X-ray Crystal and Molecular Structure Determination of 16β-(4'-Phenoxybutyl)-4-androstene-3,17-dione, 3. A small (0.12 × 0.16 × 0.60 mm) single crystal of **3** grown from acetone solution was determined to be in the monoclinic space group $P2_1$. The unit cell parameters determined from least-squares analysis of the 20 values for 25 reflections are a = 19.803 (4), b = 7.139 (F), and c = 8.849 (2) Å; β = 102.61 (2)°; unit cell volume V = 1221 (2) Å^3. Integrated intensities for 2706 independent reflections having $\theta < 75°$ ($-l \le 24$, $0 \le k \le 8$, $-11 \le l \le 11$) were measured by 20 scans on an Enraf-Nonius CAD-4 diffractometer using Cu Kα radiation. Reflections 151, 125, 1011, and 622 maintained intensity within 8% during data collection. Lp and polarization corrections applied. The structure was solved with the MULTAN program.[9] All hydrogen atoms were found from ΔF maps. The positional parameters of all atoms and anisotropic displacement parameters for non-hydrogen atoms (402 variables) were refined by full-matrix least-squaring with the 2122 reflections for which $F_o^2 > 1.75\sigma_F$. The isotropic displacement parameters for hydrogen atoms were not refined and fixed equal to the values of equivalent displacement parameters for correspondent non-hydrogen atoms. The final R, R_w, and S factors were 7.6%, 7.8%, and 2.36, respectively. The weights used were the quantities $1/\sigma_F^2$,[10] using 0.03 rather than 0.01 as the instability correction. Final difference maps showed the strongest peak of ±0.55 e Å^{-3}. The ratio of maximum least-squares shift to error in final refinement cycle $(\Delta/\sigma)_{max}$ was 0.8. The relatively high reliability index is due to thermal liberation of the extended chain, the absence of strong packing forces such as hydrogen bonding, and the small crystal size. Computations were performed with the XRAY76.[11] Atomic scattering factors were taken from the *International Tables for X-ray Crystallography*.[12]

Acknowledgment. This work was supported in part by Grant AM-26546 from the National Institute of Arthritis, Diabetes, and Digestive and Kidney Diseases (to W.L.D.) and Project MR.I.9 from the Polish Academy of Sciences (to Z.G., P.G., and Z.W.).

Registry No. **1**, 979-02-2; **3**, 119679-97-9; **4a**, 119679-98-0; **6**, 119693-94-6; **7a**, 119679-99-1; **7b**, 119680-01-2; **7c**, 119680-02-3; **8**, 119680-00-1; **9**, 25862-97-9; **10a** (isomer 1), 60533-46-2; **10a** (isomer 2), 60533-47-3; **10b** (isomer 1), 60533-48-4; **10b** (isomer 2), 60558-05-6; **10c** (isomer 1), 60533-49-5; **10c** (isomer 2), 60533-50-8; 4-phenoxybutyl bromide, 1200-03-9; phenyl bromide, 108-86-1; 16-dehydropregnenolone, 1162-53-4; ethylmagnesium bromide, 925-90-6; *n*-propyl iodide, 107-08-4; *n*-butyl bromide, 109-65-9.

Supplementary Material Available: Tables of positional and equivalent isotropic thermal parameters, anisotropic thermal parameters for non-hydrogen atoms, figures showing selected bond angles and torsion angles in **3**, and crystal and molecular packing diagram for **3** (5 pages). Ordering information is given on any current masthead page.

General Method for the Preparation of N^3- and O^4-Substituted Uridine Derivatives by Phase-Transfer Reactions

Mitsuo Sekine

Department of Environmental Chemistry and Engineering, Tokyo Institute of Technology, Nagatsuta, Midoriku, Yokohama 227, Japan

Received October 27, 1988

A general method for regioselective introduction of a variety of protecting groups into the uracil residue of 1 has been developed by use of the phase-transfer reaction. Under such conditions, acyl groups such as benzoyl, *p*-toluyl, *p*-anisoyl, (2,2,2-trichloro-1,1-dimethylethoxy)carbonyl, and (allyloxy)carbonyl were introduced to both the N^3- and O^4-positions of 1. The O^4-acylated species (**3a–f**) initially formed could be readily converted upon warming at 60–70 °C to the N^3-acylated products (**2a–f**), which were obtained ultimately in high yields. N^3-Alkylation occurred under similar conditions when alkylating agents such as methyl iodide, benzyl bromide, and allyl bromide were employed in place of acylating agents. Reactions of 1 with 2-nitrobenzenesulfenyl chloride and triphenylmethanesulfenyl chloride gave exclusively N^3-sulfenylated products (**11** and **12**) in quantitative yields, while sulfonylation of 1 with 2,4,6-triisopropylbenzenesulfonyl chloride led to the O^4-substituted product (**13**), which reacted with ammonia to give a cytidine derivative (**14**).

Introduction

In the current strategy for oligoribonucleotide synthesis, a number of research groups have suggested that the imide moiety of uridine should be protected during chain elongation to avoid side reactions.[1] It is apparently desirable that such a protecting group can be introduced conveniently and, if possible, selectively without modification of other functional groups such as ribose hydroxyl groups. In this respect, Ogilvie[2] reported a suggestive study of tetrabutylammonium fluoride catalyzed N^3-alkylations of uridine and thymidine derivatives involving the 2-cyanoethylation[2d] of thymidine and 5'-*O*-monomethoxytrityl-thymidine with acrylonitrile without O-alkylation at the sugar moieties. On the other hand, Claesen[3] has recently reported the regioselective introduction of the 2-((4-nitrophenyl)sulfonyl)ethyl group into the O^4-position of uridine by treatment with 4-nitrophenyl vinyl sulfone in the presence of tetrabutylammonium hydroxide as the base. Later, Engels[4] showed from his 2D NMR study that

(1) (a) Reese, C. B.; Ubasawa, A. *Tetrahedron Lett.* **1980**, *21*, 2265. (b) Reese, C. B.; Ubasawa, A. *Nucleic Acids Symp. Ser.* **1980**, *7*, 5. (c) Hartog, J. A. J.; Wille, G.; Scheublin, R. A.; van Boom, J. H. *Biochemistry* **1982**, *21*, 1009. (d) Rayner, B.; Reese, C. B.; Ubasawa, A. *J. Chem. Soc., Chem. Commun.* **1980**, 972. (e) Ohtsuka, E.; Wakabayashi, T.; Ikehara, M. *Chem. Pharm. Bull.* **1981**, *29*, 759. (f) Divaker, K. J.; Reese, C. B. *J. Chem. Soc., Perkin Trans. 1* **1982**, 1171. (g) Reese, C. B.; Richards, K. H. *Tetrahedron Lett.* **1985**, *26*, 2245.

