A Novel Glycosylation of 3-Deoxy-D-*glycero*-D-*galacto*-2-nonulosonic Acid (KDN) *via in Situ* Pyranose–Furanose Rearrangement

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In studies on the glycosylation of 3-deoxy-D-*glycero*-D-*galacto*-2-nonulosonic acid (KDN) derivatives, *O*-glycosides of furanose-type KDN were synthesized from benzyl 4,5,7,8,9-penta-*O*-acetyl-2-bromo-2,3-dideoxy-D-*glycero*-D-*galacto*-2-nonulopyranosonate under Köenigs–Knorr reaction conditions. The furanoid structures of the KDN moiety were supported by with ^{1}H-NMR experiments, and the reaction was considered as a novel glycosylation with ring contraction, which proceeded *via in situ* pyranose-furanose rearrangement of the KDN moiety, and subsequent coupling with acceptors.

Key words glycosylation; 3-deoxy-D-*glycero*-D-*galacto*-2-nonulosonic acid; KDN; Köenigs–Knorr reaction; pyranose-furanose rearrangement

Since a chemical method for the preparation of 3-deoxy-D-*glycero*-D-*galacto*-2-nonulosonic acid (KDN, **1**) on a large-scale was established,[1] we have synthesized several KDN derivatives,[2,3] and reported the synthesis of *N*-glycosides under Williamson reaction conditions.[4] Recently, we attempted to synthesize the 2-*O*-glycosyl derivatives of KDN from benzyl 4,5,7,8,9-penta-*O*-acetyl-2-bromo-2,3-dideoxy-D-*glycero*-D-*galacto*-2-nonulopyranosonate (**3**) under Köenigs–Knorr reaction conditions. Surprisingly, in this reaction, we found that *O*-glycosyl derivatives of furanose-type KDN were synthesized besides the desired pyranose-type glycosides from a pyranose-type glycosyl donor (**3**) (Chart 1). This was the first synthesis of *O*-glycosides of KDN having a furanoid structure from the pyranose-type glycosyl donor **3**.

We considered the possibility that the starting material was actually a mixed pyranose and furanose-type glycosyl donor **3**, but no furanose-type products were detected when we carefully reexamined every reaction used for preparing the glycosyl donor **3**. We therefore examined the glycosylation reactions in detail. The mechanism is proposed to involve glycosylation with ring contraction. We report herein the results of our studies.

Results and Discussion

The glycosylation was performed by using **3** as a glycosyl donor,[2] 2′,3′-*O*-isopropylideneuridine (**4**) or 5-fluoro-2′,3′-*O*-isopropylideneuridine (**5**) as a glycosyl acceptor, and AgOTf or $Hg(CN)_2/HgBr_2$ as a promoter. In these reactions, besides the desired products **6**, **7**, **10**, and **11**, furanose-type derivatives **8**, **9**, **12**, and **13** were also obtained in 14.7% (**8** and **9**) and 7.4% (**12** and **13**) yield, respectively (Chart 1), and both pyranose-type and furanose-type derivatives were synthesized in higher yield by using $Hg(CN)_2/HgBr_2$ in place of AgOTf (Table 1). An undesired product, benzyl 4,5,7,8,9-penta-*O*-acetyl-2,3-dehydro-2,3-dideoxy-D-*glycero*-D-*galacto*-nonulopyranosonate (**14**) was also obtained from each reaction.

The products were identified on the basis of FAB-MS and ^{1}H-NMR data. The pyranoid structures, including the stereochemistry, of products **6**, **7**, **10** and **11** were elucidated by analyses of ^{1}H-NMR data in the reported manner.[5,6] For instance, in the ^{1}H-NMR spectra, the chemical shift at H_{eq}-3 of the α-anomers **6** and **10** is usually observed at lower field than that of the β-anomers **7** and **11**, and the chemical shift at H-4 of the α-anomers at higher field than that of the β-anomers, as shown in Table 3. The furanoid structure of the KDN moiety of **8**, **9**, **12** and **13** was deduced from ^{1}H-NMR data, in which the coupling constants of ring protons of the KDN moiety were quite different from those of the pyranose derivatives, as shown in Table 2, and characteristically, the chemical

