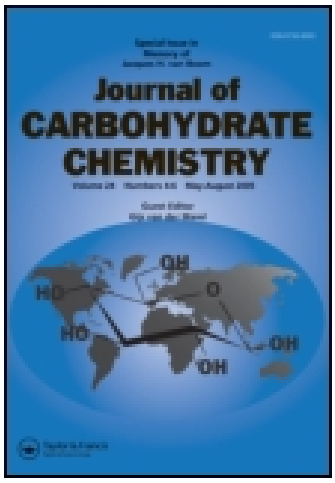


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# SYNTHESIS OF SIALYL- AND SULFO-Le$^x$/Le$^a$ ANALOGS CONTAINING N-ALKYL-1-DEOXYNOJIRIMYCIN AS POTENTIAL SELECTIN BLOCKERS

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# SYNTHESIS OF SIALYL- AND SULFO-Le$^x$/Le$^a$ ANALOGS CONTAINING *N*-ALKYL-1-DEOXYNOJIRIMYCIN AS POTENTIAL SELECTIN BLOCKERS[1]

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## ABSTRACT

A series of novel sialyl- and sulfo-Le$^x$/Le$^a$ oligosaccharides containing *N*-alkyl-1-deoxynojirimycin as potential selectin blockers have systematically been synthesized *via* the suitably protected intermediates containing *N*-benzyloxycarbonyl-1-deoxynojirimycin. Some of the synthetic oligosaccharides strongly inhibited the adhesion of HL60 cells to IL-1β-stimulated HUVECs.

## INTRODUCTION

The carbohydrate determinants, sialyl Lewis x (sLe$^x$) and sialyl Lewis a (sLe$^a$), which are frequently expressed on cancer cells,[3,4] serve as the ligands for selectin,[5] a family of cell adhesion molecules implicated in leukocyte traffic and recruitment to sites of inflammation. These carbohydrate determinants, therefore, have been thought to be involved in hematogenous metastasis of some cancer cells.[6,7]

In the course of synthetic studies on sialoglycoconjugates,[8,9] we have succeeded not only in the total syntheses[10,11] of these carbohydrate determinants but also in the synthesis of a variety of their analogs[12,13] and mimetics.[14–16] In this

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course, it has been found[17] that the glucosamine residue in these determinants could be replaced by glucose and 1-deoxynojirimycin without loss of the selectin binding activity. It has also been strongly suggested that the sialic acid residue may be substituted by the sulfate group.[18,19] This paper describes the systematic synthesis of a series of novel sialyl- and sulfo-Le$^x$/Le$^a$ oligosaccharides containing *N*-alkyl-1-deoxynojirimycin instead of the *N*-acetylglucosamine residue.

## RESULTS AND DISCUSSION

The sialyl Lewis x (sLe$^x$) (**11**–**14**) and sialyl Lewis a (sLe$^a$) (**15**–**18**) analogs containing 1-deoxynojirimycin or *N*-alkyl-1-deoxynojirimycin were synthesized from the corresponding, suitably protected tetrasaccharides[14] (**1** and **2**), respectively (Scheme 1). Hydrogenolytic removal of the benzyloxycarbonyl (Z) and benzyl (Bn) groups in **1** and **2** were carried out in the presence of palladium chloride in AcOH, to give **3** and **7**, which, upon treatment with formalin,[14] butyraldehyde or decyl aldehyde over palladium hydroxide on carbon in a hydrogen atmosphere, gave **4–6** and **8**–**10** in good yields. Complete *O*-deacylation of **3**–**6** and **7**–**10**, followed by saponification of the methyl ester group, afforded a series of sLe$^x$-type (**11**–**14**) and sLe$^a$-type (**15**–**18**) tetrasaccharides in high yields (Scheme 1).

For the synthesis of the sulfo Le$^x$ analogs (**27**, **37**, **38**), (2,3,4-tri-*O*-benzyl-α-L-fucopyranosyl)-(1→3)-2-*O*-acetyl-6-*O*-benzyl-*N*-benzyloxycarbonyl-1,5-dideoxy-1,5-imino-D-glucitol[14] (**19**) was glycosylated with the galactose donor **20**[20] to give trisaccharide **21** (70%), which was converted stepwise, by hydrolytic removal of the benzylidene group, benzoylation to **23** and selective removal of the levulinoyl group, to **24** in high yield (Scheme 2). Treatment of **24** with pyridine sulfur trioxide complex in *N,N*-dimethylformamide gave **25** in 96% yield, which underwent reductive *N*-methylation as described for **12** and **16**, to afford **26** in 83% yield. Significant signals in the $^1$H NMR spectrum of **26** were a three proton singlet at δ 2.12 (N—Me) and a one proton doublet of doublets at δ 4.72 ($J_{2,3}$ = 10.3, $J_{3,4}$ = 3.7 Hz, H-3c), showing the desired structure. Compound **27** was prepared by *O*-deacylation of **26**, quantitatively. In the ion-spray MS of **27**, the molecular ion was clearly detected at *m/z* 564.0 $(M—Na—H)^-$ and *m/z* 566.2 $(M—Na+H)^+$ in negative and positive ion modes,[21] respectively, indicating the desired structure unambiguously.

Hydrogenation of **22** over palladium black in AcOH gave **28** (79%), which was then treated with butyraldehyde or decyl aldehyde in the presence of palladium hydroxide on carbon in a hydrogen atmosphere, to give **29** (79%) or **30** (80%), respectively (Scheme 3). The remaining hydroxyls were acetylated, and then the levulinoyl group was cleaved by treatment with hydrazine acetate in EtOH to afford **33** and **35**. Sulfation of **33** and **35** was performed as described for **25** and the resulting **34** (81%) and **36** (88%) were treated with methanolic sodium methoxide to give **37** and **38**, quantitatively. In the $^1$H NMR spectra of **34** and **36**, H-3c at the sulfated position appeared at δ 4.68 (dd, $J_{2,3}$ = 10.3, $J_{3,4}$ = 2.9 Hz) for **34** and δ 4.70 (dd, $J_{2,3}$ = 10.3, $J_{3,4}$ = 3.3 Hz) for **36**, respectively. In the FAB-MS of **37** and





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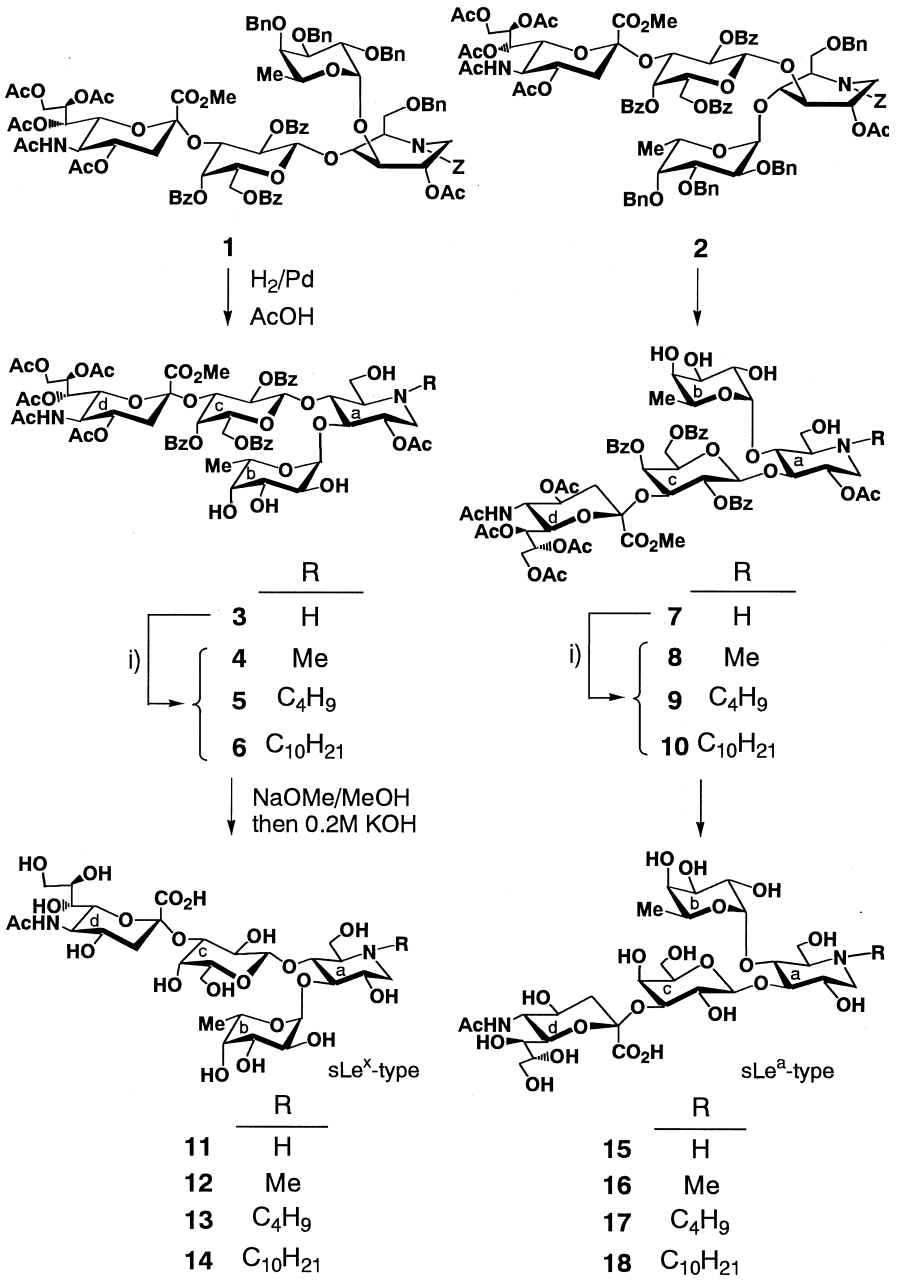
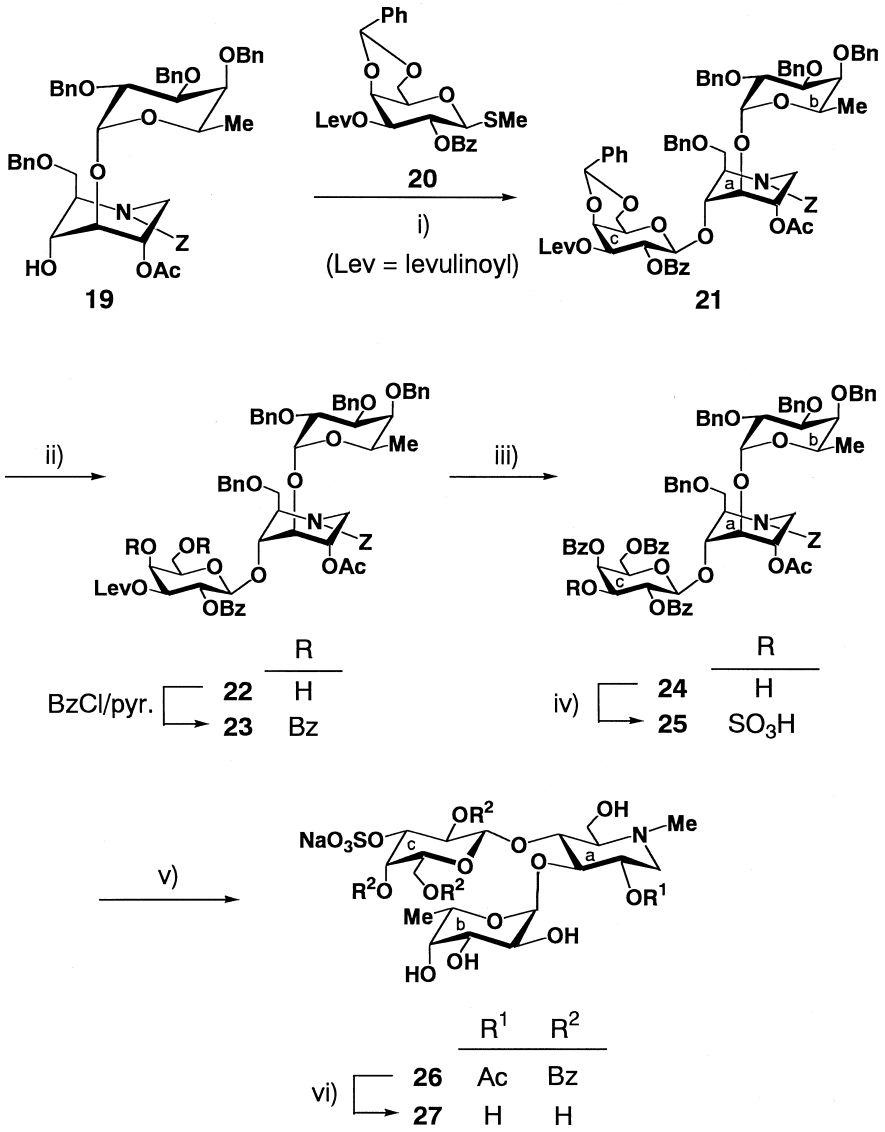



***Scheme 1.*** i) R′CHO, $H_2$, $Pd(OH)_2$-C, R′$CH_2OH$/AcOH/$H_2O$ R′ = H, $C_3H_7$, $C_9H_{19}$.

**38**, a pair of molecular ions were each clearly detected at *m/z* 628.3 $(M—H)^-$ and 606.3 $(M—Na—H)^-$ for **37**, and *m/z* 712.32 $(M—H)^-$ and 690.38 $(M—Na—H)^-$ for **38**, accompanied with a significant fragment ion $(M—Na—H—Fuc)^-$ at *m/z* 460.2 for **37** and 544.3 for **38**, respectively, providing the distinct evidence for the desired structures.