(2) (a) Ogilvie, K. K.; Beaucage, S. L.; Gillen, M. F. *Tetrahedron Lett.* **1978**, 1663; (b) **1978**, 3203; (c) Ogilvie, K. K.; Beaucage, S. L.; Gillen, M. F.; Entwistle, D. W. *Nucleic Acids Res.* **1979**, *6*, 2261. (d) Ogilvie, K. K.; Beaucage, S. L. *Ibid.* **1979**, *7*, 805.

(3) Claesen, C. A. A.; Pistorius, A. M. A.; Tesser, G. I. *Tetrahedron Lett.* **1985**, *26*, 3859.

(4) Mag, M.; Engels, J. W. *Nucleic Acids Res.* **1988**, *16*, 3525.

0022-3263/89/1954-2321$01.50/0

Table I. Conditions and Results of the Phase-Transfer Reaction of 1 and 6 with Various Electrophiles[a]

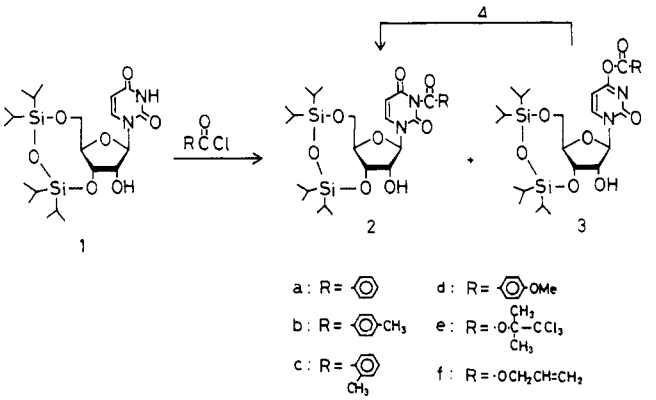
	initial reaction		O–N rearrangement			
nucleoside	RX equiv	time, min	temp, °C	time, min	product	yield, %
1	BzCl 1.3	30	rt[d]	16 h	**2a**	90
1	BzCl 1.3	30	60	15	**2a**	95
1	*p*-TolCl 1.3	45	60	45	**2b**	96
1	*o*-TolCl 1.3	60	70	2 h	**2c**	63
1	AnCl 2.0	60	60	45	**4**[b]	74
	+0.2	30				
1	TCDME-Cl 1.3	3 h	70	3.5 h	**2e**	93
1	AOC-Cl 4.0 × 4	2 h × 4[c]	65	6 h	**2f**	78
					5	19
1	AOC-Cl 32	60	70	5 h	**2f**	19
					5	75
1	BnBr 5	18 h			**7**	93
6	BnBr 1.3	4 days			**8**	90
6	MeI 1.3	5 days			**9**	86
1	AllylBr 5	2 days			**10**	87
1	2-NBSCl 1.3	10			**11**	98
1	TrSCl 1.3	2 h			**12**	98
1	TPSCl 1.3	15 h			**13**	96

[a] The reaction was carried out by using 0.5 mmol of 1 or 6 in the presence of 0.02 mmol of tetrabutylammonium bromide and 4 mmol of 0.2 M Na_2CO_3. [b] As described in the text, the product **2d** could not be purified and therefore was converted to **4**. [c] Every 2 h, 4 equiv of the reagent was added, and this interval addition was repeated four times. [d] Room temperature.

this type of Michael reaction gave not O^4- but N^3-alkylated uridine derivatives.

These results led us to consider that it might be possible to generate selectively a reactive charged imide anion, which was expected to allow a variety of N^3- or O^4-substitutions with appropriate electrophiles in organic phases, by using quarternary ammonium salts under certain conditions of phase-transfer (P-T) reactions.[5] Indeed, such P-T reactions have been first introduced into nucleic acid chemistry by Seela,[6] who has extensively studied his glycosylation process in which ionized purine bases could attack easily the anomeric carbon of 1-halogeno deoxyribose derivatives. Although Seela's successful results suggested the potential utility of the P-T reaction in this field, further extended studies have not been reported yet except for recent work of 2′,3′-O-methylenation of uridine derivatives described by Reese.[7] Therefore, to test the possibility mentioned above, we started to study the P-T catalyst mediated acylation of 3′,5′-*O*-(1,1,3,3-tetraisopropyldisiloxane-1,3-diyl)uridine (**1**)[8] as a typical substrate having an unprotected 2′-hydroxyl group. In connection with this study, Yamasita[9] has recently reported the selective benzoylation of α,α,α-trifluorothymidine by treatment with benzoyl chloride in the presence of triethylamine in dimethylacetamide, giving rise to the N^3-benzoylated product. Inoue and Ohtsuka[10] also applied this procedure to the preparation of compound **2**, which was obtained in 71% yield. This compound is a versatile intermediate in nucleoside and nucleotide chemistry since not only various protecting groups[11,12] but also the methyl group[10] can be introduced directly into the unprotected 2′-hydroxyl group of **2**.

Scheme I



In this paper, we report the detailed study of the selective N^3- or O^4-substitution of appropriately protected uridine derivatives (**1** and **6**) by means of a phase-transfer process.

Results and Discussion

When **1** (Scheme I) was allowed to react with benzoyl chloride in a two-phase solution of dichloromethane and 0.2 M aqueous sodium carbonate in the presence of a catalytic amount of tetrabutylammonium bromide (TBAB) at room temperature for 30 min, TLC showed two new spots having R_f values of 0.79 and 0.40 in CH_2Cl_2–MeOH (20:1, v/v) in a ratio of 1:3. As judged from TLC, chromatography of this mixture on a silica gel column gave 28% of **2a**, which was identified with authentic material.[10a] The product of R_f 0.40 was rather unstable during chromatography, to be decomposed to the parent nucleoside **1**. However, it was surprisingly found that the slower moving product was gradually converted to **2a** upon standing after extraction with dichloromethane. When the dichloromethane extract containing both products was kept at room temperature for 16 h, the slower moving material completely disappeared so that **2a** existed as almost the sole component in the solution. Silica gel

(5) (a) Starks, C. M.; Liotta, C. *Phase Transfer Catalysis*; Academic Press: New York, 1978. (b) Keller, W. *Phase-Transfer Reactions*; Georg Thieme Verlag: New York, 1987; Fluka-Compendium Vols. 1 and 2.

(6) (a) Winkeler, H.-D.; Seela, F. *J. Org. Chem.* **1983**, *48*, 3119. (b) Seela, F.; Steker, H. *Tetrahedron Lett.* **1984**, *25*, 5017. (c) Seela, F.; Kehne, A. *Biochemistry* **1985**, *24*, 7556. (d) Seela, F.; Steker, H. *J. Chem. Soc., Perkin Trans 1* **1985**, 2573. (e) Seela, F.; Kaiser, K. *Nucleic Acids Res.* **1986**, *14*, 1825.