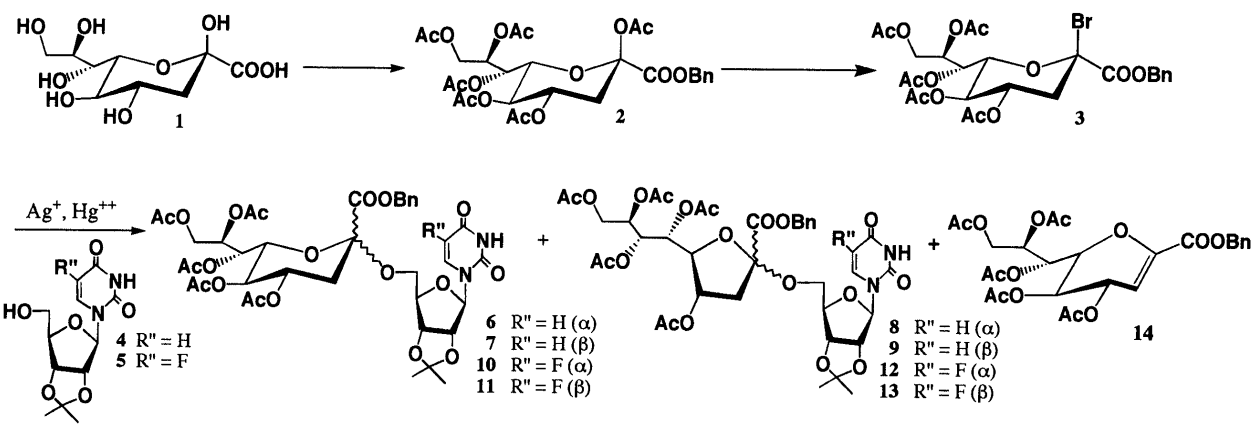

Chart 1

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Table 1. Köenigs–Knorr-like Reactions of **3** with **4** and **5** in CH_2Cl_2

Accepter	Promoter	Reaction temperature	Time (d)	Total yield[a] of **6**, **7** or **10**, **11**	Total yield[a] of **8**, **9** or **12**, **13**	**14**	**3**
4	AgOTf	r.t.	10	22	9	61	6
4	AgOTf	40 °C	7	21	7	50	12
4	$Hg(CN)_2/HgBr_2$	r.t.	3	47	15	25	3
5	AgOTf	r.t.	10	23	—	65	—
5	AgOTf	40 °C	7	15	—	68	16
5	$Hg(CN)_2/HgBr_2$	r.t.	3	32	7	36	4

a) Isolated yield. r.t. = room temperature.

Table 2. Proton Spin-Coupling Constants of the KDN Moiety of **6**—**13**

Compound	$J_{3a,3e}$	$J_{3a,4}$	$J_{3e,4}$	$J_{4,5}$	$J_{5,6}$	$J_{6,7}$	$J_{7,8}$	$J_{8,9}$	$J_{8,9'}$	$J_{9,9'}$
6	12.5	11.4	4.2	9.7	9.7	2.1	9.2	5.3	2.7	12.4
7	13.1	11.0	5.0	9.8	10.0	2.0	4.0	8.0	2.5	12.3
8	15.0	2.0	7.5	2.0	7.5	2.5	8.5	6.0	2.0	12.5
9	15.0	2.5	6.5	2.0	8.5	2.5	8.5	5.5	3.0	12.5
10	13.0	11.2	4.7	9.5	10.0	2.4	9.5	5.0	2.4	12.5
11	13.1	11.7	5.1	10.0	10.0	2.1	3.8	8.2	2.8	12.0
12	15.0	1.0	7.5	2.5	7.5	2.5	8.5	6.0	2.0	12.5
13	15.0	2.5	6.2	1.0	8.5	2.0	8.7	5.5	2.2	12.3

Recorded in $CDCl_3$.