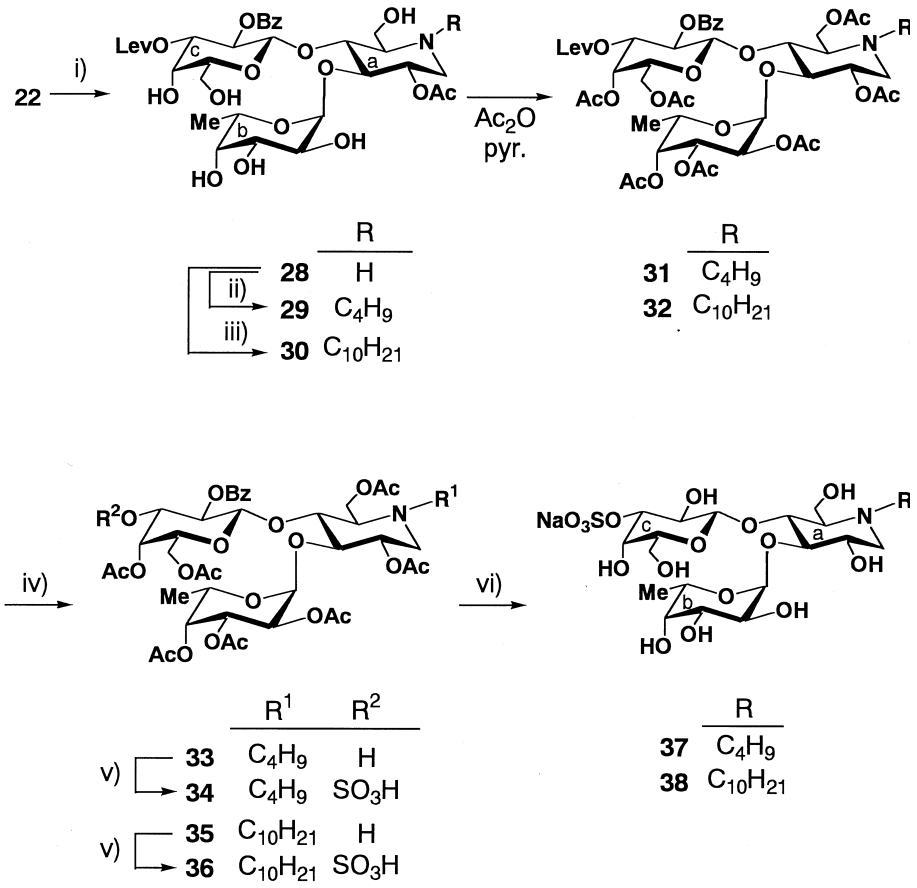



***Scheme 2.*** i) NIS, TMSOTf, $CH_2Cl_2$, 0°C → rt (70%); ii) 80% aq AcOH, 45°C (89%); iii) $NH_2NH_2$·AcOH, EtOH, rt (100%); iv) $SO_3$·pyr, DMF, rt (96%); v) Dowex-$Na^+$, then HCHO, $H_2$/Pd, MeOH (83%); vi) NaOMe, MeOH.

In the synthetic route to the sulfo $Le^a$ analogs (**50**, **60**, **61**), 2-*O*-acetyl-4,6-*O*-benzylidene-*N*-benzyloxycarbonyl-1,5-dideoxy-1,5-imino-D-glucitol (**39**)[14] was first glycosylated with the galactose donor **40** to give **41** (87%) (Scheme 4). Hydrolytic removal of the benzylidene group in **41** and the following regioselective protection of 6-OH by a *tert*-butyldimethylsilyl (TBDMS) group gave **43** in high yield. The remaining 4-OH was then fucosylated with methyl 2,3,4-tri-*O*-benzyl-1-thio-β-L-fucopyranoside[14] in the presence of dimethyl(methylthio)sulfonium tri-

flate (DMTST) in benzene to afford **44** (55%). This was converted to **46** by replacement of the TBDMS group with the benzoyl group, and then the levulinoyl group in **46** was selectively cleaved to give **47**. Sulfation (99%) of **47** as described for **25,** and reductive *N*-methylation (92%), followed by the complete *O*-deacylation, afforded **50** as the sodium salt (Scheme 4). In the ion-spray MS of **50**, the molecular ion was detected at *m/z* 564.1 $(M—Na—H)^-$, from which two major daughter ions were formed and detected at *m/z* 417.6 $(M—Na—Fuc)^-$ and *m/z* 96.8 ($HSO_4^-$), respectively.

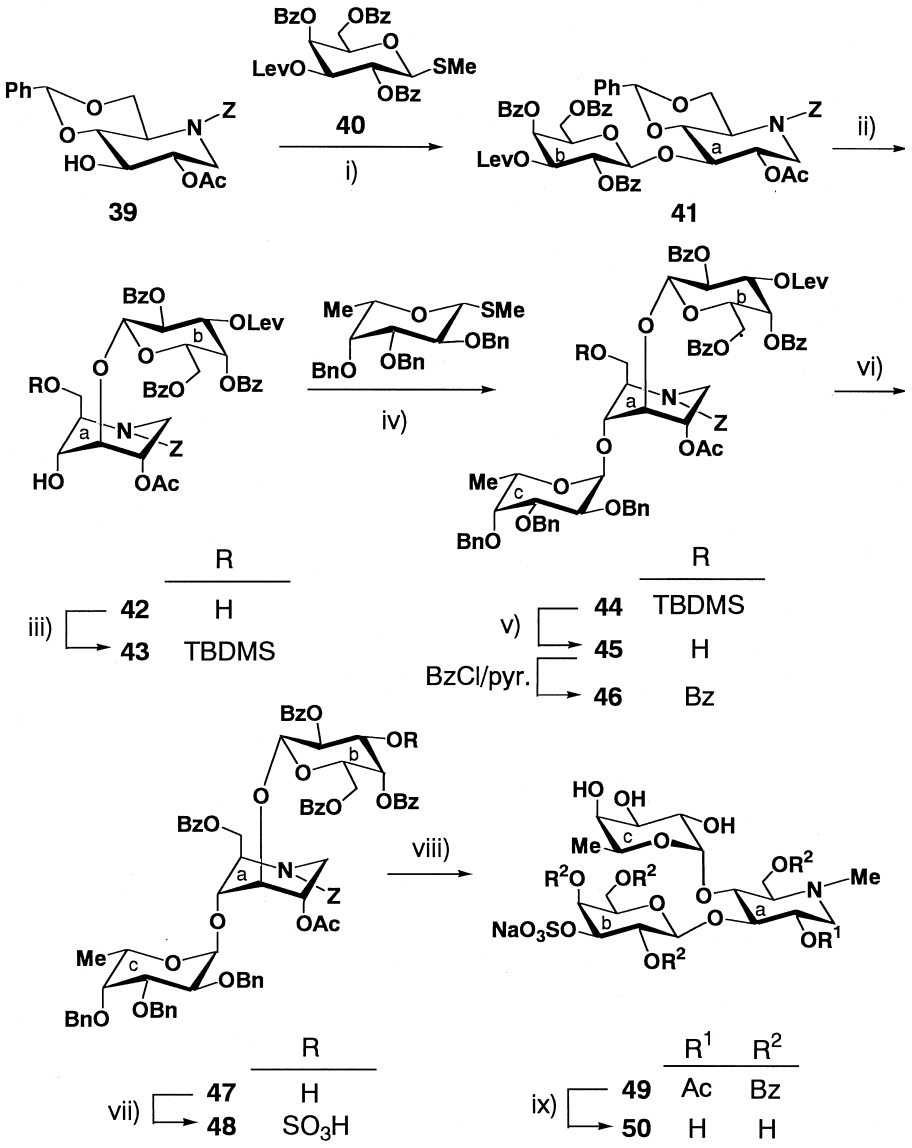
Hydrogenolysis of **46** in AcOH and the reductive *N*-alkylation as described for **29** and **30**, gave **52** (64%) and **53** (75%), respectively, which were then fully acetylated. Selective removal of the levulinoyl group in **54** and **55**, followed by *O*-sulfation as described for **34** and **36**, afforded **57** and **59**, which, upon treatment with methanolic sodium methoxide, gave the sulfo Le$^a$ analogs containing *N*-butyl- and *N*-decyl-1-deoxynojirimycin (**60** and **61**), respectively. In the FAB-MS, the




***Scheme 3.*** i) $H_2$/Pd, AcOH; ii) $C_3H_7CHO$, 1-butanol, $H_2$, $Pd(OH)_2$-C (79%); iii)$C_9H_{19}CHO$, EtOAc/THF, $H_2$, $Pd(OH)_2$-C (80%); iv) $NH_2NH_2$·AcOH, EtOH, rt; v) $SO_3$·pyr, DMF, **33** → **34** (81%), **35** → **36** (88%); VI) NaOMe, MeOH.

molecular ions were clearly detected at *m*/*z* 606.30 $(M—Na)^-$ for **60**, and *m*/*z* 712.26 $(M—H)^-$ and 690.31 $(M—Na)^-$ for **61**, respectively, showing the structure assigned.

The preferred conformation of the 1-deoxynojirimycin residue in the protected oligosaccharide intermediates, such as **1**, **2**, **19**, **21**–**25** and **42**–**48**, has been




| | | R |
|---|---|---|
| iii) | **42** | H |
| | **43** | TBDMS |

| | | R |
|---|---|---|
| v) | **44** | TBDMS |
| | **45** | H |
| BzCl/pyr. | **46** | Bz |

| | | R |
|---|---|---|
| vii) | **47** | H |
| | **48** | $SO_3H$ |

| | | $R^1$ | $R^2$ |
|---|---|---|---|
| ix) | **49** | Ac | Bz |
| | **50** | H | H |

***Scheme 4.*** i) NIS, TMSOTf, $CH_2Cl_2$, 0°C → rt (87%); ii) 80% aq AcOH, 45°C (86%); iii) TBDMSCl, pyr, $CH_2Cl_2$, 0°C → rt (92%); iv) DMTST, benzene, 7°C (55%); v) 80% aq AcOH, rt (88%); vi) $NH_2NH_2$·AcOH, EtOH, rt (93%); vii) SO3·pyr, DMF, rt (99%); viii) Dowex-$Na^+$, then HCHO, $H_2$/Pd, MeOH (92%); ix) NaOMe, MeOH.





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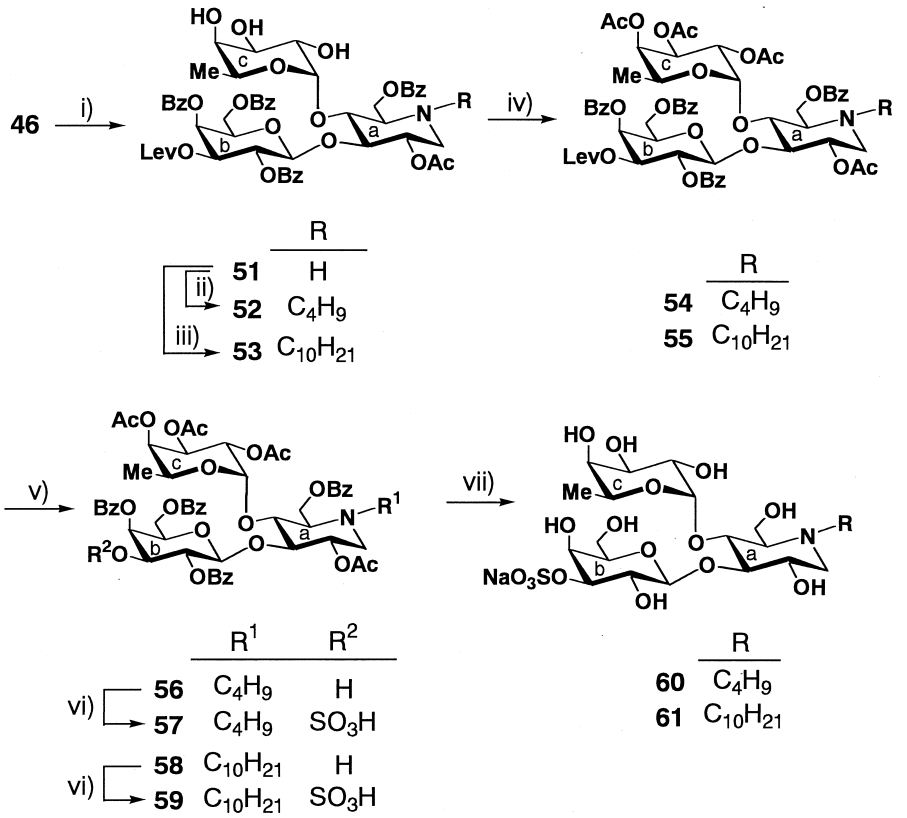


***Scheme 5.*** i) $H_2$/Pd, AcOH; ii) $C_3H_7CHO$, 1-butanol, $H_2$, $Pd(OH)_2$-C (64%); iii) $C_8H_{19}CHO$, $H_2$, $Pd(OH)_2$-C, EtOAc (75%); iv) $Ac_2O$, pyr (quant); v) $NH_2NH_2$·AcOH, EtOH, (**56**, 91%; **58**, 93%); vi) $SO_3$·pyr, DMF (~90%); vii) NaOMe, MeOH (quant).

suggested to be a flexible $^1C_4$ conformation based on $^1$H NMR data[14,22] and X-ray crystallographic analysis.[23] A dramatic conformational change ($^4C_1 \rightarrow {}^1C_4$) was observed in the reductive ring opening of the 4,6-*O*-benzylidene group (**41**→**42**). On the contrary, in the *N*-debenzyloxycarbonylation step (**1**→**3**, **2**→**7**, **25**→**26**, **22**→**28**, **48**→**49**, and **46**→**51**), the $^1C_4$ conformation changed to $^4C_1$ as shown in Scheme 1–5.

The inhibitory effect of the synthetic oligosaccharides on the adhesion of fixed HL-60 cells to IL-β-stimulated HUVECs was examined. Among a series of sialyl Le$^x$/Le$^a$ analogs (**11**–**18**, Scheme 1), the sLe$^a$-type analogs (**15**–**18**) expressed stronger activity than the corresponding sLe$^x$-type analogs (**11**–**14**). The hierarchy of inhibition potency due to the *N*-alkyl group in both sLe$^x$ and sLe$^a$ series were *N*-butyl>*N*-decyl>*N*-methyl, and the activity of *N*-butyl sLe$^a$ derivative (**17**) was most potent. Similarly, a series of sulfo Le$^a$-type analogs (**50**, **60**, **61**) showed stronger inhibitory activity than the corresponding sulfo Le$^x$-type analogs (**27**, **37**, **38**). The details of the biological study will be described elsewhere.

