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Synthetic Studies of Potential Antimetabolites. XI.[1] Syntheses of β-D-Pentofuranosyl-5-methylcytosines[2]

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1-(β-D-Arabinofuranosyl)-5-methylcytosine (III) was prepared by amination and subsequent deblocking of 1-(2′,3′,5′-tri-O-benzyl-β-D-arabinofuranosyl)-4-methoxy-5-methyl-1*H*-pyrimidine-2-one which had been prepared from 2,4-dimethoxy-5-methylpyrimidine and 1-(2′,3′,5′-tri-O-benzyl-α-D-arabinofuranosyl)chloride. 1-(β-D-2′-Deoxy threopentofuranosyl)-5-methylcytosine (II) was prepared from 1-(β-D-3′,5′-O-isopropyl indene-2′-deoxythreopentofuranosyl)-5-methyluracil (VII) by four-step procedure (thiation, S-methylation, amination, and deblocking). As one of possible approaches to II from thymidine (IV), 1-(3′,5′-anhydro-2′-deoxy-β-D-threopentofuranosyl)-thymine (V) was attempted to convert to 1-(3′,5′-anhydro-2′-deoxythreopentofuranosyl)-4-chloro-2(1*H*)-pyrimidine-2-one. However, treatment of the latter with DMF-$SOCl_2$ (Vilsmeier-Haack reagent) afforded 1-(3′,5′-dideoxy-3′,5′-dichloro-2′-deoxythreo pentofruanosyl)-thymine (XIV) in good yield.

Investigations of pyrimidine derivatives as potential antimetabolites which might inhibit *in vivo* biosynthesis of DNA or RNA have led to development and clinical study of such compounds as 5-fluoro-2′-deoxyuridine[4] and 1-β-D-arabino furanosylcytosine (I).[5] The latter analog is of special importance because of its selective antiviral activity *vs.* DNA such as helpes and vaccinia virus.[5a].

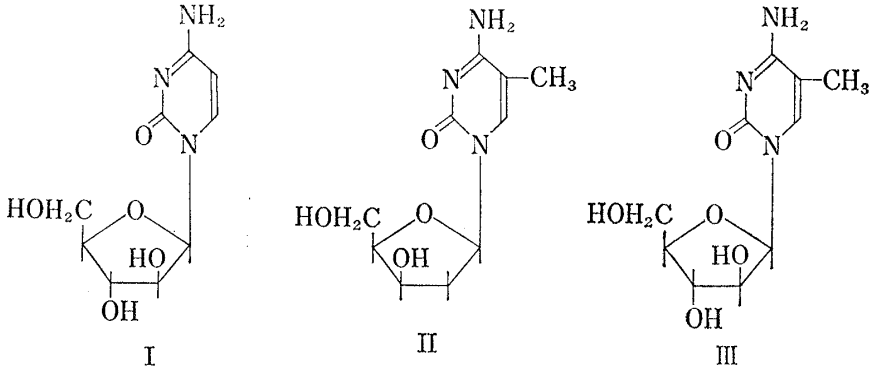


Chart 1

1) Paper X: Y. Mizuno, M. Ikehara, K. Watanabe, and S. Suzaki *J. Org. Chem.*, **28**, 3331 (1963).
2) Presented at the 27th Hokkaido Local Meeting of the Pharmaceutical Society of Japan (Feburary, 1966).
3) Location: *Sapporo, Hokkaido.*
4) C. Heiderberger, N.K. Chaudhuri, P. Dannenberg, D. Moren, L. Griesbach, R. Dushinsky, R.J. Schnitzer, E. Eleven, and J. Scheiner, *Nature*, **179**, 663 (1957).
5) *a*) E.R. Walwick, W.K. Roberts, and C.A. Dekker, *Proc. Chem. Soc.*, **1959**, 84; *b*) L.I. Pizer and S.S. Cohen, *J. Biol. Chem.*, **235**, 2387 (1960); *c*) L. Slechta, *Fed. Proc.*, **20**, 357 (1961); *d*) J.S. Evans, E.A. Musser, G.D. Mengel, and K.R. Forbald, *Proc. Soc. Exptl. Biol. Med.*, **106**, 350 (1961); *e*) M.Y. Chu and G.A. Fischer, *Biochem. Pharmacol.*, **11**, 423 (1962); *f*) G.E. Underwood, *Proc. Soc. Exptl. Biol. Med.*, **111**, 666 (1962); *g*) H.E. Renis and H.G. Johnson: *Bact. Proc.*, **1962**, 140; *h*) J.S. Evans, E.A. Musser, L. Bostwick, and G.D. Mengel, *Cancer Research*, **24**, 1285 (1964); *i*) M.Y. Chu and G.A. Fischer, *Biochem. Pharm.*, **14**, 333 (1965).

