JOC Article

Artificial Nucleosides Possessing Metal Binding Sites at the 3′- and 5′-Positions of the Deoxyribose Moieties

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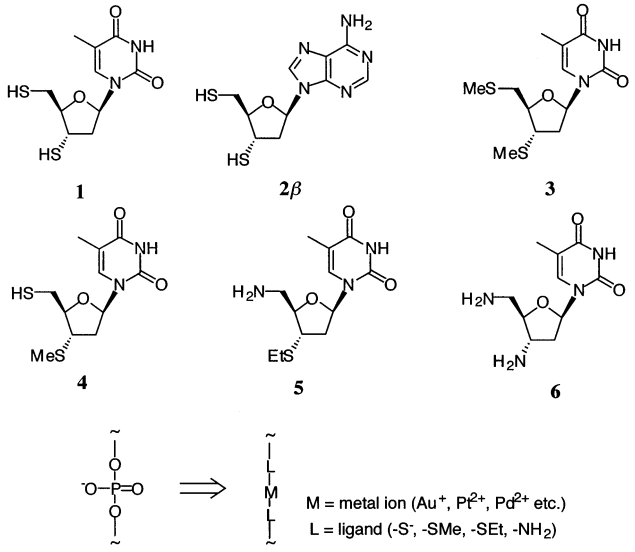
This paper describes a convenient synthetic procedure for nucleoside mimics, **1**−**6**, in which the 3′,5′-hydroxy groups of natural 2′-deoxythymidine or 2′-deoxyadenosine are replaced by thiol, amine, or alkylthiol groups. Such nucleosides would be built up into a single DNA strand with cooperative participation of metal coordination, where internucleoside linkages are replaced by metal complexation motifs. The X-ray crystal structure and complexation behaviors of 3′,5′-dithiothymidine, **1**, with Au^{I} are also reported.

Introduction

The use of information-bearing template molecules such as nucleic acids has a bright prospect for developing molecular systems that permit storage, transcription, and replication of molecular information.[1] As an approach to metal-induced DNA strand formation on a template single-stranded DNA, we previously reported Zn^{II}-mediated strand formation of "chelator-type" nucleoside mimics.[2] In this study, we have newly designed and synthesized a series of 2′-deoxyribonucleosides bearing two metal binding sites at the 3′- and 5′-positions of the deoxyribose moieties. Such nucleosides would be built up into a single DNA strand with cooperative participation of metal coordination, where the covalent phosphodiester linkage endogenous to natural DNA is replaced by coordinated metals. We have developed a convenient synthetic procedure for nucleoside mimics, **1**−**6** (Chart 1), in which the 3′- and 5′-hydroxy groups are replaced by thiol, amine, or alkylthiol functional groups. The X-ray crystal structure and complexation behaviors of 3′,5′-dithiothymidine, **1**, with Au^{I} are also described.

CHART 1. Nucleoside Mimics Prepared in This Study



Results and Discussion

We have synthesized **1** by a modified procedure (Scheme 1) of Reese's reports.[3] Thymidine **7** was first converted into 5′-*O*-mesyl-2′-deoxy-2,3′-anhydronucleoside, **8**, in two steps by treatment with MsCl in pyridine followed by heating the crude product in EtOH with an excess of Et_3N. Treatment of **8** in *N*,*N*-dimethylacetamide (DMA) with the sodium salt of 4-methoxy-α-toluenethiol afforded the *S*-bis(4-methoxybenzyl) derivative **9** in 87% overall yield for the three steps from **7**. One-step removal of the protective groups of **9** was successfully carried out by acid treatment, whereas the previous route involves a two-step deprotection involving a transient 2-nitrophenylsulfanyl intermediate.[3] The structural characterization of **1** is based on ^{1}H and ^{13}C NMR spectroscopic evidence and X-ray structural analysis (Figure 1).

The corresponding β-adenosine derivative **2*β*** was prepared by replacement of the thymine base of **10** [3] with adenine base (Scheme 2). This nucleobase-exchange reaction using N^{6}-octanoyladenine in the presence of trimethylsilyl trifluoromethanesulfonate (TMSOTf) af-

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(1) (a) Hoss, R.; Vögtle, F. *Angew. Chem., Int. Ed. Engl.* **1994**, *33*, 375. (b) Bag, B. G.; von Kiedrowski, G. *Pure Appl. Chem.* **1996**, *68*, 2145. (c) Jager, R.; Vögtle, F. *Angew. Chem., Int. Ed. Engl.* **1997**, *36*, 930. (d) Niemeyer, C. M. *Curr. Opin. Chem. Biol.* **2000**, *4*, 609. (e) Niemeyer, C. M. *Angew. Chem., Int. Ed.* **2001**, *40*, 4128. (f) Summerer, D.; Marx, A. *Angew. Chem., Int. Ed.* **2002**, *41*, 89.
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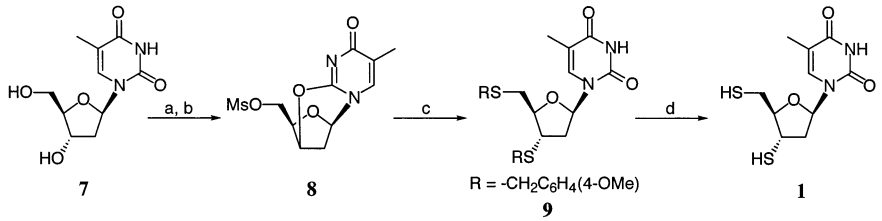
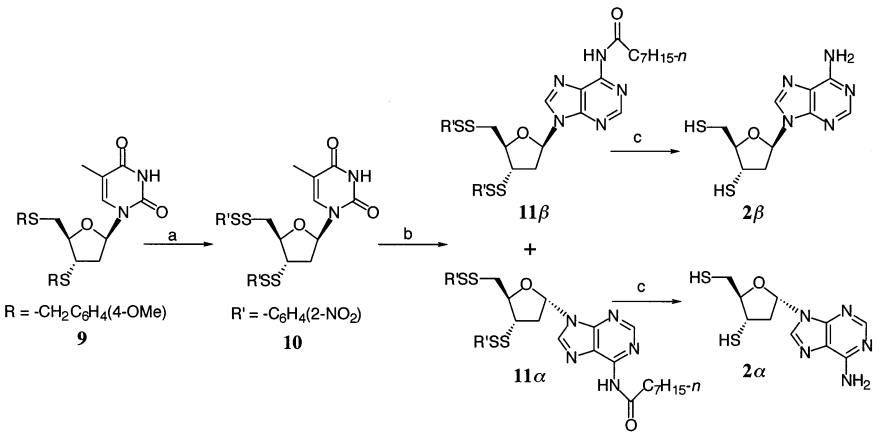
SCHEME 1. Synthetic Route for Nucleoside 1[a]



[a] Reagents and conditions: (a) MsCl, pyridine, 96%; (b) Et_3N, EtOH, 93%; (c) NaH, 4-methoxy-α-toluenethiol, DMA, 97%; (d) TFA, phenol, 72%.

SCHEME 2. A Synthetic Route for Nucleoside 2[a]



[a] Reagents and conditions: (a) 2-nitrobenzenesulfenyl chloride, 10%(v/v) acetic acid in CH_2Cl_2, 86%; (b) HMDS treated N^6-octanoyladenine, TMSOTf, DMA, 42% for **11*β*** and 40% for **11α**; (c) (i) 40%(v/v) $MeNH_2$ in MeOH; (ii) EtSH, Et_3N, CH_2Cl_2, 65% for **2*β*** and 12% for **2α**.