In conclusion, a series of novel sialyl- and sulfo-Le$^x$/Le$^a$ oligosaccharides containing *N*-alkyl-1-deoxynojirimycin have systematically been synthesized as potential selectin blockers.[17,24–26]

## EXPERIMENTAL

**General Methods.** Optical rotations were determined with a Union PM-201 polarimeter at 25°C, and IR spectra were recorded with a Jasco IRA-100 spectrophotometer. $^1$H NMR spectra were recorded on a JEOL JNM-GX 270 (270 MHz) or Varian Unity Inova 400 (400 MHz) spectrometer. FAB-MS were recorded on a JEOL JMS-SX 120A mass spectrometer/JMA-DA 7000 data system.[9] Ion-spray MS were recorded on an API-III triple quadrupole mass spectrometer (Perkin-Elmer Sciex Instruments) fitted with as atmosphere pressure ionization source.[21] All reactions were monitored by TLC (Merck silica gel aluminum plate 60F-254) and preparative column chromatography was performed on silica gel (Wako Chemical Co., 200 or 300 mesh) with the solvent systems specified. Concentrations were conducted *in vacuo*.

**(Methyl 5-Acetamido-4,7,8,9-tetra-*O*-acetyl-3,5-dideoxy-D-*glycero*-α-D-*galacto*-2-nonulopyranosylonate)-(2→3)-(2,4,6-tri-*O*-benzoyl-β-D-galactopyranosyl)-(1→4)-[α-L-fucopyranosyl-(1→3)]-2-*O*-acetyl-1,5-dideoxy-1,5-imino-D-glucitol (3).** Compound **1** (113 mg) in acetic acid (10 mL) was hydrogenolyzed in the presence of palladium chloride (200 mg) for 2 days at rt. The catalyst was filtered off and washed with MeOH. The combined filtrate and washings were concentrated. Column chromatography (15:1 $CH_2Cl_2$—MeOH) of the residue on silica gel gave **3** (37.6 mg, 75%): $[\alpha]_D$ −4° (*c* 0.5, $CH_2Cl_2$); $^1$H NMR ($CDCl_3$) δ 1.39 (d, 3H, $J_{5,6}$ = 6.6 Hz, H-6b), 1.56 (s, 3H, AcN), 1.65 (t, 1H, $J_{gem}$ = $J_{3ax,4}$ = 12.5 Hz, H-3d*ax*), 1.77, 1.90, 1.98, 2.11, 2.25 (5s, 15H, 5AcO), 2.41 (dd, 1H, $J_{gem}$ = 12.5, $J_{3eq,4}$ = 5.1 Hz, H-3d*eq*), 3.09 (dd, 1H, $J_{gem}$ = 12.3, $J_{1eq,2}$ = 5.1 Hz, H-1a*eq*), 3.82 (s, 3H, COOMe), 4.91 (d, 1H, $J_{1,2}$ = 8.42 Hz, H-1c), 5.12 (d, 1H, $J_{1,2}$ = 3.85 Hz, H-1b), 5.14 (dd, 1H, $J_{6,7}$ = 2.57 Hz, H-7d), 5.22 (d, 1H, $J_{3,4}$ = 3.1 Hz, H-4c), 5.48 (dd, 1H, $J_{2,3}$ = 9.9 Hz, H-2c), 5.80 (m, 1H, H-8d), 7.48–8.22 (m, 15H, 3Ph).

Anal. Calcd for $C_{61}H_{74}N_2O_{29}$ (1229.25): C, 56.39; H, 5.74; N, 2.16. Found: C, 56.12; H, 5.51; N, 2.08.

**(Methyl 5-Acetamido-4,7,8,9-tetra-*O*-acetyl-3,5-dideoxy-D-*glycero*-α-D-*galacto*-2-nonulopyranosylonate)-(2→3)-(2,4,6-tri-*O*-benzoyl-β-D-galactopyranosyl)-(1→4)-[α-L-fucopyranosyl-(1→3)]-2-*O*-acetyl-*N*-butyl-1,5-dideoxy-1,5-imino-D-glucitol (5).** A mixture of **3** (61 mg), butyraldehyde (1 mL), 1-butanol (10 mL), acetic acid (0.5 mL) and water (0.5 mL) was vigorously stirred with palladium hydroxide on carbon (60 mg) in a hydrogen atmosphere overnight at rt. The catalyst was filtered off and washed with MeOH. The combined filtrate and washings were concentrated. Column chromatography (15:1 $CH_2Cl_2$—MeOH)

of the residue on silica gel gave **5** (50 mg, 79%): $[\alpha]_D$ −11° (*c* 1, $CH_2Cl_2$); $^1$H NMR ($CDCl_3$) δ 0.87 (t, 3H, J = 6.4 Hz, Me), 1.24 (m, 4H, —$C_2H_4$Me), 1.38 (d, 3H, $J_{5,6}$ = 6.6 Hz, H-6b), 1.56 (s, 3H, AcN), 1.65 (t, 1H, $J_{gem} = J_{3ax,4}$ = 12.5 Hz, H-3d*ax*), 1.76, 1.90, 1.97, 2.11, 2.25 (5s, 15H, 5AcO), 2.40 (dd, 1H, $J_{gem}$ = 12.6, $J_{3eq,4}$ = 4.4 Hz, H-3d*eq*), 2.51, 2.65 (2m, 2H, N—C$H_2$—$C_3H_7$), 3.01 (dd, 1H, $J_{gem}$ = 10.8, $J_{1eq,2}$ = 5.1 Hz, H-1a*eq*), 3.54 (dd, 1H, $J_{2,3}$ = 9.9, $J_{3,4}$ = 3.7 Hz, H-3c), 3.83 (s, 3H, COOMe), 5.11 (dd, 1H, H-7d), 5.12 (d, 1H, $J_{1,2}$ = 8.8 Hz, H-1c), 5.17 (d, 1H, $J_{1,2}$ = 2.8 Hz, H-1b), 5.19 (d, 1H, $J_{3,4}$ = 3.7 Hz, H-4c), 5.50 (~t, 1H, $J_{1,2}$ = 8.8, $J_{2,3}$ = 9.9 Hz, H-2c), 5.80 (m, 1H, H-8d), 7.47–8.24 (m, 15H, 3Ph).

Anal. Calcd for $C_{65}H_{82}N_2O_{29}$ (1355.36): C, 57.60; H, 6.10; N, 2.07. Found: C, 57.52; H, 6.00; N, 1.83.

**(Methyl 5-Acetamido-4,7,8,9-tetra-*O*-acetyl-3,5-dideoxy-D-*glycero*-α-D-*galacto*-2-nonulopyranosylonate)-(2→3)-(2,4,6-tri-*O*-benzoyl-β-D-galactopyranosyl)-(1→4)-[α-L-fucopyranosyl-(1→3)]-2-*O*-acetyl-*N*-decyl-1,5-dideoxy-1,5-imino-D-glucitol (6).** A mixture of **3** (30 mg), decyl aldehyde (0.5 mL), ethyl acetate (5 mL), acetic acid (0.1 mL) and water (0.05 mL) was vigorously stirred with palladium hydroxide on carbon (30 mg) for 10 h at rt. Work-up and column chromatography (20:1 $CH_2Cl_2$—MeOH) on silica gel gave **6** (50 mg, 60%): $[\alpha]_D$ +4.3° (*c* 0.4, $CH_2Cl_2$); $^1$H NMR ($CDCl_3$) δ 0.88 (t, 3H, J = 6.2 Hz, Me), 1.25 (m, 16H, —$C_8H_{16}$Me), 1.38 (d, 3H, $J_{5,6}$ = 6.6 Hz, H-6b), 1.51 (s, 3H, AcN), 1.66 (t, 1H, $J_{gem} = J_{3ax,4}$ = 12.3 Hz, H-3d*ax*), 1.77, 1.91, 1.97, 2.11, 2.26 (5s, 15H, 5AcO), 2.40 (dd, 1H, $J_{gem}$ = 12.3, $J_{3eq,4}$ = 4.2 Hz, H-3d*eq*), 3.01 (dd, 1H, $J_{gem}$ = 10.8, $J_{1eq,2}$ = 4.4 Hz, H-1a*eq*), 3.54 (dd, 1H, $J_{2,3}$ = 9.9, $J_{3,4}$ = 3.5 Hz, H-3c), 3.81 (s, 3H, COOMe), 5.12 (d, 1H, $J_{1,2}$ = 8.6 Hz, H-1c), 5.17 (dd, 1H, H-7d), 5.19 (d, 1H, $J_{3,4}$ = 3.5 Hz, H-4c), 5.50 (~t, 1H, H-2c), 5.81 (m, 1H, H-8d), 7.52–8.35 (m, 15H, 3Ph).

Anal. Calcd for $C_{71}H_{94}N_2O_{29}$ (1439.52): C, 59.24; H, 6.58; N, 1.95. Found: C, 59.11; H, 6.45; N, 1.85.

**(Methyl 5-Acetamido-4,7,8,9-tetra-*O*-acetyl-3,5-dideoxy-D-*glycero*-α-D-*galacto*-2-nonulopyranosylonate)-(2→3)-(2,4,6-tri-*O*-benzoyl-β-D-galactopyranosyl)-(1→3)-[α-L-fucopyranosyl-(1→4)]-2-*O*-acetyl-1,5-dideoxy-1,5-imino-D-glucitol (7).** Compound **2** (179 mg) in acetic acid (10 mL) was hydrogenolyzed as described for **3**. Work-up and column chromatography (10:1 $CH_2Cl_2$—MeOH) of the product on silica gel afforded **7** (92 mg, 71%): $[\alpha]_D$ −24.1° (*c* 1.46, $CH_2Cl_2$); $^1$H NMR ($CDCl_3$) δ 1.27 (d, 3H, $J_{5,6}$ = 6.6 Hz, H-6b), 1.56 (s, 3H, AcN), 1.65 (t, 1H, $J_{gem} = J_{3ax,4}$ = 12.6 Hz, H-3d*ax*), 1.78, 1.91, 2.06, 2.16, 2.18 (5s, 15H, 5AcO), 2.42 (dd, 1H, $J_{gem}$ = 12.6, $J_{3eq,4}$ = 4.4 Hz, H-3d*eq*), 3.09 (dd, 1H, H-1a*eq*), 3.79 (s, 3H, COOMe), 4.74 (m, 1H, H-2a), 4.81 (m, 1H, H-4d), 4.95 (d, 1H, H-1b), 5.14 (d, 1H, $J_{1,2}$ = 8.3 Hz, H-1c), 5.25 (d, 1H, $J_{3,4}$ = 2.8 Hz, H-4c), 5.30 (dd, 1H, H-7d), 5.36 (t, 1H, H-2c), 5.56 (m, 1H, H-8), 7.41–8.09 (m, 15H, 3Ph).

Anal. Calcd for $C_{61}H_{74}N_2O_{29}$ (1299.25): C, 56.39; H, 5.74; N, 2.16. Found: C, 56.25; H, 5.55; N, 1.96.





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**(Methyl 5-Acetamido-4,7,8,9-tetra-*O*-acetyl-3,5-dideoxy-D-*glycero*-α-D-*galacto*-2-nonulopyranosylonate)-(2→3)-(2,4,6-tri-*O*-benzoyl-β-D-galactopyranosyl)-(1→3)-[α-L-fucopyranosyl-(1→4)]-2-*O*-acetyl-*N*-butyl-1,5-dideoxy-1,5-imino-D-glucitol (9).** A mixture of **7** (50 mg), butyraldehyde (1 mL), 1-butanol (10 mL), acetic acid (0.5 mL) and water (0.5 mL) was hydrogenated as described for **5**. Work-up and column chromatography (15:1 $CH_2Cl_2$—MeOH) of the product on silica gel gave **9** (34 mg, 65%): $[\alpha]_D$ −12° (*c* 0.74, $CH_2Cl_2$); $^1H$ NMR ($CDCl_3$) δ 0.86 (t, 3H, J = 6.6 Hz, Me), 1.24 (m, 4H, —$C_2H_4$Me), 1.25 (d, 3H, $J_{5,6}$ = 6.1 Hz, H-6b), 1.53 (s, 3H, AcN), 1.65 (t, 1H, $J_{gem}$ = $J_{3ax,4}$ = 12.8 Hz, H-3d*ax*), 1.77, 1.91, 2.07, 2.12, 2.18 (5s, 15H, 5AcO), 2.43 (dd, 1H, $J_{gem}$ = 13.4, $J_{3eq,4}$ = 4.9 Hz, H-3d*eq*), 2.45 (m, 2H, N—C$H_2$—$C_3H_7$), 2.91 (dd, 1H, H-1a*eq*), 3.81 (s, 3H, COOMe), 4.68 (m, 1H, H-2a), 4.82 (m, 1H, H-4d), 5.03 (d, 1H, $J_{1,2}$ = 3.3 Hz, H-1b), 5.16 (d, 1H, $J_{1,2}$ = 8.1 Hz, H-1c), 5.26 (dd, 1H, $J_{7,8}$ = 9.5 Hz, H-7), 5.33 (dd, 1H, $J_{3,4}$ = 3.5 Hz, H-4c), 5.36 (t, 1H, H-2c), 5.56 (m, 1H, H-8d), 7.41–8.09 (m, 15H, 3Ph).

Anal. Calcd for $C_{65}H_{82}N_2O_{29}$ (1355.36): C, 57.60; H, 6.01; N, 2.07. Found: C, 57.47; H, 6.02; N, 1.92.

