appropriate orotidine analogues, inhibition of the two enzymes, orotate-phosphoribosyltransferase and orotidin-5′-phosphate decarboxylase, involved in the direct construction and decarboxylation, respectively, of **1** can be accomplished. Such inhibitors may possess antibacterial and antiviral properties, by intervention into the life-cycle of the pathogenics. *C*-Glycosylphosphonates proved to be inhibitors of orotate-phosphoribosyltransferase,[2] while 6-azauridine derivatives have been shown to inhibit orotidin-5′-phosphate-decarboxylase, and the latter compounds have also shown up with anti RNA-viral activity.[3]

2. Results and discussion

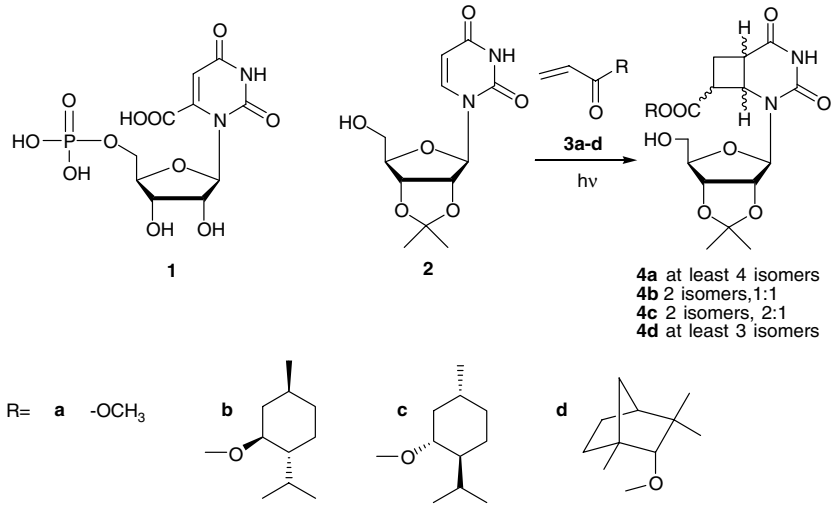
The aim of the present work was the synthesis of the cyclohomologs of dihydroorotidine by means of the simple photochemical [2+2] cycloaddition reaction of the double bond of uridine. Therefore, a solution of 2′,3′-*O*-isopropylideneuridine[4] **2** and various acrylate esters was irradiated in a Pyrex reactor with a medium-pressure mercury lamp. On the basis of the results of Swenton and co-workers[5] with the analogous reactions of related uracyl derivatives, the expected regioselectivity of the cycloaddition reaction suggested the formation of a regioisomer mimicking the C-6 carboxyl group of the orotate. Since three new stereogenic centres are generated in the reaction, the formation of eight possible stereoisomers was expected. The stereoselectivity induced by the ribofuranosyl ring cannot be strong, since rotation around the N_1–C_1' glycosidic bond is allowed.

Indeed, when the reaction was carried out with methyl acrylate **3a**, a complex mixture containing four isomers **4a** was obtained. For exploiting double chiral induction, chiral acrylates were also used for the cycloaddition. The cycloaddition of (+)-menthyl acrylate **3b** furnished a 1:1 mixture of two isomers **4b**, whereas applying of (−)-menthyl acrylate **3c** two isomers **4c** were formed in a ca. 1:1 ratio according to HPLC analysis of the reaction mixtures. The reaction of (1*R*)-fenchyl acrylate **3d** proceeded with low stereoselectivity and three isomers **4d** were produced. The number of isomers for **4a** and **4d** was estimated on the basis of methyl singlets of isopropylidene grouping. The overall yield of these reactions is low, since formation of uridine derivatives by photodimerization[6] is a concurrent process (Scheme 1).

The intramolecular cycloaddition reactions usually possess better stereoselection than those of the intramolecular processes, therefore the 5′-*O*-acrylate **5** of **2** was also prepared. Since the acrylic acid/DCC reagent

* Corresponding author. Tel.: +36-52-152-900/2463; fax: +36-52-512-914; e-mail: herczeghp@tigris.klte.hu

0957-4166/$ - see front matter © 2003 Elsevier Ltd. All rights reserved.
doi:10.1016/j.tetasy.2003.11.019



Scheme 1.

system, usually employed for acroylation, did not work sufficiently well for the esterification of **2**, the mixed-anhydride procedure (isobutyl chloroformate, acrylic acid) and the hydroxysuccinimide active ester method were applied with good results to give **5**.