Table 3. Proton Chemical Shifts of the KDN Moiety of **6**—**13**

Compound	H_{3a}	H_{3e}	H_4	H_5	H_6	H_7	H_8	H_9	$H_{9'}$
6	1.88	2.64	4.93	4.90	4.24	5.33	5.39	4.08	4.25
7	1.91	2.52	5.43	4.81	4.08	5.29	5.37	4.05	4.74
8	2.40	2.82	5.55	4.71	5.69	5.93	5.55	4.23	4.43
9	2.67	2.79	5.51	4.67	5.64	5.88	5.44	4.26	4.43
10	1.92	2.69	4.95	4.90	4.30	5.34	5.40	4.08	4.24
11	1.90	2.53	5.40	4.82	4.08	5.30	5.38	4.04	4.78
12	2.41	2.85	5.54	4.71	5.68	5.93	5.47	4.23	4.43
13	2.73	2.84	5.52	4.69	5.63	5.89	5.44	4.27	4.42

Recorded in $CDCl_3$.

shift of H-5 (4.71, 4.67 ppm) of the KDN moiety appeared at higher field than that of H-6 (5.69, 5.64 ppm) contrary to the case in pyranose-type products (Table 3). nuclear Furthermore, furanose structure was also supported by Overhauser effect (NOE) experiments. For example, in the furanose-type derivative, NOE between H-4 and H-5 was 2.9% for compound **8** and 3.3% for compound **9**, while NOE between H-5 and H-6 was 3.2% and 4.5% for compound **8**, 1.6% and 1.9% for compound **9**, respectively, whereas no NOE between H-4 and H-5 or H-5 and H-6 could be detected in pyranose-type KDN derivatives (**6**, **7**, **10** and **11**). This can be explained by presuming that the pyranoid ring of general KDN derivatives with pyranoid structure has a $^2C_5$ conformation, in which H-4, H-5, and H-6 are all in axial orientation, so that no NOE is detected. The anomeric configurations of these furanose products were determined by comparing ^{1}H-NMR data for the KDN moiety with those for the compound[4] examined by X-ray crystallographic analysis. Compounds **8** and **12** were concluded to be β-anomers, and compounds **9** and **13**, α-anomers.

The pyranose–furanose rearrangement in this reaction is different from that of common sugars, in which it occurs *via* oxygen ring opening.[7-9] The mechanism for this unusual reaction is unclear and requires further investigation. However, as shown in Chart 2, we hypothesize that when bromine at C-2 was removed by the promoter, the carbonyl group at C-1 would be conjugated with the glycosyl cation to form an α,β-unsaturated carboxyl-like unit which would stabilize the glycosyl cation **a** in pyranoid ring form without the formation of acyclic structure. However, because of the steric hindrance, *i.e.*, gauche interaction between the glycerol side chain at C-6 and the *O*-acetyl group at C-5, the chair conformation of **a** would easily change into a boat conformation, in which the *O*-acetyl group at C-5 is close to the cation at C-2, and reacts with it to form the furanoid ring structure of cation **c** *via* a bicyclic intermediate **b**. As a result, nucleophilic reagents attack cation **a** or **c** from two directions to generate the above pyranose-type and furanose-type products, respectively.

This mechanism is supported by the formation of the furan derivative **17** by treatment of the per-*O*-acetylated KDN methyl ester **15**[10] with acetic anhydride containing sulfuric acid or a Lewis acid (Chart 3). Since **17** was not obtained by treatment of **16** under the same conditions,