**(Methyl 5-Acetamido-4,7,8,9-tetra-*O*-acetyl-3,5-dideoxy-D-*glycero*-α-D-*galacto*-2-nonulopyranosylonate)-(2→3)-(2,4,6-tri-*O*-benzoyl-β-D-galactopyranosyl)-(1→3)-[α-L-fucopyranosyl-(1→4)]-2-*O*-acetyl-*N*-decyl-1,5-dideoxy-1,5-imino-D-glucitol (10).** A mixture of compound **7** (20 mg), decyl aldehyde (0.5 mL), ethyl acetate (5 mL), acetic acid (0.5 mL) and water (0.1 mL) was hydrogenated as described for **6**. Work-up and column chromatography (20:1 $CH_2Cl_2$—MeOH) on silica gel gave **10** (11 mg, 56%): $[\alpha]_D$ +2.5° (*c* 0.24, $CH_2Cl_2$); $^1H$ NMR ($CDCl_3$) δ 0.88 (t, 3H, J = 6.2 Hz, Me), 1.25 (m, 16H, —$C_8H_{16}$Me), 1.25 (d, 3H, H-6b), 1.52 (s, 3H, AcN),1.67 (t, 1H, $J_{gem}$ = $J_{3ax,4}$ = 12.6 Hz, H-3d*ax*), 1.78, 1.91, 2.07, 2.13, 2.20 (5s, 15H, 5AcO), 2.44 (dd, 1H, $J_{gem}$ = 12.5, $J_{3eq,4}$ = 4.2 Hz, H-3d*eq*), 2.45 (m, 2H, NC$H_2$), 2.95 (dd, 1H, $J_{gem}$ = 11.7, $J_{1eq,2}$ = 4 Hz, H-1a*eq*), 3.82 (s, 3H, COOMe), 4.72 (m, 1H, H-2a), 4.83 (m, 1H, H-4d), 5.03 (d, 1H, $J_{1,2}$ = 3.5 Hz, H-1b), 5.16 (d, 1H, H-1c), 5.26 (dd, 1H, $J_{6,7}$ = 2.6, $J_{7,8}$ = 9.5 Hz, H-7d), 5.31 (d, 1H, $J_{3,4}$ = 4.2 Hz, H-4c), 5.36 (dd, 1H, $J_{1,2}$ = 8.24, $J_{2,3}$ = 10.3 Hz, H-2c), 5.56 (m, 1H, H-8d), 7.42–8.10 (m, 15H, 3Ph).

Anal. Calcd for $C_{71}H_{94}N_2O_{29}$ (1439.52): C, 59.24; H, 6.58; N, 1.95. Found: C, 59.18; H, 6.44; N, 1.93.

**(5-Acetamido-3,5-dideoxy-D-*glycero*-α-D-*galacto*-2-nonulopyranosylonic acid)-(2→3)-(β-D-galactopyranosyl)-(1→4)-[α-L-fucopyranosyl-(1→3)]-1,5-dideoxy-1,5-imino-D-glucitol (11).** Compound **3** (30.3 mg) was treated with a catalytic amount of NaOMe in dry MeOH overnight. One mL of 0.2 M KOH was added and the mixture was stirred overnight at rt. The solution was neutralized with Amberlite IR-120 ($H^+$), then filtered and concentrated. The product was purified by column chromatography (1:1 MeOH—$H_2O$) on Sephadex LH-20 to give **11** (17.8 mg) in quantitative yield: $[\alpha]_D$ −19° (*c* 0.5, 1:1 MeOH—$H_2O$); $^1H$ NMR ($D_2O$) δ 1.18 (d, 3H, H-6b), 1.78 (t, 3H, J = 12 Hz, H-3d*ax*), 2.03 (s, 3H, AcN),





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2.76 (dd, 1H, $J_{gem}$ = 12, $J_{3eq,4}$ = 4.4 Hz, H-3d*eq*), 3.03 (dd, 1H, $J_{gem}$ = 12.5 Hz, H-1a*eq*), 5.39 (d, 1H, $J_{1,2}$ = 4 Hz, H-1b), 5.54 (d, 1H, $J_{1,2}$ = 7.7 Hz, H-1c): FAB-MS (negative ion mode): *m/z* 761.35 (M—H)$^-$ for $C_{29}H_{49}N_2O_{21}$ (Exact mass: 761.2828).

Anal. Calcd for $C_{29}H_{50}N_2O_{21}$ (762.71): C, 45.67; H, 6.61; N, 3.67. Found: C, 45.38; H, 6.42; N, 3.49.

**(5-Acetamido-3,5-dideoxy-D-*glycero*-α-D-*galacto*-2-nonulopyranosylonic acid)-(2→3)-(β-D-galactopyranosyl)-(1→4)-[α-L-fucopyranosyl-(1→3)]-*N*-butyl-1,5-dideoxy-1,5-imino-D-glucitol (13).** Compound **5** (50 mg) was treated with a catalytic amount of NaOMe, and then 0.2 M KOH as described for **11**. Work-up and column chromatography (1:1 MeOH—$H_2O$) on Sephadex LH-20 gave **13** (30 mg, quant): $[\alpha]_D$ −46° (*c* 0.5, 1:1 MeOH—$H_2O$); $^1$H NMR ($D_2O$) δ 0.95 (t, 3H, J = 7.3 Hz, Me), 1.19 (d, 3H, $J_{5,6}$ = 6.6 Hz, H-6b), 1.40, 1.74 (m, 4H, $C_2H_4$Me), 1.79 (t, 3H, J = 12 Hz, H-3d*ax*), 2.03 (s, 3H, AcN), 2.77 (dd, 1H, $J_{gem}$ = 12.5, $J_{3eq,4}$ = 4.4 Hz, H-3d*eq*), 3.29 (m, 2H, N—$CH_2$—), 5.36 (d, 1H, H-1b).

Anal. Calcd for $C_{33}H_{58}N_2O_{21}$ (818.82): C, 48.41; H, 7.14; N, 3.42. Found: C, 48.26; H, 6.88; N, 3.18.

**(5-Acetamido-3,5-dideoxy-D-*glycero*-α-D-*galacto*-2-nonulopyranosylonic acid)-(2→3)-(β-D-galactopyranosyl)-(1→4)-[α-L-fucopyranosyl-(1→3)]-*N*-decyl-1,5-dideoxy-1,5-imino-D-glucitol (14).** The title compound was prepared from **6** (65 mg) as described for **13** and purified by column chromatography (2:1 MeOH—$H_2O$) on Sephadex LH-20 to afford **14** (41 mg, quant): $[\alpha]_D$ −43° (*c* 0.8, 2:1 MeOH—$H_2O$); $^1$H NMR ($D_2O$) δ 0.87 (t, 3H, Me), 1.18 (d, 3H, $J_{5,6}$ = 6 Hz, H-6b), 1.28, 1.59 (m, 16H, $C_8H_{16}$Me), 1.80 (t, 3H, H-3d*ax*), 1.90 (s, 3H, AcN), 5.41 (d, 1H, H-1b).

Anal. Calcd for $C_{39}H_{70}N_2O_{21}$ (902.98): C, 51.88; H, 7.81; N, 3.10. Found: C, 51.74; H, 7.67; N, 3.00.

**(5-Acetamido-3,5-dideoxy-D-*glycero*-α-D-*galacto*-2-nonulopyranosylonic acid)-(2→3)-(β-D-galactopyranosyl)-(1→3)-[α-L-fucopyranosyl-(1→4)]-1,5-dideoxy-1,5-imino-D-glucitol (15).** The title compound was prepared from **7** (62 mg) as described for **11** to give **15** (36.4 mg, quant): $[\alpha]_D$ −30° (*c* 0.74, 1:1 MeOH—$H_2O$); $^1$H NMR ($D_2O$) δ 1.19 (d, 3H, H-6b), 1.80 (t, 1H, J = 12 Hz, H-3d*ax*), 2.03 (s, 3H, AcN), 2.77 (dd, 1H, $J_{gem}$ = 12, $J_{3eq,4}$ = 4.4 Hz, H-3d*eq*), 2.99 (dd, 1H, H-1a*eq*), 4.83 (d, 1H, $J_{1,2}$ = 8.1 Hz, H-1c), 5.02 (d, 1H, $J_{1,2}$ = 3.5 Hz, H-1b): FAB-MS (negative ion mode): *m/z* 761.32 (M—H)$^-$ for $C_{29}H_{49}N_2O_{21}$ (Exact mass: 761.2828).

Anal. Calcd for $C_{29}H_{50}N_2O_{21}$ (762.71): C, 45.67; H, 6.61; N, 3.67. Found: C, 45.42; H, 6.60; N, 3.60.

**(5-Acetamido-3,5-dideoxy-D-*glycero*-α-D-*galacto*-2-nonulopyranosylonic acid)-(2→3)-(β-D-galactopyranosyl)-(1→3)-[α-L-fucopyranosyl-(1→4)]-*N*-butyl-1,5-dideoxy-1,5-imino-D-glucitol (17).** Deprotection of **9** (34 mg) and

column chromatography as described for gave the title compound **17** (20 mg, quant): $[\alpha]_D$ −52° (*c* 0.45, 1:1 MeOH—$H_2O$); $^1$H NMR ($D_2O$) δ 0.96 (t, 3H, J = 7.3 Hz, Me), 1.22 (d, 3H, $J_{5,6}$ = 6.6 Hz, H-6b), 1.40, 1.72 (m, 4H, $C_2H_4$Me), 1.81 (t, 1H, J = 12.5 Hz, H-3d*ax*), 2.05 (s, 3H, AcN), 2.78 (dd, 1H, $J_{gem}$ = 12.5, $J_{3eq,4}$ = 4.6 Hz, H-3d*eq*), 5.11 (d, 1H, H-1b).

Anal. Calcd for $C_{33}H_{58}N_2O_{21}$ (818.82): C, 48.41; H, 7.14; N, 3.42. Found: C, 48.11; H, 7.04; N, 3.27.

**(5-Acetamido-3,5-dideoxy-D-*glycero*-α-D-*galacto*-2-nonulopyranosylonic acid)-(2→3)-(β-D-galactopyranosyl)-(1→3)-[α-L-fucopyranosyl-(1→4)]-*N*-decyl-1,5-dideoxy-1,5-imino-D-glucitol (18).** The title compound was prepared from **10** (52 mg) as described for **14** to afford **18** (33 mg, quant): $[\alpha]_D$ −35° (*c* 0.62, 2:1 MeOH—$H_2O$); $^1$H NMR ($D_2O$) δ 0.87 (t, 3H, Me), 1.18 (d, 3H, J = 6 Hz, H-6b), 1.28, 1.55 (m, 16H, $C_8H_{16}$Me), 1.80 (t, 3H, H-3d*ax*), 1.90 (s, 3H, AcN), 5.15 (d, 1H, H-1b).

Anal. Calcd for $C_{39}H_{70}N_2O_{21}$ (902.98): C, 51.88; H, 7.81; N, 3.10. Found: C, 51.69; H, 7.68; N, 2.93.

**(2-*O*-Benzoyl-4,6-*O*-benzylidene-3-*O*-levulinoyl-β-D-galactopyranosyl)-(1→4)-[2,3,4-tri-*O*-benzyl-α-L-fucopyranosyl-(1→3)]-2-*O*-acetyl-6-*O*-benzyl-*N*-benzyloxycarbonyl-1,5-dideoxy-1,5-imino-D-glucitol (21).** To a stirred mixture of **19** (154 mg, 1 equiv), methyl 2-*O*-benzoyl-4,6-*O*-benzylidene-3-*O*-levulinoyl-1-thio-β-D-galactopyranoside[20] (**20**, 182 mg, 2 equiv), molecular sieves 4Å (300 mg) and $CH_2Cl_2$ (5 mL), were added *N*-iodosuccinimide (NIS, 164 mg, 4 equiv) and trimethylsilyl trifluoromethanesulfonate (TMSOTf, 14 μL, 0.4 equiv) at 0°C, and stirring was continued overnight at 0°C∼rt. The solids were filtered off and the filtrate was successively washed with M $Na_2CO_3$, $Na_2S_2O_3$ and water, dried ($Na_2SO_4$), and concentrated. The residue was chromatographed (1:2 EtOAc-hexane) on a column of silica gel to give **21** (164 mg, 70%): $[\alpha]_D$ −30° (*c* 1.33, $CH_2Cl_2$); $^1$H NMR ($CDCl_3$) δ 1.10 (d, 3H, $J_{5,6}$ = 6.6 Hz, H-6b), 1.63 (s, 3H, AcO), 1.92 (s, 3H, Lev—Me), 2.43–2.61 (m, 4H, Lev—$C_2H_4$), 3.28 (dd, 1H, $J_{gem}$ = 11.9 Hz, H-1a), 4.44 (d, 1H, $J_{1,2}$ = 8.2 Hz, H-1c), 4.56–4.70 (4d, 4H, 2PhC$H_2$O), 4.89 (d, 1H, H-1b), 4.90 (dd, 1H, H-3c), 4.89, 4.97 (2d, 2H, $J_{gem}$ = 12.5 Hz, PhC$H_2$OCO), 5.52 (t, 1H, $J_{1,2}$ = $J_{2,3}$ = 8.24 Hz, H-2c), 5.53 (s, 1H, benzylidene CH), 7.17–7.94 (m, 35H, 7Ph).

Anal. Calcd for $C_{75}H_{79}NO_{19}$ (1298.44): C, 69.38; H, 6.13; N, 1.08. Found: C, 69.13; H, 6.06; N, 1.03.

**(2-*O*-Benzoyl-3-*O*-levulinoyl-β-D-galactopyranosyl)-(1→4)-[(2,3,4-tri-*O*-benzyl-α-L-fucopyranosyl)-(1→3)]-2-*O*-acetyl-6-*O*-benzyl-*N*-benzyloxycarbonyl-1,5-dideoxy-1,5-imino-D-glucitol (22).** A solution of **21** (164 mg) in 80% aq AcOH (10 mL) was stirred overnight at 45°C and concentrated. The residue was chromatographed (3:1 EtOAc-hexane) on a column of silica gel to give **22** (136 mg, 89%): $[\alpha]_D$ −39° (*c* 1, $CH_2Cl_2$); $^1$H NMR ($CDCl_3$) δ 1.01 (d, 3H, $J_{5,6}$ = 6 Hz, H-6b), 1.92 (s, 3H, AcO), 2.10 (s, 3H, Lev—Me), 2.37–2.69 (m, 4H,

Lev—$C_2H_4$), 3.30 (dd, 1H, H-1a), 4.92 (br s, 1H, H-1b), 5.50 (t, 1H, $J_{1,2} = J_{2,3} = 9.9$ Hz, H-2c), 7.19–7.93 (m, 30H, 4Ph).