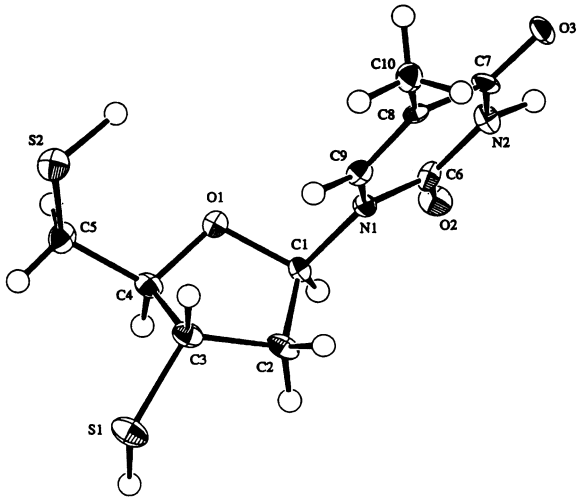


FIGURE 1. ORTEP drawing for **1** with 50% probability thermal ellipsolids.

forded a mixture of α- and *β*-anomers (**11α** and **11*β***, respectively) in 82% yields (α:*β* = 1:1). Nucleoside **2*β*** was obtained by the following in situ two-step deprotection of **11*β***.

The structural assignment for the anomeric configurations of **11α** and **11*β*** was examined by ^1H NOE studies and by correlation with the X-ray crystal structure of *β*-thymidine derivative **10**. In addition, these compounds were further characterized by ^1H and ^{13}C NMR, $^1H-^1H$ COSY, and high-resolution mass spectrometry. Proton

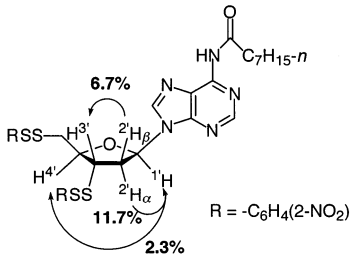


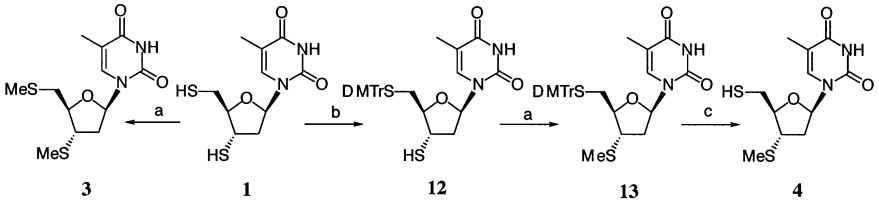
FIGURE 2. Illustration of nuclear Overhauser enhancements for **11*β***.

nuclear Overhauser effects were investigated to determine the anomeric configuration of **11*β***. Irradiation of the 2′α proton of the deoxyribose moiety gave a significant nuclear Overhauser enhancement of 11.7% at the 1′ proton, while irradiation of the 2′*β* proton gave a 6.7% enhancement at the 3′ proton and 0% at the 1′ proton. In addition, irradiation of the 1′ proton gave a 2.3% enhancement at the 4′ proton. Thus, the configuration of this compound has proven to be *β* (Figure 2). The NOE experiments were also carried out for the α-isomer **11α** and the *β*-thymidine derivative **10**. The NOE trends for **10**, whose anomeric configuration was assigned to be *β* by X-ray analysis, are quite similar to those for **11*β*** (for **10** and **11α**, see Supporting Information).[4]

Thiol groups of **1** at the 3′- and 5′-positions were further converted to methylthiol groups (Scheme 3).

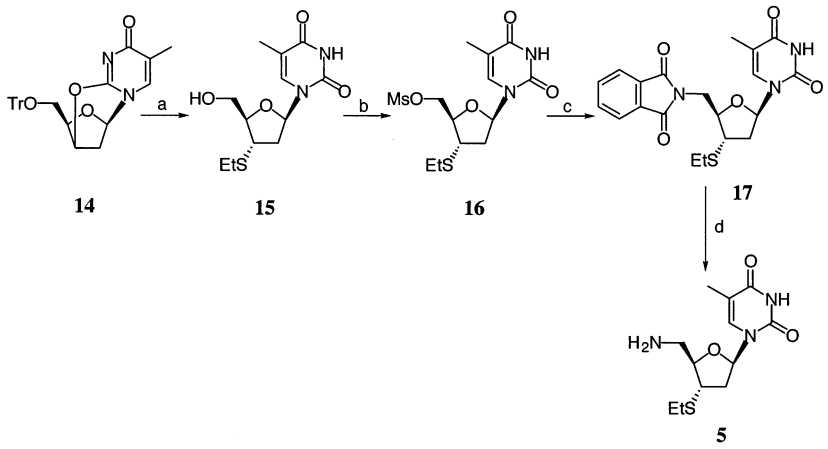
(4) The *β*-anomeric structure of **11*β*** was preliminarily confirmed by X-ray analysis of **2*β***, which was derived from **11*β***. The results will be reported elsewhere.

SCHEME 3. Synthetic Routes for Nucleosides 3 and 4[a]



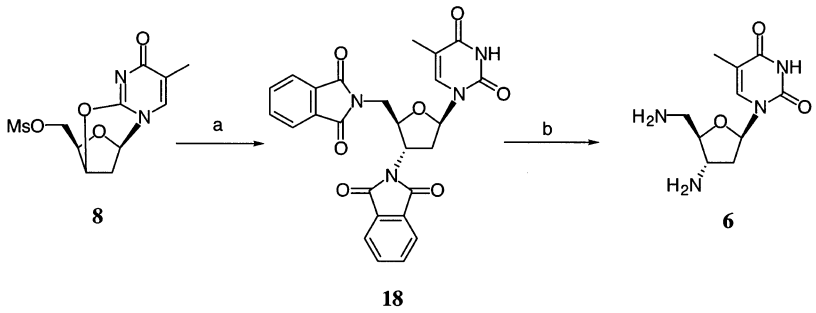
[a] Reagents and conditions: (a) MeI, K_2CO_3, THF, 97%; (b) DMTrCl, pyridine, THF, 87%; (c) (i) $AgNO_3$, NaOAc, MeOH/THF; (ii) DTE, NaOAc, MeOH/THF, 83%.

SCHEME 4. Synthetic Route for Nucleoside 5[a]



[a] Reagents and conditions: (a) (i) EtSH, NaH, DMA; (ii) HCl, EtOH, 86%; (b) MsCl, Et_3N, CH_2Cl_2, 99%; (c) potassium phthalimide, DMF, 56%; (d) 40%(v/v) $MeNH_2$ in MeOH, 30%.

SCHEME 5. Synthetic Route for Nucleoside 6[a]



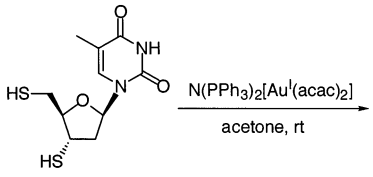
[a] Reagents and conditions: (a) potassium phthalimide, 18-crown-6, DMSO, 12%; (b) 40%(v/v) $MeNH_2$ in MeOH, 60%.

Treatment of **1** with MeI in the presence of K_2CO_3 afforded **3**. Selective protection of the 5′-thiol group of **1**, followed by methylation and deprotection, yielded monofunctionalized **4**.

Scheme 4 shows a synthetic route for *S*-ethyl-3′-thio-5′-amino-2′,5′-dideoxythymidine, **5**. The reaction of 2′,3′-anhydro-5′-protected derivative, **14**,[5] with the sodium salt of EtSH, followed by acid treatment, afforded **15** in good yield. Mesylation of the 5′-hydroxy group of **15** and the following Gabriel reaction and deprotection led to 3′-ethyl-5′-amino derivative **5** in 14% overall yield. Diamino derivative **6**[6] was obtained by Gabriel reaction starting from **8** and deprotection (Scheme 5).