Irradiation of **5** led to the formation of a single cycloadduct isomer **6** in 36% yield probably because of concurrent photodimerization and polymerization of **5**.

Determination of the configuration of the three new stereocentres in **6** was accomplished by NOESY measurements:[7] H-5 and H-6 are in NOE interaction with the 'axial' H-8 protons, while the 'equatorial' H-8 gives positive NOE with H-7. Thus, H-5 and H-6 are *cis* (which is more favoured than the *trans*), and *anti* to H-7. There is also an NOE interaction between the H-2′ of the ribose moiety and H-6. Molecular mechanics calculations (HyperChem MM+) showed that *only* H-6 and H-2′ can be close enough (2.36 Å, as estimated by this software), and this is valid only in the configurational arrangement shown in Figure 1 (5*S* and 6*S*). In the case of the (5*R*,6*R*) absolute configuration this distance should be 5–6 Å, which precludes NOE interaction between the two protons.

Opening of the lactone ring brought unexpected difficulties: the cycloadduct **6** decomposed during alkaline

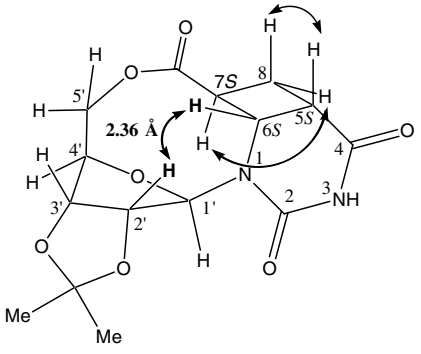
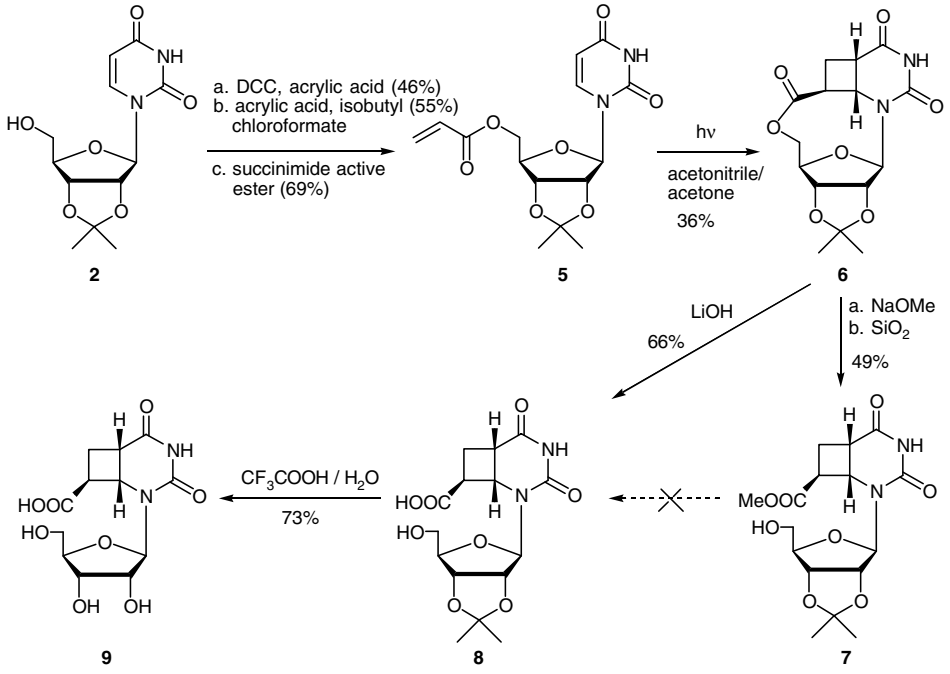


Figure 1. Conformation of cycloadduct **6**.