Anal. Calcd for $C_{68}H_{75}NO_{19}$ (1210.34): C, 67.48; H, 6.25; N, 1.16. Found: C, 67.42; H, 6.18; N, 0.98.

**(2,4,6-Tri-*O*-benzoyl-3-*O*-levulinoyl-β-D-galactopyranosyl)-(1→4)-[(2,3,4-tri-*O*-benzyl-α-L-fucopyranosyl)-(1→3)]-2-*O*-acetyl-6-*O*-benzyl-*N*-benzyloxycarbonyl-1,5-dideoxy-1,5-imino-D-glucitol (23) and (2,4,6-Tri-*O*-benzoyl-β-D-galactopyranosyl)-(1→4)-[(2,3,4-tri-*O*-benzyl-α-L-fucopyranosyl)-(1→3)]-2-*O*-acetyl-6-*O*-benzyl-*N*-benzyloxycarbonyl-1,5-dideoxy-1,5-imino-D-glucitol (24).** To a solution of **22** (48 mg) in pyridine (5 mL) was added benzoyl chloride (18 μL, 4 equiv) and the mixture was stirred overnight at rt. Work-up and column chromatography (2:3 EtOAc-hexane) gave **23** (48 mg, 86%): $[\alpha]_D$ −37° (*c* 1, $CH_2Cl_2$); $^1$H NMR ($CDCl_3$) δ 0.99 (d, 3H, H-6b), 1.64 (s, 3H, AcO), 1.88 (s, 3H, Lev—Me), 2.32–2.59 (m, 4H, Lev—$C_2H_4$), 3.23 (near d, 1H, $J_{gem} = 14.7$ Hz, H-1a), 3.62 (dd, 1H, $J_{2,3} = 10.3$, $J_{3,4} = 2.2$ Hz, H-3b), 4.53 (d, 1H, $J_{1,2} = 8.8$ Hz, H-1c), 4.58, 4.69 (2d, 2H, $J_{gem} = 12.3$ Hz, PhC*H*$_2$OCO), 4.94 (d, 1H, $J_{1,2} = 3.7$ Hz, H-1b), 5.28 (dd, 1H, $J_{2,3} = 10.3$ Hz, H-3c), 5.52 (dd, 1H, H-2c), 5.76 (d, 1H, $J_{3,4} = 3.3$ Hz, H-4c), 7.21–8.12 (m, 40H, 8Ph).

To a solution of **23** (131 mg) in EtOH (20 mL) was added hydrazine acetate (10 mg, 1.2 equiv) and the mixture was stirred for 1 h at rt, and then concentrated. The residue was chromatographed (125:1 $CH_2Cl_2$—MeOH) on a column of silica gel to afford **24** (122 mg, quant): $[\alpha]_D$ −50° (*c* 2.4, $CH_2Cl_2$); $^1$H NMR ($CDCl_3$) δ 0.98 (d, 3H, $J_{5,6} = 6$ Hz, H-6b), 1.81 (s, 3H, AcO), 3.62 (near d, 1H, $J_{gem} = 14.7$ Hz, H-1a), 3.95 (dd, 1H, $J_{2,3} = 10$ Hz, H-3c), 4.94 (s, 1H, $J_{1,2} = 3.7$ Hz, H-1b), 5.72 (d, 1H, $J_{3,4} = 3.5$ Hz, H-4c), 7.13–8.14 (m, 40H, 8Ph).

Anal. Calcd for $C_{77}H_{77}NO_{19}$ (1320.45): C, 70.04; H, 5.88; N, 1.06. Found: C, 69.88; H, 5.75; N, 1.01.

**(2,4,6-Tri-*O*-benzoyl-3-*O*-sulfo-β-D-galactopyranosyl)-(1→4)-[(2,3,4-tri-*O*-benzyl-α-L-fucopyranosyl)-(1→3)]-2-*O*-acetyl-6-*O*-benzyl-*N*-benzyloxycarbonyl-1,5-dideoxy-1,5-imino-D-glucitol (25) and (2,4,6-Tri-*O*-benzoyl-3-*O*-sulfo-β-D-galactopyranosyl)-(1→4)-[α-L-fucopyranosyl)-(1→3)]-2-*O*-acetyl-1,5-dideoxy-1,5-imino-*N*-methyl-D-glucitol sodium salt (26).** To a solution of **24** (119 mg) in *N,N*-dimethylformamide (0.5 mL) was added pyridine sulfur trioxide complex (115 mg, 8 equiv) and the mixture was stirred for 1 h at rt, then cooled to 0°C. MeOH (1 mL) was added and the mixture was stirred for 30 min at 0°C and concentrated. Column chromatography (15:1 $CH_2Cl_2$—MeOH) of the residue on silica gel gave **25** (121 mg, 96%): $[\alpha]_D$ −16.6° (*c* 2.4, $CH_2Cl_2$). Compound **25** (114 mg) in MeOH was treated with cation-exchange resin Dowex-$Na^+$, and then hydrogenolyzed in the presence of formalin (0.5 mL) and HCl-free palladium black (300 mg). Work-up and column chromatography (10:1 $CH_2Cl_2$—MeOH) afforded **26** (62 mg, 83%): $[\alpha]_D$ −30.5° (*c* 0.89, MeOH); $^1$H NMR (DMSO-$d_6$, 50°C) δ 1.18 (d, 3H, $J_{5,6} = 6.6$ Hz, H-6b), 1.99 (s, 3H, AcO), 2.04 (t, 1H, $J_{1ax,2} = 10.4$ Hz, H-1a*ax*), 2.12 (s, 3H, *N*—Me), 2.79 (dd, 1H, $J_{gem} = 10.8$, $J_{1eq,2} = 4.8$ Hz, H-1a*eq*),

4.10, 4.51 (2dd, 2H, $J_{gem}$ = 10.8, $J_{5,6}$ = 8.3, 4.8 Hz, H-6c,6′c), 4.72 (dd, 1H, $J_{2,3}$ = 10.3, $J_{3,4}$ = 3.7 Hz, H-3c), 4.94 (d, 1H, $J_{1,2}$ = 3.7 Hz, H-1b), 5.05 (d, 1H, $J_{1,2}$ = 8.2 Hz, H-1c), 5.41 (dd, 1H, $J_{2,3}$ = 10.3 Hz, H-2c), 5.82 (d, 1H, $J_{3,4}$ = 3.7 Hz, H-4c), 7.49–8.12 (m, 15H, 3Ph).

Anal. Calcd for $C_{42}H_{48}NO_{20}SNa$ (941.89): C, 53.56; H, 5.14; N, 1.49. Found: C, 53.46; H, 4.97; N, 1.44.

**(3-*O*-Sulfo-β-D-galactopyranosyl)-(1→4)-[α-L-fucopyranosyl-(1→3)]-1,5-dideoxy-1,5-imino-*N*-methyl-D-glucitol sodium salt (27).** A mixture of **26** (49 mg) and a small amount of NaOMe in MeOH was stirred overnight at rt and concentrated. The residue was chromatographed (1:1 MeOH—$H_2O$) on a column of Sephadex LH-20 to give **27** (30 mg, quant) as an amorphous mass: $^1$H NMR (DMSO-$d_6$, 55°C) δ 1.01 (d, 3H, $J_{5,6}$ = 6.4 Hz, H-6b), 2.00 (t, 1H, $J_{gem}$ = $J_{1ax,2}$ = 10.7 Hz, H-1a*ax*), 2.23 (s, 3H, *N*—Me), 2.77 (dd, 1H, $J_{gem}$ = 11, $J_{1eq,2}$ = 5.1 Hz, H-1a*eq*), 4.49 (d, 1H, $J_{1,2}$ = 8.3 Hz, H-1c), 4.60 (q, 1H, $J_{5,6}$ = 6.4 Hz, H-5b), 5.11 (d, 1H, $J_{1,2}$ = 3.6 Hz, H-1b). LRMS (ion-spray MS, negative ion mode) *m/z* 564.0 $(M—Na—H)^-$, (ion-spray MS, positive ion mode) *m/z* 566.2 $(M—Na+H)^+$. HRMS Calcd for $C_{19}H_{35}NO_{16}S$: 565.1677. Found: 565.1675.

**(2-*O*-Benzoyl-3-*O*-levulinoyl-β-D-galactopyranosyl)-(1→4)-[α-L-fucopyranosyl-(1→3)]-2-*O*-acetyl-1,5-dideoxy-1,5-imino-D-glucitol (28).** Compound **22** (457 mg) in AcOH (15 mL) was hydrogenolyzed with palladium black (500 mg). Work-up and column chromatography (5:1 $CH_2Cl_2$—MeOH) gave **28** (213 mg, 79%): $[\alpha]_D$ −50° (*c* 1.1, MeOH); $^1$H NMR ($CD_3OD$) δ 1.34 (d, 3H, H-6b), 2.10 (s, 3H, Lev—Me), 2.43–2.64 (m, 4H, Lev—$C_2H_4$), 3.42 (dd, 1H, H-1a*eq*), 5.05 (d, 1H, H-1c), 5.13 (d, 1H, H-1b), 5.55 (d, 1H, $J_{1,2}$ = $J_{2,3}$ = 9.7 Hz, H-2c).

Anal. Calcd for $C_{32}H_{45}NO_{17}$ (715.70): C, 53.70; H, 6.34; N, 1.96. Found: C, 53.64; H, 6.06; N, 1.66.

**(2-*O*-Benzoyl-3-*O*-levulinoyl-β-D-galactopyranosyl)-(1→4)-[α-L-fucopyranosyl-(1→3)]-2-*O*-acetyl-*N*-butyl-1,5-dideoxy-1,5-imino-D-glucitol (29).** A mixture of **28** (51.3 mg), 1-butanol (2 mL) and butyraldehyde (98 μL, 20 equiv) was hydrogenated in the presence of palladium hydroxide on carbon (50 mg). Work-up and column chromatography (10:1 $CH_2Cl_2$—MeOH) on silica gel afforded **29** (43.7 mg, 79%): $[\alpha]_D$ −53.6° (*c* 0.88, $CH_2Cl_2$); $^1$H NMR ($CD_3OD$) δ 0.85 (t, 3H, Me), 1.15–1.35 (m, 4H, $C_2H_4$), 1.35 (d, 3H, H-6b), 1.97 (s, 3H, AcO), 2.05 (s, 3H, Lev—Me), 2.19 (t, 1H, J = 10.6 Hz, H-1a*ax*), 2.35–2.70 (m, 6H, Lev—$C_2H_4$, N—$CH_2$), 3.02 (dd, 1H, $J_{gem}$ = 10.8, $J_{1eq,2}$ = 4.8 Hz, H-1a*eq*), 4.09 (d, 1H, $J_{3,4}$ = 3.0 Hz, H-4c), 4.90 (m, 1H, H-2a), 4.99 (d, 1H, $J_{1,2}$ = 7.9 Hz, H-1c), 5.05 (dd, 1H, $J_{2,3}$ = 10, $J_{3,4}$ = 3.0 Hz, H-3c), 5.14 (d, 1H, $J_{1,2}$ = 3.8 Hz, H-1b), 5.54 (dd, 1H, $J_{1,2}$ = 8, $J_{2,3}$ = 10 Hz, H-2c), 7.47–8.10 (m, 5H, Ph).

Anal. Calcd for $C_{36}H_{53}NO_{17}$ (771.81): C, 56.02; H, 6.92; N, 1.81. Found: C, 55.90; H, 6.84; N, 1.79.

**(2-*O*-Benzoyl-3-*O*-levulinoyl-β-D-galactopyranosyl)-(1→4)-[α-L-fucopyranosyl-(1→3)]-2-*O*-acetyl-*N*-decyl-1,5-dideoxy-1,5-imino-D-glucitol (30).** A mixture of **28** (73 mg), decyl aldehyde (296 μL, 20 equiv) and 1:1 EtOAc-THF (2 mL) was hydrogenated in the presence of palladium hydroxide on carbon (55 mg). Work-up and column chromatography as described for **29** gave **30** (70 mg, 80%): $[\alpha]_D$ −47.6° (*c* 1.4, $CH_2Cl_2$); $^1$H NMR ($CD_3OD$) δ 0.89 (t, 3H, Me), 1.15–1.35 (m, 16H, $C_8H_{16}$), 1.36 (d, 3H, H-6b), 1.98 (s, 3H, AcO), 2.05 (s, 3H, Lev—Me), 2.19 (t, 1H, J = 10.6 Hz, H-1a*ax*), 2.35–2.70 (m, 6H, Lev—$C_2H_4$, N—$CH_2$), 3.02 (dd, 1H, $J_{gem}$ = 10.8, $J_{1eq,2}$ = 4.8 Hz, H-1a*eq*), others are same as those of **29**.

Anal. Calcd for $C_{42}H_{65}NO_{17}$ (855.97): C, 58.93; H, 7.65; N, 1.64 Found: C, 58.93; H, 7.53; N, 1.60.

