Carbohydrate Research 344 (2009) 959–965

Contents lists available at ScienceDirect

Carbohydrate Research

journal homepage: www.elsevier.com/locate/carres

Sialylation using *N*-glycolylneuraminyl phosphite donors to synthesize Neu5Gc-containing glycans

Shinya Hanashima [a,b], Taku Tomiya [a], Daichi Ishikawa [a], Shoji Akai [a], Ken-ichi Sato [a,*]

[a] *Material and Life Chemistry, Faculty of Engineering, Kanagawa University, 3-27-1 Rokkakubashi, Yokohama 221-8686, Japan*
[b] *Structural Glycobiology Team, Systems Glycobiology Research Group, RIKEN Advanced Science Institutes, 2-1 Hirosawa, Wako-shi, Saitama 351-0198, Japan*

ARTICLE INFO

Article history:
Received 3 February 2009
Received in revised form 4 March 2009
Accepted 5 March 2009
Available online xxxx

Keywords:
N-Glycolylneuraminic acid
Sialic acid
Glycosylation
Phosphite

ABSTRACT

Efficient sialylations using *N*-glycolylneuraminic acid (Neu5Gc) phosphite donors having an acetyl or benzyl group on the glycolyl moiety are described in the synthesis of Neu5Gc-containing glycans. Both phosphite donors **1** and **2** were readily coupled with primary and secondary acceptor alcohols in propionitrile at −78 °C to provide the desired glycosides with good α-selectivities.

1. Introduction

Among the various sialic acids, *N*-glycolylneuraminic (Neu5Gc) and *N*-acetylneuraminic (Neu5Ac) acids are the most abundant and can be readily found in Gram-negative bacteria, echinoderms, and vertebrates.[1,2] In the case of humans, most of the sialic acid is Neu5Ac due to a deficiency of CMP–Neu5Ac hydroxylase, which produces CMP–Neu5Gc in the cytosol.[3] However, minor amounts of Neu5Gc-containing glycans have been detected in tumor-associated epitopes involving breast and colon cancer, and in the brain ganglioside GM_3.[4,5]

It has been reported that a number of infectious bacteria and viruses can recognize cell-surface glycans that bear sialic acids. In view of the recent pandemic threat of the avian influenza virus, the shift of the virus receptor from Neu5Gc to Neu5Ac is a significant factor in determining infectious properties among humans.[6]

Recently, the potent activities of echinoderm gangliosides on the stimulation of nerve cells have been reported.[7] Especially, the neurite outgrowth activities of such distinctive gangliosides that contain Neu5Gc residues have been shown to be more comparable to those of GM_1 ganglioside in the presence of nerve growth factor (NGF).

In chemical synthesis of such bioactive Neu5Gc-containing gangliosides, the use of N-substituted sialic acid building blocks can be an efficient strategy in terms of both yields and α-selectivities.[8] Upon completion of the sialylation reactions using these sialyl donors carrying the C-5 amino-protecting groups such as *N*-TFA,[9a] azide,[9b] carbamate,[9c,d] phthalimide,[9e] and oxazolidinone,[9f–h] the sialic acid unit can be subsequently transformed into the glycolyl form by substituting the functionalities with a glycolylamide.[10] The liberated C-5 amino group, however, may undergo acyl migration from the C7/8-hydroxyl-protected acetyl group, even under acidic conditions,[9c] and therefore, the direct use of a Neu5Gc building block would be a straightforward strategy in avoiding such undesirable migration reactions on important intermediates. To date, a few reports have appeared describing the synthesis of Neu5Gc gangliosides involving N-glycolylneuraminylation using less reactive methylthio/phenylthio-Neu5Gc donors.[11] In this report, N-glycolylneuraminylations using more reactive Neu5Gc phosphite donors **1** and **2** are described. Furthermore, acetyl protected **1** and benzyl protected **2** were also prepared to compare the reactivities as well as α-selectivities involving sialylations with acceptors **8**, **11**, **14**, and **16**.

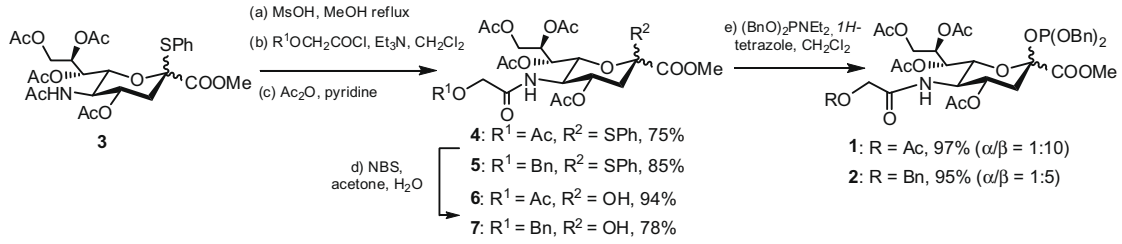
2. Results and discussion

2.1. Synthesis of sialyl phosphite donors 1 and 2

The synthesis of sialyl phosphite donors **1** and **2** was initially carried out as shown in Scheme 1. Thiophenyl sialosides **4**[11a,12] and **5**, which possess glycolylamide moieties with either benzyl or acetyl protection, were prepared from known thioglycoside **3**[13] according to Sugata and Higuchi's procedure.[11d] First, sialoside **3** was fully deacetylated using methanesulfonic acid in MeOH under reflux conditions. Next, the exposed amino group was immediately

* Corresponding author. Tel.: +81 45 481 5661x3853; fax: +81 45 413 9770.
E-mail address: satouk01@kanagawa-u.ac.jp (K. Sato).

0008-6215/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.carres.2009.03.004



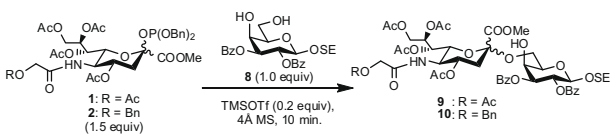
Scheme 1. Synthesis of the sialyl phosphite donors **1** and **2**.

protected with either an acetoxyacetyl or a benzyloxyacetyl group using the corresponding acid chlorides. The remaining hydroxyl groups were acetylated to afford desired sialosides **4** (75% yield) and **5** (85% yield) in three steps. Sialosides **4** and **5** were then transformed into phosphite donors **1** and **2**, respectively, via two additional steps:[14] hydrolysis of the phenylthio moiety of **4** and **5** using NBS in acetone–H_2O to give hemiketals **6** and **7** in 94% (**6**) and 78% (**7**) yields, followed by introduction of the phosphite group by treatment with *N*,*N*-dibenzylphosphoramidite and 1*H*-tetrazole to afford **1** (97% yield, α:β = 1:10) and **2** (95% yield, α:β = 1:5), respectively.

2.2. Sialylation reactions using donors 1 or 2

To investigate both reactivity and α-selectivities of the Neu5Gc phosphite donors **1** and **2**, the formation of naturally occurring Neu5Gcα(2→6)Gal linkages was carried out. As shown in Table 1, galactose 4,6-diol **8**,[15] which has benzoyl groups on the C-2 and C-3 positions for further β-selective galactosylations, was employed as a practical acceptor. In the first trials as shown in entries 1 and 2, phosphite **1** or **2** was activated with 0.2 equivalent of TMSOTf in dichloromethane at −78 °C. In the case of entry 1, the reaction went to completion within 10 min to give disaccharide **9** in 88% yield; however, the desired α-anomer was the minor component (α:β = 1:1.5, entry 1). In the choice of donor **2**, the α-selectivity was improved to afford the disaccharide **10** in 71% yield (α:β = 2.3:1, entry 2). In order to investigate a possible 'nitrile effect', the sialylation reactions were carried out in acetonitrile and propionitrile (entries 3–5).[16] In the case of acetonitrile at −40 °C with donor **2** (entry 3), although the α-selectivity was improved (α:β = 3.0:1), the yield (73%) was similar to that of entry 2 (71%). On the other hand, in the cases of propionitrile at −78 °C with donor **1**, the desired disaccharide **9** was obtained in 90% (α:β = 4.7:1, entry 4).[17] The best performance was obtained in the use of donor **2** with acceptor **8** to give disaccharide **10** in 87% yield with excellent α-selectivity (α:β = 10:1). As can be seen from the data in Table 1, donor **2** which has benzyl protection on the glycolyl

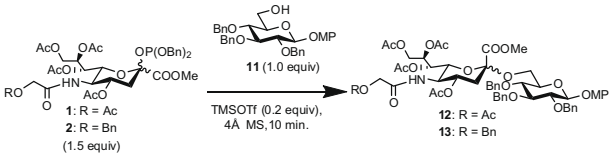
Table 1
Sialylation reactions using sialyl phosphite donors **1** or **2** with galactose acceptor **8**



Entry	Donor	Solvent	Temperature (°C)	Product (yield %)[a]	α/β ratio[b]
1	**1**	CH_2Cl_2	−78	**9** (88)	1:1.5
2	**2**	CH_2Cl_2	−78	**10** (71)	2.3:1
3	**2**	CH_3CN	−40	**10** (73)	3.0:1
4	**1**	EtCN	−78	**9** (90)	4.7:1
5	**2**	EtCN	−78	**10** (87)	10:1

[a] Isolated yields.
[b] Anomeric ratio was determined by ^{1}H NMR spectroscopy, SE: 2-trimethylsilylethyl.

Table 2
Sialylation reactions using sialyl phosphite donors **1** or **2** with glucose acceptor **11**



Entry	Donor	Solvent	Temperature (°C)	Product (yield %)[a]	α/β ratio[b]
1	**1**	CH_2Cl_2	−78	**12** (86)	1:10
2	**2**	CH_2Cl_2	−78	**13** (90)	1:10
3	**1**	EtCN	−78	**12** (85)	8:1
4	**2**	EtCN	−78	**13** (86)	8:1

[a] Isolated yields.
[b] Anomeric ratio was determined by ^{1}H NMR spectroscopy, MP: 4-methoxyphenyl.