We envisioned that the covalent phosphodiester linkage (-O−PO_2−O-) seen in natural DNA would be replaced by metal coordination (-S−M−S-). As an alternative linkage between 3′- and 5′-functional groups of nucleosides, an -S−Au^I−S- linkage in the linear coordination was introduced to form a metal-mediated strand. The complexation of 3′,5′-dithiothymidine, **1**, and PPN[Au^I(acac)$_2$][7] (PPN = bis(triphenylphosphoranylidene) ammonium) in acetone was investigated by ^{1}H NMR and

SCHEME 6. Complexation of 1 and PPN[Au^I(acac)$_2$]



1 = LH_2

(5) Jack, J. F.; Naishum, C. M. *J. Org. Chem.* **1963**, *28*, 936.
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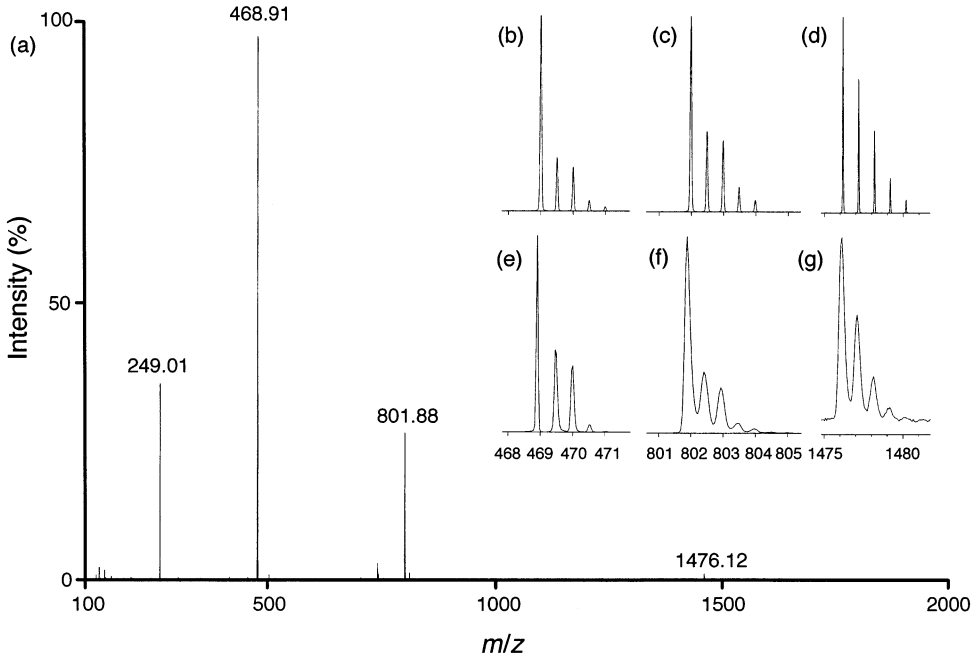

FIGURE 3. (a) ESI-TOF mass spectra for the reaction mixture of **1** and PPN[$Au^I(acac)_2$] after 1.5 h: (e−g) magnified figures of a; (b−d) theoretical isotopic distribution for e−g, respectively.

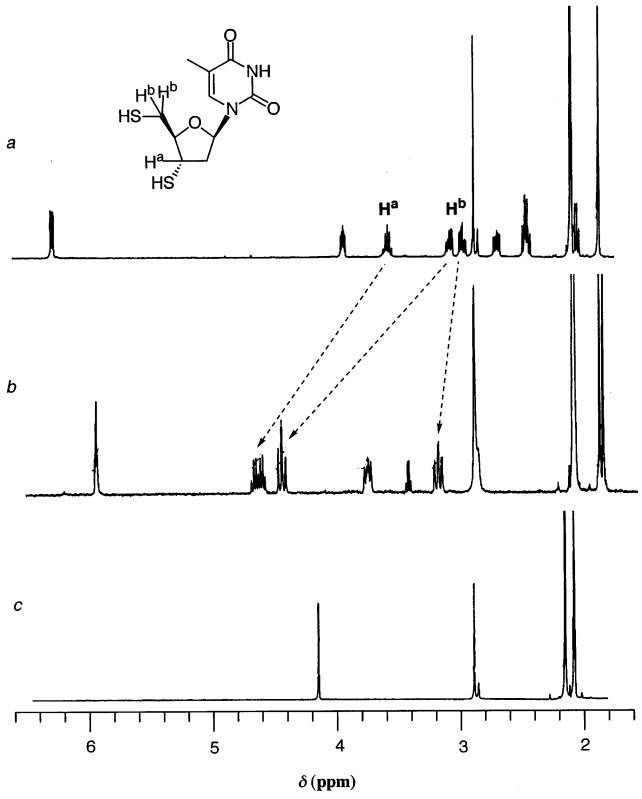

FIGURE 4. Comparison of ^1H NMR spectra for (a) **1**, (b) the precipitate isolated from Au^I complex with **1**, and (c) PPN-[$Au^I(acac)_2$] in $(CD_3)_2CO$ at room temperature.

mass spectrometry (Scheme 6). An ESI-TOF mass spectrum in the negative mode for the reaction mixture including **1** and Au^I in a 1:1 ratio is shown in Figure 3a. The signals at *m*/*z* 468.91, 801.88, and 1076.12 are in good agreement with the theoretical data for $[\mathbf{L}_2Au^I_2]^{2-}$

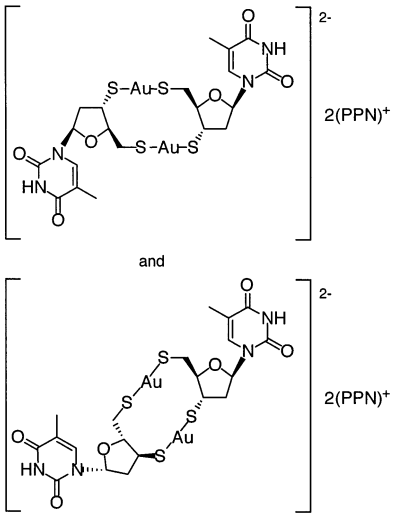

FIGURE 5. Possible dimeric structures for Au^I complexes.

($\mathbf{L}H_2 = \mathbf{1}$), $[\mathbf{L}_3Au^I_4]^{2-}$, and [PPN + $\mathbf{L}_2Au^I_2]^-$, respectively (Figure 3e−g for theoretical data and Figure 3b−d for experimental data).

Addition of the above reaction mixture to Et_2O resulted in the formation of a colorless precipitate (ca. 90% yield as $(PPN)_2\mathbf{L}_2Au^I_2$). Figure 4 shows ^1H NMR spectra of (a) **1**, (b) the precipitate, and (c) PPN[$Au^I(acac)_2$] in $(CD_3)_2$-CO at room temperature. Large downfield shifts were observed for 3′-H (H^a) and 5′,5″-H (H^b). The downfield shifts reflect the formation of Au^I−S bonds at the 3′ and 5′-thiol moieties. The ratio between PPN and **L** for the precipitate was proven to be 1:1 on the basis of their integration, and the ESI-TOF mass spectrum for the

(7) (a) Vicente, J.; Chicote, M. T. *Inorg. Synth.* **1998**, *32*, 172. (b) Vicente, J.; Chicote, M. T.; Gonzalez-Herrero, P.; Jones, G. P. *J. Chem. Soc., Dalton Trans.* **1994**, 3183. (c) Vicente, J.; Chicote, M. T.; Saura-Llamas, I.; Lagunas, M. C. *J. Chem. Soc., Chem. Commun.* **1992**, 915.

precipitate showed a main signal for $[\mathbf{L}_2Au^I_2]^{2-}$. It is most likely, taken all together, that the main component of the precipitate should be $(PPN)_2\mathbf{L}_2Au^I_2$. In the ^1H NMR spectrum, two sets of proton signals were observed in a 1:1 ratio, showing the presence of two well-defined Au^I complexes with similar structures. Additionally, the splitting patterns of 5′,5″-H (H^b) indicate their conformationally less flexible structures. On the basis of these facts, we propose here two cyclic structures consisting of two nucleosides, one of which is cross-linked by 3′S−Au^I−5′S bonds and the other by a 3′S−Au^I−3′S bond and a 5′S−Au^I−5′S bond (Figure 5).

