Available online at www.sciencedirect.com
ScienceDirect
Carbohydrate Research 343 (2008) 1754–1765
Carbohydrate RESEARCH

Synthesis of C-disaccharides via a hetero-Diels–Alder reaction and further stereocontrolled transformations

Qian Wan, André Lubineau, Régis Guillot and Marie-Christine Scherrmann*

ICMMO Université Paris-Sud 11, 91405 Orsay Cedex, France

Received 8 February 2008; received in revised form 5 March 2008; accepted 9 March 2008
Available online 14 March 2008

Abstract—The partial *de novo* synthesis of two new C-disaccharides containing D-glucosamine is described. The strategy is based on a hetero-Diels–Alder reaction leading to a 1:1 mixture of separable cycloadducts, which have been stereoselectively functionalized and converted into α-D-Gal*p*-(1→3)-*C*-D-Glc*p*NAc and α-L-Gal*p*-(1→3)-*C*-D-Glc*p*NAc.

Keywords: C-Glycoside; D-Glucosamine; Krapcho reaction; cis-Dihydroxylation

1. Introduction

Numerous studies have been devoted to the synthesis of C-glycosides,[1,2] the carbon-linked analogues of naturally occurring sugars, because these compounds are stable toward both enzymatic and chemical hydrolysis, and show biological properties similar[3] and even better[4] than those of the parent O-glycosides. To this end, several methodologies were developed by some of us, for example, the condensation of the carbanion of β-diketones and a formyl group of unprotected sugars in aqueous medium,[5] the indium-promoted condensation of bromoenopyranosides with formyl C-glucoside,[6] or the Mukaiyama aldol reaction of the latter with silyl enol ethers.[7]

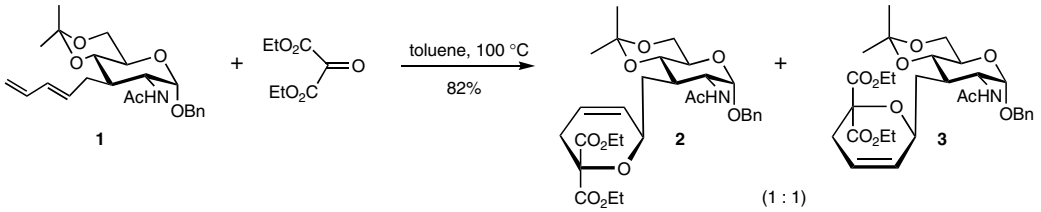
The partial *de novo* synthesis of C-disaccharide analogues may offer the advantage of allowing stereochemical variation leading to molecular diversity. Because important naturally occurring oligosaccharides feature a *N*-acetyl-glucosamine moiety substituted at the position 3 by a galactose unit, we planned on synthesizing carbon linked analogues of the disaccharides D-sugar-(1→3)-Glc*p*NAc. In particular, oligosaccharides related to the antigenic determinant of the O-specific side chain of the human pathogen *Shigella dysenteriae* type 1 contain an α-linked 2-acetamido-2-deoxy-D-glucopyranosyl residue.[8] Many studies have been carried out to achieve the synthesis of the oligosaccharides that constitute the repeating units of this lipopolysaccharide to better understand the interactions between this antigen and antibodies, with the final goal of developing a synthetic vaccine.[9] Our approach to a C-mimetic of part of this antigenic determinant is based on a hetero Diels–Alder reaction using diene **1**,[10] which could be prepared efficiently in large scale, followed by stereo-controlled transformations.

2. Results and discussion

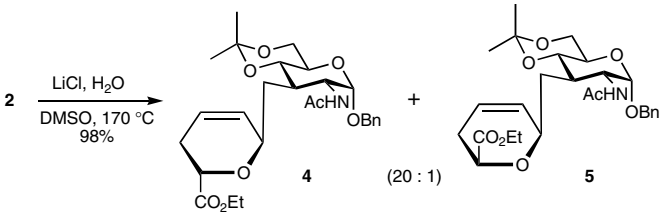
To construct the heterocycle from diene **1**,[10] we first envisaged the use of diethyl mesoxalate as the dienophile because, due to its symmetry, only two diastereoisomers resulting from the facial selectivity of the diene can be obtained. Numerous examples of hetero-Diels–Alder reactions involving diethyl mesoxalate have been described,[11] some of them being the key step of syntheses of sugars.[12] The hetero-Diels–Alder reaction between **1** and diethyl mesoxalate was carried out in toluene at 100 °C for 48 h to afford a 1:1 mixture of cycloadducts **2** and **3** in 82% yield (Scheme 1). The diastereoisomers were separated by column chromatography followed

* Corresponding author. Tel.: +33 1 69 15 72 56; e-mail: mcscherr@icmo.u-psud.fr

0008-6215/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.carres.2008.03.015



Scheme 1. Hetero Diels–Alder reaction of diene **1** with diethyl mesoxalate.