Based on the reported observations[5] on the analogs of cytidine, we designed the synthesis of 1-(β-D-2′-deoxythreopentofuranosyl)-5-methylcytosine (II) and 1-(β-D-arabinofuranosyl)-5-methylcytosine (III) as potential antimetabolites.

Several approaches to II may be anticipated: nucleoside (II) may be prepared either by a total synthesis (Hilbert-Johnson[6] or Davoll-Lowy-Fox's method[7]) or by conversion of thymidine (IV) to II. It was expected that the latter approach will have some advantages over the former, because Hilbert-Johnson or Davoll-Lowy-Fox method involving 2-deoxysugars may give an anomeric mixture of nucleosides.

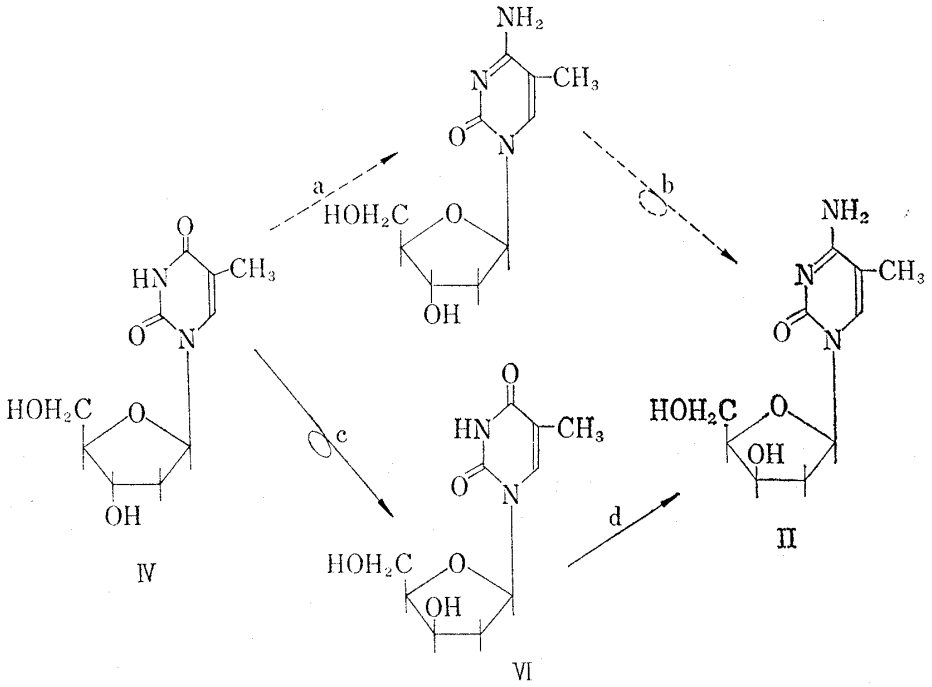
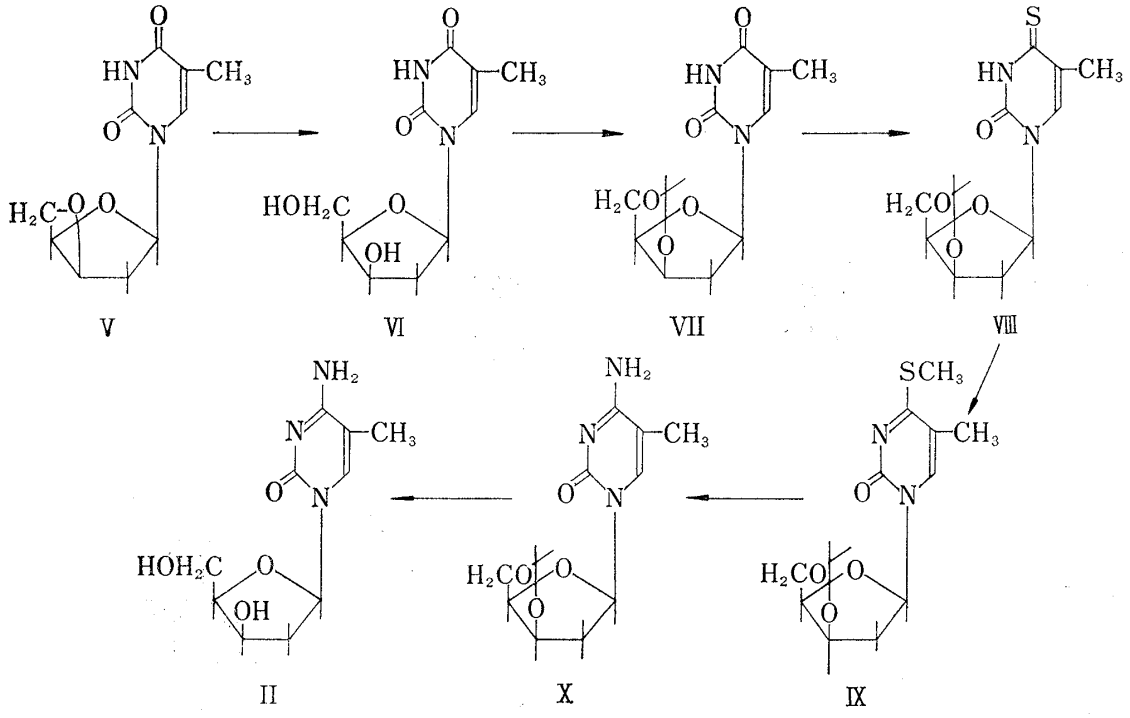