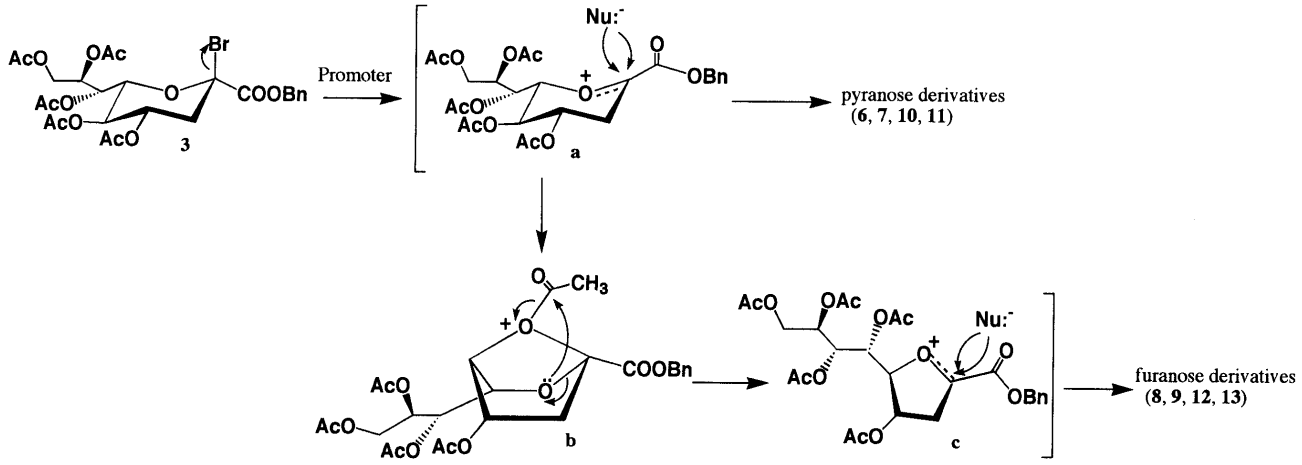

Chart 2

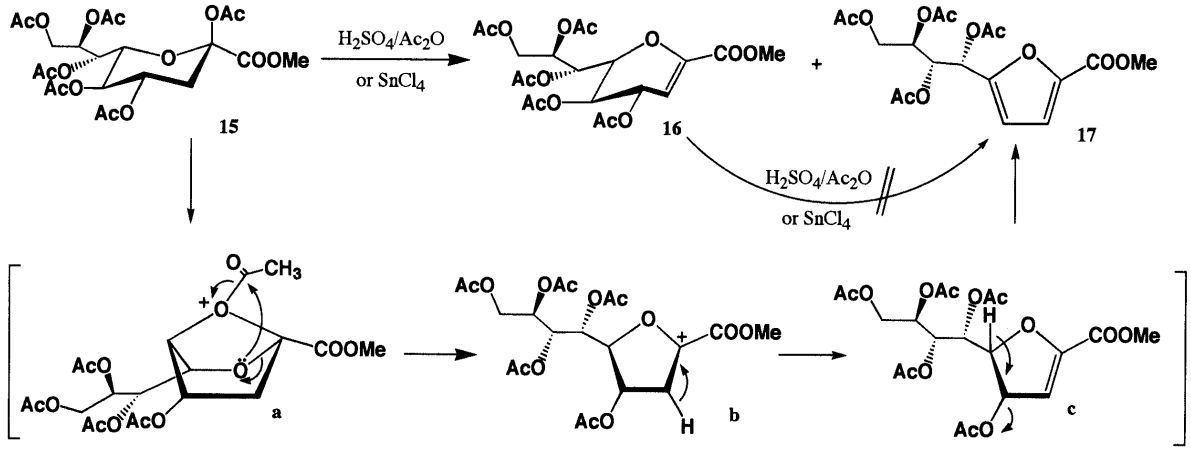

Chart 3

the formation of **17** from **15** was suggested to proceed *via* a similar mechanism through the bicyclic intermediate **b**, as in the glycosylation reaction with no nucleophile attack.

In conclusion, we obtained furanose-type *O*-glycoside derivatives of KDN from the above new glycosylation reactions. This process is a distinct chemical feature of KDN, different from common sugars and Neu5Ac, which has an acetamido group at C-5.[5] Further studies are planned.

Experimental

General Procedures Melting points were measured on a Yamato melting point apparatus without correction. Fast atom bombardment mass spectra (FAB-MS) were taken on a JEOL JMS-DX 300. Optical rotations were measured with a JASCO JIP-4 digital polarimeter (at 21 °C). Infrared (IR) spectra were obtained on a Perkin-Elmer 983G spectrometer. CD spectra were measured in a 0.1 cm cell with a JASCO J-20 spectrometer. The ^{1}H-NMR spectra were determined with Varian VXR-300 and XL-400 spectrometers, in the solution state, with tetramethylsilane (TMS) as an internal reference. Thin-layer chromatography (TLC) was performed on Kieselgel 60 F_{254} (Merck) plates, and spots were detected under ultraviolet (UV) irradiation or by spraying 5% sulfuric acid solution. Column chromatography was conducted on Silica gel 60 (70—230 mesh) (Merck).