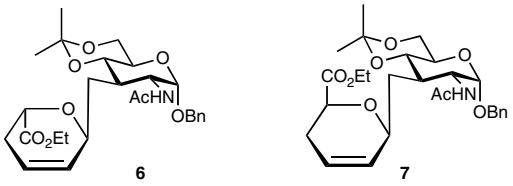


Scheme 2. Krapcho decarbethoxylation of compound **2**.

by crystallization. The stereochemistry at C-1′ for both compounds was deduced from NOE experiments and then confirmed by X-ray analysis.

The geminal diester **2** was then subjected to the Krapcho decarbethoxylation (Scheme 2).[13] Under classical conditions (LiCl, H_2O, DMSO, 170 °C), the reaction was very clean and gave the two diastereoisomers, **4** and **5**, in 98% total yield and in a 20:1 ratio as shown by ^1H NMR analysis. The major diastereoisomer, **4**, was obtained in a pure form by column chromatography, whereas **5** was recovered together with trace amounts of **4**.

Having proven the absolute configuration at the anomeric carbon (C-1′) of their precursor **2**, the stereochemical outcome of the decarbethoxylation was deduced from NMR experiments. In the case of **4**, the presence of NOEs between H-7b and H-3, H-7a and H-1′, H-1′ and H-3 suggested the preferred relative orientation of the two sugar units (Fig. 1). The NOE observed between H-7b and H-5′ allowed us to establish a trans disposition of the substituents at positions 1′ and 5′ of the enopyranoside ring, which adopts a ^5H_O half chair conformation (Fig. 1, $R_1 = H\text{-}5'$, $R_2 = CO_2Et$). In fact, the alternative half chair conformation shown in Figure 1, that is, $^OH_5$, was not compatible with the above-mentioned NOEs. From these observations, we could conclude that the newly formed ring belonged to the D stereochemical series. Therefore, **4** was bearing an α-D-enopyranosidic moiety and **5** was bearing a β-L unit.



Treated under the same conditions, the geminal diester **3** afforded a 20:1 mixture of **6** and **7** in 98% yield. The two products were isolated in a pure form by chromatography. The NOE experiments, confirmed by the

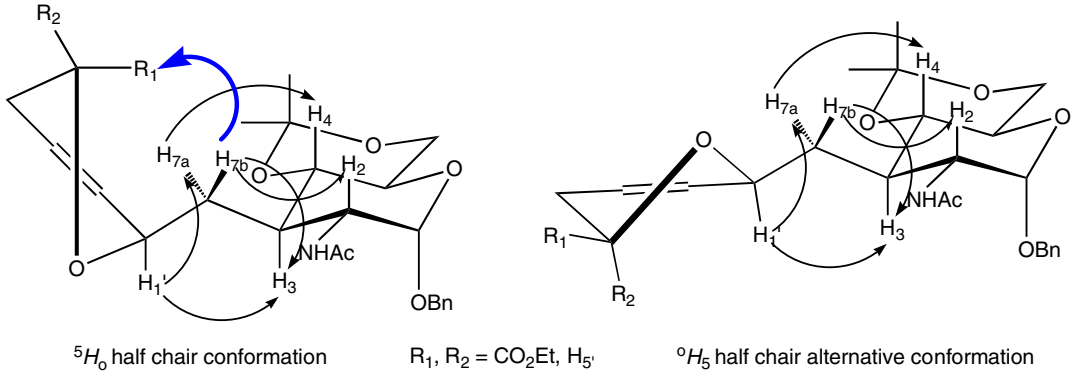


Figure 1. Structure determination of compound **4** by NOE experiments.