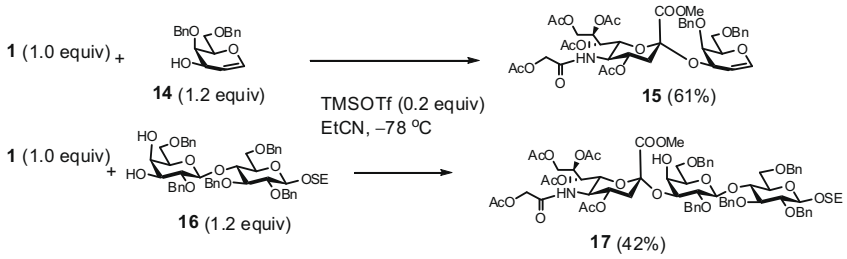
moiety, exhibited significantly better α-selectivity than the corresponding acetyl-protected donor **1**.

To study formation of the Neu5Gcα(2→6)Glc unit, which has been identified from the echinoderm gangliosides,[7,9] sialylations of donors **1** and **2** with glucoside **11**[18] were investigated (Table 2). To determine preferential dependence of donors **1** and **2** by comparison of the results shown in Table 1, all sialylations in Table 2 were carried out in either dichloromethane or propionitrile at −78 °C. Initially as indicated in entries 1 and 2, unexpected high β selectivities were obtained for the synthesis of disaccharide **12** (86% yield,α:β = 1:10) and **13** (90% yield,α:β = 1:10) in dichloromethane, respectively. On the other hand, excellent α-selectivities (α:β = 8:1) were obtained using propionitrile at −78 °C (Table 2, entries 3 and 4), which were in good agreement with those of Table 1 (entries 4 and 5, respectively). From all the entries in Table 2, no significant difference between donors **1** and **2** was found from the points of α-selectivity and yields.

Sialylation reactions between donor **1**, which showed the best results in Tables 1 and 2, and galactose C3–OH of either galactal **14** or lactose derivative **16** were also investigated in the synthesis of the Neu5Gc-terminated α(2→3)sialylgalactose units (Scheme 2). In the former case, the nucleophilic C3-hydroxyl group of 4,6-di-*O*-benzyl-D-galactal (**14**) was coupled with donor **1** to produce α-sialoside **15** (61% yield) in a stereoselective manner. Compound **15** is an intermediate in the course of forming a Neu5Gcα(2→3)galactose building block.[17] In the latter case, donor **1** was coupled with lactose acceptor **16**[19] to give trisaccharide **17** as the major product (42% yield) in the course of a GM_3-type trisaccharide synthesis.

3. Conclusion

We have herein described a direct sialylation approach toward the synthesis of the Neu5Gc-containing glycans using *N*-glycolylneuraminyl phosphite donors **1** and **2**. In the use of acceptors **8**, **11**, **14**, and **16**, the best yields and α-selectivities were achieved



Scheme 2.

via activation of the phosphite donors using TMSOTf in propionitrile at −78 °C. In the case of galactose C-4 and C-6 diol acceptor **8**, the choice of the protecting group on the glycolyl OH moiety was a significant factor in achieving the best α-selectivity. In the case of glucose acceptor **11**, on the other hand, such an effect was not observed. Finally, phosphite donor **1** was coupled with galactal **14** to afford **15**, a precursor of the Neu5Gcα(2→3)galactose building block, in 61% yield, and with lactose acceptor **16** to afford GM_3 analogue trisaccharide **17**, in 42% yield.

This approach provides an efficient synthesis for the Nue5Gc-containing glycans by avoiding protecting group manipulations, which include a removal of the *N*-protecting group and success in the introduction of the glycolyl moiety, upon obtaining the full sialoglycan sequence.

4. Experimental

4.1. General procedures

Optical rotations were measured in a 0.5-dm tube with a JASCO P-1020 polarimeter. IR spectra were recorded with a Shimadzu Prestege-21 or a JASCO FT/IR-4200 spectrometer. ^1H and ^{13}C NMR spectra were recorded with either a JEOL ECA-500 or a JEOL ECA-600 spectrometer (Chemical shifts are referenced to tetramethylsilane, 0.00 ppm). Column chromatography was performed on silica gel (Silica Gel 60, 70–230 mesh, E. Merck or Silica Gel 60 N, spherical, neutral, 70–230 mesh, Kanto Kagaku Co.). Thin-layer chromatography (TLC) on silica gel (Silica gel $60F_{254}$, E. Merck) was used to monitor the reactions. High-resolution mass spectra were recorded with a JEOL JMS-T100LC AccuTOF mass spectrometer.

4.2. Methyl (phenyl 4,7,8,9-tetra-*O*-acetyl-5-(2-benzyloxy) acetamido-3,5-dideoxy-2-thio-D-*glycero*-β-D-*galacto*-2-nonulopyranosid)onate (5)

A solution of **3** (493 mg, 0.845 mmol) in dry MeOH (20 mL) was added MsOH (330 μL, 5.0 mmol), and the mixture was stirred overnight under reflux. The mixture was cooled to room temperature and neutralized with excess Et_3N. The solvent was evaporated to give a brown syrup that was again dissolved in CH_2Cl_2 (4 mL). Et_3N (150 μL, 1.0 mmol) and benzyloxyacetyl chloride (160 μL, 1.0 mmol) were added with ice-water bath cooling. After stirring for 20 min at room temperature, the mixture was concentrated, redissolved in pyridine (2.5 mL), and Ac_2O (2.5 mL) was added. The mixture was then stirred overnight at room temperature and concentrated to a residue that was redissolved in EtOAc and washed with H_2O. The aq phase was extracted twice with EtOAc, and the combined organic layers were successively washed with 0.1 M HCl and brine, dried over $MgSO_4$, filtered, and concentrated. Purification of the crude product by silica gel chromatography (1:1 hexane–EtOAc) gave **5** (492 mg, 0.713 mmol, 84%). $[\alpha]_D^{26} -91$ (*c* 1.0, $CHCl_3$); IR (KBr, neat): ν 1739 cm^{-1} (COO), 2953 cm^{-1} (NH); ^1H NMR (600 MHz, $CDCl_3$): δ 7.51–7.33 (10H, m, Ph*H*), 6.54 (1H, d, N*H*, $J_{5,NH}$ = 10.5 Hz), 5.47 (1H, dd, H-7, $J_{6,7}$ = 2.4 Hz, $J_{7,8}$ = 2.5 Hz), 5.40 (1H, ddd, H-4, $J_{3ax,4}$ = 11.3 Hz, $J_{3eq,4}$ = 4.8 Hz, $J_{4,5}$ = 10.5 Hz), 4.99 (1H, ddd, H-8, $J_{8,9}$ = 2.4 Hz, $J_{8,9'}$ = 8.4 Hz), 4.67 (1H, dd, H-6, $J_{5,6}$ = 12.3 Hz), 4.64, 4.55 (2H, each s, PhCH_2, J_{AB} = 11.9 Hz), 4.48 (1H, dd, H-9, $J_{9,9'}$ = 12.3 Hz), 4.17 (1H, dd, H-5), 4.02 (1H, dd, H-9′), 3.91, 3.86 (2H, each s, COCH_2, J_{AB} = 15.4 Hz), 3.61 (3H, s, COOCH_3), 2.71 (1H, dd, H-3eq, $J_{3ax,3eq}$ = 13.9 Hz), 2.11 (1H, dd, H-3ax), 2.10 (3H, s), 2.07 (3H, s), 2.00 (3H, s), 1.97 (3H, s); ^{13}C NMR (150 MHz, $CDCl_3$): δ 170.7, 170.3, 170.3, 170.2, 170.2, 168.2, 136.8, 136.4, 136.2, 129.7, 129.1, 128.9, 128.6, 128.6, 128.2, 128.0, 128.0, 88.9, 73.5, 72.9, 72.6, 69.0, 68.9, 68.7, 62.6, 52.6, 48.6, 37.4, 24.0, 21.0, 20.8, 20.8, 20.8, 13.7; HRESIMS: calcd for $C_{33}H_{39}NO_{13}SNa$, *m*/*z* $[M+Na]^+$, 712.2040; found, 712.2002.

4.3. Methyl (5-(2-acetoxy)acetamido-4,7,8,9-tetra-*O*-acetyl-3,5-dideoxy-D-*glycero*-D-*galacto*-2-nonulopyranosid)onate (6)

A solution of **4** (208 mg, 0.324 mmol) in 6:1 acetone–H_2O (21 mL) was added NBS (246 mg, 1.3 mmol), and the mixture was stirred for 2 h at room temperature. The mixture was then diluted with EtOAc. The organic phase was washed with 5% aq $Na_2S_2O_3$, and the aq phase was extracted twice with EtOAc. The combined organic layers were washed twice with brine, dried over $MgSO_4$, filtered, and concentrated. Purification of the crude product by silica gel column chromatography (1:2 hexane–EtOAc) gave **6** (167 mg, 0.304 mmol, 94%). IR (KBr, neat): ν 1744 cm^{-1} (COO), 3446 cm^{-1} (OH); ^1H NMR (600 MHz, $CDCl_3$, selected β-anomer signal): δ 6.02 (1H, d, N*H*, $J_{5,NH}$ = 9.6 Hz), 5.32 (1H, ddd, H-4, $J_{3ax,4}$ = 13.3 Hz, $J_{3eq,4}$ = 5.0 Hz, $J_{4,5}$ = 8.2 Hz), 5.27 (1H, dd, H-7, $J_{6,7}$ = 1.7 Hz, $J_{7,8}$ = 6.4 Hz), 5.24 (1H, ddd, H-8, $J_{8,9}$ = 2.2 Hz, $J_{8,9'}$ = 6.9 Hz), 4.62, 4.31 (2H, each d, COCH_2, J_{AB} = 15.3 Hz,), 4.42 (1H, dd, H-9, $J_{9,9'}$ = 12.4 Hz), 4.25 (1H, s, OH), 4.20 (1H, dd, H-6, $J_{5,6}$ = 10.5 Hz), 4.17 (1H, ddd, H-5), 4.02 (1H, dd, H-9′), 3.88 (3H, s, COOCH_3), 2.29 (1H, dd, H-3eq, $J_{3ax,3eq}$ = 12.9 Hz), 2.19, 2.13, 2.11, 2.04, 2.01 (15H, each s, OCOCH_3 × 5), 2.15 (1H, dd, H-3ax); ^{13}C NMR (150 MHz, $CDCl_3$, selected β-anomer signal): δ 171.3, 170.7, 170.4, 170.3, 169.7, 169.0, 167.6, 94.8, 70.6, 70.5, 68.5, 67.6, 62.7, 62.6, 53.6, 49.7, 36.1, 21.0, 20.8, 20.8, 20.8, 20.7; MALDI-TOFMS: calcd for $C_{27}H_{35}NO_{14}Na$, *m*/*z* $[M+Na]^+$: 572.2; found, 572.3.