hydrolysis with NaOH, and Zemplén transesterification[8] gave the ester **7** only in 50% yield. The lactone **6** can also be transformed—but only partially in this case—to ester **7** with silica gel and methanol. Removal of the methyl ester to obtain **8** failed upon alkaline hydrolysis using lithium iodide[9] and boron tribromide.[10] Further attempts for the direct hydrolysis of **6** using methoxymagnesium bromide,[11] titanium tetraisopropoxide,[12] or butylstannic acid[13] were also unsuccessful. Finally, LiOH in methanol/water[14] proved to be the method of choice, and the resulting free acid **8** was deisopropylidenated with trifluoracetic acid to furnish the dihydroorothidine analogue **9** (Scheme 2).

3. Experimental

The organic extracts were dried over magnesium sulfate and the solutions were concentrated at 35–40 °C (bath) at ca. 17 mmHg. For TLC precoated aluminium-backed plates (silica gel 60 F_{254}, Merck, layer thickness: 0.2 mmol) were used. Compounds were visualized by charring with 5% sulfuric acid in ethanol or spraying with 7% ammonium molibdate in 5% sulfuric acid and heating. Column chromatography: Merck silica gel 60 (0.062–0.200 mmol). Specific rotations were measured on a Perkin–Elmer 141 MC polarimeter. The ^{1}H and ^{13}C NMR spectra were recorded on Brucker WP 200 SY (for all compounds except **6**) and Brucker DRX 500 (for compound **6**) instruments in $CDCl_3$ with TMS as the internal standard. Plasmaspray (PSP) mass spectra were recorded on a VG TRIO-2 instrument connected with a Waters 501 HPLC pump in an isocratic mode; samples were dissolved in a 1:1 0.1 M ammonium acetate buffer/methanol mixture and injected into the same solvent system at a flow rate of 1 mL/min; PSP tip interface temperature 210 °C. For the photochemical reactions a cooled medium-pressure (250 W) mercury lamp was used in a 130 mL reactor from Pyrex. Preceeding the reactions argon or nitrogen were bubbled through the solution (10 min) for the purpose of deoxygenation.



Scheme 2.

HPLC of diastereomeric mixtures was performed with a Waters 600 E pump using gradient elution (water–acetonitrile mixture) on a C_{18} column.

3.1. 1-(2′,3′-*O*-Isopropylidene-β-D-ribofuranosyl)-2,4-dioxo-1,3-diaza-bicyclo[4.2.0]-octane-7-carboxylic acid (+)-methyl ester 4a

Compound **2** (0.2 g, 0.7 mmol) and methyl acrylate (1 mL) was dissolved in acetone (50 mL) and irradiated for 8 h. After evaporation the residue was purified by column chromatography (hexane–acetone 7:3) to give a syrupy mixture of diastereomers. *m/z* 371 (M+1, PSP). ^{1}H NMR: δ (ppm) = 1.5 and 1.6 (series of singlets, 6H, isopropylidene), 2.1–3.4 (m, 4H, H-5, H-7, H-8), 2.1–3.4 (multiplets, 4H, H-5′, H-4′, H-6), 7.95 (s, 1H, NH). Anal. Calcd for $C_{16}H_{22}N_2O_8$: C, 51.89; H, 5.99; N, 7.56. Found: C, 51.71; H, 5.78; N, 7.66.

3.2. 1-(2′,3′-*O*-Isopropylidene-β-D-ribofuranosyl)-2,4-dioxo-1,3-diaza-bicyclo[4.2.0]-octane-7-carboxylic acid (+)-menthyl ester 4b

Compound **2** (0.14 g, 0.5 mmol) and (+)-menthyl acrylate[15] **3b** (0.2 mL, 1 mmol) were dissolved in dry acetone (50 mL) and the mixture was irradiated for 1 h. It was then evaporated and the slightly apolar major product was isolated with column chromatography (hexane–acetone 7:3) to give **4b** (140 mg, 58%) as a white powder. *m/z* 495 (M+H$^+$, PSP). ^{1}H NMR: δ (ppm) = 0.90 (15H, m, –CH_2– and –CH_3), 1.7 (11H, m, isoprop., menthyl –CH–, H-7), 3.35 (1H, m, menthyl –OCH–), 3.75 and 4.15 (2H, 2m, H-5, H-6), 4.4–5.2 (5H, m, H-2′, H-3′, H-4′, H-5′), 5.7 (1H, m, H-1′), 7.8 (1H, d, NH). Anal. Calcd for $C_{25}H_{38}N_2O_8$: C, 60.71; H, 7.74; N, 5.66. Found: C, 60.90; H, 7.67; N, 5.70.