(7) Norman, D. G.; Reese, C. B.; Serafinowska, H. T. *Synthesis* **1985**, 75.

(8) Markiewicz, W. T. *J. Chem. Res., Miniprint* **1979**, 173.

(9) Yamashita, J.; Takeda, S.; Matsumoto, H.; Terada, T.; Unemi, N.; Yasumoto, M. *Chem. Pharm. Bull.* **1987**, *35*, 2090.

(10) (a) Inoue, H.; Hayase, Y.; Imura, A.; Iwai, S.; Miura, K.; Ohtsuka, E. *Nucleic Acids Res.* **1987**, *15*, 6131. (b) Inoue, H.; Hayase, Y.; Asaka, M.; Imura, A.; Iwai, S.; Miura, K.; Ohtsuka, E. *Nucleic Acids Symp. Ser.* **1985**, *16*, 1650.

(11) Welch, C. J.; Chattopadhyaya, J. *Acta Chem. Scand., Ser. B* **1983**, *B37*, 147.

(12) Sandstroem, A.; Kwiatkowski, M.; Chattopadhyaya, J. *Acta Chem. Scand., Ser. B* **1985**, *B39*, 273.

Table II. ^{13}C NMR Spectral Data of N^3- and O^4-Substituted Uridine Derivatives[a]

nucleoside	C-4	C-2	C-6	C-5	C-1′	C-4′	C-2′	C-3′	C-5′	others
1	164.14	150.69	139.87	101.99	90.95	81.81	75.09	68.43	59.95	17.33, 16.96, 13.45, 13.01, 12.43
2a	161.96	148.72	139.59	101.42	90.75	81.83	74.81	68.67	59.97	17.05, 16.69, 13.10, 12.66, 12.22; 168.39 (C=O), 134.91, 131.10, 130.23, 128.91
3a	162.54	154.72	145.51	97.47	91.84	81.83	74.59	68.08	59.75	17.05, 16.76, 13.17, 12.66, 12.22; 168.39 (C=O), 134.25, 130.30, 128.55
2f	160.13	149.38[b]	139.22	101.13	90.82	81.90	75.03	68.59	59.89	17.27, 16.83, 13.25, 12.74, 12.37; 147.77[b] (C=O), 129.86, 120.21, 70.05
10	162.13	150.19	137.61	101.20	90.96	81.61	75.10	68.67	59.97	17.12, 16.76, 13.25, 12.74, 12.30; 131.25, 117.94, 42.78
11	162.178	150.85	139.15[c]	100.91	91.55	81.97	75.10	68.81	60.04	17.20, 16.83, 13.25, 12.81, 12.37; 142.80, 138.34,[c] 134.69, 125.84, 122.62
12	162.91	151.43	137.90	100.32	91.92	81.75	74.81	68.81	60.11	17.20, 16.90, 13.39, 12.74, 12.44; 142.22 (SC), 130.81, 127.23
13	167.28	154.56	145.64	94.61	91.61	81.96	74.87	68.14	59.73	17.25, 16.96, 13.38, 12.87, 12.43; 153.61, 151.20, 150.98, 140.01, 130.51, 124.07, 34.29, 29.68, 24.71, 24.35, 23.47

[a] The solvent used was $CDCl_3$. [b,c] These signals were tentatively assigned as listed in the table. Therefore, there should be another possibility.

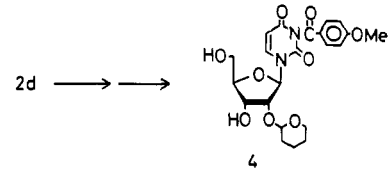
column chromatography gave ultimately 90% of **2a**. Conversion of the more polar product to **2a** could be accelerated by warming at 60 °C in 1,2-dichloroethane. Under these conditions, it took only 15 min for complete conversion to **2a**. In this case, **2a** was obtained in 95% yield.

These results suggested that the major product initially obtained should be the O^4-benzoylated species (**3a**). Further structural proof of **3a** was evidenced by ^{13}C NMR analysis of the extract containing a ca. 1:1 mixture of **2a** and **3a**. The C-5 carbon of **3a** appeared at 97.47 ppm while those of the parent nucleoside **1** and the ultimate product **2a** emerged at 101.99 and 101.42 ppm, respectively, as shown in Table II. The distinguishable difference in the chemical shift of C-5 between O^4- and N^3-acylated uridine derivatives has already been established.[13] It should be emphasized that such an O^4-acylated species could be observed for the first time as unstable but visible material on TLC. It was somewhat surprising that a great difference in R_f values between the regioisomers **2a** and **3a** was observed. When the same procedure as described by Ohtsuka[10a] was followed to obtain the authentic sample of **2a**, TLC of this mixture showed exclusive formation of **2a** from the initial stage.

Next, the effect of different solvents on the O–N rearrangement of **3a** to **2a** was examined in detail. For this purpose, a ca. 1:1 mixture of **2a** and **3a** obtained after the extractive workup was used, and 15 kinds of organic solvents were tested. The rearrangement was monitored by TLC. Almost none of the solvents tested affected this intramolecular rearrangement significantly. The reaction rates in nonpolar solvents such as hexane, benzene, toluene, and carbon tetrachloride were similar to those in rather polar solvents such as dimethylformamide, dimethylacetamide, and dimethyl sulfoxide. Similar reaction rates were also observed in solvents having medium polarity, such as dichloromethane, 1,2-dichloroethane, ether, ethyl acetate, acetone, and acetonitrile. In the solvents described above, the reactions were completed in ca. 8 h. In dioxane and tetrahydrofuran, the rearrangements proceeded slightly faster than in the other solvents examined and were completed in 5 h and 6 h, respectively. On the basis of these results, it was concluded that the reaction of **1** with benzoyl chloride in dimethylacetamide[10a] giving rise to **2a** involved direct formation of **2a** from the beginning without a process of rearrangement of **3a** to **2a**. The competitive formation of O^4-acylated products is characteristic of the present P-T reaction (vide infra).

(13) Kamimura, T.; Masegi, T.; Sekine, M.; Hata, T. *Tetrahedron Lett.* **1984**, *25*, 4241.

Scheme II



4

To see if the O–N rearrangement was general and to extend the synthetic utility of the present N^3-acylation procedure, reactions of **1** with various kinds of acyl chlorides were carried out. These results are shown in Table I. Among the acyl chlorides examined, *p*-tolyl chloride underwent similarly predominant O^4-acylation with **1** over N^3-acylation with a more than 80% selectivity. The intramolecular rearrangement of **3b** to **2b**[14] required 45 min at 60 °C in 1,2-dichloroethane. This reaction also proceeded cleanly to give **2b** in a high yield of 96%.