***O*-[Benzyl (4,5,7,8,9-penta-*O*-acetyl-3-deoxy-α/β-D-*glycero*-D-*galacto*-nonulopyranosyl)onate]-(2-5′)-2′,3′-*O*-isopropylideneuridine (6, 7) and *O*-[Benzyl (4,6,7,8,9-penta-*O*-acetyl-3-deoxy-α/β-D-*glycero*-D-*galacto*-nonulofuranosyl)onate]-(2-5′)-2′,3′-*O*-isopropylideneuridine (8, 9)** Method I: 2′,3′-*O*-Isopropylideneuridine (**4**, 170 mg, 0.60 mmol) and Molecular sieves 4A (600 mg) were added to a solution of **3** (324 mg, 0.50 mmol) in dichloromethane (24 ml) under an argon pressure. The solution was stirred for 30 min at room temperature, then AgOTf (166 mg, 1.3 eq) was added. The solution was stirred at 40 °C for 7 d in the dark. The reaction solution was filtered through Celite, which was washed with dichloromethane. The combined organic solution was washed with aqueous $NaHCO_3$ (50 ml × 3) and brine, dried over anhydrous $MgSO_4$, and concentrated to dryness under reduced pressure. The residue was purified by silica gel column chromatography ($CHCl_3$: MeOH) to yield **6** (47 mg, 11%), **7** (40 mg, 10%), **8** and **9** (28 mg, 6.8%), **14** (138 mg, 50%), and unreacted **3** (36 mg, 11.5%).

Method II: 2′,3′-*O*-Isopropylideneuridine (**4**, 340 mg, 1.20 mmol) and Molecular sieves 4A (1.2 g) were added to a solution of **3** (652 mg, 1.0 mmol) in dichloromethane (50 ml) under an argon atmosphere. The solution was stirred for 30 min at room temperature, then $Hg(CN)_2$ (150 mg, 0.60 mmol) and $HgBr_2$ (300 mg, 0.82 mmol) were added. The solution was stirred at room temperature for 3 d in the dark. The reaction solution was treated as in method I to yield **6** (153 mg, 18.3%), **7** (243 mg, 29.1%), **8** and **9** (123 mg, 14.7%), **14** (139 mg, 25.2%), and unreacted **3** (26 mg, 3.2%).

6: FAB-MS *m/z*: 835 ($M^+ + 1$) [*m*-nitrobenzyl alcohol (*m*-NBA) as matrix]. *Anal.* Calcd for $C_{38}H_{46}N_2O_{19}$: C, 54.68; H, 5.52; N, 3.36. Found: C, 55.06; H, 5.64; N, 3.01. $[\alpha]_D$ +15.8° (*c*=0.53, $CHCl_3$). IR (ν_{max}^{KBr}): 2950 (C=C), 1750 (C=O) cm^{-1}. ^{1}H-NMR (400 MHz, $CDCl_3$) δ: KDN moiety: as shown in Tables 2 and 3. Uridine moiety: 1.34, 1.57 (each 3H, S, CMe_2), 3.41 (1H, dd, *J*=3.0, 10.8 Hz, 5′-H), 4.00 (1H, dd, *J*=3.5, 10.8 Hz, 5″-H), 4.34 (1H, q, *J*=4.0 Hz, 4′-H), 4.63 (1H, dd, *J*=2.7, 6.1 Hz, 2′-H), 4.74 (1H, dd, *J*=3.0, 6.1 Hz, 3′-H), 5.41 (1H, dd, *J*=2.0, 7.2 Hz, 5-H), 5.86 (1H, d, *J*=2.7 Hz, 1′-H), 7.43 (1H, d, *J*=7.2 Hz, 6-H), 8.61 (1H, br s, NH).

7: FAB-MS *m/z*: 835 ($M^+ + 1$) (*m*-NBA as matrix). *Anal.* Calcd for $C_{38}H_{46}N_2O_{19}$: C, 54.68; H, 5.52; N, 3.36. Found: C, 54.94; H, 5.54; N, 3.10. $[\alpha]_D$ −9.6° (*c*=0.35, $CHCl_3$). IR (ν_{max}^{KBr}): 2980 (C=C), 1760, 1770 (C=O) cm^{-1}. ^{1}H-NMR (400 MHz, $CDCl_3$) δ: KDN moiety: as shown in Tables 2 and 3. Uridine moiety: 1.34, 1.54 (each 3H, S, CMe_2), 3.56

(1H, dd, J=2.9, 10.9 Hz, 5′-H), 3.88 (1H, dd, J=3.9, 10.9 Hz, 5″-H), 5.05 (1H, dd, J=1.5, 6.3 Hz, 2′-H), 5.12 (1H, dd, J=4.8, 6.8 Hz, 3′-H), 5.61 (1H, d, J=1.5 Hz, 1′-H), 5.78 (1H, dd, J=2.0, 8.0 Hz, 5-H), 7.28 (1H, d, J=8.0 Hz, 6-H), 9.10 (1H, br s, NH).