4.4. Methyl (4,7,8,9-tetra-*O*-acetyl-5-(2-benzyloxy)acetamido-3,5-dideoxy-D-*glycero*-D-*galacto*-2-nonulopyranosid)onate (7)

To a solution of **5** (205 mg, 0.297 mmol) in 6:1 acetone–H_2O (14 mL) added NBS (232 mg, 1.3 mmol), was stirred for 2 h at room temperature. Then, the mixture was diluted with EtOAc. The organic phase was washed with 5% $Na_2S_2O_3$ solution, and the aqueous phase was extracted twice with EtOAc. The combined organic layers were washed twice with brine, dried over $MgSO_4$, filtered, and concentrated. Purification by silica gel column chromatography (hexane:EtOAc = 1:2) gave **7** (138 mg, 0.231 mmol,

78%). IR (KBr, neat): ν 1745 cm^{-1} (COO), 3459 cm^{-1} (OH); ^1H NMR (600 MHz, $CDCl_3$, selected β-anomer signal): δ 7.39–7.38 (5H, m, Ph*H*), 6.51 (1H, d, N*H*, $J_{5,NH}$ = 9.8 Hz), 5.32 (1H, dd, H-7, $J_{6,7}$ = 1.7 Hz, $J_{7,8}$ = 7.0 Hz), 5.28 (1H, ddd, H-8, $J_{8,9}$ = 2.4 Hz, $J_{8,9'}$ = 6.8 Hz), 5.27 (1H, ddd, H-4, $J_{3ax,4}$ = 6.8 Hz, $J_{3eq,4}$ = 2.2 Hz, $J_{4,5}$ = 10.5 Hz), 4.60, 4.54 (2H, each d, PhCH_2, J_{AB} = 11.9 Hz), 4.36 (1H, dd, H-9, $J_{9,9'}$ = 12.5 Hz), 4.22 (1H, ddd, H-5, $J_{5,6}$ = 10.1 Hz), 4.20 (1H, dd, H-6), 4.18 (1H, s, OH), 4.04 (1H, dd, H-9′), 3.97, 3.87 (2H, each s, COCH_2, J_{AB} = 15.3 Hz), 3.87 (3H, s, COOCH_3), 2.74 (1H, dd, H-3eq, $J_{3ax,3eq}$ = 11.3 Hz), 2.26 (1H, dd, H-3ax), 2.13 (3H, s), 2.09 (3H, s), 2.02 (3H, s), 2.00 (3H, s); ^{13}C NMR (150 MHz, $CDCl_3$, selected β-anomer signal): δ 171.7, 170.5, 170.2, 170.1, 170.1, 169.1, 136.8, 128.7, 128.3, 128.1, 128.0, 94.8, 73.5, 70.4, 69.9, 69.2, 69.2, 67.5, 62.6, 53.6, 48.7, 36.1, 29.6, 21.0, 20.9, 20.8, 20.8; HRESIMS: calcd for $C_{27}H_{35}NO_{14}Na$, m/z $[M+Na]^+$, 620.1955; found, 620.1957.

4.5. Methyl (5-(2-acetoxy)acetamido-4,7,8,9-tetra-*O*-acetyl-2-dibenzylphosphityl-3,5-dideoxy-D-*glycero*-D-*galacto*-2-nonulopyranosid)onate (1)

To a solution of **6** (168 mg, 0.306 mmol) in CH_2Cl_2 (10 mL) was added 1*H*-tetrazole (86 mg, 1.2 mmol). The mixture was cooled to 0 °C, and dibenzyl *N*,*N*-diethylphosphoramidite (230 μL, 0.73 mmol) was added. After stirring for 1.5 h, the reaction was quenched with an excess of Et_3N, and the mixture was concentrated under reduced pressure. The residue was then purified by silica gel column chromatography (1:2 hexane–EtOAc with 0.5% Et_3N) to give **1** (235 mg, 0.296 mmol, 97%, α:β = 1:5). IR (KBr, neat): ν 1635 cm^{-1} (COO), 3441 cm^{-1} (OH); ^1H NMR (600 MHz, $CDCl_3$, selected β-anomer signal): δ 7.44–7.31 (10H, m, Ph*H*), 5.49 (1H, d, N*H*, $J_{5,NH}$ = 10.1 Hz), 5.22 (1H, dd, H-7, $J_{6,7}$ = $J_{7,8}$ = 2.2 Hz), 5.17 (1H, ddd, H-8, $J_{8,9}$ = 2.2 Hz, $J_{8,9'}$ = 7.1 Hz), 5.14 (1H, ddd, H-4, $J_{3ax,4}$ = 11.1 Hz, $J_{3eq,4}$ = 6.2 Hz, $J_{4,5}$ = 11.0 Hz), 4.96–4.89 (4H, m, benzyl protons) 4.61 (1H, dd, H-9, $J_{9,9'}$ = 12.4 Hz), 4.53, 4.27 (2H, each d, COCH_2, J_{AB} = 15.1 Hz,), 4.15 (1H, dd, H-6, $J_{5,6}$ = 12.1 Hz), 4.09 (1H, ddd, H-5), 3,97 (1H, dd, H-9′), 3.72 (3H, s, COOCH_3), 2.46 (1H, dd, H-3eq, $J_{3ax,3eq}$ = 13.1 Hz), 2.21 (3H, s), 2.11 (3H, s), 2.06 (3H, s), 2.02 (3H, s), 2.00 (3H, s); ^{13}C NMR (150 MHz, $CDCl_3$, selected β-anomer signal): δ 170.9, 170.6, 170.4, 170.3, 169.7, 167.5, 167.5, 128.7, 128.7, 128.7, 128.5, 128.5, 128.5, 128.1, 128.0, 127.9, 127.9, 127.7, 127.7, 127.6, 97.7, 97.6, 72.3, 71.9, 68.2, 67.6, 65.5, 65.4, 64.5, 64.4, 62.3, 62.5, 53.1, 49.0, 38.1, 21.1, 20.8, 20.8, 20.7; HRESIMS: calcd for $C_{36}H_{44}NO_{17}PNa$, m/z $[M+Na]^+$, 816.2245; found, 816.2225.

4.6. Methyl (4,7,8,9-tetra-*O*-acetyl-5-(2-benzyloxy)acetamido-2-dibenzylphosphityl-3,5-dideoxy-D-*glycero*-D-*galacto*-2-nonulopyranosid)onate (2)

To a solution of **7** (145 mg, 0.243 mmol) in CH_2Cl_2 (10 mL) added 1*H*-tetrazole (68 mg, 0.97 mmol) was cooled at 0 °C. Dibenzyl *N*,*N*-diethylphosphoramidite (180 μL, 0.570 mmol) was then added. After stirring for 2.5 h, the reaction was quenched with an excess of Et_3N, and the mixture was concentrated under reduced pressure. The residue was then purified by silica gel column chromatography (1:1 hexane–EtOAc with 0.5% Et_3N) to give **2** (193 mg, 0.229 mmol, 95%,α:β = 1:5). IR (KBr, neat): ν 1745 cm^{-1} (COO), 3441 cm^{-1} (OH); ^1H NMR (600 MHz, $CDCl_3$, selected β-anomer signal): δ 7.41–7.22 (15H, m, Ph*H*), 6.07 (1H, d, N*H*, $J_{5,NH}$ = 10.5 Hz), 5.28 (1H, dd, H-7, $J_{6,7}$ = 2.2 Hz, $J_{7,8}$ = 4.2 Hz), 5.18 (1H, ddd, H-8, $J_{8,9}$ = 2.6 Hz, $J_{8,9'}$ = 4.6 Hz), 5.08 (1H, ddd, H-4, $J_{3ax,4}$ = 8.6 Hz, $J_{3eq,4}$ = 5.0 Hz, $J_{4,5}$ = 8.6 Hz), 4.94–4.89 (4H, m, benzyl protons), 4.65, 4.56 (2H, each d, PhCH_2, J_{AB} = 12.0 Hz), 4.59 (1H, dd, H-9, $J_{9,9'}$ = 15.0 Hz), 4.15 (1H, ddd, H-5, $J_{5,6}$ = 9.8 Hz), 4.14 (1H, dd, H-9′), 3.93, 3.84 (2H, each d, COCH_2, J_{AB} = 15.3 Hz), 3.85 (1H, dd, H-6), 3.75 (3H, s, COOCH_3), 2.51 (1H, dd, H-3eq, $J_{3ax,3eq}$ = 13.1 Hz), 2.10 (3H, s), 2.07 (3H, s), 2.00 (3H, s), 1.98 (3H, s), ^{13}C NMR (150 MHz, $CDCl_3$, selected β-anomer signal): δ 170.8, 170.5, 170.3, 170.2, 170.2, 169.1, 136.8, 135.5, 128.7, 128.7, 128.7, 128.7, 128.7, 128.7, 128.7, 128.6, 128.6, 128.6, 128.6, 128.6, 128.5, 128.5, 128.5, 128.5, 128.3, 128.3, 128.2, 128.1, 128.1, 128.0, 127.9, 127.9, 127.8, 127.8, 127.7, 127.7, 127.0, 98.5, 94.8, 73.5, 73.5, 70.4, 70.0, 69.2, 69.1, 69.1, 67.5, 67.4, 67.4, 66.9, 66.9, 66.8, 65.3, 62.6, 53.6, 52.7, 48.8, 36.1, 21.2, 21.0, 20.9, 20.9, 20.9, 20.8, 20.8, 20.8; HRESIMS: calcd for $C_{41}H_{48}NO_{16}PNa$, m/z $[M+Na]^+$, 864.2608; found, 864.2579.