However, the reaction of **1** with *p*-anisoyl chloride under similar conditions gave a mixture of N^3- and O^4-anisoylated products (**2d** and **3d**) and an unknown product. The latter was formed in ca. 10% yield from TLC. After the O–N rearrangement, it was difficult to separate **2d** from the side product. Therefore, in this case, **2d** was in situ tetrahydropyranylated and then desilylated in the usual manner. Thus, N^3-anisoyl-2′-*O*-(tetrahydropyran-2-yl)uridine (**4**)[15c] (Scheme II) was obtained as a pure compound in an overall yield of 72% from **1**. This compound has been used as a key intermediate in oligoribonucleotide synthesis.[15c,16-18] In the case of 2,2,2-trichloro-1,1-dimethylethyl chloroformate (TCDME-Cl), the O^4-acylation took place relatively slowly but still predominantly over the N^3-acylation with a selectivity of more than 90%. It was, however, difficult to estimate the ratio of these two reactions from TLC. In this case, the O^4-acylated species did not appear clearly on TLC by a UV detector at 254 nm. A similar problem was also encountered in the case of **2f**. However, gentle heating of the TLC plate for a few minutes resulted in the appearance of a strong UV absorbing spot like uridine so that the approximate ratio of the N^3-

(14) Zhou, X.-X.; Chattopadhyaya, J. *Tetrahedron* **1986**, *42*, 5149.

(15) (a) Kamimura, T.; Masegi, T.; Urakami, K.; Honda, S.; Sekine, M.; Hata, T. *Chem. Lett.* **1983**, 1051. (b) Kamimura, T.; Tsuchiya, M.; Urakami, K.; Koura, K.; Sekine, M.; Hata, T. *J. Am. Chem. Soc.* **1984**, *106*, 4552. (c) Sekine, M.; Nishiyama, S.; Kamimura, T.; Osaki, Y.; Hata, T. *Bull. Chem. Soc. Jpn.* **1985**, *58*, 850.

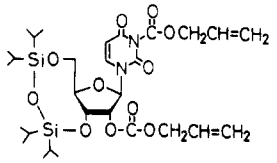
(16) Hata, T.; Kamimura, T.; Urakami, K.; Kohno, K.; Sekine, M.; Kumagai, I.; Shinozaki, K.; Miura, K. *Chem. Lett.* **1987**, 117.

(17) Sekine, M.; Heikkila, J.; Hata, T. *Tetrahedron Lett.* **1987**, *28*, 5691.

(18) Sekine, M.; Iwase, R.; Masuda, N.; Hata, T. *Bull. Chem. Soc. Jpn.* **1988**, *61*, 1669.

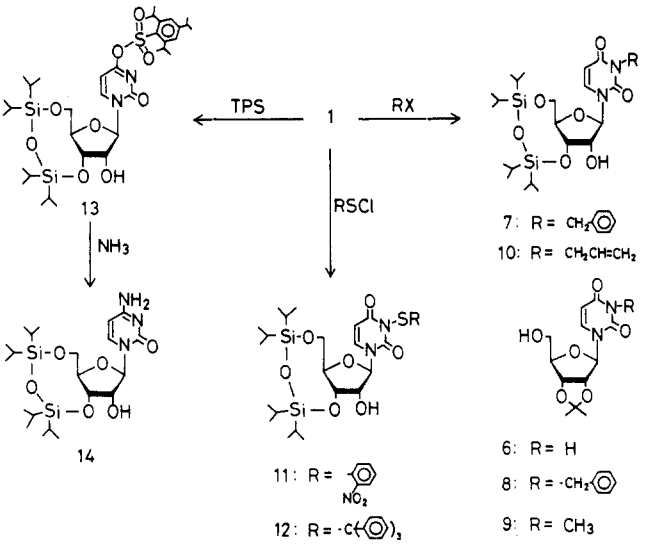
and O^4-acylated species could be read. This poorly visible O^4-acylated intermediate **3e** was converted to the intense spot corresponding to **2e**[19] upon warming in 1,2-dichloroethane at 70 °C for 3 h.[20] To measure the UV curve of **3e** and analyze spectrophotometrically the O–N rearrangement, the extract containing a mixture of **2e** and **3e**, which was obtained after the acylation, was directly monitored by a UV spectrophotometer as the rearrangement went on. The UV spectra at appropriate times are drawn in Figure 1 (supplementary material). The UV λ_{max} of **3e** could be read as approximately 296 nm. Since it is known that O^4-methyluridine exhibited its λ_{max} value at 274 nm in water,[21] the extreme UV shift of **3e** is abnormal. However, since the same tendency was observed in the case of **3f**,[22] this phenomenon seemed to be common in O^4-carbonate ester derivatives. This strong bathochromic shift is the reason why only a faint spot was detected on TLC. Figure 1 shows explicitly three isosbestic points at 219, 228, and 280 nm. The presence of these isosbestic points indicates that this reaction was a type of A–B conversion, i.e., an intramolecular rearrangement, since no reagents were present in the extract and the reaction was independent of the concentration, as shown in this UV level experiment, which was completed also in 3 h.

Unlike *p*-toluyl chloride, *o*-toluyl chloride did not give a high yield of the N^3-acylated product (**2c**). Interestingly, the N^3-acylated product (**2c**) was more predominantly formed over **3c**, in a ratio of 4:1. Even upon heating at 70 °C for 2 h, the ratio was not essentially changed. Compound **3c** was found to be thermally stable under these conditions but still too unstable during silica gel column chromatography, which was attempted to characterize **3c**. Probably, the *o*-methyl group inhibited the intramolecular acyl transfer reaction owing to steric hindrance. On the other hand, allyl chloroformate did not react with **1** under similar conditions. To obtain a satisfactory yield of **2f**, repeated stepwise addition of large excess amounts of allyl chloroformate (AOC-Cl) and sodium carbonate was required. This was due probably to competitive hydrolysis of the reagent. When a large excess of reagent was added at once to a two-phase solution containing **1**, sodium carbonate, and TBAB, a considerable amount of diacylated product (**5**) was formed. The (allyloxy)carbonyl (AOC) group has recently been introduced in the uracil moiety by Hayakawa and Noyori,[23] who tentatively assigned the position of the AOC group attached to the uracil ring as the N^3-nitrogen. In the present P-T reaction, the location of the AOC group was confirmed to be position 3 by its ^{13}C NMR[13] as well (Table II). The N^3- and O^4-acylated species **2b–f** and **3b–f** were also well separated on TLC with considerably different R_f values as observed in the case of **2a** and **3a** (see Experimental Section). This may be because the unnatural structure of **3** causes disorder of the uracil ring, producing a new basic N^3-nitrogen of the C=N—C bond compared with **2**, which preserves the original skeleton.



