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Radical mediated synthesis of *N*-acetyl-D-galactosamine containing *C*-disaccharides via a temporary phosphoramidic connection †

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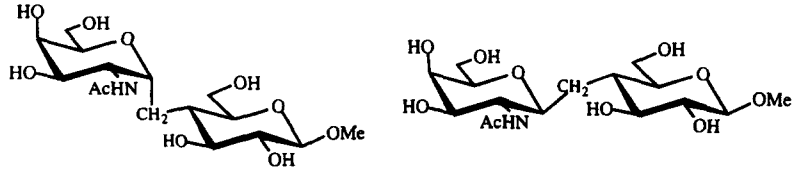
Abstract: The *C*-disaccharide {α-D-GalNAc-C-(1→4)-β-D-Glc-OMe} and its interglycosidic β anomer were synthesized by radical coupling of phenyl 2-amino-3,4,6-tri-*O*-benzyl-2-deoxy-1-seleno-α-D-galactopyranoside onto methyl 2,6-di-*O*-benzyl-4-deoxy-4-*C*-methylene-β-D-*xylo*-hexopyranoside, which are temporarily connected through a phosphoramido tether. A similar reaction was performed with methyl 2,3-di-*O*-benzyl-4-deoxy-4-*C*-methylene-α-D-*xylo*-hexopyranoside to produce the two closely related α-OMe *C*-disaccharides. © 1997 Elsevier Science Ltd

Introduction

Silicon-tethered reactions have gained increasing general importance for the successful synthesis of a variety of complex molecules[1]. The specific use of the temporary silicon connection in the carbohydrate field was originally reported by Stork in the context of *C*-glycoside synthesis[2], later applied to the stereocontrolled synthesis of disaccharides[3], *C*-glycosides and branched chain sugars[4].

We have recently developed a synthetic entry to *C*-disaccharides based on a 9-*endo*–*trig* radical cyclisation reaction from two monosaccharides temporarily connected through a silaketal[5]. *C*-Disaccharides are mimetics of disaccharides in which the interglycosidic oxygen atom has been replaced by a methylene group. Together with *C*-glycosides they have gained interest both as potential inhibitors of carbohydrate processing enzymes glycosidases or glycosyltransferases, and as stable analogues of saccharidic structures of biological relevance. Because of the importance of 2-amino-2-deoxy sugars as structural elements of glycoconjugates — in particular galactosamine — various entries to aminosugar *C*-glycosides have been reported[6]. As one step further, we now delineate a novel strategy for the synthesis of *N*-acetyl-D-galactosamine containing *C*-disaccharides. It is based on the original use of a temporary phosphorus tether and is typically exemplified in this introductory work by the construction of the following model structures:



Results and discussion

The selected radical glycosyl donor **3** was prepared (Scheme 1) by regio- and stereoselective azidophenylselenylation of the double bond of the known[7] benzylated galactal **1** according to Tingoli *et al.*[8]. The use of a limited excess of (diacetoxyiodo)benzene (1.4 eq.) and a carefully controlled reaction time minimized the oxidative debenzylation of the starting material **1**, allowing the easy isolation of **2** as a crystalline product (40% yield). Our data for **2** {mp 56°C (methanol); $[\alpha]_D^{20}$ +178 (chloroform)} are

† Dedicated to Professor Dr Hans Paulsen on the occasion of his 75th birthday.

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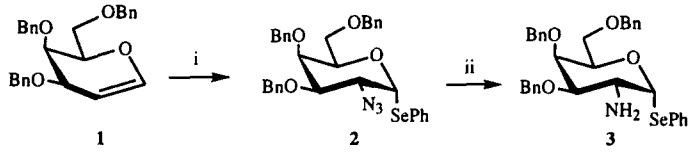
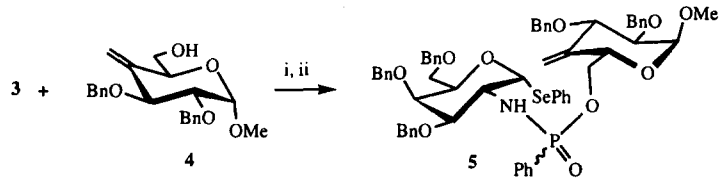
at significant variance with those reported by Czernecki *et al.*[9] for a compound prepared by a different route (oil, $[\alpha]_D^{20}$ +157). Reduction[10] of the azido group by lithium aluminum hydride uneventfully provided the target glycoside **3** in crystalline form {mp 121°C; $[\alpha]_D^{20}$ +273 (chloroform)} in 88% yield.



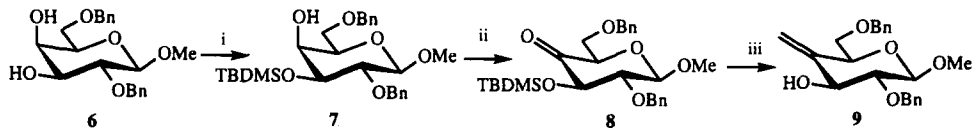
Scheme 1. Reagents: i) NaN_3, PhSeSePh, $PhI(OAc)_2$, CH_2Cl_2 (40%); ii) $LiAlH_4$, Et_2O (88%).

The selenophenyl glycoside **3** was next tethered with the known alcohol **4**[5] through phosphorus chemistry (Scheme 2). Compound **4** was reacted with an excess of phenyldichlorophosphine in tetrahydrofuran at room temperature, in the presence of triethylamine. Elimination of the excess of phosphine under vacuum was followed by reaction with the amine **3** in tetrahydrofuran at room temperature, in the presence of triethylamine. The resulting unstable phosphorus (III) intermediate was oxidized *in situ* with *tert*-butylhydroperoxide to give the tethered compound **5** (Scheme 2) in 80% yield, as a mixture of the two non-separable diastereoisomers (1:1 ratio, ^{31}P NMR spectrum).



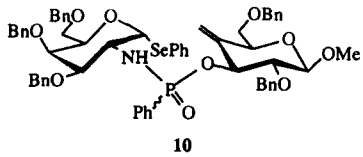
Scheme 2. Reagents: i) $PhPCl_2$, Et_3N, THF; ii) *t*BuOOH (80% overall yield).

In a similar manner, the isomeric allylic alcohol **9** was investigated. It has been obtained in crystalline form and in three steps, as shown in Scheme 3, from the known[11] methyl 2,6-di-*O*-benzyl-β-D-galactopyranoside **6**.



Scheme 3. Reagents: i) TBDMSCl, Et_3N, DMAP, DMF, 20 h (96%); ii) PCC, 4 Å molecular sieves, CH_2Cl_2, 30 min (85%); iii) Tebbe reagent, THF, Pyr, −60°C→rt; then aq. HF, THF, 24 h (61%).