Chart 2

In the latter, conversion of IV to II may be achieved by either of two alternative routes (route a—b and route c—d). Since 3′-α-hydroxyl group in thymidine may be more easily inversed into 3′-β-hydroxyl than in 5-methyl-2′-deoxycytidine, approach (c—d) will have some advantages over another. Since 1-(3′,5′-O-isopropylidene-β-D-2′-deoxythreopentofuranosyl) thymine (VII) has already been prepared by Horwitz and coworkers[8] and thiation reaction originally developed by Fox and coworkers[9] has been found to be successfully applied to O-isopropylidene-blocked nucleosides,[10] a design for the synthesis of II was worked out as shown in Flow Sheet I.

Compound (VI) was prepared essentially according to the reported method,[8] with some modifications: thus opening of the oxetane ring of V with 98% formic acid (at room temperature) afforded crude VI which in trun was without purification converted into the crystalline 3′,5′-O-isopropylidene derivative (VII) in 52% yield. Thiation of VII with phosphorous pentasulfide in refluxing pyridine[9,10] afforded a 50% yield of the corresponding crude thiated product (VIII) which was converted into the 4-methylthio-derivative (IX) in 46% yield. Treatment of IX with methanolic ammonia in a sealed tube gave X in 80% yield (mp 233—

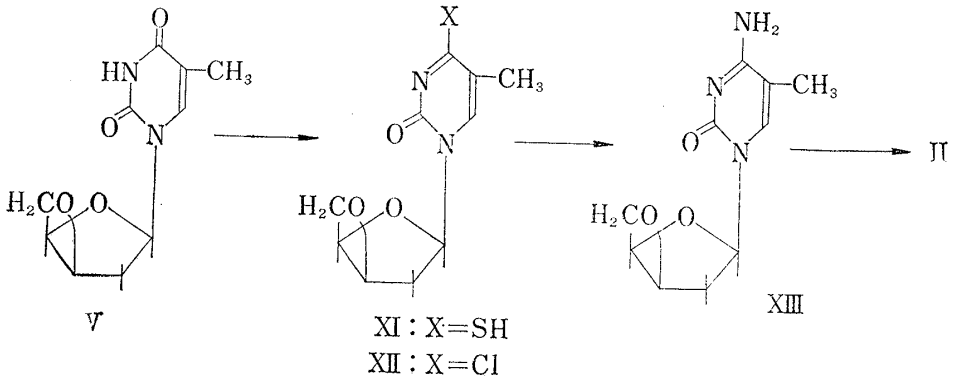
6) G.E. Hilbert and J.B. Johnson, *Am. J. Chem.*, **52**, 4489 (1936).
7) J.J. Fox, N. Yung, J.D. Davoll, and G.B. Brown, *J. Am. Chem. Soc.*, **78**, 2117 (1956).
8) J.P. Horwitz, J. Chua, J.P. Urbanski, and M. Noel, *J. Org. Chem.*, **28**, 942 (1962).
9) J.J. Fox, D.V. Praag, I. Wempen, I.L. Doer, L. Chenong, J.E. Knoll M.L. Edinoff, A. Bendich, and G.B. Brown, *J. Am. Chem. Soc.*, **81**, 178 (1959).
10) M. Ikehara, T. Ueda, and K. Ikeda, *Chem. Pharm. Bull.* (Tokyo), **10**, 767 (1962).



Flow Sheet I

236°). Subsequent de-blocking of isopropylidene group with 98% formic acid, followed by chromatographic purification afforded II. Compound (II) melted at 161—163° and possessed its absorption maximum at 288 mμ (at pH 2.0) or 278 mμ (at pH 7.5). The overall yield of II was *ca.* 3%, based on thymidine (IV).