Conclusion

In this paper, we presented the convenient syntheses of nucleoside mimics, **1**−**6**, bearing metal binding sites at the 3′- and 5′-positions of the deoxyribose moieties. For the purpose of replacement of covalent phosphodiester linkage by metal coordination, we examined the metal-binding property of 3′,5′-dithiothymidine, **1**, and Au^I. The general strategy presented here for developing the metal-mediated DNA strand formation should be applicable for information-based molecular operation as well as development of antisense molecules. Studies on template-directed self-assembly of artificial nucleoside mimics through metal coordination is now underway.

Experimental Section

General Method. All reactions were carried out in oven-dried glassware under argon atmosphere. All reagents were commercially available and used without further purification. All reactions were monitored by thin-layer chromatography (TLC) using Merck silica gel 60, F-254. Column chromatography was conducted using Wakogel C-300 (silica gel, Wako).

^1H and ^{13}C NMR spectra were recorded at 500 and 125 MHz, respectively. The spectra were referenced to tetramethylsilane (TMS) in chloroform-*d* or deuterated dimethyl sulfoxide (DMSO-d_6). Chemical shifts (δ) are reported in parts per million and coupling constants (*J*) in hertz. Mass spectra were recorded on an ESI-TOF mass or a FAB mass spectrometer.

3′,5′-Dithio-2′-deoxythymidine, 1. A solution of **9** (705 mg, 1.4 mmol) and phenol (387 mg, 4.1 mmol) in trifluoroacetic acid (TFA, 7.0 mL) was heated at reflux for 1 h. After removal of the solvent, the residue was taken up into water and extracted with CH_2Cl_2. The organic layer was dried over anhydrous $MgSO_4$ and then evaporated. The residue was chromatographed on silica gel (eluent; $CHCl_3$/MeOH = 20:1) to give **1** in 72% yield as a colorless solid. Compound **1** was recrystallized from EtOH containing 0.1%(v/v) acetic acid: Mp 164.0−166.0 °C; IR (KBr) 3175, 2540, 1710, 1660, 1040 cm^{-1}; $[\alpha]^{25}_D$ +1.85 (*c* = 1.00, CH_2ClCH_2Cl); ^1H NMR (DMSO-d_6 containing one drop of D_2O) δ 7.53 (1H, d, *J* = 1.0 Hz, 6-H), 6.12 (1H, dd, *J* = 4.0, 7.5 Hz, 1′-H), 3.79 (1H, ddd, *J* = 4.0, 5.8, 8.3 Hz, 4′-H), 3.41 (1H, ddd, *J* = 8.8, 8.8, 8.8 Hz, 3′-H), 2.94 (1H, dd, *J* = 4.0, 14.0 Hz, 5′-H), 2.81 (1H, dd, *J* = 6.0, 14.0 Hz, 5″-H), 2.30 (1H, ddd, *J* = 8.0, 8.8, 14.0 Hz, 2′-H), 2.49−2.55 (m, 2″-H including DMSO), 1.81 (3H, d, *J* = 1.0 Hz, 5-Me); ^{13}C NMR (DMSO-d_6 containing one drop of D_2O) δ 163.70, 150.42, 136.33 (6-C), 109.77 (5-C), 87.57 (4′-C), 82.82 (1′-C), 40.53 (2′-C), 37.17 (3′-C), 25.53 (5′-C), 12.10 (5-Me); FABMS (in 3-nitrobenzyl alcohol containing 50% glycerol) *m/e* 275 $(M + H)^+$. Anal. Calcd for $C_{10}H_{14}N_2O_3S_2$: C, 43.78; H, 5.14; N, 10.21; S, 23.37. Found: C, 43.71; H, 5.10; N, 10.22; S, 23.57.

S,S′*-Bis(2-nitrophenylsulfanyl)-3′,5′-dithio-2′-deoxy-*β*-4-*N*-*n*-octanoyladenosine, 11*β*, and *S,S′*-Bis(2-nitrophenylsulfanyl)-3′,5′-dithio-2′-deoxy-α-4-*N*-*n*-octanoyladenosine, 11α.** A solution of N^6-octanoyladenine (7.21 g, 27 mmol) in hexamethyldisilazane (HMDS, 50 mL) containing TMSCl (1.4 mL) was stirred for 2.5 h at 150 °C. After removal of the solvent in vacuo, the residue was dissolved in anhydrous DMA (50 mL). 3′,5′-*S*-Bis(2-nitrophenylsulfanyl)-3′,5′-dithio-2′-deoxythymidine, **10** (4.16 g, 6.7 mmol), and trimethylsilyl trifluoromethanesulfonate (TMSOTf, 4.0 mL, 22 mmol) were added to the solution, and the reaction mixture was stirred for 2 h at 85 °C. The solution was poured into 0.3% $NaHCO_3$ aqueous solution, and the resulting precipitate was collected, washed with water, and dried in vacuo. The solid was taken up into $CHCl_3$ (60 mL), and the resulting precipitate was removed by filtration. The filtrate was poured into *n*-hexane (2.0 L), and the suspension was stirred for 10 min at room temperature and then filtered. The crude product was chromatographed twice on silica gel (eluent; CH_2Cl_2/AcOEt = 10:1 and *n*-hexane/AcOEt = 2:3) to give **11*β (2.13 g, 42%) as a yellow solid and **11α** (2.04 g, 40%) as a yellow foam. Compounds **11*β*** and **11α** were purified by reprecipitation from *n*-hexane.

(a) Compound 11*β*. Mp 135.5−136.0 °C; IR (KBr) 2920, 2850, 1685, 1610, 1590, 1510, 1040 cm^{-1}; $[\alpha]^{25}_D$ +1.70 (*c* = 1.00, CH_2ClCH_2Cl); ^1H NMR ($CDCl_3$) δ 8.58 (1H, s, adenine), 8.55 (1H, brs, NH), 8.23−8.27 (3H, m, Ar), 8.15 (1H, dd, *J* = 1.3, 8.3 Hz, Ar), 8.07 (1H, s, adenine), 7.14 (1H, ddd, *J* = 1.3, 7.3, 8.3 Hz, Ar), 7.62 (1H, ddd, *J* = 1.1, 7.1, 8.1 Hz, Ar), 7.39 (1H, ddd, *J* = 1.3, 7.3, 8.3 Hz, Ar), 7.35 (1H, ddd, *J* = 1.0, 7.3, 8.0 Hz, Ar), 6.26 (1H, dd, *J* = 4.0, 7.5 Hz, 1′-H), 4.32 (1H, ddd, *J* = 4.5, 7.0, 7.0 Hz, 4′-H), 4.13 (1H, ddd, *J* = 7.5, 7.5, 7.5 Hz, 3′-H), 3.19−3.26 (2H, m, 2′-H and 5′-H), 3.14 (1H, dd, *J* = 7.0, 14.0 Hz, 5′-H), 2.86 (2H, t, *J* = 7.3 Hz, $-COCH_2-$), 2.71 (1H, ddd, *J* = 7.4, 7.4, 14.4 Hz, 2″-H), 1.77 (2H, tt, *J* = 7.4, 7.4 Hz, $-COCH_2CH_2CH_2-$), 1.26−1.44 (8H, m, $-COCH_2CH_2(CH_2)_4-CH_3$), 0.88 (3H, t, *J* = 7.0 Hz, $-COCH_2CH_2(CH_2)_4CH_3$); ^{13}C NMR ($CDCl_3$) δ 173.01, 152.28, 150.33, 149.44, 145.59, 145.41, 142.15, 136.73, 136.20, 134.37, 134.10, 127.19, 127.05, 126.92, 126.43, 126.29, 126.13, 122.65, 84.91, 83.71, 49.37, 41.43, 37.91, 36.85, 31.65, 29.16, 29.02, 24.85, 22.58, 14.05; FABMS (in 3-nitrobenzyl alcohol containing 50% glycerol) *m/e* 716 $(M + H)^+$. HRMS. Calcd for $C_{30}H_{34}N_7O_6S_4$: 716.1453. Found: 716.1452.