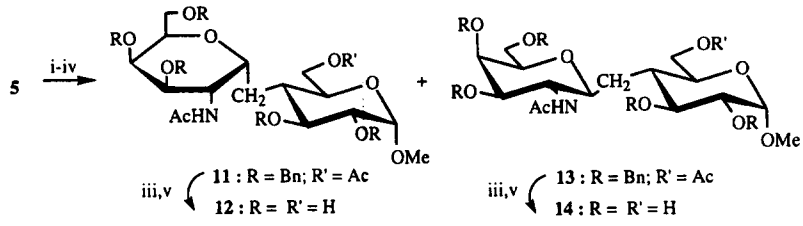
The tethering of **9** with the amine **3**, as previously described, gave the connected compound **10** (Scheme 4) in 88%, again as a mixture of the two non-separable diastereoisomers (1:1 ratio, ^{31}P NMR spectrum).



Scheme 4.

The tethered derivative **5** was first submitted to a cyclisation reaction in refluxing toluene by slow syringe pump addition of a toluene solution of tributyltin hydride and azobisisobutyronitrile.

The temporary tether was then directly removed by treatment[12] with a methanolic hydrochloric acid solution to cleave the phosphorus–nitrogen bond, followed by treatment with a solution of sodium methoxide in methanol to cleave the phosphorus oxygen bond. Final acetylation of the reaction mixture was followed by silica gel flash chromatography to provide two *C*-disaccharides in pure form: the α-*C*-disaccharide **11** (16% yield from **5**) and the *C*-disaccharide **13** (4% yield from **5**) (Scheme 5).



Scheme 5. Reagents: i) Bu_3SnH, AIBN, toluene; ii) HCl, MeOH; iii) MeONa, MeOH,; iv) Ac_2O, pyr; v) H_2, 10% Pd/C, MeOH.

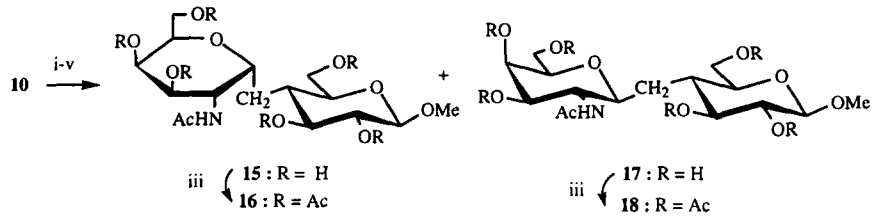
The ^1H NMR spectrum (400 MHz, acetone-d_6) of **13** (see Table 1) showed coupling constants which confirm the assigned structure and calls for an expected $^4C_1$ chain conformation of the two monosaccharide units. The examination of key coupling constants in the ^1H NMR spectrum (400 MHz, acetone-d_6) of **11** again calls for the assigned structure, with a conformation of the α-*C*-galactosyl moiety largely deviating from the $^4C_1$ chain form. This deviation, when existing, is indeed diagnostic for the observed α-configuration[5c].

The tethered derivative **10** (Scheme 6) was similarly submitted to cyclisation. Flash column chromatography of the reaction mixture gave three *C*-disaccharidic fractions. These fractions (see Experimental) were separately submitted to the following deprotection sequence. The temporary tether was first and best removed by treatment with a large excess (40 eq.) of lithium aluminum hydride in tetrahydrofuran at room temperature for 72 h. This necessary prolonged treatment resulted in partial de-*O*-debenzylation. The reaction mixture was directly peracetylated with acetic anhydride in pyridine and purified by flash chromatography. De-*O*-acetylation with sodium methoxide in methanol was followed by final catalytic hydrogenolysis in methanol (H_2, Pd/C) to give the free *C*-disaccharide. Two out of the three fractions previously purified gave the α-*C*-disaccharide **15** (28% yield from **10**). These two fractions were thus made out of the separated corresponding diastereoisomers on the phosphorus. The third fraction gave the β-*C*-disaccharide **17** (19% yield from **10**). The overall yield (47% from the tethered species **10**) of this 8-*endo trig* process is satisfactory and such a method results in a rather expeditious and simultaneous entry into the two aminosugar containing disaccharides **15** and **17**. More than that, it also delineates a practical access to this novel class of compounds. On the basis of recent results from our group in the field of neutral *C*-disaccharides[13] it is highly probable that this innovative stategy can largely be improved in terms of α-selectivity. We are currently exploring this.

The ^1H NMR structure study of **15** and **17** was achieved onto the corresponding fully acetylated derivatives **16** and **18**. The ^1H NMR spectrum of **18** (see Table 1) showed coupling constants which confirm the assigned structure and call for an expected $^4C_1$ chain conformation of two monosaccharide units. Although the coupling constant between H-1′ and H-2′ (galactosamine residue) could not be

Table 1. Selective ^1H NMR coupling constants (Hz) for the *C*-disaccharides **11**, **13**, **16**, and **18** (400 MHz, acetone-d_6)

Products	$J_{3,4}$	$J_{4,5}$	$J_{1',2'}$	$J_{4',5'}$
11	10.0	11.0	2.5	5.0
13	10.5	11.0	10.0	<1
16	9.5	11.0	-	3.5
18	11.0	11.0	10.0	<1



Scheme 6. Reagents: i) Bu_3SnH, AIBN, toluene; ii) $LiAlH_4$, THF, 0°C; iii) Ac_2O, Pyr; iv) MeONa, MeOH; v) H_2, 10% Pd/C, MeOH.

easily extracted for compound **16** due to signal overlap, the large $J_{4',5'}$ coupling constant (3.5 Hz) calls for a twisted conformation of the galactosamine unit, which is diagnostic for an α-linkage. In this study, the availability of both anomers **16** and **18** makes the structural assignment easier and safer. This work constitutes the first report on the synthesis of *N*-acetyl-D-galactosamine containing *C*-disaccharides.

Experimental section

General

Melting points (mp) were determined with a Büchi model 510 melting point apparatus and are uncorrected. Optical rotations were measured at 20±2°C with a Perkin Elmer Model 241 digital polarimeter, using a 10 cm, 1 mL cell. Mass spectra (MS) were obtained by chemical ionisation (ammonia) with a Nermag R10-10 spectrometer. Elemental analyses were performed by Service de Microanalyse de l'Université Pierre et Marie Curie, 2 place Jussieu, 75005 Paris, France. NMR spectra were recorded with a Brucker AC 250 and a Brucker AM 400 spectrometer. ^1H NMR spectra were recorded for solutions in $CDCl_3$ (internal Me_4Si, δ 0.00) at ambient temperature. Assignment were aided by COSY technique. ^{13}C NMR spectra were recorded for solution in $CDCl_3$ adopting 77.00 ppm for the central line of the solvent signal. Assignments were aided by J-mod technique and proton–carbon correlation. Single prime refers to the hydrogens or carbons of the galactosamine unit. Protons H-4a and H-4b correspond respectively to the low field and high field hydrogen of the methylene linkage. Reactions were monitored by tlc on precoated plates of silica gel 60 F_{254} (layer thickness 0.2 mm; E. Merck, Darmstadt, Germany) and detection by charring with sulfuric acid. Flash column chromatography was performed on silica gel 60 (230–400 mesh, Merck).