3.3. 1-(2′,3′-*O*-Isopropylidene-β-D-ribofuranosyl)-2,4-dioxo-1,3-diaza-bicyclo[4.2.0]-octane-7-carboxylic acid (−)-menthyl ester 4c

With the same methodology used for **4b**, the reaction of **2** with (−)-menthyl acrylate[16] **3c** gave **4c** (130 mg, 54%) as a white powder. *m/z* 495 (M+H$^+$, PSP). ^{1}H NMR: δ (ppm) = 0.90 (15H, m, –CH_2– and –CH_3), 1.7 (11H, m, isoprop., menthyl –CH–, H-7), 3.3 (1H, m, menthyl –OCH–), 3.75 and 4.15 (2H, 2m, H-5, H-6), 4.45 and 5.0 (5H, 2m, H-2′, H-3′, H-4′, H-5′), 5.75 (1H, m, H-1′), 7.8 (1H, d, NH). Anal. Calcd for $C_{25}H_{38}N_2O_8$: C, 60.71; H, 7.74; N, 5.66. Found: C, 60.82; H, 7.79; N, 5.61.

3.4. (1*R*)-(+)-*endo*-Fenchyl acrylate 3d

(1*R*)-*endo*-Fenchol (3.08 g, 20 mmol) was dissolved in dry dichloromethane (100 mL) and triethylamine (4.2 mL, 30 mmol) and acryloyl chloride (2.05 mL, 25 mmol) was added at 0 °C. After 1 h the mixture was extracted with satd $NaHCO_3$, dried (Na_2SO_4) and purified by chromatography (hexane–ethyl acetate 8:2) obtaining 2.9 g (70%) of **3d** as a syrup. *m/z* 209 (M+1, PSP). $[\alpha]_D^{23} = +44.9$ (*c* 1.0, CH_2Cl_2).

3.5. 1-(2′,3′-*O*-Isopropylidene-β-D-ribofuranosyl)-2,4-dioxo-1,3-diaza-bicyclo[4.2.0]-octane-7-carboxylic acid (1R)-*endo*-fenchyl ester 4d

Compounds **2** (200 mg, 0.7 mmol) and **3d** (280 mg, 1.5 mmol) was dissolved in acetone (150 mL) and

irradiate for 4 h. The diastereomeric mixture **4d** (195 mg, 60%) was obtained after column chromatography (hexane–acetone 7:3). *m/z* 477 (M + 1, PSP).). ^{1}H NMR: δ (ppm) = 1.3 and 1.6 (series of singlets, 3 × 3H, isoprop.), 2.45 (m, 2H, H-5 and H-7), 3.76 (m, 2H, H-5). Anal. Calcd for $C_{25}H_{36}N_2O_7$: C, 63.01; H, 7.55; N, 5.88. Found: C, 62.88; H, 7.41; N, 5.81.

3.6. 5′-*O*-Acryloyl-2′,3′-*O*-isopropylidene-uridine 5

3.6.1. Method A (DCC). Compound **2** (2 g, 7 mmol) was dissolved in dry pyridine (25 mL) and then dicyclohexyl carbodiimide (2.87 g, 14 mmol), acrylic acid (0.98 mL, 14 mmol) and *N*,*N*-dimethylaminopyridine (50 mg) were added and the mixture was stirred overnight. Dicyclohexyl carbamide was filtered off, and the filtrate was evaporated, dissolved in dichloromethane (150 mL) and washed with 10% $NaHSO_4$ solution (2 × 70 mL) and satd $NaHCO_3$ (100 mL). After drying and evaporation the crude product was purified by column chromatography (hexane–acetone 6:4) to give 1.1 g (46%) yellowish solid.