5

Scheme III



It is noteworthy that the benzoyl,[10–12] *p*-toluyl,[14] and (2,2,2-trichloro-1,1-dimethylethoxy)carbonyl (TCDME)[19] groups could be cleanly and selectively introduced into the imide function of **1** since these protecting groups have been utilized in nucleotide chemistry as well as oligoribonucleotide synthesis. These fascinating results led us to examine further if the present P-T reaction can be applied to the preparation of N^3-alkylated or sulfenylated uridine derivatives. Benzylation of **1** and 2′,3′-*O*-isopropylideneuridine (**6**)[24] with benzyl bromide under similar P-T conditions gave the corresponding N^3-substituted uridine derivatives **7** and **8**[25] in 93% and 90% yields, respectively (Scheme III). Likewise, methylation of **6** gave 2′,3′-*O*-isopropylidene-N^3-methyluridine (**9**)[26] in 86% yield. Allylation of **1** with allyl bromide gave N^3-allyl-3′,5′-*O*-(1,1,3,3-tetraisopropyldisiloxane-1,3-diyl)uridine (**10**) in a high yield.

Chattopadhyaya[28] and Takaku[29] have recently reported the use of N^3-sulfenylated uridine derivatives **11** and **12** for the synthesis of 2′-*O*-methyluridine and oligouridylates, respectively. The former was synthesized by the sulfenylation of uridine with 2 equiv of 2-nitrobenzenesulfenyl chloride via trimethylsilylation followed by desilylation and subsequent protection with the cyclic silyl group in an overall yield of 73%.[28] The latter was directly obtained in 73% yield by reaction of **1** with 2 equiv of triphenylmethanesulfenyl chloride in dichloromethane in the presence of 2 equiv of triethylamine for 8 h.[29] Application of our new approach to the synthesis of these compounds gave more smooth and quantitative formation of **11** and **12** with the use of much smaller amounts of the reagent, as shown in Table I. Moreover, the exclusive formation of the N^3-sulfenylated products was suggested by the ^{13}C NMR spectra of compounds **11** and **12**, which exhibited C-5 signals of the N^3-substituted type at 100.91 and 100.32 ppm, respectively (see Table II).

(19) Kamimura, T.; Masegi, T.; Hata, T. *Chem. Lett.* **1982**, 965.
(20) The TCDME group was also used for protection of the amino groups of cytidine, adenosine, and guanosine: Schneiderwind, R. G. K.; Ugi, I. *Tetrahedron* **1983**, *39*, 2207.
(21) Robins, M. J.; Naik, S. R. *Biochemistry* **1971**, *10*, 3591.
(22) Since the reaction of **1** with allyl bromide gave a mixture of **3f** and 2′-acylated species, the spectrophotometric analysis of this extract was not attempted.
(23) Hayakawa, Y.; Kato, H.; Uchiyama, M.; Kajino, H.; Noyori, R. *J. Org. Chem.* **1986**, *51*, 2400.
(24) Tomasz, J. In *Nucleic Acid Chemistry*; Townsend, L. B., Tipson, R. S., Eds.; John Wiley & Sons: New York, 1978; Vol. 2, p 765.
(25) Sasaki, T.; Minamoto, K.; Suzuki, H. *J. Org. Chem.* **1973**, *38*, 598.
(26) Kochetkov, N. K.; Budovskii, E. I.; Shibaev, V. N. *Biochim. Biophys. Acta* **1961**, *53*, 415.
(27) This footnote was deleted on revision.
(28) Welch, C. J.; Bazin, H.; Heikkila, J.; Chattopadhyaya, J. *Acta Chem. Scand., Ser. B* **1985**, *B39*, 203.
(29) Takaku, H.; Imai, K.; Nagai, M. *Chem. Lett.* **1988**, 857.

Little has been known about reactions of the uracil moiety of uridine derivatives with sulfonyl chlorides[13,30] though the reaction of the uracil base with condensing agents such as (arylsulfonyl)azoles has recently been well described. Therefore, sulfonylation of 1 with 2,4,6-triisopropylbenzenesulfonyl chloride (TPSCl)[31] was studied. The sulfonylation occurred regioselectively and cleanly at the O^4-position of 1 to give the sulfonate ester (13) in a nearly quantitative yield. It was found that this compound was thermally stable and did not allow the O–N rearrangement like the O^4-acylated products **3a–f**. When 13 was heated at 70 °C for 2 h in 1,2-dichloroethane, it remained unchanged. In aqueous pyridine, however, 13 was rapidly decomposed to 1. Treatment of 13 with concentrated ammonia–dioxane (1:3, v/v) afforded the corresponding cytidine derivative (14) in 85% yield. Such U–C conversions using ammonolysis of O^4-substituted uridine derivatives have been reported in several laboratories.[32]

Conclusion

The O–N rearrangement of acyl groups found throughout this study is recognized as a kind of Chapman rearrangement.[33] To our knowledge, nobody has reported this type of acyl migration in the field of nucleic acids. This is probably because O^4-acylated species were too unstable for characterization so that only N^3-acylated species have been obtained. To date, little attention has been paid to the phase-transfer reaction in the synthesis of nucleic acid derivatives except for a number of pioneering studies on glycosylation reported by Seela.[6] As exemplified by studies of Seela,[6] Reese,[7] and us, the phase-transfer reaction has proved to be useful in this field. It should be noted that all the phase-transfer reactions described have proceeded cleanly without coloration which has unexceptionally been observed in more conventional N^3-acylation procedures such as acid chloride–pyridine system. The base used in the aqueous phase was uniformly 0.2 M sodium carbonate, which exhibited relatively week basicity, i.e., pH 11.5, which is sufficient to produce the anion species of the uracil moiety that has a dissociation constant of pK_a 9.25.[34] This simplicity is in contrast to the fact that conventional reactions for introduction of protecting groups required their inherent strong bases. With these merits we emphasize that the present phase-transfer N^3/O^4-substitution could be widely applied as a practical tool to the preparation of valuable synthetic intermediates in nucleotide chemistry.

Experimental Section

^{1}H NMR spectra were recorded at 60 MHz on a Hitachi 24B spectrometer with Me_4Si as the internal standard. ^{13}C NMR spectra were measured at 22.4 MHz on a JEOL FX90Q instrument as solutions in $CDCl_3$. UV spectra were obtained on a Hitachi 220A spectrophotometer. TLC was performed on precoated TLC plates of silica gel 60 F-254 (Merck) by using the following solvent systems: CH_2Cl_2–MeOH, 40:1, v/v (solvent I), CH_2Cl_2–MeOH, 20:1, v/v (solvent II), CH_2Cl_2–MeOH, 9:1, v/v (solvent III). Column chromatography was performed with silica gel C-200 purchased from Waco Co. Ltd., and a minipump for a goldfish bowl was conveniently used to attain sufficient pressure for rapid chromatographic separation.