4.7. 2-(Trimethylsilyl)ethyl (methyl 5-(2-acetoxy)acetamido-4,7,8,9-tetra-*O*-acetyl-3,5-dideoxy-D-*glycero*-α-D-*galacto*-2-nonulopyranosylonate)-(2→6)-2,3-di-*O*-benzoyl-β-D-galactopyranoside (9)

4.7.1. Conditions in CH_2Cl_2

To a solution of donor **1** (40 mg, 0.050 mmol) and acceptor **8** (16 mg, 0.033 mmol) in EtCN (5 mL) added 4 Å MS was stirred for 15 min at −78 °C. TMSOTf (1.5 μL, 0.0078 mmol) was then added. After stirring for 10 min at −78 °C under an atmosphere of argon, the reaction mixture was neutralized with excess Et_3N and filtered through Celite. The filtrate was concentrated, and the crude product was purified by silica gel column chromatography (1:2 hexane–EtOAc) to give **9** (29 mg, 0.028 mmol, 88%, α/β = 1:1.5).

4.7.2. Conditions in EtCN

To a solution of donor **1** (43 mg, 0.054 mmol) and acceptor **8** (18 mg, 0.037 mmol) in EtCN (5 mL) added 4 Å MS was stirred for 15 min at −78 °C. TMSOTf (1.5 μL, 0.0078 mmol) was then added. After stirring for 10 min at −78 °C under an atmosphere of argon, the reaction mixture was neutralized with excess Et_3N and filtered through Celite. The filtrate was concentrated, and the crude product was purified by silica gel column chromatography (1:2 hexane–EtOAc) to give **9** (36 mg, 0.035 mmol, 74%, α/β = 4.7:1). Compound **9α**: R_f 0.19 (1:2 hexane–EtOAc); $[\alpha]_D^{24}$ + 14 (*c* 0.3, $CHCl_3$); IR (KBr, neat): ν 1750 cm^{-1} (COO), 2955 cm^{-1} (NH), 3483 cm^{-1} (OH); ^1H NMR (600 MHz, $CDCl_3$): δ 8.04–7.96, 7.51–7.36 (10H, each m, Ph*H*), 5.90 (1H, d, Neu-N*H*, $J_{5,NH}$ = 10.0 Hz), 5.74 (1H, dd, Gal-H-2, $J_{1,2}$ = 7.9 Hz, $J_{2,3}$ = 10.2 Hz), 5.37 (1H, ddd, Neu-H-4, $J_{3ax,4}$ = 11.4 Hz, $J_{3eq,4}$ = 4.6 Hz, $J_{4,5}$ = 10.4 Hz), 5.29 (1H, dd, Neu-H-7, $J_{6,7}$ = 2.1 Hz, $J_{7,8}$ = 1.9 Hz), 5.28 (1H, dd, Gal-H-3, $J_{3,4}$ = 3.3 Hz), 4.95 (1H, ddd, Neu-H-8, $J_{8,9}$ = 2.6 Hz, $J_{8,9'}$ = 9.7 Hz), 4.81 (1H, d, Gal-H-1), 4.59, 4.30 (2H, each d, Neu-COCH_2, J_{AB} = 15.3 Hz,), 4.42 (1H, dd, Neu-H-9, $J_{9,9'}$ = 12.3 Hz), 4.36 (1H, dd, Gal-H-4, $J_{4,5}$ = 5.0 Hz), 4.18 (1H, dd, Neu-H-6, $J_{5,6}$ = 10.7 Hz), 4.08 (1H, ddd, Neu-H-5), 4.07 (1H, dd, Gal-H-6, $J_{5,6}$ = 4.0 Hz, $J_{6,6'}$ = 10.0 Hz), 4.04 (1H, dd, Gal-H-6′, $J_{5,6'}$ = 4.3 Hz), 4.03 (1H, dd, Neu-H-9′), 3.91–3.88, 3.63–3.58 (2H, each m, Gal-OCH_2), 3.87 (1H, ddd, Gal-H-5), 3.84 (3H, s, Neu-COOCH_3), 2.91 (1H, br s, Gal-OH), 2.60 (1H, dd, Neu-H-3eq, $J_{3ax,3eq}$ = 12.8 Hz), 2.18, 2.16, 2.13, 2.02, 1.94 (15H, each s, Neu-OCOCH_3 × 5), 0.97–0.81 (2H, m, SiCH_2), −0.09 (9H, m, Si(CH_3)$_3$); ^{13}C NMR (150 MHz, $CDCl_3$): δ 171.0, 170.9, 170.4, 170.1, 169.6, 168.0, 167.6, 166.0, 165.3, 133.2, 132.9, 130.0, 129.8, 129.7, 129.4, 128.4, 128.2, 100.9, 99.0, 93.1, 87.3, 74.6, 72.9, 72.5, 69.8, 69.2, 68.1, 67.5, 67.3, 66.6, 62.7, 62.5, 53.1, 49.4, 48.6, 37.1, 35.9, 32.6, 29.7, 21.0, 20.8, 20.7, 20.7, 20.6, 17.9, 13.6, 7.3, −1.4; HRESIMS: calcd for $C_{47}H_{61}NO_{22}SiNa$, m/z $[M+Na]^+$, 1042.3352; found, 1042.3325. Compound **9β**: R_f 0.22 (1:2 hexane–EtOAc); $[\alpha]_D^{25}$ + 18 (*c* 0.4, $CHCl_3$); ^1H NMR (600 MHz, $CDCl_3$): δ 8.04–7.96, 7.51–7.36 (10H, each m, Ph*H*), 6.29 (1H, d, Neu-N*H*, $J_{5,NH}$ = 9.1 Hz), 5.69 (1H, dd, Gal-H-2, $J_{1,2}$ = 7.9 Hz, $J_{2,3}$ = 10.3 Hz), 5.49 (1H, ddd, Neu-H-4, $J_{3ax,4}$ = 11.7 Hz, $J_{3eq,4}$ = 5.0 Hz, $J_{4,5}$ = 10.9 Hz), 5.37 (1H, dd, Gal-H-3, $J_{3,4}$ = 3.1 Hz),

5.34 (1H, ddd, Neu-H-8, $J_{7,8}$ = 2.1 Hz, $J_{8,9}$ = 2.2 Hz, $J_{8,9'}$ = 6.7 Hz), 5.27 (1H, dd, Neu-H-7, $J_{6,7}$ = 2.1 Hz,), 4.68 (1H, d, Gal-H-1), 4.67 (1H, dd, Neu-H-9, $J_{9,9'}$ = 6.3 Hz), 4.49, 4.19 (2H, each d, Neu-COCH_2, J_{AB} = 15.1 Hz,), 4.45 (1H, dd, Gal-H-4, $J_{4,5}$ = 4.1 Hz), 4.37 (1H, dd, Neu-H-6, $J_{5,6}$ = 10.7 Hz), 4.17 (1H, dd, Gal-H-6, $J_{5,6}$ = 5.7 Hz, $J_{6,6'}$ = 12.0 Hz), 3.98 (1H, ddd, Gal-H-5, $J_{5,6'}$ = 4.8 Hz), 3.92 (1H, dd, Gal-H-6′), 3.85–3.82, 3.59–3.54 (2H, each m, Gal-OCH_2), 3.83 (3H, s, Neu-COOCH_3), 3.73 (1H, ddd, Neu-H-5), 3.60 (1H, dd, Neu-H-9′) 3.59 (1H, s, Gal-OH), 2.53 (1H, dd, Neu-H-3eq, $J_{3ax,3eq}$ = 12.9 Hz), 2.14, 2.10, 2.07, 2.06, 2.00 (15H, each s, Neu-OCOCH_3 × 5), 1.81 (1H, dd, Neu-H-3ax), 0.91–0.80 (2H, m, SiCH_2), −0.08 (9H, m, Si(CH_3)$_3$); ^{13}C NMR (150 MHz, $CDCl_3$): δ 171.5, 171.0, 170.7, 170.6, 169.7, 168.0, 167.2, 165.9, 165.4, 133.2, 132.9, 130.0, 129.8, 129.7, 129.5, 128.3, 128.2, 100.9, 98.4, 74.2, 72.2, 71.3, 70.6, 70.0, 68.9, 67.4, 66.3, 62.7, 62.2, 60.9, 52.9, 50.3, 37.5, 29.7, 29.7, 21.1, 20.9, 20.8, 20.5, 18.0, −1.4, −1.5; HRESIMS: calcd for $C_{47}H_{61}NO_{22}SiNa$, m/z [M+Na]$^+$, 1042.3352; found, 1042.3348.

4.8. 2-(Trimethylsilyl)ethyl (methyl 4,7,8,9-tetra-*O*-acetyl-5-(2-benzyloxy)acetamido-3,5-dideoxy-D-*glycero*-α-D-*galacto*-2-nonulopyranosylonate)-(2→6)-2,3-di-*O*-benzoyl-β-D-galactopyranoside (10)

4.8.1. Conditions in CH_2Cl_2

To a solution of donor **2** (37 mg, 0.044 mmol) and acceptor **8** (14 mg, 0.029 mmol) in EtCN (5 mL) was added 4 Å MS, and the mixture was stirred for 15 min at −78 °C. TMSOTf (1.5 μL, 0.0078 mmol) was then added. After stirring for 10 min at −78 °C under an atmosphere of argon, the reaction mixture was neutralized with excess Et_3N, and filtered through Celite. The filtrate was concentrated, and the crude product was purified by silica gel column chromatography (1:1 hexane–EtOAc) to give **10** (22 mg, 0.021 mmol, 71%, α/β = 2.3:1).