3.6.2. Method B (mixed anhydride). To a solution of acrylic acid (0.75 mL, 10.5 mmol) and triethylamine (1.8 mL, 11 mmol) in dry dichloromethane (100 mL) isobutyl chloroformate (1.35 mL, 10.5 mmol) was added at 0 °C and the solution was kept at this temperature for 3–4 h. 2′,3′-*O*-Isopropylideneuridine **2** (1 g, 3.5 mmol) was dissolved in this mixture and kept under 0 °C overnight. The reaction mixture was washed with satd $NaHCO_3$ (100 mL), dried, evaporated and chromatographed to give **5** (0.65 g, 55%) as a yellow syrup.

3.6.3. Method C (succinimide). 2′,3′-*O*-isopropylideneuridine **2** (0.57 g, 2 mmol) was dissolved in dry dichloromethane and *N*-acryloylsuccinimide (0.42 g, 2.5 mmol) and *N*,*N*-dimethylaminopyridine (30 mg) were added. After 24 h the active ester (0.17 g, 1 mmol) was added again, and the solution was stirred at room temperature for additional 3 h and extracted with satd $NaHCO_3$ (50 mL). After purification 0.47 g (69%) of **5** was obtained. *m/z* 339 (M+H$^+$, PSP), $[\alpha]_D^{23} = +5.1$ (*c* 0.45, CH_2Cl_2). ^{1}H NMR: δ (ppm) = 1.3 and 1.65 (6H, 2s, isoprop.), 4.4 (3H, m, H-4′, H-5′), 4.8–5.0 (2H, m, H-2′, H-3′), 5.65 (2H, m, H-1′, H-6), 5.9 (d, 1H, =CH$_2$), 6.15 (dd, 1H, –CH=, acryloyl), 6.45 (1H, d, =CH$_2$), 7.3 (1H, d, H-5), 8.55 (1H, s, NH). Anal. Calcd for $C_{15}H_{18}N_2O_7$: C, 53.25; H, 5.36; N, 8.28. Found: C, 53.46; H, 5.23; N, 8.22.

3.7. (5*S*,6*S*,7*S*)-1-(2′,3′-*O*-Isopropylidene-β-D-ribofuranosyl)-2,4-dioxo-1,3-diaza-bicyclo[4.2.0]-octane-7-carboxylic acid-5′-lactone 6

Compound **5** (200 mg, 0.59 mmol) was dissolved in a 9:1 mixture of dry acetonitrile and acetone (150 mL) and irradiated for 6 h. TLC showed a polar UV inactive product which was isolated with column chromatography (hexane–acetone 6:4). Adduct **6** was obtained as a white powder (72 mg, 36%), mp 250–270 °C (dec), *m/z* 339 (M+H$^+$, PSP), $[\alpha]_D^{23} = +40.6$ (*c* 0.48, CH_2Cl_2). ^{1}H NMR (500 MHz): δ (ppm) = 1.35 and 1.65 (6H, 2s, isoprop.), 2.4 (1H, m, H-8a), 2.65 (1H, m, H-8b), 3.45 (1H, m, H-7, $J_{5,7} = 9.0$ Hz), 3.6 (1H, m, H-5, $J_{5,6} = 8.5$ Hz), 3.85 (1H, d, H-5′a, $J_{5'a,5'b} = 11.6$ Hz), 4.35 (1H, d, H-4′, $J_{4',5'b} = 2.5$ Hz), 4.65 (1H, t, H-6), 4.78 (1H, d, H-3′), 4.95 (1H, dd, H-5′b), 5.15 (1H, t, H-2′, $J_{1',2'} = 4.3$ Hz, $J_{2',3'} = 5.0$ Hz), 6.1 (1H, d, H-1′), 7.7 (1H, s, NH). ^{13}C NMR: δ (ppm) = 24.5, 25.3 (isoprop.), 27.1 (C-8), 32.8 (C-7), 43.7 (C-5), 50.5 (C-6), 66.5 (C-5′), 78.8 (C-2′), 81.5 (C-4′), 84.2 (C-3′), 95.8 (C-1′), 113.8 (C-4° isoprop.), 151.9, 168.7, 168.9 (3C=O). Anal. Calcd for $C_{15}H_{18}N_2O_7$: C, 53.25; H, 5.36; N, 8.28. Found: C, 53.35; H, 5.32; N, 8.36.