Phenyl 2-azido-3,4,6-tri-O-benzyl-2-deoxy-1-seleno-α-D-galactopyranoside **2**

A suspension of **1** (12 g, 29 mmol), diphenyldiselenide (5.4 g, 17 mmol), diacetoxyiodobenzene (10.6 g, 40 mmol) and sodium azide (4.5 g, 70 mmol) in dry dichloromethane (120 mL) was stirred at room temperature under argon for 20 h aq. $NaHCO_3$ (350 mL, sat.) and dichloromethane were added. The organic phase was washed with water, dried ($MgSO_4$) and concentrated. Flash chromatography (cyclohexane to cyclohexane/ethyl acetate: 9/1) of the residue gave **2** (7.5 g, 43%). mp 56°C (methanol). $[\alpha]_D$ +178 (*c* 1, $CHCl_3$). lit.[8]: oil, $[\alpha]_D$ +157. ^1H NMR (400 MHz): 7.70–7.60 (m, 2H, Ph), 7.55–7.20 (m, 18H, Ph), 5.95 (d, 1H, $J_{1,2}$ 10.2 Hz, H-1), 4.95, 4.60 (AB, 2H, J_{AB} 11.2 Hz, $PhCH_2$), 4.80 (s, 2H, $PhCH_2$), 4.42–4.40 (m, 4H, H-2, H-5, $PhCH_2$), 4.12 (d, 1H, $J_{3,4}$ 2.5 Hz, H-4), 3.78 (dd, 1H, $J_{2,3}$ 10.4 Hz, H-3), 3.68 (dd, 1H, $J_{6a,6b}$ 9.2, $J_{5,6a}$ 7.1 Hz, H-6a), 3.50 (dd, 1H, $J_{6b,5}$ 5.9 Hz, H-6b). ^{13}C NMR (63 MHz): 138.2, 137.5, 137.4, 134.7, 129.0–127.0 (Ph), 95.5 (C-1), 80.2 (C-3), 74.7 ($PhCH_2$), 73.4 ($PhCH_2$), 73.0 (C-5), 72.4 ($PhCH_2$), 71.9 (C-4), 68.3 (C-6), 61.0 (C-2). MS (m/z, %): 633 ($M+NH_4$, 100), 430 ($M-SePh-N_3$, 70), 588 ($M-N_3$, 40). Anal. Calcd. for $C_{33}H_{33}N_3O_4Se$: C 64.49, H 5.42, N 6.83. Found: C 64.40, H 5.42, N 6.93.

*Phenyl 2-amino-3,4,6-tri-*O*-benzyl-2-deoxy-1-seleno-α-*D*-galactopyranoside 3*

$LiAlH_4$ (0.32 g, 1.5 eq.) was added portionwise at 0°C to solution of **2** (3.5 g, 5.6 mmol) in dry ether (100 mL). The reaction mixture was stirred for 5 min, diluted with water, filtered through celite, eluted with ether. The organic phase was dried ($MgSO_4$) and concentrated to give **3** (2.9 g, 88%). mp 121°C (ethyl acetate/pentane). $[\alpha]_D$ +273 (*c* 1, $CHCl_3$). ^1H NMR (400 MHz): 7.68–7.62 (m, 2H, Ph), 7.46–7.30 (m, 18H, Ph), 6.05 (d, 1H, $J_{1,2}$ 4.7 Hz, H-1), 4.93 and 4.63 (AB, 2H, J_{AB} 11.2 Hz, $PhCH_2$), 4.81 and 4.59 (AB, 2H, J_{AB} 11.4 Hz, $PhCH_2$), 4.51 and 4.48 (AB, 2H, J_{AB} 12.0 Hz, $PhCH_2$), 4.45 (ddd, 1H, $J_{5,6a}$ 7.5, $J_{5,6b}$ 5.5, $J_{4,5}$ 2 Hz, H-5), 4.11 (d, 1H, H-4), 3.73 (dd, 1H, $J_{2,3}$ 10.5 Hz, H-2), 3.72 (dd, 1H, $J_{6a,6b}$ 9.5 Hz, H-6a), 3.57 (dd, 1H, H-6b), 3.47 (dd, 1H, $J_{2,3}$ 10.5, $J_{3,4}$ 2.5 Hz, H-3), 1.58 (m, 2H, NH_2). ^{13}C NMR (63 MHz): 138.5, 137.9, 137.8, 134.3, 129.3–127.4 (Ph), 91.0 (C-1), 82.1 (C-3), 74.2 ($PhCH_2$), 73.1 ($PhCH_2$), 72.35, 72.30 (C-4, C-5), 71.8 ($PhCH_2$), 68.6 (C-6), 51.8 (C-2). MS (m/z, %): 432 (M−SePh, 100), 590 (M+H, 70). Anal. Calcd. for $C_{33}H_{35}NO_4Se$: C 67.33, H 5.99, N 2.38. Found: C 67.38, H 6.09, N 2.50.

*Methyl 2,6-di-*O*-benzyl-3-*O*-tert-butyldimethylsilyl-β-*D*-galactopyranoside 7*

A solution of methyl 2,6-*O*-dibenzyl-β-D-galactopyranoside **6** (4 g, 10 mmol), TBDMSCl (1.93 g, 12 mmol, 1.2. eq.), DMAP (0.52 g, 4 mmol, 0.4 eq.) and triethylamine (2.96 mL, 20 mmol, 2 eq.) in DMF (40 mL) was stirred at room temperature for 20 h. The reaction mixture was diluted with ether, washed with water, dried ($MgSO_4$) and concentrated. Flash column chromatography of the residue (cyclohexane/ethyl acetate: 6/1) gave **7** (5.1 g, 97%). $[\alpha]_D$ +2 (*c* 1, $CHCl_3$). ^1H NMR (400 MHz): 7.39–7.30 (m, 10H, Ph), 4.92, 4.65 (AB, 2H, J_{AB} 11 Hz, $PhCH_2$), 4.67, 4.63 (AB, 2H, J_{AB} 12 Hz, $PhCH_2$), 4.29 (d, 1H, $J_{1,2}$ 8 Hz, H-1), 3.86 (d, 1H, $J_{6a,6b}$ 10, $J_{5,6a}$ 5.5 Hz, H-6a), 3.82 (d, 1H, $J_{3,4}$ 3.5 Hz, H-4), 3.80 (dd, 1H, $J_{5,6b}$ 5.5 Hz, H-6b), 3.71 (dd, 1H, $J_{2,3}$ 8.5 Hz, H-3), 3.66 (ddd, 1H, H-5), 3.59 (s, 3H, OMe), 3.48 (dd, 1H, H-2), 2.52 (s, 1H, OH), 0.95 (s, 9H, *t*BuSi), 0.14 (s, 3H, MeSi), 0.11 (s, 3H, MeSi). ^{13}C NMR (63 MHz): 138.78, 138.28, 128.58–127.62 (Ph), 104.98 (C-1), 79.78, 75.13, 74.40, 73.89, 73.28, 69.94, 69.53 (C-2, C-3, C-4, C-5, C-6, 2 $PhCH_2$), 57.14 (OMe), 25.95 (3 *t*BuSi), 18.16 (*t*BuSi), −4.31, −4.71 (2 MeSi). MS (m/z, %): 506 (M+18, 100), 474 (M−OMe+17, 30), 457 (M−OMe, 10). Anal. Calcd. for $C_{27}H_{40}O_6Si$: C 66.36, H 8.25. Found: C 66.25, H 8.38.