4.8.2. Conditions in EtCN

To a solution of donor **2** (44 mg, 0.052 mmol) and acceptor **8** (17 mg, 0.035 mmol) in EtCN (5 mL) added 4 Å MS was stirred for 15 min at −78 °C. TMSOTf (1.5 μL, 0.0078 mmol) was then added. After stirring for 10 min at −78 °C under an atmosphere of argon, the reaction mixture was neutralized with excess Et_3N and filtered through Celite. The filtrate was concentrated, and the crude product was purified by silica gel column chromatography (1:1 hexane–EtOAc) to give **10** (36 mg, 0.034 mmol, 87%, α/β = 10:1). Compound **10α**: R_f 0.19 (40:1 $CHCl_3$–MeOH); $[\alpha]_D^{25}$ + 27 (*c* 0.6, $CHCl_3$); IR (KBr, neat): ν 1747 cm^{-1} (COO), 2954 cm^{-1} (NH), 3362 cm^{-1} (OH); ^{1}H NMR (600 MHz, $CDCl_3$): δ 8.01–7.97 (4H, m, Ph*H*), 7.49–7.36 (11H, m, Ph*H*), 6.35 (1H, d, Neu-N*H*, $J_{5,NH}$ = 9.6 Hz), 5.75 (1H, dd, Gal-H-2, $J_{1,2}$ = 7.9 Hz, $J_{2,3}$ = 10.1 Hz), 5.38 (1H, ddd, Neu-H-4, $J_{3ax,4}$ = 13.8 Hz, $J_{3eq,4}$ = 2.8 Hz, $J_{4,5}$ = 8.0 Hz), 5.34 (1H, dd, Neu-H-7, $J_{6,7}$ = 1.5 Hz, $J_{7,8}$ = 2.4 Hz), 5.29 (1H, dd, Gal-H-3, $J_{3,4}$ = 3.1 Hz), 4.89 (1H, ddd, Neu-H-8, $J_{8,9}$ = 2.4 Hz, $J_{8,9'}$ = 9.1 Hz), 4.72 (1H, d, Gal-H-1), 4.59 (1H, d, Neu-PhCH_2, J_{AB} = 11.9 Hz), 4.54 (1H, d, Neu-PhCH_2, J_{AB} = 11.9 Hz), 4.57 (1H, dd, Neu-H-6, $J_{5,6}$ = 13.1 Hz), 4.38 (1H, dd, Neu-H-9, $J_{9,9'}$ = 12.6 Hz), 4.37 (1H, dd, Gal-H-4, $J_{4,5}$ = 5.2 Hz), 4.14 (1H, ddd, Neu-H-5), 4.12 (1H, dd, Neu-H-9′), 4.07 (1H, dd, Gal-H-6, $J_{5,6}$ = 6.0 Hz, $J_{6,6'}$ = 10.1 Hz), 4.03 (1H, dd, Gal-H-6′, $J_{5,6'}$ = 5.3 Hz), 3.90 (1H, m, Gal-OCH_2), 3.61 (1H, m, Gal-OCH_2), 3.91, 3.82 (2H, each d, NHCOCH_2, J_{AB} = 15.1 Hz), 3.86 (1H, ddd, Gal-H-5), 3.83 (3H, s, Neu-COOCH_3), 2.89 (1H, br s, Gal-OH), 2.62 (1H, dd, Neu-H-3eq, $J_{3ax,3eq}$ = 11.0 Hz), 2.13 (1H, dd, Neu-H-3ax), 2.15, 2.13, 2.00, 1.93 (12H, each s, Neu-OCOCH_3 × 4), 1.04–0.88 (2H, m, SiCH_2), −0.08 (9H, m, Si(CH_3)$_3$); ^{13}C NMR (150 MHz, $CDCl_3$): δ 170.8, 170.4, 170.2, 170.1, 170.0, 167.8, 165.9, 165.3, 136.8, 133.2, 132.9, 129.9, 129.9, 129.7, 129.4, 128.6, 128.4, 128.3, 128.2, 128.0, 100.9, 99.0, 74.5, 73.5, 72.7, 72.5, 69.9, 69.1, 68.7, 67.3, 67.2, 66.7, 62.5, 62.5, 53.1, 48.4, 37.2, 21.0, 20.8, 20.8, 20.6, 17.9, −1.5; HRESIMS: calcd for $C_{52}H_{65}NO_{21}SiNa$ m/z [M+Na]$^+$: 1090.3716; found, 1090.3717. Compound **10β**: R_f 0.21 (40:1 $CHCl_3$–MeOH); $[\alpha]_D^{25}$ + 14 (*c* 0.4, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ 8.00–7.96, 7.51–7.29 (15H, each m, Ph*H*), 6.72 (1H, d, Neu-N*H*, $J_{5,NH}$ = 9.3 Hz), 5.69 (1H, dd, Gal-H-2, $J_{1,2}$ = 8.1 Hz, $J_{2,3}$ = 10.2 Hz), 5.47 (1H, ddd, Neu-H-4, $J_{3ax,4}$ = 11.5 Hz, $J_{3eq,4}$ = 5.0 Hz, $J_{4,5}$ = 10.8 Hz), 5.40 (1H, dd, Gal-H-3, $J_{3,4}$ = 2.1 Hz), 5.36 (1H, ddd, Neu-H-8, $J_{7,8}$ = 2.4 Hz, $J_{8,9}$ = 2.2 Hz, $J_{8,9'}$ = 5.3 Hz), 5.35 (1H, dd, Neu-H-7, $J_{6,7}$ = 3.1 Hz), 4.67 (1H, d, Gal-H-1), 4.65 (1H, dd, Neu-H-9, $J_{9,9'}$ = 12.5 Hz), 4.51, 4.48 (2H, each d, Neu-PhCH_2, J_{AB} = 11.9 Hz), 4.46 (1H, dd, Neu-H-6, $J_{5,6}$ = 11.7 Hz), 4.44 (1H, dd, Gal-H-4, $J_{4,5}$ = 8.6 Hz), 4.19 (1H, dd, Gal-H-6, $J_{5,6}$ = 6.4 Hz, $J_{6,6'}$ = 12.5 Hz), 3.98, 3.56 (2H, each m, OCH_2), 3.91 (1H, dd, Gal-H-6′, $J_{5,6'}$ = 5.5 Hz), 3.84 (3H, s, Neu-COOCH_3), 3.80 (1H, ddd, Gal-H-5), 3.71 (1H, br s, Gal-OH), 3.60 (1H, dd, Neu-H-9′), 2.55 (1H, dd, Neu-H-3eq, $J_{3ax,3eq}$ = 12.9 Hz), 2.14, 2.14, 2.03, 1.97 (12H, each s, Neu-OCOCH_3 × 4), 1.80 (1H, dd, Neu-H-3ax), 0.92–0.79 (2H, m, SiCH_2), −0.08 (9H, m, Si(CH_3)$_3$); ^{13}C NMR (150 MHz, $CDCl_3$): δ 171.2, 170.9, 170.5, 170.4, 170.2, 167.2, 165.8, 165.4, 136.7, 133.0, 132.9, 130.0, 130.0, 129.7, 129.6, 128.6, 128.2, 127.9, 100.9, 98.4, 74.1, 73.4, 72.2, 71.0, 70.1, 69.0, 68.5, 67.8, 67.3, 66.2, 62.2, 60.9, 52.9, 37.4, 21.1, 20.9, 20.9, 20.8, 18.0, −1.5, −1.5; HRESIMS: calcd for $C_{52}H_{65}NO_{21}Na$, m/z [M+Na]$^+$, 1090.3716; found, 1090.3713.

4.9. 4-Methoxyphenyl (methyl 5-(2-acetoxy)acetamido-4,7,8,9-tetra-*O*-acetyl-3,5-dideoxy-D-*glycero*-α-D-*galacto*-2-nonulopyranosylonate)-(2→6)-2,3,4-tri-*O*-benzyl-β-D-glucopyranoside (12)

4.9.1. Conditions in CH_2Cl_2

To a solution of donor **1** (38 mg, 0.048 mmol) and acceptor **11** (18 mg, 0.032 mmol) in CH_2Cl_2 (5 mL) added 4 Å MS was stirred for 15 min at −78 °C. TMSOTf (1.5 μL, 0.0078 mmol) was then added. After stirring for 10 min at −78 °C under an atmosphere of argon, the mixture was neutralized with excess Et_3N and filtered through Celite. The filtrate was concentrated, and the crude product was purified by silica gel column chromatography (1:2 hexane–EtOAc) to give **12** (30 mg, 0.028 mmol, 86%, α/β = 1:10).