3.8. (5*S*,6*S*,7*S*)-1-(2′,3′-*O*-Isopropylidene-β-D-ribofuranosyl)-2,4-dioxo-1,3-diaza-bicyclo[4.2.0]-octane-7-carboxylic acid methyl ester 7

Compound **6** (92 mg, 0.27 mmol) was dissolved in dry methanol (10 mL) and a few drops of NaOMe solution (~2 M in methanol) was added and the mixture was kept overnight at room temperature. It was then evaporated and purified by column chromatography (hexane–acetone 6:4) to give 30 mg starting material **6** and the ester **7** as a syrup (45 mg, 49%). *m/z* 371 (M+H$^+$, PSP), $[\alpha]_D^{23} = -49.4$ (*c* 1.0, CH_2Cl_2). ^{1}H NMR: δ (ppm) = 1.35 and 1.65 (6H, 2s, isoprop.), 2.45 (2H, m, H-8a,b), 3.4 (2H, m, H-5, H-7), 3.75 (5H, m, –OMe, H-4′, H-5′a), 4.05 (1H, m, H-3′), 4.4 (1H, m, H-6), 4.7 (1H, t, H-2′, $J_{1',2'} = 4.1$ Hz, $J_{2',3'} = 5.3$ Hz), 4.85 (1H, m, H-5′b), 5.7 (1H, d, H-1′), 7.5 (1H, s, NH). ^{13}C NMR: δ (ppm) = 25.4, 25.7, 27.3, 36.8, 46.7, 49.8, 52.4 (OMe), 62.0, 77.6, 81.3, 83.8, 90.4, 114.9, 151.1, 171.0, 173.8. Anal. Calcd for $C_{16}H_{22}N_2O_8$: C, 51.89; H, 5.99; N, 7.56. Found: C, 51.97; H, 5.92; N, 7.54.

3.9. (5*S*,6*S*,7*S*)-1-(2′,3′-*O*-Isopropylidene-β-D-ribofuranosyl)-2,4-dioxo-1,3-diaza-bicyclo[4.2.0]-octane-7-carboxylic acid 8

The ester **7** (60 mg, 0.16 mmol) was dissolved in methanol (10 mL) and water (1 mL), lithium hydroxide was added and the mixture was stirred overnight. The alkaline solution was neutralized with a slightly acidic resin (*Lewatit CNP 80*), filtered and evaporated. Column chromatography with 8:2 dichloromethane–methanol resulted in the polar product **8** (42 mg, 66%) as a white powder, mp 224–228 °C. *m/z* 357 (M+H$^+$, PSP), $[\alpha]_D^{23} = -12.0$ (*c* 0.84, methanol). ^{1}H NMR (CD_3OD): δ (ppm) = 1.3 and 1.5 (6H, 2s, isoprop.), 2.45 (2H, m, H-8a,b), 3.25 (2H, m, H-5, H-7), 3.65 (1H, m, H-5′a), 3.8 (4H, m, H-3′, H-4′, H-5′b), 4.4 (1H, t, H-6, $J_{5,6} = J_{6,7} = 8.4$ Hz), 4.7 (1H, m, H-2′), 5.7 (1H, d, H-1′, $J_{1',2'} = 4.2$ Hz), 7.4 (1H, s, NH). ^{13}C NMR (CD_3OD): δ (ppm) = 25.4 and 27.6 (isoprop.), 27.2 (C-8), 38.0 (C-7), 51.4 and 51.2 (C-5, C-6), 63.0 (C-5′), 81.3, 83.2, 86.2 (C-2′, C-3′, C-4′), 90.4 (C-1′), 115.8 (C-isoprop.), 153.4, 174.0, 181.2 (3C=O). Anal. Calcd for $C_{15}H_{20}N_2O_8$: C, 50.56; H, 5.66; N, 7.86. Found: C, 50.65; H, 5.60; N, 7.81.