General Procedure for N^3- and/or O^4-Substitution of 3′,5′-*O*-(1,1,3,3-Tetraisopropyldisiloxane-1,3-diyl)uridine (1) and 3′,5′-*O*-Isopropylideneuridine (6). A mixture of 1[8] or 6[24] (0.5 mmol) Na_2CO_3 (424 mg, 4 mmol), and tetrabutylammonium bromide (7 mg, 0.02 mmol) was dissolved in a two-phase solution of CH_2Cl_2–H_2O (10–20 mL). An appropriate electrophile was added to the mixture with vigorous stirring. Vigorous stirring was continued at room temperature until 1 or 6 had disappeared on TLC. Then the mixture was transferred into a separatory funnel. The organic phase was collected, and the aqueous phase was extracted with CH_2Cl_2 (20 mL × 2). The extracts were combined, dried over Na_2SO_4, filtered, and evaporated under reduced pressure. The residue was chromatographed on a column of silica gel (15–20 g) with CH_2Cl_2–hexane/CH_2Cl_2–MeOH (100:0/98:2, v/v) to give the product listed in Table I. In the case of the acylation of 1, the residue was dissolved in 1,2-dichloroethane (5 mL) and the solution was kept at room temperature or warmed at an appropriate temperature for the time listed in Table I. After the O–N rearrangement was completed, the solvent was removed by evaporation under reduced pressure and the residue was similarly chromatographed. The detailed conditions and results are summarized in Table I.

***N*^{3}-Benzoyl-3′,5′-*O*-(1,1,3,3-tetraisopropyldisiloxane-1,3-diyl)uridine (2a).**[10-12] R_f 0.55 (solvent I), 0.79 (solvent II); ^{1}H NMR ($CDCl_3$) δ 1.07 (24 H, m, $(CH_3)_2CH$), 2.50 (4 H, br, $(CH_3)_2CH$), 3.80–4.60 (5 H, m, 2′,3′,4′,5′-H), 5.68 (1 H, s, 1′-H), 5.73 (1 H, d, J = 8 Hz, 5-H), 7.10–8.10 (6 H, m, 6-H and Ar H). Anal. Calcd for $C_{28}H_{42}N_2O_8Si_2$: C, 56.92; H, 7.17; N, 4.74. Found: C, 57.49; H, 7.19; N, 4.61.

3a: R_f 0.19 (solvent I), 0.40 (solvent II).

***N*^{3}-*p*-Toluyl-3′,5′-*O*-(1,1,3,3-tetraisopropyldisiloxane-1,3-diyl)uridine (2b):**[14] R_f 0.57 (solvent I), 0.81 (solvent II); ^{1}H NMR ($CDCl_3$) δ 1.06 (24 H, m, $(CH_3)_2CH$), 2.40 (3 H, s, $ArCH_3$), 2.90 (1 H, br, OH), 3.95–4.55 (5 H, m, 2′,3′,5′-H), 5.70 (1 H, s, 1′-H), 5.74 (1 H, d, J = 8 Hz, 5-H), 7.21 (2 H, d, J = 8 Hz, Ar H), 7.72 (1 H, d, J = 8 Hz, 6-H). Anal. Calcd for $C_{29}H_{44}N_2O_8Si_2 \cdot H_2O$: C, 56.74; H, 7.39; N, 4.56. Found: C, 56.84; H, 7.40; N, 4.56.

3b: R_f 0.20 (solvent I), 0.50 (solvent II).

***N*^{3}-*o*-Toluyl-3′,5′-*O*-(1,1,3,3-tetraisopropyldisiloxane-1,3-diyl)uridine (2c)**: R_f 0.67 (solvent I), 0.81 (solvent II); ^{1}H NMR ($CDCl_3$) δ 1.06 (24 H, m, $(CH_3)_2CH$), 1.74 (4 H, m, $(CH_3)_2CH$), 2.67 (3 H, s, $ArCH_3$), 2.84 (1 H, br, OH), 3.90–4.55 (5 H, m, 2′,3′,5′-H), 5.67 (1 H, s, 1′-H), 5.72 (2 H, d, J = 8 Hz, 5-H), 7.30 (3 H, m, Ar H), 7.67 (1 H, d, J = 8 Hz, 6-H). Anal. Calcd for $C_{29}H_{44}N_2O_8Si_2 \cdot H_2O$: C, 56.74; H, 7.39; N, 4.56. Found: C, 56.93; H, 7.53; N, 4.58.

3c: R_f 0.20 (solvent I), 0.50 (solvent II).

2d: R_f 0.46 (solvent I), 0.77 (solvent II).

3d: R_f 0.15 (solvent I), 0.39 (solvent II).

***N*^{3}-((2,2,2-Trichloro-1,1-dimethylethoxy)carbonyl)-3′,5′-*O*-(1,1,3,3-tetraisopropyldisiloxane-1,3-diyl)uridine (2e):**[19] ^{1}H NMR ($CDCl_3$) δ 1.04 (24 H, s, $(CH_3)_2CH$), 2.07 (6 H, s, $(CH_3)_2CO$), 2.83 (1 H, m, OH), 4.12 (5 H, m, 2′,3′,4′,5′-H), 5.66 (1 H, s, 1′-H), 5.67 (1 H, d, J = 8 Hz, 5-H), 5.79 (1 H, d, J = 8 Hz, 6-H). Anal. Calcd for $C_{26}H_{43}N_2O_9Si_2Cl_3$: C, 45.25; H, 6.28; N, 4.06. Found: C, 45.14; H, 6.21; N, 4.13.

***N*^{3}-((Allyloxy)carbonyl)-3′,5′-*O*-(1,1,3,3-tetraisopropyldisiloxane-1,3-diyl)uridine (2f)**: R_f 0.47 (solvent I), 0.80 (solvent II); ^{1}H NMR ($CDCl_3$) δ 1.05 (24 H, s, $(CH_3)_2CH$), 3.02 (1 H, s, OH), 4.12 (5 H, m, 2′,3′,4′,5′-H), 4.85 (2 H, d, J = 5 Hz, OCH_2), 5.92 (2 H, m, C=CH_2), 5.66 (1 H, d, J = 8 Hz, 5-H), 5.67 (1 H, s, 1′-H), 5.48–6.34 (1 H, m, CH=C), 7.65 (1 H, d, J = 8 Hz, 6-H). Anal. Calcd for $C_{25}H_{42}N_2O_9Si_2$: C, 52.61; H, 7.42; N, 4.91. Found: C, 53.11; H, 7.75; N, 4.96.