(b) Compound 11α. Mp 66.5−67.5 °C; IR (KBr) 3280, 2925, 2850, 1695, 1575, 1510, 1040 cm^{-1}; $[\alpha]^{25}_D$ −0.67 (*c* = 1.00, CH_2ClCH_2Cl); ^1H NMR ($CDCl_3$) δ 8.79 (1H, brs, NH), 8.53 (1H, s, adenine), 8.11−8.23 (5H, m, Ar and adenine), 7.69 (1H, ddd, *J* = 0.7, 7.8, (not separated) Hz, Ar), 6.26 (1H, dd (pseudo-triplet), *J* = 6.2, 6.2 Hz, 1′-H), 4.69 (1H, ddd, *J* = 3.9, 7.4, 7.4 Hz, 4′-H), 3.54 (1H, ddd, *J* = 8.4, 8.4, 8.4 Hz, 3′-H), 3.23 (1H, dd, *J* = 3.7, 14.2 Hz, 5′-H), 2.96−3.08 (3H, m, 2′-H, 2″-H, 5″-H), 2.91 (2H, t, *J* = 7.5 Hz, $-COCH_2-$), 1.80 (2H, tt, *J* = 7.5, 7.5 Hz, $-COCH_2CH_2CH_2-$), 1.29−1.47 (8H, m, $-COCH_2CH_2-(CH_2)_4CH_3$), 0.89 (3H, t, *J* = 6.7 Hz, $-COCH_2CH_2(CH_2)_4CH_3$); ^{13}C NMR ($CDCl_3$) δ 152.26, 150.59, 149.32, 145.51, 145.39, 141.25, 136.82, 136.18, 134.34, 133.67, 127.16, 127.09, 126.94, 126.30, 126.28, 125.89, 122.56, 84.60, 83.09, 50.77, 41.62, 37.94, 37.69, 31.68, 29.20, 29.06, 24.89, 22.60, 14.07; FABMS *m/e* 716 $(M + H)^+$. HRMS. Calcd for $C_{30}H_{34}N_7O_6S_4$: 716.1453. Found: 716.1443.

3′,5′-Dithio-2′-deoxy-*β*-adenosine, 2*β*. MeOH containing 40%(v/v) $MeNH_2$ (6.0 mL) was added to a solution of **11*β*** (648 mg, 0.91 mmol) in CH_2Cl_2 (12 mL). The reaction mixture was stirred for 1 h at room temperature. After removal of the solvent, the residue was dissolved in CH_2Cl_2 (18 mL). EtSH (9.0 mL, 120 mmol) and Et_3N (5.4 mL, 40 mmol) were added to the solution, and the reaction mixture was stirred for 1.5 h at room temperature. After removal of the solvent, the residue was chromatographed on silica gel (eluent; $CHCl_3$/MeOH = 20:1) to give **2*β*** (reprecipitation from *n*-hexane) in 65% yield as a colorless solid. Mp 208.5−210.0 °C; IR (KBr) 3270, 3120, 2560, 1670, 1600,1070 cm^{-1}; $[\alpha]^{25}_D$ ±0.00 (*c* = 1.00, DMA); ^1H NMR ($CDCl_3$ containing 20%(v/v) CD_3OD) δ 8.27 (1H, s, adenine), 8.17 (1H, s, adenine), 6.34 (1H, dd, *J* = 2.8, 7.6 Hz, 1′-H), 4.03 (1H, ddd, *J* = 4.0, 4.8, 8.9 Hz, 4′-H), 3.74 (1H, ddd, *J* = 8.4, 8.9, 9.6 Hz, 3′-H), 3.07 (1H, dd, *J* = 4.0, 14.5 Hz, 5′-

H), 3.02 (1H, ddd, J = 2.8, 8.4, 13.9 Hz, 2′-H), 2.91 (1H, dd, J = 4.8, 14.5 Hz, 5″-H), 2.58 (1H, ddd, J = 7.6, 9.6, 13.9 Hz, 2″-H); ^{13}C NMR (DMSO-d_6) δ 156.08, 152.67, 148.94, 139.55, 119.06, 88.61, 82.31, 40.80, 37.77, 25.99; FABMS (in glycerol) m/e 284 $(M + H)^+$. HRMS. Calcd for $C_{10}H_{14}N_5OS_2$: 284.0640. Found: 284.0622.

3′,5′-Dithio-2′-deoxy-α-adenosine, 2α. A solution of **11α** (117 mg, 0.16 mmol) in MeOH containing 40%(v/v) $MeNH_2$ (1.0 mL) was stirred for 1.5 h at room temperature. After removal of the solvent, the residue was dissolved in CH_2Cl_2 (3.0 mL). EtSH (1.5 mL, 20 mmol) and Et_3N (0.90 mL, 6.7 mmol) were added to the solution, and the reaction mixture was stirred for 1.5 h at room temperature. After removal of the solvent, the residue was chromatographed on silica gel (eluent; $CHCl_3$/MeOH = 10:1) to give **2α** (reprecipitation from n-hexane) in 12% yield as a colorless solid. Mp 150.5−151.0 °C; IR (KBr) 3300, 3140, 2550, 1665, 1600 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 8.37 (1H, s, adenine), 7.96 (1H, s, adenine), 6.23 (1H, dd, J = 6.3, 7.0 Hz, 1′-H), 5.76 (1H, brs, NH_2), 4.46 (1H, ddd, J = 4.3, 4.3, 8.7 Hz, 4′-H), 3.46 (1H, dddd, J = 9.2, 9.2, 9.2, 9.2 Hz, 3′-H), 3.13 (1H, ddd, J = 7.3, 8.5, 13.8 Hz, 2′-H), 3.06 (1H, ddd, J = 3.6, 7.3, 14.4 Hz, 5′-H), 2.86 (1H, ddd, J = 6.1, 9.9, 13.8 Hz, 2″-H), 2.79 (1H, ddd, J = 4.7, 9.6, 14.3 Hz, 5″-H), 2.16 (1H, d, J = 9.3 Hz, 3′-SH), 1.60 (1H, dd, J = 7.3, 9.5 Hz, 5′-SH); ^{13}C NMR ($CDCl_3$) δ 155.50, 153.01, 149.46, 139.45, 120.51, 87.21 (4′-C), 84.24 (1′-C), 42.12 (2′-C), 38.27 (3′-C), 25.96 (5′-C); FABMS (in 3-nitrobenzyl alcohol containing 50% glycerol) m/e 284 $(M + H)^+$. HRMS. Calcd for $C_{10}H_{14}N_5OS_2$: 284.0640. Found: 284.0616.

***S,S′*-Dimethyl-3′,5′-dithio-2′-deoxythymidine, 3.** A solution of **1** (274 mg, 1.0 mmol), MeI (1.25 mL, 20 mmol), and K_2CO_3 (8.30 g, 60 mmol) in anhydrous THF (20 mL) was stirred for 15 h at room temperature. After removal of the solvent, the residue was taken up into water and extracted with $CHCl_3$. The organic layer was dried over anhydrous $MgSO_4$ and then evaporated. The residue was chromatographed on silica gel (eluent; $CHCl_3$) to give **3** in 97% yield as a colorless oil. IR (KBr) 3180, 1700, 1680, 1060 cm^{-1}; $[\alpha]^{25}_D$ +3.03 (c = 1.00, CH_2ClCH_2Cl); ^{1}H NMR ($CDCl_3$) δ 8.81 (1H, brs, 3-NH), 7.55 (1H, d, J = 1.1 Hz, 6-H), 6.17 (1H, dd, J = 4.6, 7.1 Hz, 1′-H), 4.04 (1H, ddd, J = 4.1, 4.1, 8.3 Hz, 4′-H), 3.30 (1H, ddd, J = 8.3, 8.3, 8.3 Hz, 3′-H), 3.01 (1H, dd, J = 4.0, 14.4 Hz, 5′-H), 2.89 (1H, dd, J = 4.5, 14.3 Hz, 5″-H), 2.40−2.51 (2H, m, 2′-H and 2″-H), 2.21 (3H, s, −SMe), 2.17 (3H, s, −SMe), 1.95 (3H, d, J = 0.9 Hz, 5-Me); ^{13}C NMR ($CDCl_3$) δ 163.52, 150.15, 135.61, 111.10, 84.45, 83.95, 45.06, 39.38, 37.01, 17.42, 14.28, 12.55; FABMS (in glycerol) m/e 303 $(M + H)^+$. HRMS. Calcd for $C_{12}H_{19}N_2O_3S_2$: 303.0837. Found: 303.0847.