*Methyl 2,6-di-*O*-benzyl-3-*O*-tert-butyldimethylsilyl-β-*D*-xylo-hexopyranosid-4-ulose 8*

A solution of **7** (2.5 g, 5.1 mmol) in dry dichloromethane (25 mL) was stirred in the presence of 4 Å molecular sieves (3.3 g), at room temperature, under argon, for 30 min PCC (4.2 g, 18 mmol, 3.5 eq.) was added and the reaction mixture was stirred for 24 h, filtered through silica gel (cyclohexane/ethyl acetate: 8/1). Flash column chromatography of the residue (cyclohexane/ethyl acetate: 10/1) gave **8** (2.1 g, 85%) (unstable product). ^1H NMR (200 MHz): 7.30–7.15 (m, 10H, Ph), 4.76 and 4.66 (AB, 2H, J_{AB} 11 Hz, $PhCH_2$), 4.65 (d, 1H, $J_{1,2}$ 6.7 Hz, H-1), 4.55 and 4.47 (AB, 2H, J_{AB} 12 Hz, $PhCH_2$), 4.27 (d, 1H, $J_{2,3}$ 9.3 Hz, H-3), 4.13 (dd, 1H, $J_{5,6a}$ 3.5, $J_{5,6b}$ 7.5 Hz, H-5), 3.91 (d, 1H, $J_{6a,6b}$ 10.8 Hz, H-6a), 3.65 (dd, 1H, H-6b), 3.54 (dd, 1H, H-2), 3.52 (s, 3H, OMe), 0.88 (s, 9H, *t*BuSi), 0.11 (s, 3H, MeSi), 0.09 (s, 3H, MeSi). ^{13}C NMR (63 MHz): 204.34 (C-4), 137.96, 137.83, 128.38–127.67 (Ph), 104.39 (C-1), 84.27, 77.20, 74.55, 73.63, 68.66, 69.94, 69.53 (C-2, C-3, C-5, C-6, 2 $PhCH_2$), 56.97 (OMe), 25.67 (*t*BuSi), 16.43 (*t*BuSi), −4.74, −5.25 (2 MeSi). MS (m/z, %): 504 (M+18, 100).

*Methyl 2,6-di-*O*-benzyl-4-deoxy-4-*C*-methylene-β-*D*-xylo-hexopyranoside 9*

Tebbe reagent (15.2 mL, 0.5 M in PhMe, 2.5 eq.) was added to a solution of **8** (1.48 g, 3.04 mmol) in THF/pyridine (8.5 mL, 5/1) at −60°C, under argon. The reaction mixture was allowed to warm to room temperature during 20 min. After careful addition of aq. NaOH 20% (5 mL) and ether, the reaction mixture was filtered through celite and concentrated. The residue was filtered through silica gel (cyclohexane/ethyle acetate: 9/1). The resulting solution was concentrated, the residue was dissolved in a mixture of aq. HF 40% (3 mL) and THF (12 mL) and stirred for 24 h at room temperature. The reaction mixture was diluted with dichloromethane, washed with aq. $NaHCO_3$ (sat.), dried ($MgSO_4$)

and concentrated to give **9** (680 mg, 60.5%). mp 86.5°C (diisopropyl ether/pentane). $[\alpha]_D$ +19 (*c* 1, $CHCl_3$). ^1H NMR (400 MHz): 7.38–7.31 (m, 10H, Ph), 5.34 (m, 1H, H-4a), 5.05 (m, 1H, H-4b), 4.93, 4.66 (AB, 2H, J_{AB} 11.5 Hz, $PhCH_2$), 4.64 (s, 2H, $PhCH_2$), 4.46 (d, 1H, $J_{1,2}$ 7.2 Hz, H-1), 4.18–4.09 (m, 2H, H-5, H-3), 3.91 (d, 1H, $J_{6a,6b}$ 10, $J_{5,6a}$ 4.5 Hz, H-6a), 3.76 (dd, 1H, $J_{5,6b}$ 4 Hz, H-6b), 3.59 (s, 3H, OMe), 3.24 (dd, 1H, $J_{2,3}$ 7.7 Hz, H-2). ^{13}C NMR (63 MHz): 142.44 (C-4), 138.24, 137.84, 128.51–127.74 (Ph), 108.43 (C-methylene), 104.42 (C-1), 83.97, 73.96, 73.60, 72.80, 72.61, 70.28 (C-2, C-3, C-5, C-6, 2 $PhCH_2$), 56.64 (OMe). MS (m/z, %): 356 (M−OMe+17, 100), 339 (M−OMe, 60), 388 (M+18, 55). Anal. Calcd. for $C_{22}H_{26}O_5$: C 71.33, H 7.07. Found: C 71.14, H 7.17

Tethered compound ***5***

A solution of **4** (380 mg, 1.0 mmol, 1.2 eq.) in dry THF (7.5 mL) was added to a solution of triethylamine (0.15 mL, 1.3 eq.) and dichlorophenylphosphine (0.55 mL, 4.8 eq.) in dry tetrahydrofuran (7 mL) under argon at −78°C in a dry Schlenk tube. The reaction mixture was slowly allowed to warm to room temperature over a period of 3 h and kept at room temperature for 21 h. The reaction mixture was concentrated under high vacuum (0.02 mmHg) at 50°C, in the Schlenk tube, for 1.5 h. The residue was dissolved in dry tetrahydrofuran (8 mL) and a solution of **3** (500 mg, 1 eq.) and triethylamine (0.25 mL, 2 eq.) in dry tetrahydrofuran (7.5 mL) was added. After stirring for 72 h at room temperature, the reaction mixture was cooled at −10°C and a solution of *tert*-butylhydroperoxide in dry octane (3 M, 0.5 mL, 1.8 eq.) was added. After stirring for 2 h, the reaction mixture was treated by an excess of sodium hydrogencarbonate, filtered, dried ($MgSO_4$) and concentrated. Flash chromatography (toluene/ethyl acetate: 3/1) of the residue gave **5** (0.734 g, 80%) as a mixture of the two diastereoisomers (55/45). ^1H NMR (250 MHz, acetone-d_6): 5.76 (d, 1H, $J_{1',2'}$ 4.5 Hz, H-1'), 5.42 (d, 1H, $J_{1',2'}$ 4.7 Hz, H-1'), 5.19 (m, 1H, H-4a), 5.13 (m, 1H, H-4a). ^{13}C NMR (63 MHz, acetone-d_6) 141.7 (C-4), 141.6 (C-4), 108.2 (C-4a), 107.9 (C-4a), 98.6 (C-1), 98.5 (C-1), 92.7 (C-1'). ^{31}P NMR (101 MHz, acetone-d_6) 22.64, 21.78. MS(m/z, %): 1082 (M+H, 100), 924 (M−SePh, 30). Anal. Calcd. for $C_{61}H_{64}NO_{10}PSe$: C 67.76, H 5.97, N 1.29. Found: C 67.73, H 6.01, N 1.27.