Some attempts to reduce the preparative steps to raise the overall yield of II have been made. Route *via* 1-(3′,5′-anhydro-2′-deoxy-β-D-threopentofuranosly)-4-thiothymine (XII) was examined. Thiation of V actually did take place because the UV maximum has shifted on thiation from 265 mμ (of V) to 330 mμ (of XI). However, thin-layer chromatography (TLC) of the products has revealed the presence of several UV-absorbing materials, presumably coming from fission of the oxetane ring and subsequent thiation of resulting hydroxyl groups. Thus, the thiation of V afforded an intractable mixture.



XI : X=SH
XII : X=Cl

Chart 3

Next, we turned our attention to Vilsmeier-Haack reaction.[11,12] Treatment of V with a mixture of thionylchloride and dimethylformamide afforded a crystalline chlorinous product

11) A. Vilsmeier and A. Haack, *Ber.*, **60B**, 119 (1927).
12) *a*) M. Ikehara, H. Uno, and F. Ishikawa, *Chem. Pharm. Bull.* (Tokyo), **12**, 267 (1964); *b*) M. Ikehara and H. Uno, *ibid.* **13**, 221 (1965).

(mp 150—151°, λ_{max} 266 mμ) in good yield. However, it turned out that this was not actually the expected 4-chloro-derivative (XII), but 1-(3′,5′-dideoxy-3′,5′-dichloro-β-D-2′-deoxy-erythropentofuranosyl)-thymine (XIV). The structure assignment rests upon spectral (UV, IR, and NMR) properties and combustion values. The structure was confirmed by comparison with an authentic sample of XIV, prepared from 3′,5′-O-dimesylthymidine by an unambiguous route.[13] Compound (XIV) could be converted to 1-(2,3′-anhydro-2′,5′-dideoxy-5′-chloro-β-D-threopentofuranosyl) thymine (XV), indicating that 3′-chlorine atom of XIV is α-(or down)-configuration.

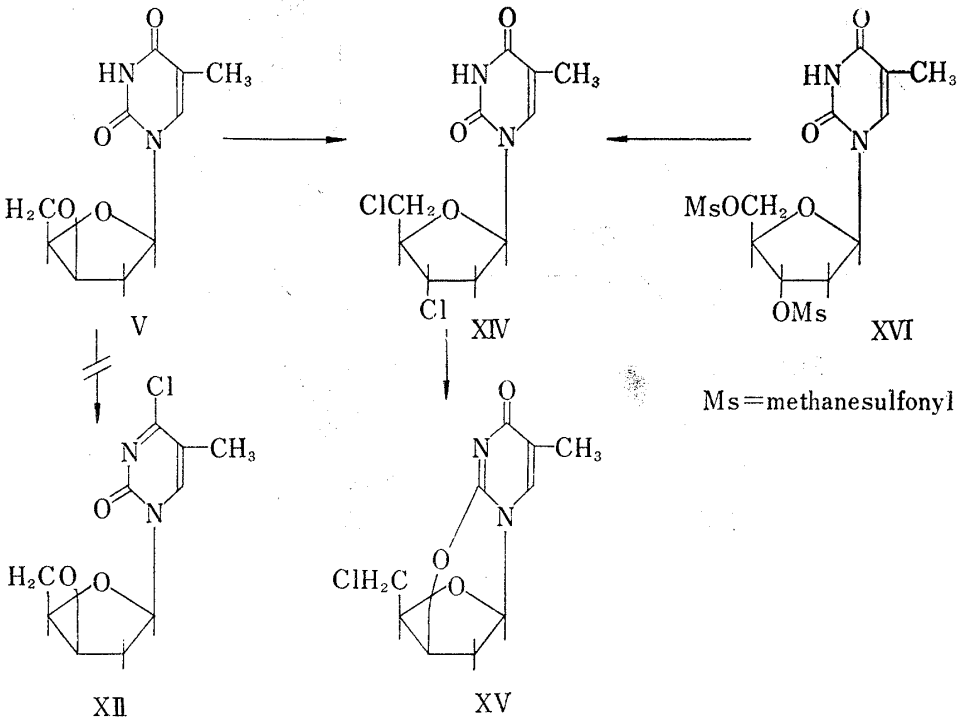
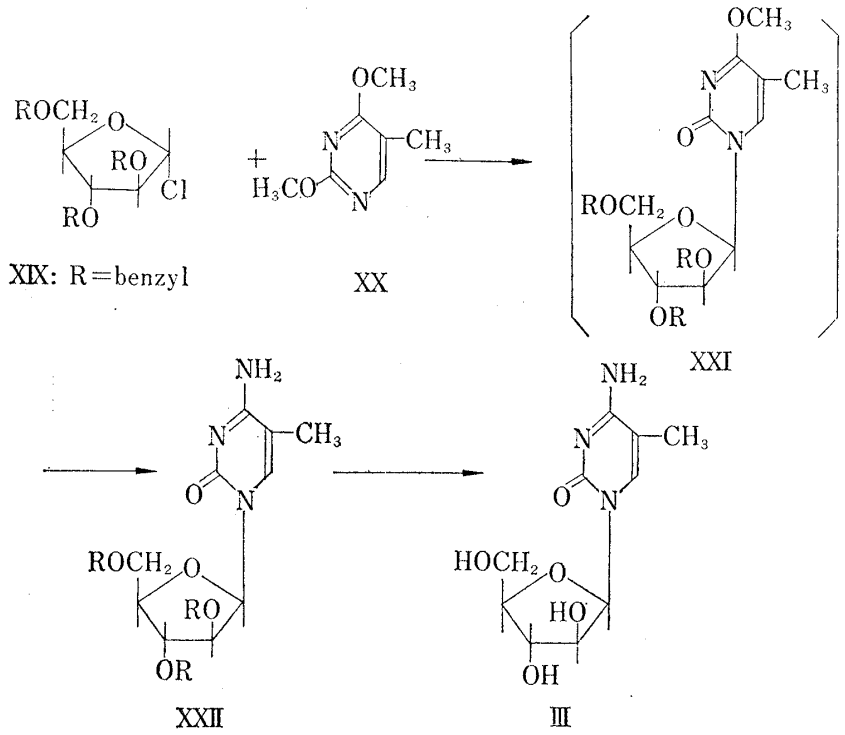