4.9.2. Conditions in EtCN

To a solution of donor **1** (42 mg, 0.053 mmol) and acceptor **11** (21 mg, 0.038 mmol) in EtCN (5 mL) added 4 Å MS was stirred for 15 min at −78 °C. TMSOTf (1.5 μL, 0.0078 mmol) was then added. After stirring for 10 min at −78 °C under an atmosphere of argon, the mixture was neutralized with excess Et_3N and filtered through Celite. The filtrate was concentrated, and the crude product was purified by silica gel column chromatography (1:2 hexane–EtOAc) to give **12** (35 mg, 0.032 mmol, 85%, α/β = 8:1). Compound **12α**: R_f 0.19 (1:2 hexane–EtOAc); $[\alpha]_D^{24}$ − 18 (*c* 1.0, $CHCl_3$); IR (KBr, neat): ν 1455 cm^{-1} (C=C), 1747 cm^{-1} (COO), 2932 cm^{-1} (NH), 3369 cm^{-1} (OH); ^{1}H NMR (600 MHz, $CDCl_3$): δ 7.28–7.21 (15H, m, Ph*H*), 6.95–6.94, 6.77–6.76 (4H, each m, Ph*H*), 5.72 (1H, d, Neu-N*H*, $J_{5,NH}$ = 10.1 Hz), 5.35 (1H, ddd, Neu-H-4, $J_{3ax,4}$ = 12.6 Hz, $J_{3eq,4}$ = 4.6 Hz, $J_{4,5}$ = 8.8 Hz), 5.18 (1H, dd, Neu-H-7, $J_{6,7}$ = 2.2 Hz, $J_{7,8}$ = 8.9 Hz), 4.96, 4.72 (2H, each d, PhCH_2, J_{AB} = 10.8 Hz), 4.85 (1H, ddd, Neu-H-8, $J_{8,9}$ = 2.6 Hz, $J_{8,9'}$ = 12.5 Hz), 4.83, 4.72 (2H, each d, Glc-PhCH_2, J_{AB} = 11.0 Hz), 4.75, 4.72 (2H, each d, Glc-PhCH_2, J_{AB} = 10.0 Hz), 4.74 (1H, d, Glc-H-1, $J_{1,2}$ = 7.7 Hz), 4.51, 4.21 (2H, each d, Neu-COCH_2, J_{AB} = 15.3 Hz,), 4.14 (1H, dd, Neu-H-9, $J_{9,9'}$ = 12.5 Hz), 4.09 (1H, dd, Glc-H-3, $J_{3,4}$ = 4.5 Hz, $J_{2,3}$ = 11.3 Hz), 4.07 (1H, dd, Neu-H-6, $J_{5,6}$ = 10.7 Hz), 3.96 (1H, ddd, Neu-H-5), 3.91 (1H, dd, Neu-H-9′), 3.72 (3H, s, Neu-COOCH_3), 3.64 (1H, dd,

Glc-H-4, $J_{4,5}$ = 9.1 Hz), 3.61 (3H, s, Glc-OCH_3), 3.60 (1H, dd, Glc-H-2), 3.60 (1H, ddd, Glc-H-5, $J_{5,6}$ = 1.4 Hz, $J_{5,6'}$ = 1.7 Hz), 3.56 (1H, dd, Glc-H-6, $J_{6,6'}$ = 11.2 Hz), 3.43 (1H, dd, Glc-H-6′), 2.61 (1H, dd, Neu-H-3eq, $J_{3ax,3eq}$ = 12.8 Hz), 2.11 (3H, s), 2.07 (3H, s), 1.96 (3H, s), 1.94 (3H, s), 1.84 (3H, s), 1.88 (1H, dd, Neu-H-3ax); ^{13}C NMR (150 MHz, $CDCl_3$): δ 171.0, 170.6, 170.2, 169.9, 169.6, 168.0, 167.6, 155.3, 151.6, 138.5, 138.3, 138.3, 128.4, 128.4, 128.4, 128.3, 128.2, 128.2, 128.0, 127.9, 127.8, 127.8, 127.8, 127.7, 127.6, 118.4, 114.5, 102.8, 98.8, 84.5, 81.9, 75.8, 75.0, 75.0, 74.0, 72.2, 68.2, 68.0, 67.0, 63.6, 62.8, 62.1, 55.7, 52.7, 49.4, 38.2, 21.2, 20.8, 20.7, 20.7, 20.6; HRESIMS: calcd for $C_{56}H_{65}NO_{21}Na$, m/z $[M+Na]^+$, 1110.3947; found, 1110.3965. Compound **12β**: R_f 0.2 (1:2 hexane–EtOAc); $[\alpha]_D^{25}$ + 15 (*c* 1.1, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ 7.35–7.26 (15H, m, Ph*H*), 7.03–7.01, 6.84–6.83 (4H, each m, Ph*H*), 5.84 (1H, d, Neu-N*H*, $J_{5,NH}$ = 10.0 Hz), 5.27 (1H, ddd, Neu-H-4, $J_{3ax,4}$ = 10.9 Hz, $J_{3eq,4}$ = 4.8 Hz, $J_{4,5}$ = 10.8 Hz), 5.23 (1H, dd, Neu-H-7, $J_{6,7}$ = 2.2 Hz, $J_{7,8}$ = 3.5 Hz), 5.13 (1H, ddd, Neu-H-8, $J_{8,9}$ = 2.2 Hz, $J_{8,9'}$ = 8.1 Hz), 4.96, 4.76 (2H, each d, Glc-PhCH_2, J_{AB} = 10.8 Hz), 4.87, 4.77 (2H, each d, Glc-PhCH_2, J_{AB} = 11.0 Hz), 4.86 (1H, d, Glc-H-1, $J_{1,2}$ = 6.7 Hz), 4.82, 4.66 (2H, each d, Glc-PhCH_2, J_{AB} = 10.8 Hz), 4.77 (1H, dd, Neu-H-9, $J_{9,9'}$ = 10.8 Hz), 4.43, 4.14 (2H, each d, Neu-COCH_2, J_{AB} = 15.3 Hz,), 4.16 (1H, dd, Neu-H-6, $J_{5,6}$ = 10.3 Hz), 4.12 (1H, dd, Glc-H-3, $J_{2,3}$ = $J_{3,4}$ = 10.3 Hz), 4.14 (1H, ddd, Neu-H-5), 4.01 (1H, dd, Neu-H-9′), 3.80 (1H, dd, Glc-H-6, $J_{5,6}$ = 2.4 Hz, $J_{6,6'}$ = 11.3 Hz), 3.74 (1H, ddd, Glc-H-5, $J_{4,5}$ = 8.8 Hz, $J_{5,6'}$ = 3.6 Hz), 3.72 (3H, s, Glc-OCH_3), 3.67 (1H, dd, Glc-H-2), 3.64 (1H, dd, Glc-H-4), 3.57 (3H, s, Neu-COOCH_3), 3.50 (1H, ddd, Glc-H-6′), 2.41 (1H, dd, Neu-H-3eq, $J_{3ax,3eq}$ = 12.9 Hz), 2.18, 2.14, 2.03, 2.02, 1.91 (15H, each s, Neu-OCOCH_3 × 5); ^{13}C NMR (150 MHz, $CDCl_3$): δ 171.0, 170.6, 170.1, 170.0, 169.7, 167.6, 166.9, 155.5, 151.5, 138.4, 138.2, 138.1, 128.4, 128.4, 128.1, 127.9, 127.8, 127.8, 127.8, 127.8, 127.8, 127.7, 118.5, 114.7, 103.3, 97.9, 84.4, 82.1, 76.7, 75.7, 75.2, 74.9, 73.8, 71.8, 71.5, 68.3, 68.2, 62.5, 61.4, 55.6, 52.6, 48.8, 37.3, 20.8, 20.8, 20.7, 20.6; HRESIMS: calcd for $C_{56}H_{65}NO_{21}Na$, m/z $[M+Na]^+$, 1100.3947; found, 1110.3983.

4.10. 4-Methoxyphenyl (methyl 4,7,8,9-tetra-*O*-acetyl-5-(2-benzyloxy)acetamido-3,5-dideoxy-D-*glycero*-α-D-*galacto*-2-nonulopyranosylonate)-(2→6)-2,3,4-tri-*O*-benzyl-β-D-glucopyranoside (13)

4.10.1. Conditions in CH_2Cl_2

To a solution of donor **2** (44 mg, 0.052 mmol) and acceptor **11** (19 mg, 0.034 mmol) in CH_2Cl_2 (5 mL) added 4 Å MS was stirred for 15 min at −78 °C. TMSOTf (1.5 μL, 0.0078 mmol) was then added. After stirring for 10 min at −78 °C under an atmosphere of argon, the reaction mixture was neutralized with excess Et_3N and filtered through Celite. The filtrate was concentrated, and the crude product was purified by silica gel column chromatography (1:1 hexane–EtOAc) to give **13** (35 mg, 0.031 mmol, 90%, α/β = 1:10).