Tethered compound ***10***

It was prepared, as described for **5**, starting from **9** (378 mg, 1.0 mmol, 1.2 eq.) and **3** (500 mg, 1 eq.) (1.02 g, 88%) as a mixture of the two diastereoisomers (55/45) ^1H NMR (250 MHz, acetone-d_6) 6.12 (d, 1H, $J_{1',2'}$ 5 Hz, H-1'), 5.80 (d, 1H, $J_{1',2'}$ 4.7 Hz, H-1'), 5.41 (m, 1H, H-4a), 5.34 (m, 1H, H-4a). ^{13}C NMR (63 MHz, acetone-d_6): 140.8 (C-4), 140.3 (C-4), 111.1 (C-4a), 109.9 (C-4a), 104.8 (C-1), 104.5 (C-1), 93.8 (C-1'), 91.8 (C-1'). ^{31}P NMR (101 MHz, acetone-d_6): 21.76, 21.41. MS (m/z, %): 924 (M−SePh, 100), 1082 (M+H, 40). Anal. Calcd. for $C_{61}H_{64}NO_{10}PSe$: C 67.76, H 5.97, N 1.29. Found: C 67.68, H 5.89, N 1.22.

Methyl 6-O-acetyl-2,3-di-O-benzyl-4-deoxy-4-C-(2-acetamido-3,4,6-tri-O-benzyl-2-deoxy-α-D-galactopyranosylmethyl)-α-D-glucopyranoside ***11*** *and methyl 6-O-acetyl-2,3-di-O-benzyl-4-deoxy-4-C-(2-acetamido-3,4,6-tri-O-benzyl-2-deoxy-β-D-galactopyranosylmethyl)-α-D-glucopyranoside* ***13***

A solution of Bu_3SnH (0.3 mL, 2 eq.) and AIBN (18.3 mg, 0.2 eq.) in dry toluene (7.5 mL) was added over a period of 17 h with a syringe pump to a refluxing solution of **5** (600 mg, 0.55 mmol) in dry toluene (30 mL), under argon. The reaction mixture was concentrated. A solution of the residue in acetonitrile was washed repeatedly with hexane (to remove tin compounds). The acetonitrile layer was concentrated. Flash chromatography on silica gel (toluene/ethyl acetate: 3/7, acetone/ethyl acetate: 1/1, acetone) of the residue gave two fractions, first F1 (170 mg, 33.4%, containing *C*-disaccharide) and then F2 (310 mg, 61%, reduced product). Fraction F1 was treated by a solution of HCl in methanol (2 M, 4 mL) for 2 h at room temperature and the solution was neutralised with NaOMe in methanol. After concentration, the residue was dissolved in a solution of NaOMe in methanol (2 M, 4 mL) and heated at reflux for 2 h. The reaction mixture was concentrated. The residue was diluted with dichloromethane, filtered and concentrated again. A solution of the residue in a mixture of acetic

anhydride and pyridine (3 mL, 1/2 ratio) was stirred for 12 h at room temperature and concentrated. Flash chromatography (hexane/ethyl acetate: 3/7) of the residue gave first **11** (82 mg, 16%), then **13** (20 mg, 4%).

Methyl 6-O-acetyl-2,3-di-O-benzyl-4-deoxy-4-C-(2-acetamido-3,4,6-tri-O-benzyl-2-deoxy-α-D-galactopyranosylmethyl)-α-D-glucopyranoside ***11***

$[\alpha]_D$ +32 (*c* 0.83, $CHCl_3$). ^1H NMR (400 MHz, acetone-d_6): 7.40–7.18 (m, 25H, Ph), 7.09 (d, 1H, $J_{NH,2'}$ 8.7 Hz, NHAc), 5.09, 4.90 (AB, 2H, J_{AB} 11.0 Hz, $PhCH_2$), 4.47 (d, 1H, $J_{1,2}$ 3.5 Hz, H-1), 4.81, 4.77 (AB, 2H, J_{AB} 12.0 Hz, $PhCH_2$), 4.80 (s, 2H, $PhCH_2$), 4.70, 4.63 (AB, 2H, J_{AB} 12.0 Hz, $PhCH_2$), 4.69, 4.60 (AB, 2H, J_{AB} 12.0 Hz, $PhCH_2$), 4.53 (ddd, 1H, $J_{1',2'}$ 2.5, $J_{1',4a}$ 2.5, $J_{1',4b}$ 2.5 Hz, H-1'), 4.41 (dd, 1H, $J_{5,6a}$ 2, $J_{6a,6b}$ 12 Hz, H-6a), 4.40–4.30 (m, 1H, H-2'), 4.30–4.23 (m, 3H, H-5', H-6'a, H-6b), 4.10 (dd, 1H, $J_{3',4'}$ 3.0, $J_{4',5'}$ 5.0 Hz, H-4'), 4.01 (dd, 1H, $J_{2',3'}$ 4.5 Hz, H-3'), 3.92 (dd, $J_{2,3}$ 9.5, $J_{3,4}$ 10.0 Hz, H-3), 3.90 (dd, $J_{5',6'b}$ 2, $J_{6'a,6'b}$ 11.0 Hz, H-6'b), 3.84 (ddd, $J_{4,5}$ 11.0, $J_{5,6b}$ 6 Hz, H-5), 3.59 (dd, 1H, H-2), 3.48 (s, 3H, OMe), 2.11 (s, 3H, CH_3CO), 2.09–2.00 (m, 4H, H-4, $3CH_3CO$), 1.83 (ddd, 1H, $J_{4,4a}$ 10.0, $J_{4a,4b}$ 14.0 Hz, H-4a), 1.60 (ddd, 1H, $J_{4,4b}$ 5.0 Hz, H-4b). MS (m/z, %): 888 (M+H, 100), 856 (M−OMe, 35). Anal. Calcd. for $C_{28}H_{41}NO_{16}$: C 71.68, H 6.92. Found: C 71.66, H 7.06.

Methyl 6-O-acetyl-2,3-di-O-benzyl-4-deoxy-4-C-(2-acetamido-3,4,6-tri-O-benzyl-2-deoxy-β-D-galactopyranosylmethyl) α-D-glucopyranoside ***13***