5′-*S*-(4,4′-Dimethoxytrityl)-3′,5′-dithio-2′-deoxythymidine, 12. To a solution of **1** (137 mg, 0.50 mmol) in anhydrous THF (10 mL) was added pyridine (0.40 mL) and DMTrCl (169 mg, 0.50 mmol) at −20 °C. The reaction mixture was stirred at −20 °C for 12 h and then evaporated. The residue was chromatographed on silica gel (eluent; CH_2Cl_2/AcOEt = 10:1) to give **12** in 87% yield as a colorless foam. IR (KBr) 3190, 1700, 1680, 1040 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 8.33 (1H, brs, 3-NH), 7.48 (1H, d, J = 0.5 Hz, 6-H), 7.41 (2H, d, J = 7.5 Hz, DMTr), 7.21−7.33 (7H, m, DMTr), 6.81−6.84 (4H, m, DMTr), 6.07 (1H, dd, J = 3.5, 7.0 Hz, 1′-H), 3.73−3.80 (7H, m, 4′-H and −OMe), 3.18 (1H, dddd, J = 8.4, 8.4, 8.4, 8.4 Hz, 3′-H), 2.87 (1H, dd, J = 4.0, 13.0 Hz, 5′-H), 2.54 (1H, dd, J = 4.5, 13.0 Hz, 5″-H), 2.39 (1H, ddd, J = 3.8, 8.3, 14.3 Hz, 2′-H), 2.25 (1H, ddd, J = 7.6, 9.6, 14.4 Hz, 2″-H), 1.85 (3H, d, J = 0.5 Hz, 5-Me), 1.43 (1H, d, J = 7.5 Hz, 3′-SH): ^{13}C NMR ($CDCl_3$) δ 163.36, 158.29, 149.93, 144.98, 136.69, 135.67, 130.66, 129.34, 128.06, 126.88, 113.31, 110.81, 86.98, 84.02, 66.22, 55.28, 42.26. 36.86, 33.25, 12.46 ; FABMS (in 3-nitrobenzyl alcohol containing 50% glycerol with NaI) m/e 599 $(M + Na)^+$. HRMS. Calcd for $C_{31}H_{32}N_2O_5S_2Na$: 599.1650. Found: 599.1654.

5′-*S*-(4,4′-Dimethoxytrityl)-3′-*S*-methyl-3′,5′-dithio-2′-deoxythymidine, 13. A solution of **12** (288 mg, 0.50 mmol), MeI (0.31 mL, 5.0 mmol), and K_2CO_3 (346 mg, 2.5 mmol) in anhydrous THF (10 mL) was stirred for 12 h at room temperature. After removal of the solvent, the residue was taken up into water and extracted with $CHCl_3$. The organic layer was dried over anhydrous K_2CO_3 and then evaporated. The residue was chromatographed on silica gel (eluent; $CHCl_3$) to give **13** in 92% yield as a colorless foam. IR (KBr) 3060, 1700, 1040 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 8.36 (1H, brs, 3-NH), 7.55 (1H, d, J = 1.0 Hz, 6-H), 7.40 (2H, dd, J = 0.8, 8.3 Hz, DMTr), 7.20−7.32 (7H, m, DMTr), 6.80−6.83 (4H, m, DMTr), 6.08 (1H, dd, J = 5.3, 6.8 Hz, 1′-H), 3.86 (1H, ddd, J = 4.6, 4.6, 7.5 Hz, 4′-H), 3.80 (6H, s, −OMe), 3.04 (1H, dd, J = 7.3, 7.3, 7.3 Hz, 3′-H), 2.76 (1H, dd, J = 4.0, 13.0 Hz, 5′-H), 2.54 (1H, dd, J = 5.0, 13.0 Hz, 5″-H), 2.26−2.37 (2H, m, 2′-H and 2″-H), 2.01 (3H, s, −SMe), 1.87 (3H, d, J = 1.0 Hz, 5-Me); ^{13}C NMR ($CDCl_3$) δ 163.41, 158.24, 149.94, 145.01, 136.69, 135.71, 130.62, 129.30, 127.99, 126.82, 113.24, 110.75, 84.61, 83.47, 66.11, 55.26, 45.14, 39.22, 35.15, 14.15, 12.50; FABMS (in 3-nitrobenzyl alcohol containing 50% glycerol with NaI) m/e 613 $(M + Na)^+$. HRMS. Calcd for $C_{32}H_{34}N_2O_5S_2Na$: 613.1807. Found: 613.1805.

3′-*S*-Methyl-3′,5′-dithio-2′-deoxythymidine, 4. To a solution of **13** (413 mg, 0.7 mmol) in THF containing 25%(v/v) MeOH (16 mL) was added an aqueous solution of NaOAc (1.5 mL, 3.0 M). Separately, a solution of $AgNO_3$ (238 mg, 1.4 mmol) in water (1.0 mL) was diluted with MeOH (5.0 mL), and the solution was added to **13**. The mixture was stirred for 5 min, the solids were collected by filtration, and the pellet was washed with three portions of MeOH (each 2 mL) to remove dimethoxytrityl-containing byproducts. To a suspension of the pellet in THF containing 50%(v/v) MeOH (40 mL) was added aqueous NaOAc (1.5 mL, 3.0 M) and dithioerythreitol (DTE, 431 mg, 2.8 mmol). The mixture was stirred for 2 h at room temperature and then filtered through Celite. The filtrate was evaporated, and the residue was taken up into water and extracted with $CHCl_3$. The organic layer was washed with water, dried over anhydrous $MgSO_4$, and then evaporated. The title compound **4** was obtained in 83% yield as a colorless oil. IR (KBr) 3190, 2560, 1680, 1060 cm^{-1}; $[\alpha]^{25}_D$ +1.92 (c = 1.00, CH_2ClCH_2Cl); ^{1}H NMR ($CDCl_3$) δ 9.54 (1H, brs, NH), 7.47 (1H, d, J = 1.2 Hz, 6-H), 6.19 (1H, dd, J = 4.9, 7.1 Hz, 1′-H), 3.97 (1H, ddd, J = 4.1, 4.1, 8.1 Hz, 4′-H), 3.32 (1H, ddd, J = 8.3, 8.3, 8.3 Hz, 3′-H), 3.07 (1H, ddd, J = 3.8, 8.3, 14.4 Hz, 5′-H), 2.89 (1H, ddd, J = 4.5, 8.8, 14.4 Hz, 5″-H), 2.41−2.52 (2H, m, 2′-H and 2″-H), 2.18 (3H, s, SMe), 1.95 (3H, d, J = 1.2 Hz, 5-Me), 1.61 (1H, d, J = 8.5 Hz, 3′-SH); ^{13}C NMR ($CDCl_3$) δ 163.45, 150.11, 135.55, 111.22, 84.11, 83.71, 44.23, 39.16, 26.91, 14.18, 12.65; FABMS (in glycerol) m/e 289 $(M + H)^+$. HRMS. Calcd for $C_{11}H_{17}N_2O_3S_2$: 289.0681. Found: 289.0638.