Chart 4

For the preparation of 1-(β-D-arabinofuranosyl)-5-methylcytosine (III), the so-called Hilbert-Johnson synthesis[6] was adapted by use of 2,3,5-tri-O-benzyl-α-D-arabinofuranosyl chloride (XIX)[14] and 2,4-dimethoxy-5-methylpyrimidine (XX)[15] as key intermediates. The reaction was carried out as described by Shen and coworkers,[16] for the synthesis of several pyrimidine spongonucleosides. 1-(2′,3′,5′-tri-O-Benzyl-β-D-arabinofuranosyl)-4-methoxy-5-methyl-2(1*H*)-pyrimidinone[17] was isolated as a glass. Because of the lack of crystallinity of XXI, this was handled as partially purified intermediate when used for the subsequent amination. Upon treatment with methanolic ammonia at 110—120°, amorphous product whose absorption maximum appeared at 286 mμ (at pH 1[18]) was isolated from the amination mixture in good yield. The benzyl group was removed by a reported procedure.[19] Completely pure sample (III, mp 153.5°, $[\alpha]_D^{15}$ +136°) was obtained by crystallization from ethanol in 24% overall yield (based on 1-O-*p*-nitrobenzoyl-2,3,5-tri-O-benzyl-β-D-arabinofuranoside).

13) A.M. Michelson and A.R. Todd, *J. Chem. Soc.*, **1955**, 816.
14) 2,3,5-tri-O-Benzyl-β-D-arabinofuranosyl chloride was originally prepared by C.P.J. Glaudemans and H.G. Fletcher (*J. Org. Chem.*, **28**, 3004 (1963)), and was successfully used for the synthesis of the spongopyrimidine nucleosides by Shen and coworkers.[16]
15) W. Schmidt-Nichols and T.B. Johnson, *Am. J. Chem.*, **52**, 4511 (1930).
16) T.Y. Shen, H.M. Lewis, and W.V. Ruyle, *J. Org. Chem.*, **30**, 835 (1965).
17) F. Keller and A.R. Tyrrill, *J. Org. Chem.*, **31**, 1289 (1966).
18) This peak in acidic media is typical of 1-alkylsubstituted-5-methylcytosines.
19) E.J. Reiwt, V.J. Bartuska, and L. Goodman, *J. Org. Chem.*, **29**, 3725 (1964).

Low yield of III was partially due to the concomitant reduction of 5,6-double bond in pyrimidine ring on debenzylation with sodium amide in liquid ammonia.