$[\alpha]_D$ +23 (*c* 0.94, $CHCl_3$). ^1H NMR (400 MHz, acetone-d_6): 7.55–7.33 (m, 25H, Ph), 7.05 (d, 1H, $J_{NH,2'}$ 10.0 Hz, NHAc), 5.02, 4.80 (AB, 2H, J_{AB} 11.5 Hz, $PhCH_2$), 5.05, 4.75 (AB, 2H, J_{AB} 11.5 Hz, $PhCH_2$), 4.95 (d, 1H, $J_{1,2}$ 3.5 Hz, H-1), 4.93, 4.72 (AB, 2H, J_{AB} 11.0 Hz, $PhCH_2$), 4.82, 4.78 (AB, 2H, J_{AB} 12.0 Hz, $PhCH_2$), 4.70, 4.62 (AB, 2H, J_{AB} 12.0 Hz, $PhCH_2$), 4.40–4.38 (m, 2H, H-6a, H-6b), 4.26 (d, 1H, $J_{3',4'}$ 3.0 Hz, H-4'), 4.22 (ddd, 1H, $J_{1',2'}$ 10, $J_{2',3'}$ 11 Hz, H-2'), 4.19 (ddd, $J_{4,5}$ 11.0, $J_{5,6a}$ 3.0, $J_{5,6b}$ 3.0 Hz, H-5), 3.93 (dd, 1H, $J_{2',3'}$ 11.0 Hz, H-3'), 3.88 (dd, $J_{2,3}$ 9.5, $J_{3,4}$ 10.5 Hz, H-3), 3.81–3.78 (m, 1H, H-5'), 3.76–3.72 (m, 2H, H-6'a, H-6'b), 3.70 (ddd, 1H, $J_{1',4a}<1$, $J_{1',4b}$ 10.0 Hz, H-1'), 3.39 (s, 3H, OMe), 2.29 (ddd, 1H, $J_{4,4a}$ 5, $J_{4a,4b}$ 15.0 Hz, H-4a), 2.15–2.09 (m, 4H, H-4, $3CH_3CO$), 1.81 (s, 3H, CH_3CO), 1.80 (ddd, 1H, $J_{4,4b}$ 3.0 Hz, H-4b). MS (m/z, %): 888 (M+H, 100), 856 (M−OMe, 40). Anal. Calcd. for $C_{28}H_{41}NO_{16}$: C 71.68, H 6.92. Found: C 71.62, H 7.02.

Methyl 4-deoxy-4-C-(2-acetamido-2-deoxy-α-D-galactopyranosylmethyl)-β-D-glucopyranoside ***15*** *and methyl 4-deoxy-4-C-(2-acetamido-2-deoxy-β-D-galactopyranosylmethyl)-β-D-glucopyranoside* ***17***

Treatment of **10** (734 mg) with tributyltin hydride according to previous procedure, gave, after flash chromatography (toluene/acetone: 85/25, 3/1, 7/3, then acetone), four fractions: first F1 (220 mg, 35%, containing *C*-disaccharide and reduced product), F2 (97 mg, 15.4%, which did not contain *C*-disaccharide), F3 (140 mg, 22.2%, containing *C*-disaccharide) and finely F4 (160 mg, 25.4%, containing *C*-disaccharide). The fractions containing tethered *C*-disaccharides were treated separately with $LiAlH_4$ (40 eq.) in tetrahydrofuran, for 72 h. The reaction mixture was cooled to 0°C, diluted with water, filtered through celite, eluted with tetrahydrofuran and concentrated. A solution of the residue in a mixture acetic anhydride/pyridine (1/2 v/v) was stirred for 17 h at room temperature, concentrated, filtered through silica gel (toluene/ethyl acetate 4/1) and concentrated. A solution of the residue in methanol in the presence of a catalytic amount of NaOMe was stirred for 3 h at room temperature, neutralised with Amberlite IR 120 H^+ and concentrated. A solution of the residue in methanol was stirred in the presence of a catalytic amount of Pd/C under hydrogen (1.5 atm) at room temperature for 24 h, filtered and concentrated, to give the *N*-acetylated *C*-disaccharide which was dissolved in water and lyophilised. F1 gave **15** (45 mg), F3 gave **15** (30 mg) and F4 gave **17** (51 mg). The cyclisation, detethering, deprotection yields were 28% (for **15**) and 19% (for **17**).

Methyl 4-deoxy-4-C-(2-acetamido-2-deoxy-α-D-galactopyranosylmethyl)-β-D-glucopyranoside **15**

$[\alpha]_D$ +71 (*c* 1.41, H_2O). ^1H NMR (400 MHz, D_2O, 298 K): 4.37 (ddd, 1H, $J_{1',2'}$ 6.0, $J_{1',4a}$ 11.5, $J_{1',4b}$ 2.5 Hz, H-1'), 4.28 (d, 1H, $J_{1,2}$ 8.5 Hz, H-1), 4.15 (dd, 1H, $J_{2',3'}$ 11.0 Hz, H-2'), 3.93 (dd, 1H, $J_{3',4'}$ 3.0, $J_{4',5'}$ 1.5 Hz, H-4'), 3.89–3.85 (m, 1H, H-5'), 3.84 (dd, 1H, H-3'), 3.80 (dd, 1H, $J_{5,6a}$ 2.0, $J_{6a,6b}$ 12.0 Hz, H-6a), 3.73 (dd, 1H, $J_{5',6'a}$ 5.0, $J_{6'a,6'b}$ 11.5 Hz, H-6'a), 3.70 (dd, 1H, $J_{5',6'b}$ 4.5 Hz, H-6'b), 3.60 (dd, 1H, $J_{2,3}$ 9.2, $J_{3,4}$ 11.0 Hz, H-3), 3.61 (dd, 1H, $J_{5,6b}$ 5.5 Hz, H-6b), 3.52 (ddd, 1H, $J_{4,5}$ 10.0 Hz, H-5), 3.52 (s, 3H, OMe), 3.14 (dd, 1H, H-2), 2.10 (s, 3H, CH_3CO), 1.96 (ddd, $J_{4,4a}$ 3.0, $J_{4a,4b}$ 15.5 Hz, H-4a), 1.72 (dddd, 1H, $J_{4,4b}$ 6.0 Hz, H-4), 1.51 (ddd, 1H, H-4b). MS (m/z, %): 396 (M+H, 100), 364 (M−OMe, 960).

Methyl 4-deoxy-4-C-(2-acetamido-2-deoxy-β-D-galactopyranosylmethyl)-β-D-glucopyranoside **17**

$[\alpha]_D$ +21 (*c* 0.80, H_2O). ^1H NMR (400 MHz, D_2O, 298 K): 4.27 (d, 1H, $J_{1,2}$ 8.2 Hz, H-1), 3.91 (d, 1H, $J_{3',4'}$ 3.5, H-4'), 3.91 (dd, 1H, $J_{5,6a}<1$, $J_{6a,6b}$ 10.5 Hz, H-6a), 3.74 (dd, 1H, $J_{1',2'}$ 10.0, $J_{2',3'}$ 10.0 Hz, H-2'), 3.73 (dd, 1H, $J_{5',6'a}$ 8.0, $J_{6'a,6'b}$ 12.0 Hz, H-6'a), 3.70–3.62 (m, 2H, H-5', H-6'), 3.65 (dd, 1H, H-3'), 3.60 (dd, 1H, $J_{5,6b}$ 4.0 Hz, H-6b), 3.57 (ddd, 1H, $J_{4,5}$ 10.0 Hz, H-5), 3.52 (s, 3H, OMe), 3.43 (dd, 1H, $J_{2,3}$ 8.6, $J_{3,4}$ 10.5 Hz, H-3), 3.35 (ddd, 1H, $J_{1',4a}<1$, $J_{1',4b}$ 10.0 Hz, H-1'), 3.19 (dd, 1H, H-2), 1.78 (ddd, $J_{4,4a}$ 5.0, $J_{4a,4b}$ 15.5 Hz, H-4a), 1.77 (s, 3H, CH_3CO), 1.73 (dddd, 1H, $J_{4,4b}$ 10.5 Hz, H-4), 1.61 (ddd, 1H, H-4b). MS (m/z, %): 396 (M+H, 100), 364 (M−OMe, 60).