3f: R_f 0.19 (solvent I), 0.50 (solvent II).

***N*^{3},2′-*O*-Bis((allyloxy)carbonyl)-3′,5′-*O*-(1,1,3,3-tetraisopropyldisiloxane-1,3-diyl)uridine (5)**: R_f 0.71 (solvent I); ^{1}H NMR ($CDCl_3$) δ 1.04 (24 H, s, $(CH_3)_2CH$, 3.70–4.70 (4 H, m, 3′,4′,5′-H), 4.61 (2 H, d, J = 5 Hz, OCH_2), 2 H, d, J = 5 Hz, OCH_2),

(30) (a) Baerwolff, D.; Demirov, G. D.; Golovinskii, E. V. Ger. Patent 140,254, 1980; *Chem. Abstr.* **1980**, *93*, P168560b; (b) Kawada, M.; Matsumoto, K.; Tsurushima, M. Jpn. Patent 62-89667, 1987; *Chem. Abstr.* **1987**, *106*, P214307m.

(31) Lohrman, R.; Khorana, H. G. *J. Am. Chem. Soc.* **1966**, *88*, 829.

(32) (a) Sung, W. *J. Chem. Soc., Chem. Commun.* **1981**, 1089. (b) Sung, W. *Nucleic Acids Res.* **1981**, *9*, 6139. (c) Norman, D. G.; Reese, C. B.; Serafinowska, H. T. *Synthesis* **1985**, 751. (d) Matsuda, A.; Obi, K.; Miyasaka, T. *Chem. Pharm. Bull.* **1985**, *33*, 2575. (e) Nyilas, A.; Chattopadhyaya, J. *Acta Chem. Scand., Ser. B* **1986**, *B40*, 826. (f) Zhou, X.-X.; Welch, C. J.; Chattopadhyaya, J. *Ibid.* **1986**, *B40*, 806. (g) Vial, J.-M.; Balgobin, N.; Remaund, G.; Nyilas, A.; Chattopadhyaya, J. *Nucleosides Nucleotides* **1987**, *6*, 209. (h) Zhou, X.-X.; Nyliase, A.; Remaund, G.; Chattopadhyaya, J. *Tetrahedron* **1987**, *43*, 4685.

(33) Moller, F. In *Methoden der Organishen Chemie*; Muller, E., Ed.; Georg Thieme Verlag: Stuttgart, 1957; Vol. 11, Part 1, p 910.

(34) Wempen, I.; Duschinsky, R.; Kaplan, L.; Fox, J. J. *J. Am. Chem. Soc.* **1961**, *83*, 4755.

5.05–6.00 (9 H, m, 1′,2′-H, 5-H, and allyl H), 7.68 (1 H, d, J = 8 Hz, 6-H). Anal. Calcd for $C_{29}H_{46}N_2O_{11}Si_2$: C, 53.19; H, 7.08; N, 4.28. Found: C, 53.01; H, 7.09; N, 4.33.

N^3-Benzyl-3′,5′-*O*-(1,1,3,3-tetraisopropyldisiloxane-1,3-diyl)uridine (7): R_f 0.51 (solvent I); ^{1}H NMR ($CDCl_3$) δ 1.06 (24 H, m, $(CH_3)_2CH$), 2.90 (1 H, s, OH), 3.72–4.55 (5 H, m, 2′,3′,4′,5′-H), 5.05 (2 H, s, NCH_2), 5.66 (1 H, d, J = 8 Hz, 5-H), 5.68 (1 H, s, 1′-H), 7.06–7.55 (5 H, m, Ar H), 7.53 (1 H, d, J = 8 Hz, 6-H). Anal. Calcd for $C_{28}H_{44}N_2O_7Si_2$: C, 58.30; H, 7.69; N, 4.86. Found: C, 58.29; H, 7.78; N, 4.84.

N^3-Benzyl-2′,3′-*O*-isopropylideneuridine (8):[25] R_f 0.60 (solvent III); ^{1}H NMR ($CDCl_3$) δ 1.35 (3 H, s, CH_3), 1.57 (3 H, s, CH_3), 2.93 (1 H, m, OH), 3.82 (2 H, m, 5′-H), 4.25 (1 H, m, 4′-H), 4.92 (2 H, m, 2′,3′-H), 5.03 (2 H, s, $ArCH_2$), 5.56 (1 H, s, 1′-H), 5.69 (1 H, d, J = 8 Hz, 5-H), 7.30 (6 H, m, 6-H and Ar H). Anal. Calcd for $C_{19}H_{22}N_2O_6$: C, 60.96; H, 5.92; N, 7.48. Found: C, 60.88; H, 5.73; N, 7.27.

N^3-Methyl-2′,3′-*O*-isopropylideneuridine (9):[26] R_f 0.49 (solvent III); ^{1}H NMR ($CDCl_3$) δ 1.35 (3 H, s, CH_3), 1.53 (3 H, s, CH_3), 3.27 (3 H, s, NCH_3), 3.83 (2 H, m, 5′-H), 4.37 (1 H, m, 4′-H), 4.90 (2 H, m, 2′,3′-H), 5.58 (1 H, m, 1′-H), 5.70 (1 H, d, J = 8 Hz, 5-H), 7.37 (1 H, d, J = 8 Hz, 6-H). Anal. Calcd for $C_{13}H_{18}N_2O_6 \cdot {}^1/_4H_2O$: C, 51.79; H, 6.19; N, 8.73. Found: C, 51.57; H, 6.16; N, 9.25.

N^3-Allyl-3′,5′-*O*-(1,1,3,3-tetraisopropyldisiloxane-1,3-diyl)uridine (10): R_f 0.38 (solvent I); ^{1}H NMR ($CDCl_3$) δ 1.07 (24, m, $(CH_3)_2CH$), 3.24 (1 H, br, OH), 3.78–4.60 (5 H, m, 2′,3′,4′,5′-H), 4.46 (2 H, d, J = 5 Hz, NCH_2), 5.01 (1 H, d, J = 2.5 Hz, C=CH), 5.23 (1 H, d, J = 8 Hz, C=CH), 5.64 (1 H, d, J = 8 Hz, 5-H), 5.67 (1 H, s, 1′-H), 5.50–6.15 (1 H, m, CH=C), 7.57 (1 H, d, J = 8 Hz, 6-H). Anal. Calcd for $C_{24}H_{42}N_2O_7Si_2$: C, 54.72; H, 8.04; N, 5.32. Found: C, 54.43; H, 8.06; N, 5.22.