***S*-Ethyl-3′-thio-2′-deoxythymidine, 15.** To a suspension of NaH (154 mg, 6.4 mmol; washed thoroughly with n-hexane prior to use) in DMA (5.0 mL) was added dropwise EtSH (1.19 mL, 16 mmol) at room temperature. The suspension was stirred for 30 min at room temperature and then turned to a clear yellow solution. This solution was added to a solution of 2,3′-anhydro-1-(5′-*O*-trityl-2′-deoxy-β-D-lyxosyl)thymine, **14**,[5] (1.50 g, 3.2 mmol) in DMA (20 mL) at room temperature. The reaction mixture was stirred for 4.5 h at 65 °C. After removal of the solvent in vacuo, the residue was taken up into water and extracted with AcOEt. The organic layer was washed with brine and dried over anhydrous $MgSO_4$. After removal of the solvent, the residue was dissolved in EtOH (30 mL) and concentrated HCl (one drop) was added. The reaction mixture was stirred for 6 h at 85 °C and then evaporated. The residue was chromatographed on silica gel (eluent; toluene/AcOEt = 1:1) to give **15** in 86% yield as a colorless oil. IR (KBr) 3425, 3180, 1695, 1680, 1060 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 8.98 (1H, brs, NH), 7.55 (1H, d, J = 1.2 Hz, 6-H), 6.11 (1H, dd, J = 4.1, 7.2 Hz, 1′-H), 4.05 (1H, ddd, J = 2.3, 4.3, 12.1 Hz, 5′-H), 3.90 (1H, ddd, J = 2.4, 2.4, 8.2 Hz, 4′-H), 3.85 (1H, ddd, J = 2.7, 6.2, 12.1 Hz, 5″-H), 3.51 (1H, ddd, J = 8.3, 8.3, 8.3 Hz, 3′-H), 2.70

(1H, dd, J = 4.7, 5.8 Hz, −OH), 2.64 (2H, q, J = 7.4 Hz, $-SCH_2$-CH_3), 2.56 (1H, ddd, J = 4.1, 8.2, 13.8 Hz, 2′-H), 2.42 (1H, ddd, J = 7.3, 8.7, 14.3 Hz, 2″-H), 1.96 (3H, d, J = 1.1 Hz, 5-Me), 1.29 (3H, t, J = 7.4 Hz, $-SCH_2CH_3$); ^{13}C NMR ($CDCl_3$) δ 163.83, 150.25, 136.64, 110.73, 85.95, 85.82, 61.27, 40.37, 40.26, 25.85, 14.96, 12.54; FABMS (in glycerol) *m/e* 287 $(M + H)^+$. HRMS. Calcd for $C_{12}H_{19}N_2O_4S$: 287.1066. Found: 287.1052.

3′-*S*-Ethyl-5′-*O*-mesyl-3′-thio-2′-deoxythymidine, 16. To a solution of **15** (787 mg, 2.8 mmol) and Et_3N (0.45 mL, 3.2 mmol) in CH_2Cl_2 (20 mL) was added dropwise MsCl (0.50 mL, 6.5 mmol) at 0 °C. The reaction mixture was stirred for 25 h at 0 °C, and then H_2O (one drop) was added. After removal of the solvent, the residue was taken up into water and extracted with AcOEt. The organic layer was washed with brine and dried over anhydrous $MgSO_4$. After removal of the solvent, the residue was chromatographed on silica gel (eluent; $CHCl_3$/MeOH = 70:1) to give **16** in 99% yield as a colorless oil. IR (KBr) 3180, 3020, 1680, 1350, 1175, 1095 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 8.86 (1H, brs, NH), 7.40 (1H, d, J = 1.1 Hz, 6-H), 6.17 (1H, dd, J = 4.4, 7.0 Hz, 1′-H), 4.58 (1H, dd, J = 2.3, 11.4 Hz, 5′-H), 4.49 (1H, dd, J = 3.3, 11.4 Hz, 5″-H), 4.03 (1H, ddd, J = 2.8, 5.5, 5.5 Hz, 4′-H), 3.39 (1H, ddd, J = 8.3, 8.3, 8.3 Hz, 3′-H), 3.05 (3H, s, Ms), 2.66 (2H, q, J = 7.4 Hz, $-SCH_2CH_3$), 2.53 (1H, ddd, J = 4.7, 8.6, 13.7 Hz, 2′-H), 2.47 (1H, ddd, J = 7.1, 8.4, 14.0 Hz, 2″-H), 1.95 (3H, d, J = 1.0 Hz, 5-Me), 1.30 (3H, t, J = 7.5 Hz, $-SCH_2CH_3$); ^{13}C NMR ($CDCl_3$) δ 163.57, 150.14, 135.40, 111.33, 85.24, 82.73, 67.98, 40.93, 40.31, 37.68, 25.96, 14.92, 12.40; FABMS (in glycerol) *m/e* 365 $(M + H)^+$. HRMS. Calcd for $C_{13}H_{21}N_2O_6S_2$: 365.0841. Found: 385.0876.

***S*-Ethyl-5′-phthalimido-3′-thio-2′,5′-dideoxythymidine, 17.** A solution of **16** (578 mg, 1.6 mmol) and potassium phthalimide (295 mg, 1.6 mmol) in DMF (20 mL) was stirred for 20 h at 90 °C. After removal of the solvent under vacuum, the residue was taken up into water and extracted with CH_2Cl_2. The organic layer was washed with brine and dried over anhydrous $MgSO_4$. The solution was filtrated, and the filtrate was then concentrated to ca. 20 mL and was allowed to stand overnight. The resulting precipitate **17** (276 mg, 42%) was collected by filtration. The filtrate was evaporated and chromatographed on silica gel (eluent; toluene/AcOEt = 2:1) to give **17** in 56% total yield as a colorless solid. Mp 225.5−226.5 °C; IR (KBr) 3170, 1770, 1710, 1680, 1050 cm^{-1}; ^{1}H NMR (DMSO-d_6) δ 11.29 (1H, brs, NH), 7.85−7.91 (4H, m, Ar), 7.54 (1H, s, 6-H), 6.02 (1H, dd, J = 6.0, 7.1 Hz, 1′-H), 3.89−4.04 (3H, m, 4′-H and 5′-H and 5″-H), 3.46 (1H, ddd, J = 7.4, 7.4, 7.4 Hz, 3′-H), 2.63 (2H, q, J = 7.4 Hz, $-SCH_2CH_3$), 2.52−2.57 (m, 2′-H including DMSO), 2.29 (1H, ddd, J = 7.1, 7.1, 14.2 Hz, 2″-H), 1.75 (3H, s, 5-Me), 1.19 (3H, t, J = 7.4 Hz, $-SCH_2CH_3$); ^{13}C NMR (DMSO-d_6) δ 167.83, 163.72, 150.29, 136.28, 134.61, 131.42, 123.20, 109.41, 84.20, 81.20, 42.98, 40.24, 38.37, 24.49, 15.00, 12.02; FABMS (in 3-nitrobenzyl alcohol containing 50% glycerol with NaI) *m/e* 438 $(M + Na)^+$. HRMS. Calcd for $C_{20}H_{21}N_3O_5SNa$: 438.1100. Found: 438.1103. Crystal data for **17** are summarized in Supporting Information.