**(4,6-Di-*O*-acetyl-2-*O*-benzoyl-3-*O*-levulinoyl-β-D-galactopyranosyl)-(1→4)-[(2,3,4-tri-*O*-acetyl-α-L-fucopyranosyl)-(1→3)]-2,6-di-*O*-acetyl-*N*-butyl-1,5-dideoxy-1,5-imino-D-glucitol (31) and (4,6-Di-*O*-acetyl-2-*O*-benzoyl-β-D-galactopyranosyl)-(1→4)-[(2,3,4-tri-*O*-acetyl-α-L-fucopyranosyl)-(1→3)]-2,6-di-*O*-acetyl-*N*-butyl-1,5-dideoxy-1,5-imino-D-glucitol (33).** Compound **29** (45 mg) in pyridine (1 mL) was treated with $Ac_2O$ (66 μL) overnight at rt. Work-up and column chromatography (50:1 $CH_2Cl_2$—MeOH) on silica gel gave **31** (60 mg, quant): $[\alpha]_D$ −62° (*c* 1.12, $CH_2Cl_2$); $^1$H NMR ($CD_3OD$) δ 0.83 (t, 3H, Me), 1.10–1.30 (m, 4H, $C_2H_4$), 1.34 (d, 3H, H-6b), 1.98–2.24 (8s, 24H, 7AcO, Lev—Me), 2.30–2.70 (m, 6H, Lev—$C_2H_4$, *N*—$CH_2$), 3.02 (dd, 1H, $J_{gem}$ = 11.2, $J_{1eq,2}$ = 5.3 Hz, H-1a*eq*), 3.74, 3.85 (2t, 2H, J = 9 Hz, H-3a,4a), 3.90 (t, 1H, J = 7 Hz, H-5c), 4.19, 4.28 (2dd, 2H, H-6a,6′a), 4.34, 4.57 (2dd, 2H, $J_{gem}$ = 11.4, $J_{5,6}$ = 7.7, $J_{5,6'}$ = 6.6 Hz, H-6c,6′c), 4.61 (d, 1H, $J_{1,2}$ = 8.2 Hz, H-1c), 4.90 (m, 1H, H-2a), 5.03 (q, 1H, J = 6 Hz, H-5b), 5.07 (dd, $J_{1,2}$ = 4, $J_{2,3}$ = 10.8 Hz, H-2b), 5.11 (dd, 1H, $J_{2,3}$ = 10.3, $J_{3,4}$ = 3.5 Hz, H-3c), 5.22 (dd, 1H, $J_{2,3}$ = 10.8, $J_{3,4}$ = 3.3 Hz, H-3b), 5.39 (dd, 1H, $J_{1,2}$ = 8.2, $J_{2,3}$ = 10.3 Hz, H-2c), 5.45–5.50 (m, 3H, H-1b, H-4b, H-4c), 7.45–8.10 (m, 5H, Ph).

A mixture of **31** (55.2 mg) and hydrazine acetate (6.1 mg, 1.2 equiv) in ethanol was stirred for 1.5 h at rt. Work-up and column chromatography (100:1 $CH_2Cl_2$—MeOH) afforded **33** (46.5 mg, 93%): $[\alpha]_D$ −74.4° (*c* 0.93, $CH_2Cl_2$); $^1$H NMR ($CD_3OD$) δ 1.98–2.24 (7s, 21H, 7AcO), 2.87 (br s, 1H, 3-OH of Gal), 3.95 (br dd, 1H, $J_{2,3}$ = 10.4, $J_{3,4}$ = 4 Hz, H-3c), 5.20 (dd, 1H, $J_{1,2}$ = 8.2, $J_{2,3}$ = 10.4 Hz, H-2c), 5.38 (dd, 1H, $J_{3,4}$ = 3.7 Hz, H-4c), 5.44 (d, 1H, $J_{3,4}$ = 2.9 Hz, H-4b), 5.47 (d, 1H, $J_{1,2}$ = 4 Hz, H-1b), other peaks are similar to those of **31**.

Anal. Calcd for $C_{43}H_{59}NO_{21}$ (925.93): C, 55.78; H, 6.42; N, 1.51. Found: C, 55.53; H, 6.37; N, 1.25.

**(4,6-Di-*O*-acetyl-2-*O*-benzoyl-3-*O*-levulinoyl-β-D-galactopyranosyl)-(1→4)-[(2,3,4-tri-*O*-acetyl-α-L-fucopyranosyl)-(1→3)]-2,6-di-*O*-acetyl-*N*-decyl-1,5-dideoxy-1,5-imino-D-glucitol (32) and (4,6-Di-*O*-acetyl-2-*O*-benzoyl-β-D-galactopyranosyl)-(1→4)-[(2,3,4-tri-*O*-acetyl-α-L-fucopyranosyl)-(1→3)]-2,6-di-*O*-acetyl-*N*-decyl-1,5-dideoxy-1,5-imino-D-glucitol (35).** Acetylation of **30** (70 mg) was performed as described for **31**. Column chromatography (100:1

$CH_2Cl_2$—MeOH) on silica gel gave **32** (91 mg, quant): $[\alpha]_D$ −58.4° (*c* 1.64, $CH_2Cl_2$); $^1$H NMR ($CD_3OD$) δ 0.88 (t, 3H, Me), 1.10–1.30 (m, 16H, $C_8H_{16}$), 1.98–2.24 (8s, 24H, 7AcO, Lev—Me), 5.11 (dd, 1H, $J_{2,3}$ = 10, $J_{3,4}$ = 3.5 Hz, H-3c), other peaks are similar to those of **31**.

The levulinoyl group of **32** (81.7 mg) was selectively removed by treatment with hydrazine acetate (8.4 mg, 1.2 equiv) as described for **33** to afforded **35** (71 mg, 95%): $[\alpha]_D$ −67.4° (*c* 1.42, $CH_2Cl_2$); $^1$H NMR ($CD_3OD$) δ 1.98–2.24 (7s, 21H, 7AcO), 2.86 (br s, 1H, 3-OH of Gal), 3.01 (dd, 1H, $J_{gem}$ = 11.2, $J_{1eq,2}$ = 5.3 Hz, H-1a*eq*), 3.73, 3.82 (2t, 2H, $J_{3,4}$ = $J_{4,5}$ = 9.2 Hz, H-3a, H-4a), 3.85 (t, 1H, H-5c), 3.95 (dd, 1H, $J_{2,3}$ = 10.4, $J_{3,4}$ = 3.7 Hz, H-3c), 4.25, 4.37 (2dd, 2H, H-6a, H-6′a), 4.34, 4.54 (2dd, 2H, H-6c, H-6′c), 4.50 (d, 1H, $J_{1,2}$ = 8 Hz, H-1c), 4.89 (m, 1H, $J_{1ax,2}$ = $J_{2,3}$ = 10, $J_{1eq,2}$ = 5 Hz, H-2a), 5.03 (q, 1H, $J_{5,6}$ = 6 Hz, H-5b), 5.07 (dd, 1H, $J_{1,2}$ = 4, $J_{2,3}$ = 10.8 Hz, H-2b), 5.20 (dd, 1H, $J_{1,2}$ = 8, $J_{2,3}$ = 10.4 Hz, H-2c), 5.21 (dd, 1H, $J_{2,3}$ = 10.8, $J_{3,4}$ = 3 Hz, H-3b), 5.38 (d, 1H, H-4c), 5.44 (d, 1H, H-4b), 5.47 (d, 1H, H-1b), 7.45–8.15 (m, 5H, Ph).

Anal. Calcd for $C_{49}H_{71}NO_{21}$ (1010.09): C, 58.27; H, 7.09; N, 1.39. Found: C, 58.25; H, 6.92; N, 1.29.

**(4,6-Di-*O*-acetyl-2-*O*-benzoyl-3-*O*-sulfo-β-D-galactopyranosyl)-(1→4)-[(2,3,4-tri-*O*-acetyl-α-L-fucopyranosyl)-(1→3)]-2,6-di-*O*-acetyl-*N*-butyl-1,5-dideoxy-1,5-imino-D-glucitol (34) and (3-*O*-Sulfo-β-D-galactopyranosyl)-(1→4)-[α-L-fucopyranosyl-(1→3)]-*N*-butyl-1,5-dideoxy-1,5-imino-D-glucitol sodium salt (37).** To a solution of **33** (38.4 mg) in *N,N*-dimethylformamide (2 mL) was added pyridine sulfur trioxide complex (33.7 mg, 5 equiv) and the mixture was stirred for 2 h at rt, then cooled to 0°C. MeOH (1 mL) was added and the mixture was stirred for 30 min at 0°C and concentrated. Column chromatography (10:1 $CH_2Cl_2$—MeOH) of the residue on silica gel gave **34** (36.4 mg, 81%): $[\alpha]_D$ −42° (*c* 0.75, $CH_2Cl_2$); $^1$H NMR (DMSO-$d_6$) δ 4.68 (dd, 1H, $J_{2,3}$ = 10.3, $J_{3,4}$ = 2.9 Hz, H-3c), 4.75 (d, 1H, $J_{1,2}$ = 8 Hz, H-1c).

A mixture of **34** (40 mg) and methanolic sodium methoxide (3 mL) was stirred overnight at rt, and then concentrated. Column chromatography (1:1 MeOH—$H_2O$) of the residue on Sephadex LH-20 afforded **37** (41 mg, quant): $[\alpha]_D$ −40° (*c* 0.92, 1:1 MeOH—$H_2O$); $^1$H NMR (DMSO-$d_6$) δ 0.86 (t, 3H, Me), 1.00 (d, 3H, $J_{5,6}$ = 6.4 Hz, H-6b), 1.10–1.40 (m, 4H, $C_2H_4$), 2.08 (t, 1H, $J_{gem}$ = $J_{1ax,2}$ = 11 Hz, H-1a*ax*), 2.79 (dd, 1H, $J_{1eq,2}$ = 5 Hz, H-1a*eq*), 4.42 (d, 1H, $J_{1,2}$ = 7.7 Hz, H-1c), 4.52 (q, 1H, H-5b), 5.04 (d, 1H, $J_{1,2}$ = 3.7 Hz, H-1b). LRMS (FAB-MS, negative ion mode) *m/z* 628.27 $(M—H)^-$, 606.27 $(M—Na—H)^-$. HRMS Calcd for $C_{22}H_{39}NO_{16}SNa$: 628.1887. Found: 628.1886.

**(4,6-Di-*O*-acetyl-2-*O*-benzoyl-3-*O*-sulfo-β-D-galactopyranosyl)-(1→4)-[(2,3,4-tri-*O*-acetyl-α-L-fucopyranosyl)-(1→3)]-2,6-di-*O*-acetyl-*N*-decyl-1,5-dideoxy-1,5-imino-D-glucitol (36) and (3-*O*-Sulfo-β-D-galactopyranosyl)-(1→4)-[α-L-fucopyranosyl-(1→3)]-*N*-decyl-1,5-dideoxy-1,5-imino-D-glucitol sodium salt (38).** To a solution of **35** (46.4 mg) in DMF (2 mL) was added pyridine sulfur trioxide complex (74.6 mg, 10 equiv) and the mixture was stirred for

1.5 h at rt. Work-up and column chromatography (20:1 $CH_2Cl_2$—MeOH) as described for **34** gave **36** (47.5 mg, 88%): $[\alpha]_D$ −35.7° (*c* 0.85, $CH_2Cl_2$); $^1$H NMR (DMSO-$d_6$) δ 4.70 (dd, 1H, $J_{2,3}$ = 10.3, $J_{3,4}$ = 3.3 Hz, H-3c), 4.76 (d, 1H, $J_{1,2}$ = 8.6 Hz, H-1c).

A mixture of **36** (45 mg) in methanolic sodium methoxide (3 mL) was treated as described for **37** to afford **38** (46 mg, quant): $[\alpha]_D$ −51° (*c* 1, 1:1 MeOH—$H_2O$); $^1$H NMR (DMSO-$d_6$) δ 0.86 (t, 3H, Me), 1.00 (d, 3H, $J_{5,6}$ = 6.4 Hz, H-6b), 1.10–1.40 (m, 16H, $C_8H_{16}$), 2.08 (t, 1H, J = 10 Hz, H-1a*ax*), 2.79 (dd, 1H, $J_{gem}$ = 11, $J_{1eq,2}$ = 5 Hz, H-1a*eq*), 4.43 (d, 1H, $J_{1,2}$ = 7.5 Hz, H-1c), 4.53 (q, 1H, H-5b), 5.06 (d, 1H, $J_{1,2}$ = 3.7 Hz, H-1b). LRMS (FAB-MS, negative ion mode) *m/z* 712.32 (M—H)$^-$, 690.38 (M—Na—H)$^-$. HRMS Calcd for $C_{28}H_{51}NO_{16}SNa$: 712.2826. Found: 712.2824.

**Methyl 2,4,6-Tri-*O*-benzoyl-3-*O*-levulinoyl-1-thio-β-D-galactopyranoside (40).** To a stirred solution of methyl 2,6-di-*O*-benzoyl-1-thio-β-D-galactopyranoside[27] (740 mg) in 1:1 $CH_2Cl_2$-pyridine (40 mL) was added dropwise a solution of levulinic anhydride (570 mg, 1.5 equiv) in $CH_2Cl_2$ (10 mL) at −50°C. The mixture was stirred for 20 min at −50°C and washed successively with 2 M HCl and water, dried ($Na_2SO_4$), and concentrated. The residue was chromatographed (1:2 EtOAc-hexane) on silica gel to give methyl 2,6-di-*O*-benzoyl-3-*O*-levulinoyl-1-thio-β-D-galactopyranoside (760 mg, 84%): $[\alpha]_D$ +29° (*c* 1, $CH_2Cl_2$); $^1$H NMR ($CDCl_3$) δ 2.11 (s, 3H, Lev—Me), 2.23 (s, 3H, SMe), 2.43–2.73 (m, 4H, Lev—$C_2H_4$), 3.08 (d, 1H, J = 4.2 Hz, 4-OH), 4.03 (t, 1H, $J_{5,6}$ = $J_{5,6'}$ = 6.3 Hz, H-5), 4.30 (br t, 1H, H-4), 4.55 (d, 1H, $J_{1,2}$ = 9.9 Hz, H-1), 4.62, 4.67 (2dd, 2H, $J_{5,6}$ = 6.0, $J_{5,6'}$ = 6.6 Hz, H-6,6′), 5.13 (dd, 1H, $J_{2,3}$ = 10, $J_{3,4}$ = 3.1 Hz, H-3), 5.68 (t, 1H, $J_{1,2}$ = $J_{2,3}$ = 10 Hz, H-2), 7.40–8.10 (m, 10H, 2Ph). This compound was benzoylated with benzoyl chloride in pyridine to afford the title compound **40**: $[\alpha]_D$ +50° (*c* 0.74, $CH_2Cl_2$); $^1$H NMR ($CDCl_3$) δ 5.88 (dd, 1H, $J_{3,4}$ = 3.3, $J_{4,5}$ = 0.73 Hz, H-4).