8: FAB-MS m/z: 835 ($M^+ + 1$) (*m*-NBA as matrix). *Anal.* Calcd for $C_{38}H_{46}N_2O_{19}$: C, 54.68; H, 5.52; N, 3.36. Found: C, 54.74; H, 5.58; N, 3.40. $[\alpha]_D$ +10.6° (c=0.26, $CHCl_3$). IR (ν_{max}^{KBr}): 2982 (C=C), 1764, 1772 (C=O) cm^{-1}. ^{1}H-NMR (400 MHz, $CDCl_3$) δ: KDN moiety: as shown in Tables 2 and 3. Uridine moiety: 1.36, 1.55 (each 3H, S, CMe_2), 3.93 (1H, dd, J=4.5, 10.5 Hz, 5′-H), 4.13 (1H, dd, J=4.5, 10.5 Hz, 5″-H), 4.43 (1H, dt, J=3.5, 4.5 Hz, 4′-H), 5.04 (1H, dd, J=2.5, 3.0 Hz, 2′-H), 5.06 (1H, dd, J=3.0, 3.5 Hz, 3′-H), 6.26 (1H, d, J=2.5 Hz, 1′-H), 5.81 (1H, d, J=8.0 Hz, 5-H), 7.75 (1H, d, J=8.0 Hz, 6-H).

9: FAB-MS m/z: 835 ($M^+ + 1$) (*m*-NBA as matrix). *Anal.* Calcd for $C_{38}H_{46}N_2O_{19}$: C, 54.68; H, 5.52; N, 3.36. Found: C, 54.86; H, 5.47; N, 3.32. $[\alpha]_D$ −8.2° (c=0.32, $CHCl_3$). IR (ν_{max}^{KBr}): 2985 (C=C), 1758, 1774 (C=O) cm^{-1}. ^{1}H-NMR (400 MHz, $CDCl_3$) δ: KDN moiety: as shown in Tables 2 and 3. Uridine moiety: 1.35, 1.52 (each 3H, S, CMe_2), 3.95 (1H, dd, J=5.0, 10.0 Hz, 5′-H), 4.24 (1H, dd, J=4.5, 10.0 Hz, 5″-H), 4.55 (1H, m, 4′-H), 5.05—5.12 (2H, m, 2′-H, 3′-H), 6.22 (1H, d, J=1.0 Hz, 1′-H), 5.75 (1H, d, J=8.5 Hz, 5-H), 7.75 (1H, d, J=8.5 Hz, 6-H).

***O*-[Benzyl (4,6,7,8,9-penta-*O*-acetyl-3-deoxy-α/β-D-*glycero*-D-*galacto*-nonulopyranosyl)onate]-(2—5′)-5-fluoro-2′,3′-*O*-isopropylideneuridine (10, 11) and *O*-[Benzyl (4,6,7,8,9-penta-*O*-acetyl-3-deoxy-α/β-D-*glycero*-D-*galacto*-nonulofuranosyl)onate]-(2—5′)-5-fluoro-2′,3′-*O*-isopropylideneuridine (12, 13)** 5-Fluoro-2′,3′-*O*-isopropylideneuridine (**5**, 362 mg, 1.2 mmol) and Molecular sieves 4A (1.2 g) were added to a solution of **3** (652 mg, 1.0 mmol) in dichloromethane (50 ml) under an argon pressure. The solution was stirred for 30 min at room temperature, then $Hg(CN)_2$ (150 mg, 0.60 mmol) and $HgBr_2$ (300 mg, 0.82 mmol) were added. The reaction mixture was stirred at room temperature for 3 d in the dark, then treated as in method I to yield **10** (102 mg, 12.0%), **11** (171 mg, 20.1%), **12** and **13** (63 mg, 7.4%), **14** (200 mg, 36.3%), and unreacted **3** (29 mg, 4.2%).