Methyl 4-deoxy-4-C-(2-acetamido-2-deoxy-α-D-galactopyranosylmethyl)-α-D-glucopyranoside **12**

A solution of **11** (60 mg, 0.067 mmol) and NaOMe (catalytic) in methanol (3 mL) was stirred for 5 h at room temperature, neutralised with Amberlite IR 120 H^+ and concentrated. The residue was dissolved in methanol and stirred under dihydrogen (1.5 atm) in the presence of a catalytic amount of Pd/C at room temperature for 24 h, filtered and concentrated, to give **12** (24 mg, 90%). $[\alpha]_D$ +162 (*c* 1.86, H_2O). ^1H NMR (400 MHz, D_2O, 298 K) 4.38 (ddd, 1H, $J_{1',2'}$ 5.7, $J_{1',4a}$ 11.0, $J_{1',4b}$ 2.2 Hz, H-1'), 4.16 (dd, 1H, $J_{2',3'}$ 11.0 Hz, H-2'), 3.96–3.94 (m, 1H, H-4'), 3.90–3.85 (m, 1H, H-5), 3.84 (dd, 1H, $J_{3',4'}$ 3.0 Hz, H-3'), 3.79 (dd, 1H, $J_{2,3}$ 9.5, $J_{3,4}$ 10.5 Hz, H-3), 3.76 (d, $J_{1,2}$ 3.5 Hz, H-1), 3.77–3.68 (m, 4H, H-5', H-6a, H-6'a, H-6'b), 3.63 (dd, 1H, $J_{5,6b}$ 5.0, $J_{6a,6b}$ 12.0 Hz, H-6b), 3.46 (dd, 1H, H-2), 3.37 (s, 3H, OMe), 2.02 (s, 3H, CH_3CO), 1.96 (ddd, 1H, $J_{4,4a}$ 2.5, $J_{4a,4b}$ 15.5 Hz, H-4a), 1.76 (dddd, 1H, $J_{4,5}$ 10.5, $J_{4,4b}$ 5.5 Hz, H-4), 1.50 (ddd, 1H, H-4b). MS (m/z, %): 396 (M+H, 100), 364 (M−OMe, 30).

Methyl 4-deoxy-4-C-(2-acetamido-2-deoxy-β-D-galactopyranosylmethyl)-α-D-glucopyranoside **14**

The compound **13** (18 mg, 0.020 mmol) was treated as previously described to give **14** (7 mg, 87%). $[\alpha]_D$ +43 (*c* 0.38, H_2O). ^1H NMR (400 MHz, D_2O, 298 K): 4.78 (d, $J_{1,2}$ 4.0 Hz, H-1), 3.89 (d, 1H, $J_{3',4'}$ 3.0 Hz, H-4'), 3.86–3.79 (m, 2H, H-5, H-6a), 3.72 (dd, 1H, $J_{1',2'}$ 10.0, $J_{2',3'}$ 10.0 Hz, H-2'), 3.71 (dd, 1H, $J_{5',6'a}$ 8.5, $J_{6'a,6'b}$ 11.5 Hz, H-6'a), 3.65 (dd, 1H, $J_{5',6'b}$ 4.0 Hz, H-6'b), 3.64 (dd, 1H, H-3'), 3.62 (dd, 1H, $J_{2,3}$ 9.5, $J_{3,4}$ 11.0 Hz, H-3), 3.55 (dd, 1H, H-5'), 3.49 (dd, 1H, H-2), 3.36 (ddd, 1H, $J_{1',4a}<1$, $J_{1',4b}$ 10.0 Hz, H-1'), 3.35 (s, 3H, OMe), 2.00 (s, 3H, CH_3CO), 1.83–1.71 (m, 2H, H-4, H-4a), 1.50 (ddd, 1H, $J_{4,4b}$ 2.5, $J_{4a,4b}$ 15.0 Hz, H-4b). MS (m/z, %): 396 (M+H, 100).

Methyl 2,3,6-tri-O-acetyl-4-deoxy-4-C-(2-acetamido-3,4,6-tri-O-acetyl-2-deoxy-α-D-galactopyranosylmethyl) β-D-glucopyranoside **16**

The compound **15** was acetylated in a mixture of acetic anhydride and pyridine to give **16** after flash chromatography (toluene/acetone 1/4). $[\alpha]_D$ +12 (*c* 0.68, $CHCl_3$); ^1H NMR (400 MHz, acetone-d_6): 7.50 (d, 1H, $J_{NH,2'}$ 7.5 Hz, NHAc), 5.49 (dd, 1H, $J_{3',4'}$ 3.5, $J_{4',5'}$ 3.5 Hz, H-4'), 5.28 (dd, 1H, $J_{2,3}$ 9.5, $J_{3,4}$ 11.0 Hz, H-3), 5.23 (dd, 1H, $J_{2',3'}$ 8.7 Hz, H-3'), 4.87 (dd, 1H, $J_{1,2}$ 7.8 Hz, H-2), 4.65 (d, 1H, H-1), 4.58 (dd, 1H, $J_{5,6a}$ 2.5, $J_{5a,6b}$ 12.0 Hz, H-6a), 4.55–4.34 (m, 5H, H-6b, H-1', H-2', H-5', H-6'a), 4.27 (dd, 1H, $J_{5',6'b}$ 5.0, $J_{6'a,6'b}$ 11.5 Hz, H-6'b), 2.92 (ddd, 1H, $J_{4,5}$ 11.0, $J_{5,6b}$ 6.0 Hz, H-5), 3.57 (s, 3H, OMe), 2.22–2.05 (m, 23H, 7×3Ac, H-4, H-4a), 1.66 (ddd, 1H, $J_{4,4b}$ 2.5, $J_{1',4b}$ 7.0, $J_{4a,4b}$ 16.0 Hz, H-4b). MS (m/z, %): 665 (M+NH_4, 100), 648 (M+H, 30), 616 (M−OMe, 60).