3.10. (5*S*,6*S*,7*S*)-1-β-D-Ribofuranosyl-2,4-dioxo-1,3-diaza-bicyclo[4.2.0]-octane-7-carboxylic acid 9

Compound **8** (17 mg, 0.05 mmol) was dissolved in trifluoracetic acid (3 mL) and water (0.3 mL) and kept at 50 °C for 3 h. The solution was evaporated and the rest of the acid was removed by the co-evaporation with dry toluene (2×10 mL). The residue was purified on a small column (dichloromethane–methanol 6:4), and freeze-drying afforded **9** (11 mg, 73%) as a white powder, mp 236–239 °C. *m*/*z* 317 ($M+H^+$), 334 ($M+NH_4^+$). $[\alpha]_D^{23} = -20.3$ (*c* 1.0, methanol). ^{1}H NMR (D_2O): δ (ppm) = 2.55 (2H, m, H-8a,b), 3.45 (2H, t, H-5, H-7), 3.63 (1H, m, H-5′a), 3.85 (2H, m, H-3′, H-4′), 4.0 (1H, m, H-5′b), 4.25 (1H, t, H-2′, $J_{1',2'} = 6.6$ Hz), 4.5 (1H, t, H-6, $J_{5,6} = J_{6,7} = 9.2$ Hz), 5.75 (1H, d, H-1′), 7.5 (1H, s, NH). ^{13}C NMR (D_2O): δ (ppm) = 26.0 (C-8), 37.0 (C-7), 47.2, 49.1 (C-5, C-6), 62.4 (C-5′), 70.6, 71.8, 84.2 (C-2′, C-3′, C-4′), 88.0 (C-1′), 154.4, 175.0, 180.1 (3C=O). Anal. Calcd for $C_{12}H_{16}N_2O_8$: C, 45.57; H, 5.10; N, 8.86. Found: C, 45.43; H, 5.15; N, 8.92.

Acknowledgements

The authors thank the Hungarian Scientific Research Fund for financial support (OTKA T 30138, 42512, 42567 and 36776).

References and notes

1. Stryer, L. *Biochemistry*; W. H. Freeman and Company, 1988; p 608.
2. McLard, R. W.; White, J. F. *Bioorg. Chem.* **1990**, *18*, 165–178.
3. Gabrielsen, B.; Kirsi, J. J.; Kwong, C. D.; Carter, D. A.; Krauth, C. A.; Hanna, L. K.; Huggins, J. W.; Monath, T. P.; Kefauver, D. F. *Antiviral Chem. Chemother.* **1994**, *5*, 209–220.
4. Townsend, L. B. In *Nucleic Acid Chemistry*; Wiley-Interscience, 1978, p 785.
5. Wexler, A. J.; Hyatt, A.; Raynolds, P. W.; Cottrell, C.; Swenton, J. S. *J. Am. Chem. Soc.* **1978**, 512–520.
6. Lamola, A. A. *Pure Appl. Chem.* **1973**, *34*, 281–303.
7. Macura, S.; Ernst, R. R. *Mol. Phys.* **1980**, *41*, 95–117.
8. Zemplén, G.; Pacsu, E. *Chem. Ber.* **1929**, *62*, 1613–1618.
9. Meinwald, J.; Putzig, D. E. *J. Org. Chem.* **1970**, *35*, 1891–1894.
10. Manchard, P. S. *J. Chem. Soc., Chem. Commun.* **1971**, 667–668.
11. Walba, D. M.; Przybyla, C. A.; Walker, C. B. *J. Am. Chem. Soc.* **1990**, *112*, 5624–5625.
12. Schnurrenberger, P.; Züger, M. F.; Seebach, D. *Helv. Chim. Acta* **1982**, *65*, 1197–1201.
13. Furlán, R. L. E.; Mata, E. G.; Mascaretti, O. E. *Tetrahedron Lett.* **1998**, *39*, 2257–2260.
14. Corey, E. J.; Székely, I.; Shiner, C. S. *Tetrahedron Lett.* **1977**, *18*, 3529–3534.
15. Farmer, R. F.; Hamer, J. *J. Org. Chem.* **1966**, *31*, 2418–2419.
16. Lee-Ruff, E.; Xi, F.; Qie, J. H. *J. Org. Chem.* **1996**, *61*, 1547–1550.