10: FAB-MS m/z: 853 ($M^+ + 1$) (*m*-NBA as matrix). *Anal.* Calcd for $C_{38}H_{45}FN_2O_{19}$: C, 53.52; H, 5.28; N, 3.29. Found: C, 53.23; H, 5.36; N, 3.30. $[\alpha]_D$ +18.0° (c=0.33, $CHCl_3$). IR (ν_{max}^{KBr}): 2960 (C=C), 1760, 1725 (C=O) cm^{-1}. ^{1}H-NMR (300 MHz, $CDCl_3$) δ: KDN moiety: as shown in Tables 2 and 3. 5-Fluorouridine moiety: 1.35, 1.57 (each 3H, S, CMe_2), 3.43 (1H, dd, J=2.4, 11.0 Hz, 5′-H), 4.03 (1H, dd, J=2.9, 11.0 Hz, 5″-H), 4.34 (1H, q, J=2.8 Hz, 4′-H), 4.57 (1H, dd, J=2.8, 6.1 Hz, 2′-H), 4.79 (1H, dd, J=3.0, 6.1 Hz, 3′-H), 5.95 (1H, dd, J=1.1, 2.8 Hz, 1′-H), 7.69 (1H, d, J=6.5 Hz, 6-H), 8.90 (1H, br s, NH).

11: FAB-MS m/z: 835 ($M^+ + 1$) (*m*-NBA as matrix). *Anal.* Calcd for $C_{38}H_{46}N_2O_{19}$: C, 53.52; H, 5.28; N, 3.29. Found: C, 53.50; H, 5.46; N, 3.16. $[\alpha]_D$ 0° (c=0.43, $CHCl_3$). IR (ν_{max}^{KBr}): 2950 (C=C), 1725 (C=O) cm^{-1}. ^{1}H-NMR (300 MHz, $CDCl_3$) δ: KDN moiety: as shown in Tables 2 and 3. 5-Fluorouridine moiety: 1.35, 1.54 (each 3H, S, CMe_2), 3.56 (1H, dd, J=3.3, 11.0 Hz, 5′-H), 3.89 (1H, dd, J=4.3, 11.0 Hz, 5″-H), 5.11 (1H, d, J=2.0 Hz, 3′-H), 5.11 (1H, s, 2′-H), 5.47 (1H, s, 1′-H), 7.40 (1H, d, J=7.2 Hz, 6-H), 9.38 (1H, br s, NH).

12: FAB-MS m/z: 835 ($M^+ + 1$) (*m*-NBA as matrix). *Anal.* Calcd for $C_{38}H_{46}N_2O_{19}$: C, 53.52; H, 5.28; N, 3.29. Found: C, 53.29; H, 5.54; N, 3.41. $[\alpha]_D$ +12.2° (c=0.21, $CHCl_3$). IR (ν_{max}^{KBr}): 2956 (C=C), 1720 (C=O) cm^{-1}. ^{1}H-NMR (300 MHz, $CDCl_3$) δ: KDN moiety: as shown in Tables 2 and 3. 5-Fluorouridine moiety: 1.36, 1.56 (each 3H, S, CMe_2), 3.92 (1H, dd, J=4.0, 11.0 Hz, 5′-H), 4.14 (1H, dd, J=4.0, 11.0 Hz, 5″-H), 4.45 (1H, m, 4′-H), 5.04 (1H, dd, J=2.0, 6.0 Hz, 2′-H), 5.11 (1H, dd, J=6.0, 3.5 Hz, 3′-H), 6.30 (1H, d, J=2.0 Hz, 1′-H), 8.04 (1H, d, J=8.0 Hz, 6-H).

13: FAB-MS m/z: 835 ($M^+ + 1$) (*m*-NBA as matrix). *Anal.* Calcd for $C_{38}H_{46}N_2O_{19}$: C, 53.52; H, 5.28; N, 3.29. Found: C, 53.41; H, 5.45; N, 3.18. $[\alpha]_D$ −5.0° (c=0.23, $CHCl_3$). IR (ν_{max}^{KBr}): 2958 (C=C), 1724 (C=O) cm^{-1}. ^{1}H-NMR (300 MHz, $CDCl_3$) δ: KDN moiety: as shown in Tables 2 and 3. 5-Fluorouridine moiety: 1.33, 1.56 (each 3H, S, CMe_2), 3.92 (1H, dd, J=5.0, 10.0 Hz, 5′-H), 4.24 (1H, dd, m, 5″-H), 4.55 (1H, m, 4′-H), 5.11 (2H, m, 2′-H, 3′-H), 6.32 (1H, s, 1′-H), 8.09 (1H, d, J=7.0 Hz, 6-H).