Flow Sheet II

Experimental[20]

1-(3′,5′-Anhydro-2′-deoxy-β-D-threopentofuranosyl) Thymine (V)——V was prepared according to a reported method[8] with slight modifications. To a suspension of 20 g of 3′,5′-di-O-mesylthymidine (XVI)[13] in 2 liters of water was added 252 ml of 1N NaOH solution. A resulting solution was refluxed for 2 hr. Initially yellow-colored solution turned colorless during heating. The cooled solution was neutralized with 1N sulfuric acid, concentrated to dryness *in vacuo*. The residue was extracted with three 100 ml portions of $CHCl_3$. The solvent was removed to leave 17 g of residue. The residue was crystallized from hot water or ethanol (rather than EtOAc[8]); yield, 11.5 g (86%); mp 193—194° (reported mp 193—195.5°).[8]

1-(β-D-2′-Deoxy-threopentofuranosyl) Thymine (VI)——A solution of 3.44 g of V in 90 ml of 98% formic acid was kept at 25° (in an incubator) for 64 hr. Paper chromatograhy in BuOH–H_2O (86:14 v/v) of the reaction mixture showed only the presence of a single spot (*Rf* 0.52). The solvent was removed *in vacuo*. To the residue was added 15 ml of MeOH. The solvent was removed. The process was repeated with 15 ml portions of MeOH until the residue was free of formic acid. The final residue was dissolved in 50 ml of a mixture of MeOH and CH_3COCH_3 (1:1). The solution was dried over magnesium sulfate overnight. The salt was filtered off, washed with CH_3COCH_3. The combined filtrate and washings were concentrated to dryness to afford 4.0 g of crude 1-(β-D-2′-deoxy-threopentofuranosyl) thymine. Without further purification, the crude nucleoside was subjected to acetonization.

1-(3′,5′-O-Isopropylidene-β-D-2′-deoxythreopentofuranosyl) Thymine (VII)——To a suspension of 4.0 g of crude VI in 100 ml of CH_3COCH_3 was added successively 2.6 g of 2,2-dimethoxypropane and 3.6 g of *p*-toluenesulfonic acid (monohydrate). The solution was kept at 25° overnight. The solution was then poured with stirring into a solution of 2.5 g of $NaHCO_3$ in 80 ml of water. After making sure that the solution was slightly alkaline, the solution was concentrated to dryness *in vacuo*. The residue was extracted with

20) All melting poinsts are corrected. Ultraviolet spectra were recorded with a Hitachi recording spectrophotometer. Except where noted, removal of the solvent was performed *in vacuo*. Paper chromatography was carried out by use of the ascending technique. Infrared spectra were determined using a Koken Model DS-301 infrared recording spectrophotometer. NMR spectra were taken on A Varian A-60 spectrometer.

three 50 ml portions of $CHCl_3$. Removal of the solvent left 3.22 g of residue. Crystallization from MeOH gave pure VII, yield 2.23 g (52% overall yield from V). Mp and mixed mp 164—165°.[8]

1-(3′,5′-O-Isopropyildene-β-D-2′-deoxythreopentofuranosyl)-4-thiothymine (VIII)——A solution of 2 g of VII in 100 ml of pyridine was added 4.6 g of P_4S_{10} and 1.14 ml of H_2O. The solution was stirred for 6 hr at refluxing temperature. The solution was decanted from a slurry while hot. The slurry was washed with a small volume of hot pyridine. The combined pyridine solution was concentrated to dryness *in vacuo*. Residual pyridine was removed by repeated co-distillation with MeOH to afford fluffy substance; yield, 1.1 g (50%). UV: λ_{max}^{MeOH} mμ: 336,266, *Rf* in BuOH–H_2O (86:14): 0.71 (a single spot). Crude VIII was used for the subsequent step without further purification.

1-(3′,5′-O-Isopropylidene-β-D-2′-deoxythreopentofuranosyl)-4-methylthio-5-methyl-2(1*H*)pyrimidone (IX)——A solution of 1.2 g (3.8 mmole) of crude VIII in a mixture of 3.8 ml of 1N NaOH and 12 ml of 50% aq. MeOH, filtered to remove insoluble material. To the filtrate was added dropwise 5 ml of methanolic MeI (38 mmole) in 2 hr at room temperature. After making sure that the solution was alkaline, the solution was repeatedly extracted with 30 ml portions of $CHCl_3$. Paper chromatography of the $CHCl_3$ layer showed the presence of a single spot (*Rf* 0.81), whereas the aqueous layer contained only the starting material (VIII *Rf* 0.68) and discarded. The $CHCl_3$ solution was dried over $MgSO_4$. The filtrate was concentrated to dryness; yield 0.58 g (46.4%). For the analytical sample crystallization from EtOAc afforded 385 mg of pure IX, mp 125—126°. UV λ_{max}^{pH1} mμ: 309, UV $\lambda_{max}^{H_2O}$ mμ: 309. *Anal.* Calcd. for $C_{14}H_{20}O_4N_2S$: C, 53.85; H, 6.41; N, 8.97. Found: C, 53.72; H, 6.38; N, 8.80.