Anal. Calcd for $C_{33}H_{32}O_{10}S$ (620.68): C, 63.86; H, 5.20. Found: C, 63.85; H, 5.04.

**(2,4,6-Tri-*O*-benzoyl-3-*O*-levulinoyl-β-D-galactopyranosyl)-(1→3)-2-*O*-acetyl-4,6-*O*-benzylidene-*N*-benzyloxycarbonyl-1,5-dideoxy-1,5-imino-D-glucitol (41).** A mixture of **39** (53 mg), **40** (92 mg, 1.2 equiv), molecular sieves 4Å (200 mg) and $CH_2Cl_2$ (4 mL) was stirred overnight at rt, then cooled to 0°C. NIS (67 mg, 2.4 equiv) and TMSOTf (6 μL, 0.24 equiv) were added, and the mixture was stirred overnight at 0°C∼rt as described for **21**. Work-up and column chromatography (500:1 $CH_2Cl_2$—MeOH) gave **41** (108 mg, 87%): $[\alpha]_D$ −14.4° (*c* 2.17, $CH_2Cl_2$); $^1$H NMR ($CDCl_3$) δ 1.69 (s, 3H, AcO), 1.91 (s, 3H, Lev—Me), 2.27–2.62 (m, 4H, Lev—$C_2H_4$), 3.33 (dd, 1H, $J_{gem}$ = 14, $J_{1ax,2}$ = 6.4 Hz, H-1a*ax*), 3.42 (m, 1H, $J_{4,5}$ = $J_{5,6}$ = 10, $J_{5,6'}$ = 4.3 Hz, H-5a), 3.78 (dd, 1H, $J_{gem}$ = 14, $J_{1eq,2}$ = 2.4 Hz, H-1a*eq*), 4.32, 4.46 (2dd, 2H, $J_{gem}$ = 11.3, $J_{5,6}$ = 7.6, $J_{5,6'}$ = 5.8 Hz, H-6b,6′b), 4.77 (m, 1H, $J_{2,3}$ = 6.7 Hz, H-2a), 4.85 (dd, 1H, $J_{gem}$ = 11, $J_{5,6'}$ = 4.3 Hz, H-6′a), 5.05 (d, 1H, $J_{1,2}$ = 7.9 Hz, H-1b), 5.10 (2d, 2H, Z—$CH_2$), 5.33 (dd, 1H,

$J_{2,3}$ = 10, $J_{3,4}$ = 3.4 Hz, H-3b), 5.55 (dd, 1H, H-2b), 5.60 (s, 1H, benzylidene CH), 5.78 (d, 1H, $J_{3,4}$ = 3.4 Hz, H-4b), 7.20–8.20 (m, 25H, 5Ph).

Anal. Calcd for $C_{55}H_{53}NO_{17}$ (1000.02): C, 66.06; H, 5.34; N, 1.40. Found: C, 65.93; H, 5.11; N, 1.37.

**(2,4,6-Tri-*O*-benzoyl-3-*O*-levulinoyl-β-D-galactopyranosyl)-(1→3)-2-*O*-acetyl-*N*-benzyloxycarbonyl-1,5-dideoxy-1,5-imino-D-glucitol (42)** and **(2,4,6-Tri-*O*-benzoyl-3-*O*-levulinoyl-β-D-galactopyranosyl)-(1→3)-2-*O*-acetyl-*N*-benzyloxycarbonyl-6-*O*-*tert*-butyldimethylsilyl-1,5-dideoxy-1,5-imino-D-glucitol (43).** A mixture of **41** (323 mg) and 80% aq AcOH (20 mL) was stirred overnight at 45°C, then concentrated. Column chromatography (125:1 $CH_2Cl_2$—MeOH) of the residue on silica gel gave **42** (252 mg, 86%): $[\alpha]_D$ −39° (*c* 0.66, $CH_2Cl_2$); $^1$H NMR ($CDCl_3$) δ 1.43 (s, 3H, AcO), 1.89 (s, 3H, Lev—Me), 4.67 (m, 1H, J = 4∼5 Hz, H-2a), 4.88 (d, 1H, $J_{1,2}$ = 7.9 Hz, H-1b), 5.02, 5.15 (2d, 2H, $J_{gem}$ = 12.5 Hz, Z—$CH_2$), 5.42 (dd, 1H, $J_{2,3}$ = 10.6, $J_{3,4}$ = 3.1 Hz, H-3b), 5.61 (dd, 1H, H-2b), 5.83 (d, 1H, H-4b).

To a cooled solution of **42** (213 mg) in $CH_2Cl_2$ (10 mL) and pyridine (5 mL) was added *tert*-butyldimethylsilyl chloride (176 mg, 3 equiv), and the mixture was stirred overnight at rt. Work-up and column chromatography (250:1 $CH_2Cl_2$—MeOH) on silica gel afforded **43** (221 mg, 92%): $[\alpha]_D$ +34.6° (*c* 1.66, $CH_2Cl_2$); $^1$H NMR ($CDCl_3$) δ 0.86 (s, 9H, t-butyl), 1.27 (s, 3H, AcO), 1.92 (s, 3H, Lev—Me), 2.30–2.60 (m, 4H, Lev—$C_2H_4$), 3.30 (dd, 1H, $J_{gem}$ = 12.8 Hz, H-1a), 4.69 (narrow m, 1H, H-2a), 4.85 (d, 1H, $J_{1,2}$ = 7.9 Hz, H-1b), 5.03, 5.16 (2d, 2H, $J_{gem}$ = 12.3 Hz, Z—$CH_2$), 5.40 (dd, 1H, $J_{2,3}$ = 10.4, $J_{3,4}$ = 3 Hz, H-3b), 5.63 (dd, 1H, H-2), 5.84 (d, 1H, $J_{3,4}$ = 3 Hz, H-4b), 7.20–8.20 (m, 20H, 4Ph).

Anal. Calcd for $C_{54}H_{63}NO_{17}Si$ (1026.17): C, 63.21; H, 6.19; N, 1.36. Found: C, 63.17; H, 6.00; N, 1.21.

**(2,4,6-Tri-*O*-benzoyl-3-*O*-levulinoyl-β-D-galactopyranosyl)-(1→3)-[(2,3,4-tri-*O*-benzyl-α-L-fucopyranosyl)-(1→4)]-2-*O*-acetyl-*N*-benzyloxycarbonyl-6-*O*-*tert*-butyldimethylsilyl-1,5-dideoxy-1,5-imino-D-glucitol (44).** To a stirred mixture of **43** (47 mg), methyl 2,3,4-tri-*O*-benzyl-1-thio-β-L-fucopyranoside[14] (26 mg, 1.2 equiv) and molecular sieves 4Å (100 mg) in benzene was added dimethyl(methylthio)sulfonium triflate (DMTST, 63 mg, 4 equiv) at 7°C, and stirring was continued for 1.5 h at 7°C. Work-up and column chromatography (1:2 EtOAc-hexane) gave **44** (36 mg, 55%): $[\alpha]_D$ −43° (*c* 0.5, $CH_2Cl_2$); $^1$H NMR ($CDCl_3$) δ 0.87 (s, 9H, t-butyl), 1.07 (d, 3H, $J_{5,6}$ = 6.4 Hz, H-6c), 1.81 (s, 3H, AcO), 1.91 (s, 3H, Lev—Me), 5.09 (d, 1H, $J_{1,2}$ = 3.7 Hz, H-1c), 7.10–8.15 (m, 35H, 7Ph).

Anal. Calcd for $C_{81}H_{91}NO_{21}Si$ (1442.69): C, 67.44; H, 6.36; N, 0.97. Found: C, 67.25; H, 6.19; N, 0.72.

**(2,4,6-Tri-*O*-benzoyl-3-*O*-levulinoyl-β-D-galactopyranosyl)-(1→3)-[(2,3,4-tri-*O*-benzyl-α-L-fucopyranosyl)-(1→4)]-2-*O*-acetyl-*N*-benzyloxycarbonyl-1,5-dideoxy-1,5-imino-D-glucitol (45) and (2,4,6-Tri-*O*-benzoyl-3-*O*-lev-**

**ulinoyl-β-D-galactopyranosyl)-(1→3)-[(2,3,4-tri-*O*-benzyl-α-L-fucopyranosyl)-(1→4)]-2-*O*-acetyl-6-*O*-benzoyl-*N*-benzyloxycarbonyl-1,5-dideoxy-1,5-imino-D-glucitol (46).** A mixture of **44** (36 mg) and 80% aq AcOH (10 mL) was stirred for 3 h at rt, then concentrated. Column chromatography (125:1 $CH_2Cl_2$—MeOH) of the residue on silica gel gave **45** (29 mg, 88%): $[\alpha]_D$ −43° (*c* 1, $CH_2Cl_2$); $^1$H NMR ($CDCl_3$) δ 1.12 (d, 3H, $J_{5,6}$ = 6.2 Hz, H-6c), 1.79 (s, 3H, AcO), 1.93 (s, 3H, Lev—Me), 4.90 (d, 1H, $J_{gem}$ = 11.5 Hz, Z—$CH_2$), 4.93 (d, 1H, $J_{1,2}$ = 7.9 Hz, H-1b), 5.38 (dd, 1H, $J_{2,3}$ = 10.4, $J_{3,4}$ 3 Hz, H-3b), 5.55 (d, 1H, H-2b), 5.83 (d, 1H, H-4b), 7.2–8.2 (m, 35H, 7Ph).

To a solution of **45** (29 mg) in pyridine (10 mL) was added benzoyl chloride (3 μL, 1.2 equiv) and the mixture was stirred overnight at rt. Work-up and column chromatography (250:1 $CH_2Cl_2$—MeOH) afforded **46** (31 mg, quant): $[\alpha]_D$ −60° (*c* 2.37, $CH_2Cl_2$); $^1$H NMR ($CDCl_3$) δ 1.10 (d, 3H, $J_{5,6}$ = 6.2 Hz, H-6c), 1.79 (s, 3H, AcO), 1.89 (s, 3H, Lev—Me), 4.93 (d, 1H, $J_{1,2}$ = 7.9 Hz, H-1b), 5.40 (d, 1H, H-3b), 5.60 (dd, 1H, $J_{2,3}$ = 10.4 Hz, H-2b), 5.82 (d, 1H, $J_{3,4}$ = 3.3 Hz, H-4b).

Anal. Calcd for $C_{82}H_{81}NO_{22}$ (1432.54): C, 68.75; H, 5.70; N, 0.98. Found: C, 68.48; H, 5.42; N, 0.70.

**(2,4,6-Tri-*O*-benzoyl-3-*O*-sulfo-β-D-galactopyranosyl)-(1→3)-[(α-L-fucopyranosyl)-(1→4)]-2-*O*-acetyl-6-*O*-benzyl-1,5-dideoxy-1,5-imino-*N*-methyl-D-glucitol sodium salt (49) and (3-*O*-sulfo-β-D-galactopyranosyl)-(1→3)-[(α-L-fucopyranosyl)-(1→4)]-1,5-dideoxy-1,5-imino-*N*-methyl-D-glucitol sodium salt (50).** Treatment of **46** (155 mg) with hydrazine acetate (10 mg) in EtOH, as described for **24**, gave **47** (135 mg, 93%): $[\alpha]_D$ −76° (*c* 2, $CH_2Cl_2$); $^1$H NMR ($CDCl_3$) δ 1.08 (d, 3H, $J_{5,6}$ = 6.4 Hz, H-6c), 1.82 (s, 3H, AcO), 3.23 (bs, 1H, H-1a), 4.87 (d, 1H, $J_{gem}$ = 12.1 Hz, C$H_2$ of Z), 4.92 (d, 1H, $J_{1,2}$ = 8.1 Hz, H-1b), 5.08 (bs, 1H, H-1c), 5.40 (dd, 1H, $J_{2,3}$ = 10.1 Hz, H-2b), 5.77 (d, 1H, $J_{3,4}$ = 3.3 Hz, H-4b). A mixture of **47** (101 mg) and pyridine sulfur trioxide complex (96 mg, 8 equiv) in *N,N*-dimethylformamide (0.5 mL) was stirred for 2 h at rt. Work-up and column chromatography on silica gel, as described for **25**, afforded **48** (109 mg, quant): $[\alpha]_D$ −56° (*c* 2, $CH_2Cl_2$). Compound **48** (99 mg) in MeOH was treated with cation-exchange resin Dowex-$Na^+$, and then hydrogenolyzed in MeOH (5 mL) in the presence of formalin (0.5 mL) and HCl-free palladium black (200 mg) for 4 days at rt. Work-up and column chromatography (10:1 $CH_2Cl_2$—MeOH) on silica gel gave **49** (66 mg, 92%): $[\alpha]_D$ −30.5° (*c* 0.9, MeOH); $^1$H NMR (DMSO-$d_6$, 50°C) δ 1.20 (d, 3H, $J_{5,6}$ = 6.4 Hz, H-6c), 1.99 (s, 3H, AcO), 2.05 (t, 1H, J = 10.1 Hz, H-1a*ax*), 2.20 (s, 3H, N—Me), 2.81 (dd, $J_{gem}$ = 11, $J_{1eq,2}$ = 5.1 Hz, H-1a*eq*), 4.75 (d, 1H, $J_{1,2}$ = 3.7 Hz, H-1c), 4.79 (dd, 1H, H-3b), 5.16 (d, 1H, $J_{1,2}$ = 8.2 Hz, H-1b), 5.36 (dd, 1H, $J_{2,3}$ = 10.4 Hz, H-2b), 5.86 (d, 1H, $J_{3,4}$ = 3.1 Hz, H-4b), 7.44–8.05 (m, 20H, 4Ph).