Methyl 4,5,7,8,9-Penta-*O*-acetyl-2,3-dehydro-2,3-dideoxy-D-*glycero*-D-*galacto*-nonulopyranosonate (16) and Methyl (1′*S*,2′*R*,3′*R*)-5-(1′,2′,3′,4′-Tetraacetoxybutyl)-2-furancarboxylate (17) Method I: A solution of concentrated sulfuric acid (60 mg) in acetic anhydride (2 ml) was added to a solution of **15** (855 mg, 1.60 mmol) in acetic anhydride (10 ml). The mixture was stirred for 6 h at room temperature, then poured into ice-water, and extracted with EtOAc (30 ml × 3). The combined extract was washed with sodium hydrogen carbonate solution, dried with anhydrous Na_2SO_4, and concentrated to dryness. The residue was purified by silica gel column chromatography (*n*-hexane–EtOAc) to yield **16** (320 mg, 42%) and **17** (120 mg, 18%).

Method II: Tin(IV) chloride (488 mg, 1.87 mmol) was added to a solution of **15** (500 mg, 0.94 mmol) in THF (20 ml) at room temperature. The mixture was stirred at room temperature for 24 h, then saturated $NaHCO_3$ aqueous solution (10 ml) was added with stirring, and the whole was concentrated to dryness under reduced pressure. The residue was extracted with dichloromethane (30 ml × 3), and the combined extracts were washed with water and brine, dried over anhydrous Na_2SO_4 and concentrated to a syrup *in vacuo*. The syrup was purified by silica gel column chromatography with *n*-hexane–EtOAc to yield **16** (195 mg, 44%) and **17** (31 mg, 8%).

16: Colorless syrup. FAB-MS m/z: 475 ($M^+ + 1$) (*m*-NBA as matrix). *Anal.* Calcd for $C_{20}H_{26}O_{13}$: C, 50.63; H, 5.49. Found: C, 50.55; H, 5.57. ^{1}H-NMR (300 MHz, $CDCl_3$) δ: 5.94 (1H, d, J=3.0 Hz, 3-H), 5.55 (1H, dd, J=8.2, 3.0 Hz, 4-H), 5.20 (1H, dd, J=9.6, 8.2 Hz, 5-H), 4.32 (1H, dd, J=9.6, 3.3 Hz, 6-H), 5.46 (1H, dd, J=6.6, 3.3 Hz, 7-H), 5.35 (1H, ddd, J=6.6, 6.6, 2.7 Hz, 8-H), 4.16 (1H, dd, J=12.6, 6.6 Hz, 9-H), 4.55 (1H, dd, J=12.6, 2.7 Hz, 9-H), 3.80 (3H, s, $COOCH_3$), 2.01, 2.03, 2.04, 2.05, 2.07 (each 3H, s, OAc × 5).

17: mp 89—91 °C. FAB-MS m/z: 415 ($M^+ + 1$) (*m*-NBA as matrix). *Anal.* Calcd for $C_{18}H_{22}O_{11}$: C, 52.17; H, 5.31. Found: C, 52.35; H, 5.17. $[\alpha]_D$ −29° (c=0.61, MeOH). ^{1}H-NMR (300 MHz, $CDCl_3$) δ: 7.07 (1H, d, J=3.9 Hz, 3-H), 6.42 (1H, d, J=3.9 Hz, 4-H), 6.12 (1H, d, J=3.3 Hz, 6-H), 5.58 (1H, dd, J=9.3, 3.3 Hz, 7-H), 5.22 (1H, ddd, J=5.1, 3.0, 9.3 Hz, 8-H), 4.24 (1H, dd, J=12.6, 3.0 Hz, 9′-H), 4.13 (1H, dd, J=12.6, 5.1 Hz, 9-H), 3.86 (3H, s, $COOCH_3$), 2.03, 2.06, 2.08, 2.09 (each 3H, s, OAc × 4). ^{13}C-NMR (75 MHz, $CDCl_3$) δ: 20.35, 20.57, 20.72 ($CO\underline{C}H_3$), 51.92 ($COO\underline{C}H_3$), 61.56 (C-9), 65.78 (C-6), 68.19 (C-8), 69.37 (C-7), 111.15 (C-4), 118.29 (C-3), 144.73 (C-2), 152.92 (C-5), 158.615 (C-1), 169.30, 169.54, 169.66, 170.49 ($COCH_3$ × 4).

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