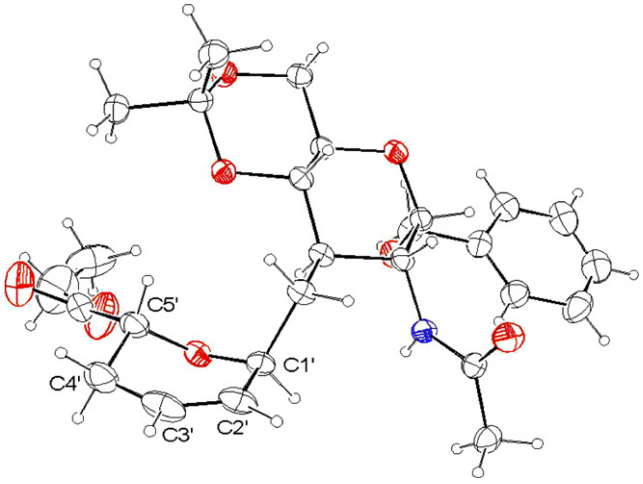
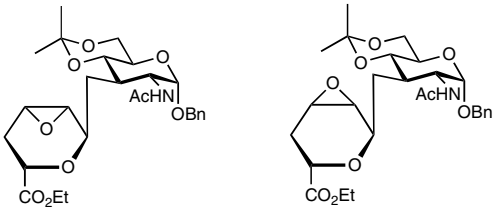


Figure 2. ORTEP depiction of compound **6**.

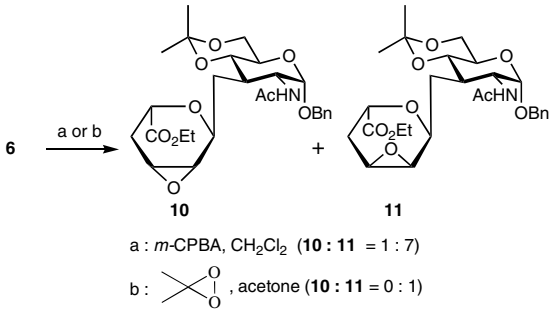
X-ray analysis on the major isomer **6** (Fig. 2), led to the conclusion that a trans orientation for the substituents at C-1′ and C-5′ was obtained also in this case. Thus, the configuration of the enopyranosidic moiety was α-L in **6** (in a $^{O}H_5$ conformation) and β-D in **7**.

Aiming to simplify the synthesis, we envisaged the replacement of the two previous steps (cycloaddition and Krapcho reaction) by a unique cycloaddition involving ethyl glyoxalate. The reaction between the latter and diene **1** was carried out in toluene at 125 °C for 48 h to give a mixture of four diastereoisomers in 58% yield. Cycloadducts **4**–**7** were obtained in a 1:1.7:1:1.3 ratio as determined by ^{13}C NMR analysis. Unfortunately, these compounds were difficult to separate and we returned to the two-step protocol.

To functionalize the 2′, 3′, and 4′ positions, we first planned to oxidize the allylic position (at C-4′) and then to hydroxylate the double bond. Using CrO_3 in CH_2Cl_2, we observed partial oxidation of the benzyl group into benzoate, whereas the use of SeO_2 as the oxidizing agent was unsuccessful. Thus, we changed our strategy and decided to first epoxidize the double bond and then transform the epoxides into allylic alcohols. The major isomers **4** and **6** were treated with *m*-CPBA to give the diastereomeric epoxides **8** and **9** (1:4 ratio) and **10** and **11** (1:7 ratio, Scheme 3), respectively.



The stereochemistry of the epoxides was rather difficult to establish by NMR analysis; fortunately, we were able to obtain **11** in a crystalline form suitable for X-ray



Scheme 3. Epoxidation of compound **6**.

diffraction analysis. This analysis proved that the epoxidation took place on the opposite face to the carboxyethyl group (Fig. 3). As none of the conditions tested to obtain crystals from **9** was satisfying, at this stage it was assumed that the stereochemical outcome of the epoxidation of **4** was the same as that for **6**. However, the structure of **9** was confirmed in the following steps (vide infra). The use of dimethyloxirane gave quantitatively **11** from **6**, but no improvement of the yield or the selectivity of the epoxidation was observed when these conditions were applied to **4**.

The next task was to develop a suitable method to transform the epoxides into allylic alcohols. Several methods for this transformation are reported in the literature. These involve, for instance, organoselenium compounds,[14] lithium amide bases,[15] dialkylboryl triflates, and tertiary amines,[16] *tert*-butyldimethylsilyl iodide,[17] trimethylsilyl trifluoromethanesulfonate and DBU,[18] or methylmagnesium *N*-cyclohexylisopropylamide.[19] First, we tried the conditions described by Falk and co-workers, involving the use of methylmagnesium *N*-cyclohexylisopropylamide.[19] Unfortunately, under these conditions a complex mixture of products was obtained, and the use of LDA or *n*-BuLi gave the same results. Then, we turned to the conditions described by Noyori and co-workers.[18] Compound **9** was treated with