To a solution of **49** (56 mg) in MeOH (5 mL) was added a small amount of NaOMe (pH = 12), and the mixture was stirred for 2 days at rt. and concentrated. The residue was chromatographed (1:1 MeOH—$H_2O$) on a column of Sephadex LH-20 to give **50** (31 mg, quant) as an amorphous mass: $[\alpha]_D$ −56° (*c* 0.114, 1:1 MeOH—$H_2O$); $^1$H NMR (DMSO-$d_6$, 50°C) δ 0.99 (d, 3H, H-6c), 2.01 (t, 1H, J

= 10.4 Hz, H-1a*ax*), 2.23 (s, 3H, *N*—Me), 2.82 (dd, 1H, $J_{gem}$ = 10.8, $J_{1eq,2}$ = 4.8 Hz, H-1a*eq*), 4.62 (d, 1H, $J_{1,2}$ = 7.7 Hz, H-1b), 4.77 (q, 1H, $J_{5,6}$ = 6.6 Hz, H-5c), 4.93 (d, 1H, $J_{1,2}$ = 3.7 Hz, H-1c). Ion-spray MS (negative-ion mode) *m/z* 564.1 $(M—Na—H)^-$; MS/MS (P = *m/z* 563.9) *m/z* 417.6 $(M—Na—Fuc)^-$. 96.8 $(HSO_4)^-$.

**(2,4,6-Tri-*O*-benzoyl-3-*O*-levulinoyl-β-D-galactopyranosyl)-(1→3)-[(α-L-fucopyranosyl)-(1→4)]-2-*O*-acetyl-1,5-dideoxy-1,5-imino-D-glucitol (51).** Compound **46** (1.34 g) in AcOH (25 mL) was hydrogenolyzed with palladium black (1.30 g) as described for **28** to give **51** (660 mg, 71%): $[\alpha]_D$ −45° (*c* 1.63, MeOH); $^1$H NMR ($CD_3OD$) δ 1.41 (d, 3H, H-6c), 1.82 (s, 3H, AcO), 2.10 (s, 3H, Lev—Me), 2.26–2.54 (m, 4H, Lev—$C_2H_4$), 3.11 (dd, 1H, $J_{gem}$ = 12.5 Hz, H-1a*eq*), 3.64 (t, 1H, $J_{3,4}$ = 9.7 Hz, H-3a), 4.56 (m, 1H, $J_{1ax,2}$ = $J_{2,3}$ = 10.3, $J_{1eq,2}$ = 5.3 Hz, H-2a), 5.05 (d, 1H, $J_{1,2}$ = 3.9 Hz, H-1c), 5.28 (d, 1H, $J_{1,2}$ = 7.7 Hz, H-1b),7.43–8.12 (m, 15H, 3Ph).

Anal. Calcd for $C_{46}H_{53}NO_{19}$ (923.92): C, 59.80; H, 5.78; N, 1.52. Found: C, 59.63; H, 5.71; N, 1.41.

**(2,4,6-Tri-*O*-benzoyl-3-*O*-levulinoyl-β-D-galactopyranosyl)-(1→3)-[(α-L-fucopyranosyl)-(1→4)]-2-*O*-acetyl-1,5-imino-*N*-butyl-D-glucitol (52)** and **(2,4,6-Tri-*O*-benzoyl-3-*O*-levulinoyl-β-D-galactopyranosyl)-(1→3)-[(2,3,4-tri-*O*-acetyl-α-L-fucopyranosyl)-(1→4)]-2,6-di-*O*-acetyl-1,5-dideoxy-1,5-imino-*N*-butyl-D-glucitol (54).** A mixture of **51** (67.5 mg), 1-butanol (3 mL) and butyraldehyde (129 μL, 20 equiv) was hydrogenated with palladium hydroxide on carbon (68 mg) overnight at rt. Work-up and column chromatography (25:1 $CH_2Cl_2$-MeOH) on silica gel gave **52** (46 mg, 64%): $[\alpha]_D$ −32.3° (*c* 1.0, $CH_2Cl_2$); $^1$H NMR ($CDCl_3$) δ 0.85 (t, 3H, Me), 1.15–1.35 (m, 4H, $C_2H_4$), 1.37 (d, 3H, H-6c), 1.91 (s, 3H, AcO), 2.02 (s, 3H, Lev—Me), 2.34–2.60 (m, 4H, Lev—$C_2H_4$), 2.95 (dd, 1H, $J_{gem}$ = 11.9, = $J_{1eq,2}$ = 4.2 Hz, H-1a*eq*), 5.51 (dd, 1H, $J_{1,2}$ = 8.1, $J_{2,3}$ = 10.4 Hz, H-2b), 7.30–8.13 (m, 15H, 3Ph). Treatment of **52** (46.7 mg) with $Ac_2O$ (36 μL, 8 equiv) in pyridine (1 mL) afforded **54**: $[\alpha]_D$ −53° (*c* 1.0, $CH_2Cl_2$); δ 0.85 (t, 3H, Me), 1.23–1.30 (m, 4H, $C_2H_4$), 1.30 (s, 3H, H-6c), 1.93–2.20 (5s, 15H, 5AcO), 2.06 (s, 3H, Lev—Me), 2.14 (t, 1H, $J_{gem}$ = $J_{1ax,2}$ = 11.7 Hz, H-1a*ax*), 2.35–2.63 (m, 4H, Lev—$C_2H_4$), 3.02 (dd, 1H, $J_{gem}$ = 11.7, = $J_{1eq,2}$ = 4.8 Hz, H-1a*eq*), 5.06 (d, 1H, $J_{1,2}$ = 3.5 Hz, H-1c), 5.49 (dd, 1H, $J_{1,2}$ = 8.1, $J_{2,3}$ = 10.4 Hz, H-2b), 7.40–8.11 (m, 15H, 3Ph).

Anal. Calcd for $C_{58}H_{69}NO_{23}$ (1148.17): C, 60.67; H, 6.06; N, 1.22. Found: C, 60.66; H, 5.83; N, 0.99.

**(2,4,6-Tri-*O*-benzoyl-3-*O*-levulinoyl-β-D-galactopyranosyl)-(1→3)-*O*-[(α-L-fucopyranosyl)-(1→4)]-2-*O*-acetyl-1,5-dideoxy-1,5-imino-*N*-decyl-D-glucitol (53)** and **(2,4,6-Tri-*O*-benzoyl-3-*O*-levulinoyl-β-D-galactopyranosyl)-(1→3)-*O*-[(2,3,4-tri-*O*-acetyl-α-L-fucopyranosyl)-(1→4)]-2,6-di-*O*-acetyl-1,5-dideoxy-1,5-imino-*N*-decyl-D-glucitol (55).** A mixture of **51** (79 mg), EtOAc (1 mL) and decyl aldehyde (320 μL, 20 equiv) was hydrogenated with palladium hy-





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droxide on carbon (79 mg) for 2 days at rt., and worked up as described for **52** to afford **53** (67.3 mg, 75%): $[\alpha]_D$ −30.3° (*c* 1.36, $CH_2Cl_2$); $^1$H NMR ($CDCl_3$) δ 0.87 (t, 3H, Me), 1.23 (m, 16H, $C_8H_{16}$), 1.37 (d, 3H, H-6c), 1.91 (s, 3H, AcO), 2.02 (s, 3H, Lev—Me), 2.34–2.60 (m, 4H, Lev—$C_2H_4$). Treatment of **53** (66.6 mg) with $Ac_2O$ (47 μL) and pyridine (1 mL) gave **55** (77 mg): $[\alpha]_D$ −51° (*c* 1.43, $CH_2Cl_2$); $^1$H NMR ($CDCl_3$) δ 0.88 (t, 3H, Me), 1.24 (m, 16H, $C_8H_{16}$), 1.31 (s, 3H, H-6c), 1.93–2.21 (5s, 15H, 5AcO), 2.07 (s, 3H, Lev—Me), 2.31–2.63 (m, 4H, Lev—$C_2H_4$), 3.03 (dd, 1H, $J_{gem}$ = 11.7, $J_{1eq,2}$ = 5.1 Hz, H-1a*eq*), 5.05 (d, 1H, $J_{1,2}$ = 3.1 Hz, H-1c), 5.50 (dd, 1H, $J_{1,2}$ = 8.2, $J_{2,3}$ = 10.4 Hz, H-2b), 7.40–8.11 (m, 15H, 3Ph).

Anal. Calcd for $C_{64}H_{81}NO_{23}$ (1232.34): C, 62.38; H, 6.63; N, 1.14. Found: C, 62.31; H, 6.62; N, 0.92.

**(3-*O*-Sulfo-β-D-galactopyranosyl)-(1→3)-[(α-L-fucopyranosyl)-(1→4)]-1,5-dideoxy-1,5-imino-*N*-butyl-D-glucitol sodium salt (60).** Compound **54** (50.3 mg) was treated with hydrazine acetate (5 mg, 1.2 equiv) in EtOH (1 mL) as described for **24** to give **56** (42 mg, 91%): $[\alpha]_D$ −64° (*c* 0.84, $CH_2Cl_2$); $^1$H NMR ($CDCl_3$) δ 0.85 (d, 3H, Me), 1.19 (d, 3H, H-6c), 1.18–1.26 (m, 4H, $C_2H_4$), 1.92–2.18 (5s, 15H, 5AcO), 2.43–2.56 (m, 2H, N—$CH_2$), 3.05 (dd, 1H, $J_{gem}$ = 11.7 Hz, H-1a*eq*), 4.12 (dd, 1H, H-3b), 4.53, 4.83 (2dd, 2H, $J_{gem}$ = 11.4, $J_{5,6}$ = 6.8, $J_{5,6'}$ = 5.9 Hz, H-6b,6′b), 5.08 (d, 1H, $J_{1,2}$ = 8.4 Hz, H-1b), 5.77 (d, 1H, $J_{3,4}$ = 3.7 Hz, H-4b), 7.41–8.12 (m, 15H, 3Ph), and complete loss of the Lev group. A mixture of **56** (55 mg) and pyridine sulfur trioxide complex (74.6 mg, 10 equiv) in *N,N*-dimethylformamide (2 mL) was stirred for 1.5 h at rt, worked up as described for **48**, and purified on a column of silica gel (20:1 $CH_2Cl_2$—MeOH) to give **57** (56 mg): $[\alpha]_D$ −41.3° (*c* 0.4, $CH_2Cl_2$); $^1$H NMR (DMSO-$d_6$) δ 0.86 (t, 3H, Me), 1.24 (m, 4H, $C_2H_4$), 1.99–2.11 (5s, 15H, 5AcO), 5.12 (d, 1H, $J_{1,2}$ = 9.3 Hz, H-1b), 5.25 (d, 1H, $J_{1,2}$ = 3.1 Hz, H-1c), 5.90 (d, 1H, $J_{3,4}$ = 3.1 Hz, H-4b), 7.46–8.13 (m, 15H, 3Ph). *O*-Deacylation of **57** (56 mg) and chromatography on a column of Sephadex LH-20, as described for **50**, afforded **60** (quant) as an amorphous mass: $[\alpha]_D$ −67° (*c* 0.33, 1:1 MeOH—$H_2O$); $^1$H NMR (DMSO-$d_6$) δ 0.86 (t, 3H, Me), 0.99 (d, 3H, H-6c), 1.10–1.40 (m, 4H, $C_2H_4$), 2.80 (dd, 1H, H-1a*eq*), 4.60 (d, 1H, $J_{1,2}$ = 7.7 Hz, H-1b), 4.90 (d, 1H, $J_{1,2}$ = 3.5 Hz, H-1c). FAB-MS (negative ion mode) *m/z* 606.30 $(M—Na)^-$, ($C_{22}H_{40}NO_{16}S$: Exact 606.2068).

**(3-*O*-Sulfo-β-D-galactopyranosyl)-(1→3)-[(α-L-fucopyranosyl)-(1→4)]-1,5-dideoxy-1,5-imino-*N*-decyl-D-glucitol sodium salt (61).** Treatment of **55** with hydrazine acetate in EtOH, as described for **56**, gave **58**: $[\alpha]_D$ −58° (*c* 1.32, $CH_2Cl_2$); $^1$H NMR ($CDCl_3$) δ 0.88 (t, 3H, Me), 1.91–1.21 (m, 16H, $C_8H_{16}$), 1.92–2.18 (5s, 15H, 5AcO), 2.20–2.55 (m, 2H, N—$CH_2$), 3.06 (dd, 1H, H-1a*eq*), 4.14 (dd, 1H, H-3b), 4.54, 4.84 (2dd, 2H, $J_{gem}$ = 11.5, $J_{5,6}$ = $J_{5,6'}$ = 7.0 Hz, H-6b,6′b), 5.31 (dd, 1H, $J_{1,2}$ = 8.3, $J_{2,3}$ = 3.7 Hz, H-2b), 5.32 (dd, 1H, $J_{1,2}$ = 3.5, $J_{2,3}$ = 9.0 Hz, H-2c), 5.76 (d, 1H, $J_{3,4}$ = 3.7 Hz, H-4b), and complete loss of the Lev group. Sulfation of **58** (60 mg) was carried out as described for **57** to give **59** (61 mg), which was treated with NaOMe in MeOH to afford **61** (quant) as an amor-

phous mass: $^1$H NMR (DMSO-$d_6$) δ 0.86 (t, 3H, Me), 0.98 (d, 3H, H-6c), 1.25 (m, 16H, $C_8H_{16}$), 2.15–2.19 (m, 2H, N—$CH_2$), 2.81 (dd, 1H, $J_{gem}$ = 11.4 Hz, H-1a*eq*), 4.59 (d, 1H, $J_{1,2}$ = 7.7 Hz, H-1b), 4.89 (d, 1H, $J_{1,2}$ = 3.5 Hz, H-1c). FAB-MS (negative ion mode) *m/z* 712.26 (M—H)$^-$, ($C_{28}H_{51}NO_{16}SNa$: Exact 712.2826), 690.31 (M—Na)$^-$ ($C_{28}H_{52}NO_{16}S$: Exact 690.3007).

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