1-(3′,5′-O-Isopropylidene-β-D-2′-deoxythreopentofuransoyl)-5-methylcytosine (X)——In a pressure bomb a solution of 32 mg of IX in 5 ml of absolute MeOH was saturated with NH_3 at 0°. The solution was heated at 105—115° for 17 hr. The solvent was removed to leave a gum. Crystallization from EtOH afforded a pure sample of X; mp 233—236°, yield 23 mg (80%). UV $\lambda_{max}^{H_2O}$ mμ: 278; $\lambda_{min}^{H_2O}$ mμ: 254; λ_{max}^{pH2} mμ: 288; $\lambda_{min}^{H_2O}$ mμ: 245. *Anal.* Calcd. for $C_{13}H_{19}O_4N_3$: C, 55.51; H, 6.81; N, 14.91. Found: C, 55.49; H, 6.52; N, 14.78.

1-(β-D-2′-Deoxythreopentofuranosyl)-5-methylcytosine (II)——A solution of crude X (contaminated with equal amount of VII, 900 mg) in 50 ml of 98% HCOOH was kept at room temperature for 2 days. The solution was then concentrated to dryness. The residue was dissolved in 50 ml of EtOH and was again concentrated to dryness. The residue was dissolved in several ml of H_2O. The solution was applied to the top of column (1.5×30 cm) of Dowex 1 (×8, OH^- form). The column was washed with 0.5 liter of H_2O. The effluent was concentrated to dryness. The residue was crystallized from *n*-C_3H_7OH to afford 120 mg (*ca.* 31%) of II. Analytical sample was obtained by two recrystallizations from EtOH, mp 161.5—163°. UV $\lambda_{max}^{H_2O}$ mμ: 278; $\lambda_{max}^{0.1N\ HCl}$ mμ: 289. $[\alpha]_D^{19}$ +50 (*c*, 1.0, H_2O). *Aanl.* Calcd. for $C_{10}H_{15}O_4N_3 \cdot {}^1/_2H_2O$: C, 48.00; H, 6.40; N, 16.80. Found: C, 48.00; H, 6.48; N, 17.10.

1-(2′,3′,5′-Trideoxy-3′,5′-dichloro-β-D-erythropentofuranosyl)-thymine (XIV)——$SOCl_2$ (0.22 ml, 3.0 mmole) was dissolved in a solution of dry $CHCl_3$ (15 ml) and DMF (0.2 ml, 3.0 mmole). After, 10 min, 448 mg (2 mmole) of V was added to the resulting solution. The solution was refluxed for 3 hr with exclusion of atmospheric moisture. The solvent was removed to leave a gummy substance. The residue was added to ice and water. The mixture was treated with three 30 ml portions of $CHCl_3$. The $CHCl_3$ solution was washed with 5% $NaHCO_3$ solution and then with H_2O, and dried. The dried solution was concentrated to dryness. The residue was co-distilled with three 10 ml portions of EtOH. The residue was crystallized from EtOH. Needles, mp 150—151°, yield, 457 mg (82%). $[\alpha]_D^{15}$ 20° (*c*, 1.0 MeOH). UV λ_{max}^{MeOH} mμ: 265.5; λ_{min}^{MeOH}mμ: 235. The NMR spectra of XIV in chloroform solution exhibited singals characteristic of 1-alkyl-substituted thymine. *Anal.* Calcd. for $C_{10}H_{12}O_3N_2Cl_2$: C, 43.03; H, 4.33; N, 10.04; Cl, 25.40. Found: C, 42.97; H, 4.40; N, 9.89; Cl, 25.14.

Preparation of 2,3′-Anhydro-2′,5′-dideoxy-5′-chloro-β-D-threopentofuranosyl Thymine (XV) from XIV——To a solution of XIV (112 mg, 0.4 mmole) in 4 ml of DMF was added 0.8 ml of *t*-BuONa solution (prepared by dissolving 0.5 atom of sodium in 10 ml of *t*-BuOH). The solution was reflxed for 1 hr. The solvent was removed *in vacuo* . The residue was extracted with $CHCl_3$. Removal of the solvent left a crystalline residue; mp 219—221° (after recrystallization from $CHCl_3$); yield, 29.4 mg (30%). *Rf* in (*n*-BuOH–H_2O 86:16): 0.50. UV λ_{max}^{EtOH} mμ: 249, λ_{max}^{pH2} mμ: 256, 231; λ_{max}^{pH11} mμ: 249. *Anal.* Calcd. for $C_{10}H_{11}O_3N_2Cl$: C, 49.48; H, 4.57; N, 11.55. Found: C, 49.42; H, 4.41; N, 11.63.