N^3-((2-Nitrophenyl)sulfenyl)-3′,5′-*O*-(1,1,3,3-tetraisopropyldisiloxane-1,3-diyl)uridine (11):[28] R_f 0.48 (solvent I); ^{1}H NMR ($CDCl_3$) δ 1.03 (24 H, s, $(CH_3)_2CH$), 2.88 (1 H, m, OH), 4.13 (5 H, m, 2′,3′,4′,5′-H), 5.70 (1 H, s, 1′-H), 5.88 (1 H, d, J = 8 Hz, 5-H), 6.58–8.48 (5 H, m, 6-H and Ar H). Anal. Calcd for $C_{27}H_{41}N_3O_9SSi_2$: C, 50.68; H, 6.46; N, 6.57. Found: C, 50.57; H, 6.60; N, 6.45.

N^3-((Triphenylmethyl)sulfenyl)-3′,5′-*O*-(1,1,3,3-tetraisopropyldisiloxane-1,3-diyl)uridine (12):[29] R_f 0.61 (solvent I); ^{1}H NMR ($CDCl_3$) δ 1.05 (24 H, s, $(CH_3)_2CH$), 2.68 (1 H, s, OH), 3.50–4.55 (5 H, m, 2′,3′,4′,5′-H), 5.25 (1 H, s, 1′-H), 5.45 (1 H, d, J = 8 Hz, 5-H), 7.00–7.60 (16 H, m, 6-H and Ar H). Anal. Calcd for $C_{40}H_{52}N_2O_7SSi_2$: C, 63.13; H, 6.89; N, 3.68. Found: C, 62.66; H, 6.83; N, 3.66.

4-*O*-((2,4,6-Triisopropylphenyl)sulfonyl)-3′,5′-*O*-(tetraisopropyldisiloxane-1,3-diyl)uridine (13): R_f 0.50 (solvent I); ^{1}H NMR ($CDCl_3$) δ 1.17 (42 H, m, $(CH_3)_2CH$), 2.90 (3 H, $(CH_3)_2CH$), 3.45 (1 H, br, OH), 3.77–4.60 (5 H, m, 2′,3′,4′,5′-H), 5.69 (1 H, s, 1′-H), 5.99 (1 H, d, J = 8 Hz, 5-H), 7.14 (2 H, s, Ar H), 8.19 (1 H, d, J = 8 Hz, 6-H). Anal. Calcd for $C_{36}H_{60}N_2O_9SSi_2$: C, 57.42; H, 8.03; N, 3.72. Found: C, 57.57; H, 8.26; N, 3.66.

N^3-Anisoyl-2′-*O*-(tetrahydropyran-2-yl)-3′,5′-*O*-(1,1,3,3-tetraisopropyldisiloxane-1,3-diyl)uridine (4).[15c] A similar reaction using anisoyl chloride was done as described in the general procedure. After the O–N rearrangement was completed, dihydropyran (0.91 mL, 10 mmol) and trifluoroacetic acid (69 μL, 0.75 mmol) were added to the 1,2-dichloroethane solution containing **2d**. After being kept at room temperature for 19 h, the mixture was neutralized by the addition of saturated $NaHCO_3$ (30 mL) and transferred into a separatory funnel with CH_2Cl_2 (20 mL). The organic phase was collected, and the aqueous layer was extracted with CH_2Cl_2 (10 mL × 2). The combined CH_2Cl_2 extract was dried over Na_2SO_4, filtered, and evaporated under reduced pressure. The resulting gummy material was coevaporated with toluene (10 mL × 2) to remove the excess dihydropyran. To the residue were added KF (168 mg, 3 mmol), Et_4NBr (630 mg, 3 mmol), acetonitrile (6 mL), and water (0.18 mL, 10 mmol). The resulting mixture was stirred vigorously at 60 °C for 2.5 h and then cooled to room temperature. Extraction with CH_2Cl_2–H_2O was performed. The organic phase was collected, and the aqueous layer was further extracted twice with CH_2Cl_2. Each CH_2Cl_2 extract was washed with H_2O. The CH_2Cl_2 extracts were combined, dried over Na_2SO_4, filtered, and concentrated under reduced pressure to a gum. The gum was dissolved in CH_2Cl_2 and subjected to a silica gel column (25 g). Elution with CH_2Cl_2–MeOH gave **4** as foam (167 mg, 72%). This compound was identified with an authentic sample[15c] by comparison of their ^{1}H NMR spectra: R_f 0.09 and 0.15 (solvent II).

3′,5′-*O*-(1,1,3,3-Tetraisopropyldisiloxane-1,3-diyl)cytidine (14). Compound **13** (151 mg, 0.2 mmol) was dissolved in dioxane (10 mL), and concentrated aqueous ammonia (3.3 mL) was added. The mixture was kept at room temperature for 4 h and then evaporated under reduced pressure. The residue was chromatographed on a column of silica gel (5 g) with CH_2Cl_2–MeOH to give **14** (82 mg, 85%) and **1** (6 mg, 6%): R_f 0.32 (solvent III).

Measurement of the UV Spectra of a Mixture of 2e and 3e during O–N Rearrangement. The reaction of **1** with 2,2,2-trichloro-1,1-dimethylethyl chloroformate was carried out as described in the general procedure. The glassy material containing **2e** and **3e** obtained after the extraction followed by evaporation was diluted with 1,2-dichloroethane to a concentration of ca. 0.3 M. The solution was put in a UV cell, which was tightly sealed with a Teflon stopper. The cell was warmed at 70 °C in a water bath. At appropriate times of 0, 10, 20, 30, 90, and 150 min, the cell was taken out, cooled to room temperature, and directly measured by a spectrophotometer.

Acknowledgment. We thank Prof. T. Hata, Department of Life Chemistry, Tokyo Institute of Technology, for his encouragement throughout this study and T. Itoh for ^{13}C NMR spectral analysis. We also thank Prof. H. Tanaka, Shouwa University, for his kind information about ref 30b. This study was supported by a Grant-in-Aid for Scientific Research from the Ministry of Education, Science and Culture.

Registry No. **1**, 69304-38-7; **2a**, 86988-35-4; **2b**, 108782-95-2; **2c**, 119694-61-0; **2e**, 83167-62-8; **2f**, 119694-62-1; **4**, 98889-30-6; **5**, 119694-63-2; **6**, 362-43-6; **7**, 119694-64-3; **8**, 32464-90-7; **9**, 32471-59-3; **10**, 119694-65-4; **11**, 98889-55-5; **12**, 117901-68-5; **13**, 119694-66-5; **14**, 69304-42-3; TCBOC-Cl, 66270-36-8; AOC-Cl, 2937-50-0; 2-NBSCl, 7669-54-7; TrSCl, 24165-03-5; TPSCl, 6553-96-4.

Supplementary Material Available: Figure 1 showing the change of the UV curve of a mixture of **2e** and **3e** in 1,2-dichloroethane upon warming at 70 °C (1 page). Ordering information is given on any current masthead page.