*Methyl-2,3,6-tri-*O*-acetyl-4-deoxy-4-*C*-(2-acetamido-3,4,6-tri-*O*-acetyl-2-deoxy-β-*D*-galactopyranosylmethyl)-β-*D*-glucopyranoside **18***

The compound **17** was acetylated as described before to give **18**. $[\alpha]_D$ −40 (*c* 0.69, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$): 5.61 (d, 1H, $J_{NH,2'}$ 10.0 Hz, NHAc), 5.37 (dd, 1H, $J_{3',4'}$ 3.5, $J_{4',5'}$ <1 Hz, H-4'), 5.14 (dd, 1H, $J_{2,3}$ 9.2, $J_{3,4}$ 11.0 Hz, H-3), 4.92 (dd, 1H, $J_{1,2}$ 8.1 Hz, H-2), 4.91 (dd, 1H, $J_{2',3'}$ 11.0 Hz, H-3'), 4.43 (dd, 1H, $J_{5,6a}$ 2.0, $J_{5a,6b}$ 12.0 Hz, H-6a), 4.36 (d, 1H, H-1), 4.32 (dd, 1H, $J_{5,6b}$ 4.8 Hz, H-6b), 4.18 (ddd, 1H, $J_{1',2'}$ 10 Hz, H-2'), 4.09 (dd, $J_{5',6'a}$ 5.2, $J_{6'a,6'}$ 11.5 Hz, H-6'a), 4.02 (dd, 1H, $J_{5',6'b}$ 7.5 Hz, H-6'b), 3.90 (ddd, 1H, $J_{4,5}$ 11.0 Hz, H-5), 3.86 (ddd, 1H, H-5'), 3.54 (ddd, $J_{1',4a}$ 10.0, $J_{1',4b}$<1 Hz, H-1'), 3.50 (s, 3H, OMe), 2.20 (s, 3H, Ac), 2.21 (s, 3H, Ac), 2.10–2.05 (m, 10H, 3×Ac, H-4), 2.02 (s, 3H, Ac), 1.93 (s, 3H, Ac), 1.77 (ddd, 1H, $J_{4,4a}$ 3.5, $J_{4a,4b}$ 15.5 Hz, H-4a), 1.69 (ddd, 1H, H-4b). MS (m/z, %): 665 ($M+NH_4$, 100), 648 (M+H, 90), 616 (M−OMe, 30).

References

1. Bols, M.; Skrydstrup, T. *Chem. Rev.* 1995, **95**, 1253.
2. Stork, G.; Suh, H. S.; Kim, G. *J. Am. Chem. Soc.* 1991, **113**, 7054.
3. a) Stork, G.; Kim, G. *J. Am. Chem. Soc.* 1992, **114**, 1087; b) Bols, M. *J. Chem. Soc., Chem. Commun.* 1992, 913; c) Bols, M. *ibid*, 1993, 791; d) Bols, M. *Tetrahedron* 1993, **49**, 10049; e) Bols, M. *Acta Chem. Scand.* 1993, **47**, 829; f) Bols, M.; Hansen, H. C. *Chem. Lett.* 1994, 1049; g) Stork, G.; La Clair J. J. *J. Am. Chem. Soc.* 1996, **118**, 247.
4. a) Pedretti, V.; Mallet, J.-M.; Sinaÿ, P. *Carbohydr. Res.* 1993, **244**, 247; b) Lopez, J. C.; Gomez, A. R.; Fraser-Reid, B. *J. Chem. Soc., Chem. Commun.* 1993, 762; c) Lopez, J. C.; Gomez, A. R.; Fraser-Reid, B. *J. Chem. Soc., Chem. Commun.* 1994, 1533; d) Mazeas, D.; Skrydstrup, T.; Doumeix, O.; Beau, J.-M. *Angew. Chem. Int. Ed. Engl.* 1994, **33**, 1383; e) Lopez, J. C.; Gomez, A. R.; Fraser-Reid, B. *Aust. J. Chem.* 1995, **48**, 333; f) Gomez, A. R.; Lopez, J. C.; Fraser-Reid, B. *J. Org. Chem* 1995, **60**, 3859; g) Lopez, J. C.; Gomez, A. R.; Fraser-Reid, B. *J. Org. Chem.* 1995, **60**, 3871.
5. a) Xin, Y. C.; Mallet, J.-M.; Sinaÿ, P. *J. Chem. Soc., Chem. Commun.* 1993, 864; b) Chénedé, A.; Perrin, E.; Rekaï, E. D.; Sinaÿ, P. *Synlett*, 1994, 420; c) Mallet, A.; Mallet, J.-M.; Sinaÿ, P. *Tetrahedron: Asymmetry* 1994, 2593.
6. a) Zhdanov, Y. A.; Alexeev, Y.; Alexeeva, V. G. *Adv. Carbohydr. Chem. Biochem.* 1972, **27**, 227; b) Nicotra, F.; Russo, G.; Ronchetti, F.; Toma, L. *Carbohydr. Res.* 1983, **124**, C5; c) Myers, R. W.; Lee, Y. C. *Carbohydr. Res.* 1984, **132**, 61; d) Hoffmann, M. G.; Schmidt, R. R. *Liebigs Ann. Chem.* 1985, 2403; e) Giannis, A.; Sandhoff, K. *Carbohydr. Res.* 1987, **171**, 201; f) Giannis, A.; Münster, P.; Sandhoff, K.; Steglich, W. *Tetrahedron* 1988, **44**, 7177; g) Carcano, M.; Nicotra, F.; Panza, L.; Russo, G. *J. Chem. Soc., Chem. Commun.* 1989, 297; h) Grondin, R.; Leblanc, Y.; Hoogsteen K. *Tetrahedron Lett.* 1991, **32**, 5021; i) Bertozzi, C. R.; Bednarski, M. D. *Tetrahedron Lett.* 1992, **33**, 3109; j) Lay, L.; Nicotra, F.; Panza, L.; Verani, A. *Gazz. Chim. Ital.* 1992, **122**, 345; k) Mbongo, A.; Fréchou, C.; Beaupère, D.; Uzan, R.; Demailly, G. *Carbohydr. Res.* 1993, 246, 361; l) Leteux, C.; Veyrières, A. *J. Chem. Soc. Perkin Trans I* 1994, 2647; m) Hoffmann, M.; Kessler, H. *Tetrahedron Lett.* 1994, **35**, 6067; n) Kim, K.-I.; Hollingsworth, R. I. *Tetrahedron Lett.* 1994, **35**, 1031; o) Jobron, L.; Leteux, C.; Veyrières, A.; Beau, J.-M. *J. Carbohydr. Chem.* 1994, **13**, 507; p) Ayadi, E.; Czernecki, S.; Xie, J. *J. Chem. Soc., Chem. Commun.* 1996, 347; q) Cipolla L.; Lay, L.; Nicotra, F. *Carbohydr. Lett.* 1996, **2**, 131.
7. Bovin, N. V.; Zurabyan, S. E.; Khorlin, A. Ya. *Carbohydr. Res.* 1981, **98**, 25.
8. Tingoli, M.; Tiecco, M.; Chianelli, D.; Balducci, R.; Temperi A. *J. Org. Chem.* 1991, **56**, 6809.
9. a) Czernecki, S.; Ayadi, E., *Can. J. Chem.* 1995, **73**, 343; b) Benhaddou, R.; Czernecki, S.; Randriamandimby, D. *Synlett* 1992, 967.
10. Boyer, J. M. *J. Am. Chem. Soc.* 1951, **73**, 5865.
11. Garegg, P. J.; Lindberg, K. B.; Swahn, C.-G. *Acta Chem. Scand.* B, 1974, **28**, 381.

12. a) Hall, C. R.; Inch, T. D.; Lewis, G. J.; Chittenden, R. A. *J. Chem. Soc., Chem. Commun.* 1975, 720; b) Harrison, J. M.; Inch, T. D.; Lewis G. J. *J. Chem. Soc. Perkin I* 1975, 1892.
13. Sinaÿ, P. *Pure & Appl. Chem.* 1997, in press.

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