4.10.2. Conditions in EtCN

To a solution of donor **2** (45 mg, 0.053 mmol) and acceptor **11** (20 mg, 0.036 mmol) in EtCN (5 mL) added 4 Å MS was stirred for 15 min at −78 °C. TMSOTf (1.5 μL, 0.0078 mmol) was then added. After stirring for 10 min at −78 °C under an atmosphere of argon, the reaction mixture was neutralized with excess Et_3N and filtered through Celite. The filtrate was concentrated, and the crude product was purified by silica gel column chromatography (1:1 hexane–EtOAc) to give **13** (31 mg, 0.027 mmol, 76%, α/β = 8:1). Compound **13α**: R_f 0.11 (1:1 hexane–EtOAc); $[\alpha]_D^{25}$ − 11 (*c* 0.7, $CHCl_3$); IR (KBr, neat): ν 1455 cm^{-1} (C=C), 1746 cm^{-1} (COO), 2927 cm^{-1} (NH), 3368 cm^{-1} (OH); ^{1}H NMR (600 MHz, $CDCl_3$): δ 7.46–7.29 (20H, m, Ph*H*), 6.96–6.94, 6.79–6.77 (4H, each m, Ph*H*), 6.24 (1H, d, Neu-N*H*, $J_{5,NH}$ = 10.3 Hz), 5.44 (1H, dd, Neu-H-7, $J_{6,7}$ = 2.3 Hz, $J_{7,8}$ = 2.7 Hz), 5.36 (1H, ddd, Neu-H-4, $J_{3ax,4}$ = 11.5 Hz, $J_{3eq,4}$ = 4.8 Hz, $J_{4,5}$ = 9.4 Hz), 5.05 (1H, ddd, Neu-H-8, $J_{8,9}$ = 2.5 Hz, $J_{8,9'}$ = 5.0 Hz), 4.97, 4.75 (2H, each d, Glc-PhCH_2, J_{AB} = 11.0 Hz), 4.86 (1H, d, Glc-H-1, $J_{1,2}$ = 6.7 Hz), 4.84, 4.82 (2H, each d, Glc-PhCH_2, J_{AB} = 10.1 Hz), 4.76, 4.74 (2H, each d, Glc-PhCH_2, J_{AB} = 11.2 Hz), 4.59 (1H, dd, Neu-H-6, $J_{5,6}$ = 11.4 Hz), 4.53, 4.48 (2H, each d, Neu-PhCH_2, J_{AB} = 11.9 Hz), 4.39 (1H, dd, Neu-H-9, $J_{9,9'}$ = 12.6 Hz), 4.13 (1H, ddd, Neu-H-5), 3.92 (1H, dd, Neu-H-9′), 3.84, 3.77 (2H, each d, Neu-COCH_2, J_{AB} = 15.3 Hz), 3.80 (1H, dd, Glc-H-6, $J_{5,6}$ = 4.0 Hz, $J_{6,6'}$ = 9.7 Hz), 3.77 (1H, ddd, Glc-H-5, $J_{4,5}$ = 9.8 Hz, $J_{5,6'}$ = 4.8 Hz), 3.74 (1H, dd, Glc-H-3, $J_{2,3}$ = $J_{3,4}$ = 8.9 Hz), 3.73 (3H, s, Glc-OCH_3), 3.66 (1H, dd, Glc-H-2), 3.62 (3H, s, Neu-COOCH_3), 3.55 (1H, dd, Glc-H-4), 3.44 (1H, dd, H-6′), 2.65 (1H, dd, Neu-H-3eq, $J_{3ax,3eq}$ = 12.7 Hz), 2.08, 2.00, 1.94, 1.84 (12H, each s, Neu-OCOCH_3 × 4); ^{13}C NMR (150 MHz, $CDCl_3$): δ 170.6, 170.4, 170.1, 170.0, 169.8, 167.8, 155.3, 151.6, 138.6, 138.3, 138.3, 136.8, 128.6, 128.4, 128.4, 128.4, 128.4, 128.3, 128.2, 128.1, 128.1, 127.8, 127.8, 127.7, 127.6, 118.4, 114.5, 104.4, 102.8, 98.7, 84.5, 81.9, 77.1, 77.1, 76.9, 75.6, 75.1, 75.0, 74.0, 73.5, 72.6, 72.1, 69.2, 69.0, 67.6, 66.9, 63.5, 62.1, 55.7, 52.7, 48.5, 38.1, 21.2, 20.8, 20.8, 20.6, −11.1; HRESIMS: calcd for $C_{61}H_{69}NO_{20}Na$, m/z $[M+Na]^+$, 1158.4311; found, 1158.4330. Compound **13β**: R_f 0.09 (1:1 hexane–EtOAc); $[\alpha]_D^{25}$ − 8.5 (*c* 1.1, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ 7.33–7.25 (20H, m, Ph*H*), 7.01–7.00, 6.84–6.83 (4H, each m, Ph*H*), 6.42 (1H, d, Neu-N*H*, $J_{5,NH}$ = 9.8 Hz), 5.36 (1H, dd, Neu-H-7, $J_{6,7}$ = 1.7 Hz, $J_{7,8}$ = 3.8 Hz), 5.32 (1H, ddd, Neu-H-4, $J_{3ax,4}$ = 11.3 Hz, $J_{3eq,4}$ = 4.8 Hz, $J_{4,5}$ = 10.6 Hz), 5.20 (1H, ddd, Neu-H-8, $J_{8,9}$ = 1.5 Hz, $J_{8,9'}$ = 7.9 Hz), 5.00, 4.80 (2H, each d, Glc-PhCH_2, J_{AB} = 10.8 Hz), 4.93, 4.80 (2H, each d, PhCH_2, J_{AB} = 11.0 Hz), 4.90 (1H, d, Glc-H-1, $J_{1,2}$ = 7.4 Hz), 4.88, 4.73 (2H, each d, PhCH_2, J_{AB} = 11.0 Hz), 4.79 (1H, dd, Neu-H-6, $J_{5,6}$ = 10.5 Hz), 4.52, 4.47 (2H, each d, Neu-PhCH_2, J_{AB} = 12.2 Hz), 4.22 (1H, ddd, Neu-H-5), 4.20 (1H, dd, Neu-H-9, $J_{9,9'}$ = 12.5 Hz), 4.09 (1H, dd, Neu-H-9′), 3.85 (1H, dd, Glc-H-6, $J_{5,6}$ = 2.4 Hz, $J_{6,6'}$ = 7.4 Hz), 3.84, 3.78 (2H, each d, Neu-COCH_2, J_{AB} = 15.3 Hz), 3.79 (1H, dd, Glc-H-3, $J_{2,3}$ = $J_{3,4}$ = 10.5 Hz), 3.75 (1H, dd, Glc-H-4, $J_{4,5}$ = 9.6 Hz), 3.75 (3H, s, Glc-OCH_3), 3.72 (1H, dd, Glc-H-2), 3.71 (1H, ddd, Glc-H-5, $J_{5,6'}$ = 7.4 Hz), 3.61 (3H, s, Neu-COOCH_3), 3.55 (1H, dd, H-6′), 2.56 (1H, dd, Neu-H-3eq, $J_{3ax,3eq}$ = 13.0 Hz), 2.12, 2.00, 1.99, 1.89 (12H, each s, Neu-OCOCH_3 × 4), 1.90 (1H, dd, Neu-H-3ax); ^{13}C NMR (150 MHz, $CDCl_3$): δ 170.6, 170.3, 170.2, 170.1, 169.9, 166.9, 155.4, 151.5, 138.4, 138.3, 138.2, 136.8, 128.5, 128.4, 128.4, 128.4, 128.4, 128.4, 128.3, 128.1, 128.1, 128.0, 128.0, 127.9, 127.7, 127.7, 127.6, 118.6, 114.6, 103.2, 98.1, 84.4, 82.1, 76.9, 75.7, 75.1, 74.8, 73.8, 73.2, 71.6, 71.5, 68.9, 68.8, 68.3, 62.5, 61.8, 55.5, 52.6, 48.1, 37.3, 20.9, 20.8, 20.8, 20.7; HRESIMS: calcd for $C_{56}H_{65}NO_{21}Na$, m/z $[M+Na]^+$, 1158.4284; found, 1158.4311.

4.11. Methyl 5-(2-acetoxy)acetamido-4,7,8,9-tetra-*O*-acetyl-3,5-dideoxy-D-*glycero*-α-D-*galacto*-2-nonulopyranosylonate-(2→3)-4,6-di-*O*-benzyl-D-galactal (15)

To a solution of donor **1** (47 mg, 0.059 mmol) and acceptor **14** (23 mg, 0.070 mmol) in EtCN (5 mL) added 4 Å MS was stirred for 15 min at −78 °C. TMSOTf (1% in EtCN, 230 μL, 12 μmol) was then added. After stirring for 10 min at −78 °C under an atmosphere of argon, the mixture was neutralized with excess Et_3N and filtered through Celite. The filtrate was concentrated, and the crude product was purified by silica gel column chromatography (1:2 hexane–EtOAc) to give **15** (31 mg, 0.036 mmol, 61%). Compound **15**: R_f 0.17 (1:2 hexane–EtOAc); $[\alpha]_D^{25}$ − 32 (*c* 2.4, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ 7.40–7.24 (10H, m), 6.37 (1H, dd, *J* = 1.5, 6.2 Hz), 5.89 (1H, d, *J* = 9.8 Hz), 5.40 (1H, ddd, *J* = 2.6, 5.7, 8.4 Hz), 5.25 (1H, dd, *J* = 2.1, 8.2 Hz), 5.01 (1H, ddd, *J* = 4.5, 7.6, 10.3 Hz),

4.84 (1H, d, J = 12.0 Hz), 4.81 (1H, m,), 4.61 (1H, m), 4.60 (1H, d, J = 15.3 Hz), 4.56 (1H, d, J = 11.9 Hz), 4.47 (1H, d, J = 11.9 Hz), 4.38 (1H, d, J = 11.9 Hz), 4.31 (1H, d, J = 15.5 Hz), 4.30 (1H, dd, J = 2.6, 12.5 Hz), 4.15–4.09 (4H, m), 3.74 (3H, s), 3.72 (1H, m), 3.67 (1H, dd, J = 7.0, 10.5 Hz), 3.54 (1H, dd, J = 5.7, 10.3 Hz), 2.65 (1H, dd, J = 4.6, 12.9 Hz), 2.19, 2.15, 2.13, 2.03, 2.02 (15H, each s, NeuOCOCH_3 × 5), 2.01 (1H, dd, overlapping); ^{13}C NMR (150 MHz, $CDCl_3$) δ: 170.0, 170.6, 170.3, 169.8, 169.6, 167.6, 144.2, 138.4, 137.9, 128.4–127.6, 102.0, 99.1, 75.5, 73.3, 72.4, 68.6, 68.5, 68.1, 67.3, 62.7, 62.2, 52.8, 49.5, 38.2, 21.1–20.6; HRESIMS: calcd for $C_{42}H_{51}NO_{18}Na$, m/z $[M+Na]^+$, 880.3004; found, 880.3009.