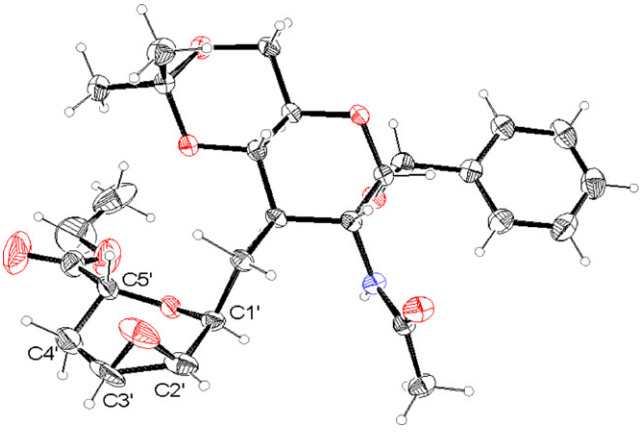
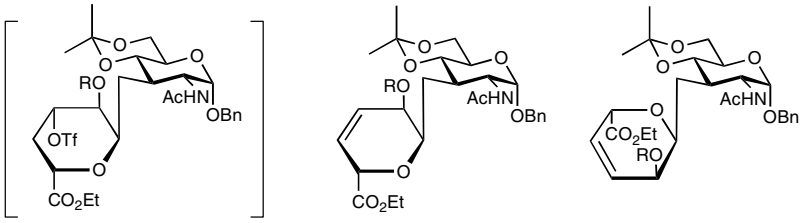


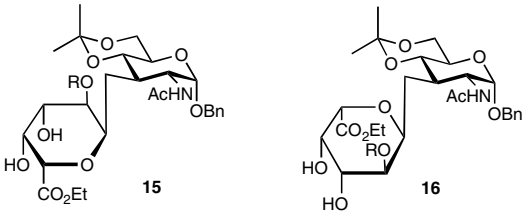
Figure 3. ORTEP depiction of compound **11**.

TBDMSOTf and DBU in toluene, to obtain the allylic ether **13** by electrophile-assisted opening of the epoxide by TBDMSOTf, followed by the DBU-promoted β-elimination of the triflate. After 20 h at room temperature, we observed the total conversion of **9** (tlc analysis) but NMR and MS analyses revealed the formation of intermediate **12**, which gave **13** upon further heating in pyridine. On the basis of this result, we modified Noyori's procedure using TBDMSOTf and pyridine (1.25 equiv) in toluene to open the epoxide, the reaction mixture was then diluted with pyridine and heated to 55 °C to promote triflic acid elimination. This procedure avoids the use of strong base (DBU) that could give side reactions such as epimerization.



12 **13** **14**

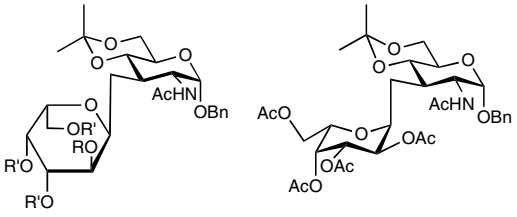
The same protocol applied to **11** gave **14** in 92% yield. The two allylic silyl ethers **13** and **14** were then subjected to cis-dihydroxylation (OsO_4, NMO) to afford quantitatively **15** and **16**, respectively, as single diastereoisomer. At this stage, the stereochemistry of the diols was difficult to assign by NMR analysis, but it was anticipated that an *anti* hydroxylation of the allylic ether occurred as predicted by the Kishi model.[20]



15 **16**

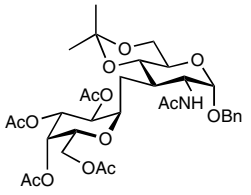
Reduction of the ethyl ester at C-5′ of **16**, performed by means of $LiAlH_4$ in THF, gave triol **17**, characterized as the tri-acetate **18**. Although all the signals of the ^1H NMR spectrum could be assigned, the configurations of C-3′ and C-4′ could not be established because the newly formed heterocycle did not adopt a chair conformation as shown by the relevant coupling constants ($J_{1',2'} = 3.5$ Hz, $J_{2',3'} = 6.8$ Hz, $J_{3',4'} = 3.4$ Hz, $J_{4',5'} = 4.1$ Hz). Treatment of **18** with Bu_4NF followed by acetylation of the free hydroxyl groups gave **19**. The ^1H NMR spectrum of **19** clearly indicated that the C-pyranoside unit was in a chair conformation and possessed the *galacto* configuration ($J_{3',4'} = 3.5$ Hz, $J_{4',5'} = 2.0$ Hz, $J_{2',3'} = 10.0$ Hz). Because this unit belonged to the L series, as proven by the X-ray analysis of its precursor, the vicinal coupling constant of the anomeric proton ($J_{1',2'} = 5.5$ Hz) allowed us to assign the α-L absolute configuration at this residue.