Alternative Synthesis of XIV——Compound (XIV) was also prepared from 3′,5′-di-O-mesylthymidine (XVI) according to a reported method.[13] To a solution of XVI (1.24 g, 3 mmoles) in CH_3COCH_3 (15 ml) was added LiCl (507 mg, 17 mmoles). The solution was put in a pressure bomb and heated at 130—140° (bath temp.) for 12 hr. After cooling, the solvent was removed to leave a gummy substance. The gum was dissolved in $CHCl_3$. The $CHCl_3$ solution was well washed with H_2O, and dried over Na_2SO_4. The salt was filtered off. The filtrate was concentrated to dryness (985 mg). The residue was purified by preparative silica gel chromatography (solvent: cyclohexane–EtOAc 1:3 v/v). XIV was recovered from the fast travelling fraction, mp 150—151° (after recrystallization from $CHCl_3$); yield 500 mg (56.1%). The product had the same ultraviolet absorption properties with those of the sample of XIV described before. Mixed mp with the authentic sample did not show depression. *Anal.* Calcd. for $C_{10}H_{12}O_3N_2Cl_2$: C, 43.03; H, 4.33; N, 10.04. Found: C, 43.08; H, 4.55; N, 9.85.

1-(β-D-Arabinofuranosyl)-5-methylcytosine (III)——1-O-*p*-Nitrobenzoyl-2,3,5-tri-benzylarabinofuranose (11.4 g) was dissolved in CH_2Cl_2 (50 ml). Dry HCl gas was bubbled through the solution at 0° until the solution was saturated with the gas. The solution was kept at 5° for 3 hr to deposit solid *p*-nitrobenzoic acid. The solid was filtered off. The filtrate was concentrated to dryness *in vacuo*. The residue was dissolved in CH_2Cl_2 and the solvent was removed. Thus, co-distillation with CH_2Cl_2 was repeated until the residue was free of HCl. The resulting HCl-free 2,3,5-tri-O-benzyl-α-arabinofuranosyl chloride was dissolved in 30 ml of CH_2Cl_2. To the solution was added 2,4-dimethoxy-5-methylpyrimidine (6.61 g). The solution was kept at room temperature for 4 days. After this period, the solvent was removed *in vacuo* to leave syrupy XXI. In a pressure bomb XXI was dissolved in CH_3OH (100 ml) saturated with NH_3 at 0°. The solution was heated at 110—120° for 15 hr. The cooled solution was concentrated to dryness. The residue (XXII) was mixed with 50 ml of liquid NH_3. Metalic sodium was added with stirring until blue color persisted (4.5 g of sodium was required). Stirring was continued for further 30 min. NH_4Cl was added to the reaction mixture until the blue color disappeared. NH_3 gas allowed to evaporate to leave a gummy substance. The gum was dissolved in 50 ml of H_2O. The solution was acidified with AcOH. The solution was treated with ether to remove bibenzyl formed. The aqueous layer was concentrated to dryness. The residue was subjected to preparative paper chromatography (solvent system. *n*-BuOH-H_2O-NH_4OH 86:14:1). After crystallization from EtOH, yield 1.23 g (24% calculated on 1-O-*p*-nitrobenzoyl-2,3,5-tri-O-benzyl-D-arabinofuranose); mp 153.5° $[\alpha]_D^{15}$ +136° (*c*, 1.0 H_2O). *Rf* in *n*-BuOH-NH_4OH-H_2O (86:14:1 v/v): 0.20; *Rf* in *n*-C_3H_7OH-H_2O (3:1 v/v): 0.45. UV $\lambda_{max}^{H_2O}$ mμ (ε): 278 (8100); $\lambda_{min}^{H_2O}$ mμ (ε): 255 (4600); $\lambda_{max}^{pH\,1.7}$ mμ (ε): 289 (11300); $\lambda_{min}^{pH\,1.7}$ mμ (ε): 245 (900); $\lambda_{max}^{0.1N\,NaOH}$ mμ (ε): 280 (8800); $\lambda_{min}^{0.1N\,NaOH}$ mμ (ε): 255 (4600). *Anal.* Calcd. for $C_{10}H_{15}O_5N_3 \cdot H_2O$: C, 43.63; H, 6.23; N, 15.27. Found: C, 43.60; H, 6.32; N, 15.01.

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