4.12. 2-(Trimethylsilyl)ethyl (methyl 5-(2-acetoxy)acetamido-4,7,8,9-tetra-*O*-acetyl-3,5-dideoxy-α-D-*glycero*-D-*galacto*-2-nonulopyranosylonate)-(2→3)-2,6-di-*O*-benzyl-β-D-galactopyranosyl-(1→4)-2,3,6-tri-*O*-benzyl-β-D-glucopyranoside (17)

To a solution of donor **1** (45 mg, 0.057 mmol) and acceptor **16** (34 mg, 0.044 mmol) in EtCN (5 mL) was added 4 Å MS, and the mixture was stirred for 15 min at −78 °C. TMSOTf (1% in EtCN, 170 μL, 8.8 μmol) was then added. After stirring for 10 min at −78 °C under an atmosphere of argon, the reaction mixture was neutralized with excess Et_3N and filtered through Celite. The filtrate was concentrated, and the crude product was purified by silica gel column chromatography (1:2 hexane–EtOAc) to give **17** (24 mg, 0.018 mmol, 42%). Compound **17**: R_f 0.23 (1:2 hexane–EtOAc); $[\alpha]_D^{25}$ − 0.5 (c 0.7, $CHCl_3$); ^{1}H NMR (600 MHz, $CDCl_3$): δ 746–7.18 (25H, m), 5.82 (1H, d, J = 9.6 Hz), 5.40 (1H, ddd, J = 2.5, 6.1, 8.1 Hz), 5.25 (1H, dd, J = 1.2, 7.9 Hz), 4.98 (1H, d, J = 10.7 Hz), 4.92 (1H, ddd, J = 4.3, 9.8, 11.9 Hz), 4.90 (1H, d, J = 11.0 Hz), 4.78 (1H, d, J = 11.9 Hz), 4.75 (1H, d, J = 10.8 Hz), 4.71 (1H, d, J = 11.2 Hz), 4.69 (1H, d, J = 11.9 Hz), 4.59 (1H, d, J = 15.5 Hz), 4.58 (1H, d, J = 7.6 Hz), 4.51 (1H, d, J = 12.4 Hz), 4.47 (1H, d, J = 11.9 Hz), 4.42 (1H, d, J = 11.9 Hz), 4.37 (1H, d, J = 7.9 Hz), 4.33 (1H, d, J = 12.0 Hz), 4.31 (1H, dd, J = 2.6, 12.4 Hz), 4.28 (1H, d, J = 15.3 Hz), 4.07–4.05 (3H, m), 3.99 (1H, m), 3.97–3.92 (2H, m), 3.83 (1H, dd, J = 3.3, 3.3 Hz), 3.77 (3H, s), 3.76 (1H, dd, J = 1.5, 10.1 Hz), 3.71 (1H, dd, J = 5.2, 11.0 Hz), 3.67 (1H, dd, J = 5.8, 8.2 Hz), 3.58 (1H, m), 3.55 (1H, dd, J = 9.3, 9.3 Hz), 3.54 (1H, dd, J = 9.3, 9.3 Hz), 3.50–3.45 (2H, m), 3.39 (1H, dd, J = 8.9, 8.9 Hz), 3.37 (1H, m), 2.71 (1H, d, J = 3.4 Hz), 2.51 (1H, dd, J = 4.5, 12.9 Hz), 2.19, 2.10, 2.00, 1.98, 1.88 (15H, each s), 2.00 (1H, dd, overlapping), 1.03 (2H, m), 0.02 (9H, s); ^{13}C NMR (150 MHz, $CDCl_3$) δ : 170.9, 170.6, 170.1, 170.0, 169.6, 168.4, 167.7, 139.2, 138.9, 138.8, 138.5, 138.4, 128.3–127.1, 103.1, 102.4, 98.4, 83.0, 82.0, 78.4, 76.7, 76.4, 75.3, 75.1, 74.9, 73.3, 73.0, 72.7, 72.4, 68.9, 68.6, 68.4, 68.2, 67.3, 67.2, 62.7, 62.2, 60.4, 53.1, 49.2, 36.6, 21.2–20.5, 18.5, 14.2, −1.4; HRESIMS: calcd for $C_{74}H_{93}NO_{25}SiNa$, m/z $[M+Na]^+$, 1446.5704; found, 1446.5747.

Acknowledgements

This work was supported by a 'Science Frontier Project of Kanagawa University' from the Ministry of Education, Science, Sports and Culture, Japan, and by Grants-in-Aid for Scientific Research for Young Scientists B (No. 20710171 to S.H.) from Japan Society for the Promotion of Science.

Supplementary data

Supplementary data (^{1}H and ^{13}C NMR spectra of compounds **1**, **2**, **5**, **6**, **7**, **9**, **10**, **12**, **13**, **15**, and **17**) associated with this article can be found, in the online version, at doi:10.1016/j.carres.2009.03.004.

References

1. Angata, T.; Varki, A. *Chem. Rev.* **2002**, *102*, 439–469.
2. Lowe, J. B.; Marth, J. D. In *Essentials of Glycobiology*; Varki, A., Esko, J., Freeze, H., Hart, G., Marth, J., Eds.; Cold Spring Harbor Laboratory: New York, 1999; pp 195–201.
3. Hedlund, M.; Tangvoranuntakul, P.; Takematsu, H.; Long, J. M.; Housley, G. D.; Kozutsumi, Y.; Suzuki, A.; Wynshaw-Boris, A.; Ryan, A. F.; Gallo, R. L.; Varki, N.; Varki, A. *Mol. Cell. Biol.* **2007**, 4340–4346.
4. Mikami, T.; Kashiwagi, M.; Tsuchihashi, K.; Daino, T.; Akino, T.; Gasa, S. *J. Biochem. (Tokyo)* **1998**, *123*, 487–491.
5. (a) Higashi, H.; Hirabayashi, Y.; Fukui, Y.; Naiki, M.; Matsumoto, M.; Ueda, S.; Kato, S. *Cancer Res.* **1985**, *45*, 3796–3802; (b) Devine, P. L.; Clark, B. A.; Birrell, G. W.; Layton, G. T.; Ward, B. G.; Alewood, P. F.; McKenzie, F. C. *Cancer Res.* **1991**, *51*, 5826–5836.
6. Masuda, H.; Suzuki, T.; Sugiyama, Y.; Horiike, G.; Murakami, K.; Miyamoto, D.; Hidari, K. I.-P. J.; Ito, T.; Kida, H.; Kiso, M.; Fukunaga, K.; Ohuchi, M.; Toyoda, T.; Ishihama, A.; Kawaoka, Y.; Suzuki, Y. *FEBS Lett.* **1999**, *464*, 71–74.
7. Kaneko, M.; Yamada, K.; Miyamoto, T.; Inagaki, M.; Higuchi, R. *Chem. Pharm. Bull.* **2007**, *55*, 462–463.
8. (a) Boons, G.-J.; Demchenko, A. V. *Chem. Rev.* **2000**, *100*, 4539–4565; (b) Halcomb, R. L.; Chappell, M. D. *J. Carbohydr. Chem.* **2002**, *21*, 723–768; (c) Ando, H.; Imamura, A. *Trend Glycosci. Glycotechnol.* **2004**, *16*, 293–303.
9. (a) De Meo, C.; Demachenko, A. V.; Boons, G.-J. *J. Org. Chem.* **2001**, *66*, 5490–5497; (b) Yu, C.-S.; Niikura, K.; Lin, C.-C.; Wong, C.-H. *Angew. Chem., Int. Ed.* **2001**, *40*, 2900–2903; (c) Ando, H.; Koike, Y.; Ishida, H.; Kiso, M. *Tetrahedron Lett.* **2003**, *44*, 6883–6886; (d) Tanaka, H.; Adachi, M.; Takahashi, T. *Chem. Eur. J.* **2005**, *11*, 849–862; (e) Tanaka, S.; Goi, T.; Tanaka, K.; Fukase, K. *J. Carbohydr. Chem.* **2007**, *26*, 369–394; (f) Tanaka, H.; Nishiura, Y.; Takahashi, T. *J. Am. Chem. Soc.* **2006**, *128*, 7124–7125; (g) Farris, M. D.; De Meo, C. *Tetrahedron Lett.* **2007**, *48*, 1225–1227; (h) Crich, D.; Li, W. *J. Org. Chem.* **2007**, *72*, 7794–7797.
10. Ando, H.; Koike, Y.; Koizumi, S.; Ishida, H.; Kiso, M. *Angew. Chem., Int. Ed.* **2005**, *44*, 6759–6763.
11. (a) Hasegawa, A.; Uchimira, A.; Ishida, H.; Kiso, M. *Biosci. Biotech. Biochem.* **1995**, *59*, 1091–1094; (b) Tanahashi, E.; Fukunaga, K.; Ozawa, Y.; Toyoda, T.; Ishida, H.; Kiso, M. *J. Carbohydr. Chem.* **2000**, *19*, 747–768; (c) Fukunaga, K.; Toyoda, T.; Ishida, H.; Kiso, M. *J. Carbohydr. Chem.* **2003**, *22*, 919–937; (d) Sugata, T.; Higuchi, R. *Tetrahedron Lett.* **1996**, *37*, 2613–2614; (e) Higuchi, R.; Mori, T.; Sugata, T.; Yamada, K.; Miyamoto, T. *Eur. J. Org. Chem.* **1999**, 145–147.
12. (a) Sherman, A. A.; Yudina, O. N.; Shashkov, A. S.; Menshov, V. M.; Nifantiev, N. E. *Carbohydr. Res.* **2002**, *337*, 451–457; (b) Ikeda, K.; Miyamoto, K.; Sato, M. *Tetrahedron Lett.* **2007**, *48*, 7431–7435; (c) Schroven, A.; Meinke, S.; Ziegelmüller, P.; Thiem, J. *Chem. Eur. J.* **2007**, *13*, 9012–9021.
13. Kirchner, E.; Thiem, F.; Dernick, R.; Heukeshoven, J.; Thieina, J. *J. Carbohydr. Chem.* **1988**, *7*, 453–486.
14. (a) Martin, T. J.; Schmidt, R. R. *Tetrahedron Lett.* **1992**, *33*, 6123–6126; (b) Kondo, H.; Ichikawa, Y.; Wong, C.-H. *J. Am. Chem. Soc.* **1992**, *114*, 8748–8750.
15. Lee, Y. S.; Rho, E. S.; Min, Y. K.; Kim, B. T.; Kim, K. H. *J. Carbohydr. Chem.* **2001**, *20*, 503–506.
16. (a) Kanie, O.; Kiso, M.; Hasegawa, A. *J. Carbohydr. Chem.* **1988**, *7*, 501–506; (b) Schmidt, R. R.; Behrendt, M.; Toepfer, A. *Synlett* **1990**, 694–696.
17. Hanashima, S.; Castagner, B.; Esposito, D.; Nokami, T.; Seeberger, P. H. *Org. Lett.* **2007**, *9*, 1777–1779.
18. Fairweather, J. K.; Karoli, T.; Ferro, V. *Bioorg. Med. Chem.* **2004**, *12*, 6063–6075.
19. Jansson, K.; Ahlfors, S.; Frejd, T.; Kihlberg, J.; Magnuson, G. *J. Org. Chem.* **1988**, *53*, 5629–5647.