***S*-Ethyl-3′-thio-5′-amino-2′,5′-dideoxythymidine, 5.** A solution of **17** (1.6 g, 3.9 mmol) in MeOH containing 40%(v/v) $MeNH_2$ (10 mL) was stirred for 8 h at room temperature. After removal of the solvent, the residue was chromatographed on silica gel (eluent; $CHCl_3$/MeOH = 70:1) to give **5** in 30% yield as a colorless oil. IR (KBr) 3500, 3180, 2920, 1680, 1060 cm^{-1}; ^{1}H NMR (DMSO-d_6 containing one drop of D_2O) δ 7.85 (1H, d, J = 1.1 Hz, 6-H), 6.18 (1H, dd, J = 5.2, 7.0 Hz, 1′-H), 3.78 (1H, ddd, J = 4.3, 4.4, 7.2 Hz, 4′-H), 3.53−3.64 (m, 3′-H including HOD), 2.97 (1H, dd, J = 3.9, 13.7 Hz, 5′-H), 2.87 (1H, dd, J = 5.1, 13.7 Hz, 5″-H), 2.73 (2H, q, J = 7.4 Hz, $-SCH_2CH_3$), 2.54 (1H, ddd, J = 5.3, 8.2, 13.6 Hz, 2′-H), 2.35 (1H, ddd, J = 7.0, 7.0, 14.0 Hz, 2″-H), 1.91 (3H, d, J = 0.9 Hz, 5-Me), 1.32 (3H, t, J = 7.4 Hz, $-SCH_2CH_3$); ^{13}C NMR (DMSO-d_6 containing one drop of D_2O) δ 163.82, 150.45, 136.55, 109.61, 86.03, 83.31, 43.15, 41.56, 38.63, 24.60, 15.09, 12.24; FABMS (in glycerol) *m/e* 286 $(M + H)^+$. HRMS. Calcd for $C_{12}H_{20}N_3O_3S$: 286.1225. Found: 286.1245.

3′,5′-Diphthalimido-2′,3′,5′-trideoxythymidine, 18. A solution of **8** (605 mg, 2.0 mmol), potassium phthalimide (1.1 g, 6.0 mmol), and 18-crown-6 in anhydrous DMSO (20 mL) was stirred for 6 h at 160 °C. The reaction mixture was taken up into water and extracted with AcOEt. The organic layer was washed with brine and dried over anhydrous $MgSO_4$. After removal of the solvent, the residue was chromatographed on silica gel (eluent; AcOEt/*n*-hexane = 1:1) to give **18** in 12% yield as a colorless solid. Mp 289.5−290.5 °C; IR (KBr) 3260, 1770, 1700, 1080 cm^{-1}; ^{1}H NMR (DMSO-d_6) δ 11.33 (1H, brs, NH), 7.80−7.87 (8H, m, Ar), 7.72 (1H, d, J = 1.0 Hz, 6-H), 6.45 (1H, dd, J = 7.3, 7.3 Hz, 1′-H), 4.90 (1H, ddd, J = 4.6, 5.9, 10.6 Hz, 3′-H), 4.60 (1H, ddd, J = 6.3, 6.3, 6.3 Hz, 4′-H), 3.99 (1H, dd, J = 7.0, 14.0 Hz, 5′-H), 3.90 (1H, dd, J = 5.5, 14.0 Hz, 5″-H), 2.63 (1H, ddd, J = 4.5, 6.8, 14.0 Hz, 2′-H), 2.50−2.54 (m, 2″-H including DMSO), 1.83 (3H, d, J = 1.0 Hz, 5-Me); ^{13}C NMR (DMSO-d_6) δ 167.75, 167.42, 163.76, 150.38, 136.86, 134.55, 134.50, 131.41, 131.36, 123.10, 109.72, 84.77, 77.12, 50.65, 40.44, 33.99, 12.11; FABMS (in 3-nitrobenzyl alcohol containing 50% glycerol) *m/e* 501 $(M + H)^+$. HRMS. Calcd for $C_{26}H_{21}N_4O_7$: 501.1410. Found: 501.1417.

3′,5′-Diamino-2′,3′,5′-trideoxythymidine, 6. A solution of **18** (60 mg, 0.12 mmol) in MeOH containing 40%(v/v) $MeNH_2$ (2 mL) was stirred for 7 h at room temperature. After removal of the solvent, the residue was taken up into the water and washed with AcOEt. The water phase was evaporated and chromatographed on silica gel (eluent; 2-propanol/28%NH_3(aq)/H_2O = 20:1:1) to give **6** in 62% yield as a colorless solid. Mp 164.5−166.0 °C; IR (KBr) 3350, 3280, 3180, 1700, 1650, 1060 cm^{-1}; $[\alpha]^{25}_D$ +0.50 (c = 1.00, H_2O); ^{1}H NMR (DMSO-d_6 containing one drop of D_2O) δ 7.64 (1H, d, J = 1.5 Hz, 6-H), 6.08 (1H, dd, J = 5.0, 7.0 Hz, 1′-H), 3.45 (1H, ddd, J = 7.0, 7.0, 7.0 Hz, 4′-H), 3.32 (1H, ddd, J = 7.0, 7.0, 7.0 Hz, 3′-H), 2.81 (1H, dd, J = 4.0, 13.5 Hz, 5′-H), 2.74 (1H, dd, J = 5.5, 13.5 Hz, 5″-H), 2.12 (1H, ddd, J = 5.0, 7.9, 13.0 Hz, 2′-H), 2.00 (1H, ddd, J = 7.0, 7.0, 13.9 Hz, 2″-H), 1.79 (3H, d, J = 1.0 Hz, 5-Me); ^{13}C NMR (DMSO-d_6 containing one drop of D_2O) δ 163.74, 150.39, 136.37, 109.31, 87.95, 82.96, 51.86, 43.14, 40.24, 12.13; FABMS (in glycerol) *m/e* 241 $(M + H)^+$. HRMS. Calcd for $C_{10}H_{17}N_4O_3$: 241.1301. Found: 241.1267.

X-ray Analysis of 1. A single crystal of nucleoside **1** suitable for X-ray analysis was obtained from EtOH containing 0.5%(v/v) acetic acid. Measurements were made on a diffractometer with graphite monochromated Mo Kα radiation. A colorless needle crystal of $C_{10}H_{14}N_2O_3S_2$ is orthorhombic, space group $P2_12_12_1$ (No. 19), with a = 5.7703(4) Å, b = 13.323(1) Å, and c = 15.976(1) Å, V = 1228.2(2) Å^3, Z = 4 with calculated density 1.484 g/cm^3. The data were collected at −150 ± 1 °C to a maximum 2θ value of 60.0°. A total of 74 images, corresponding to 222.0° oscillation angles were collected with two different goniometer settings. Exposure time was 3.50 min/deg. The camera radius was 127.40 mm. Readout was performed in the 0.100 mm pixel mode. Data were processed by the PROCESS-AUTO program package. Of the 7759 reflections which were collected, 2044 were unique (R_{int} = 0.095); equivalent reflections were merged. The non-hydrogen atoms were refined anisotropically. Hydrogen atoms were included but not refined. The final cycle of full-matrix least-squares refinement was based on 2036 observed reflections ($I > -3.00\sigma(I)$, $2\theta < 60.02$) and 155 variable parameters and converged (largest parameter shift was 0.00 times its estimated standard deviation) with unweighted and weighted agreement factors of R = 0.054 and R_w = 0.115. The standard deviation of an observation of unit weight was 1.07. The maximum and minimum peaks on the final difference Fourier map corresponded to +0.64 and −0.63 e$^-$/Å^3, respectively. All calculations were performed using the teXsan crystallographic software package of Molecular Structure Corp.

Preparation of Au(I) Complex with 1. A solution of bis(triphenylphosphoranylidene) ammonium bis(2,4-pentanedi-

onato)aurate(I) (PPN[$Au^{I}(acac)_2$]) (46.7 mg, 0.05 mmol) in acetone (1.5 mL) was added dropwise to a solution of **1** (13.7 mg, 0.05 mmol) in acetone (3.0 mL). The reaction mixture was stirred for 1.5 h at room temperature. Crystal data for PPN-[$Au^{I}(acac)_2$] are summarized in the Supporting Information.

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Supporting Information Available: Tables of X-ray crystal data for **10**, **17**, and PPN[$Au^{I}(acac)_2$] and figures of NOE data for **10** and **11α**. This material is available free of charge via the Internet at http:// pubs.acs.org.

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