Similarly, compound **15** was treated with $LiBH_4$ to reduce the ester, then with Bu_4NF to remove the silyl group at the position 2′, and finally with Ac_2O in pyridine to acetylate the four hydroxyl groups. These three sequential steps allowed us to obtain **20** in 83% yield. Also in this case, the constructed C-pyranoside moiety adopted a chair conformation after desilylation. The spectrum of the acetylated derivative **20** clearly indicated the *galacto* relative configuration ($J_{3',4'} = 3.5$, $J_{4',5'} = 2.0$ Hz) and an α-D absolute configuration ($J_{1',2'} = 5.5$ Hz).



17 R = $SiMe_2tBu$; R' = H
18 R = $SiMe_2tBu$; R' = Ac

19



20

3. Conclusion

In this paper, we have shown that the hetero-Diels–Alder reaction involving benzyl 2-acetamido-2,3-dideoxy-4,6-*O*-isopropylidene-3-*C*-(1′-pentadienyl)-α-D-glucopyranoside **1** and diethyl mesoxalate is a good entry to the preparation of two C-disaccharides. Each cycloadduct was transformed in seven stereoselective steps affording α-D-Gal*p*-(1→3)-*C*-D-Glc*p*NAc derivatives **20** in 59% total yield and in α-L-Gal*p*-(1→3)-*C*-D-Glc*p*NAc **19** in 62% total yield.

4. Experimental

4.1. General

Melting points were determined with a capillary apparatus and are uncorrected. NMR spectra were recorded at rt with Bruker AC 400 spectrometer. Mass spectrometry was recorded on a MAT 95S instrument. Elemental analyses were performed at the C. N. R. S. Microanalytical Laboratory (Gif sur Yvette, France). All moisture-sensitive reactions were performed under an argon atmosphere using oven-dried glassware. All solvents were dried over standard drying agents and freshly distilled prior to use. Flash column chromatography was performed with Silica Gel 60A C. C. (6–35 μm, SDS). Reactions were monitored by TLC using Silica Gel 60 F_{254} with detection by UV light (254 nm) and by charring with sulfuric acid.

4.2. Benzyl 2-acetamido-2,3-dideoxy-3-C-[(ethyl (1′*R*)-2′,3′,4′-trideoxy-5′-C-ethoxycarbonyl-hex-2′-enopyranosyluronate)methyl]-4,6-*O*-isopropylidene-α-D-glucopyranoside (2) and benzyl 2-acetamido-2,3-dideoxy-3-C-[(ethyl (1′*S*)-2′,3′,4′-trideoxy-5′-C-ethoxycarbonyl-hex-2′-enopyranosyluronate)methyl]-4,6-*O*-isopropylidene-α-D-glucopyranoside (3)

A solution of diene-*E* **1** (1.71 g, 4.26 mmol) and diethyl mesoxalate (3.8 mL, 10.16 mmol) in freshly distilled toluene (40 mL) was heated at 100 °C for 43 h. The reaction mixture was cooled to room temperature, diluted with toluene (40 mL), washed with water until a neutral solution was obtained, dried ($MgSO_4$), and concentrated. Column chromatography over silica gel using 20:1→4:1 CH_2Cl_2–Et_2O gave a 1:1 mixture of the two cycloadducts **2** and **3** (2.01 g, 3.49 mmol, 82%). A second flash chromatography gave first pure **2** (940 mg, 38%). Recrystallization from diethyl ether or petroleum ether–EtOAc afforded **2** as white crystals. $[\alpha]_D^{30}$ 127 (*c* 1.0, $CHCl_3$); mp 110 °C; IR (KBr, *v* cm^{-1}): 3399, 3063, 3034, 2981, 2947, 2928, 2910, 2878, 2848, 1761, 1742, 1672, 1520, 1470, 1455, 1427, 1372, 1259, 1207, 1188, 1145, 1084, 1063, 1001, 955, 855, 739; ^1H NMR ($CDCl_3$, 400 MHz): δ 7.40–7.23 (m, 5H, Ph), 6.95 (d, 1H, $J_{NH,2} = 8.5$ Hz, N*H*), 5.82–5.73 (m, 1H, H-2′), 5.66–5.58 (m, 1H, H-3′), 4.94 (d, 1H, $J_{1,2} = 3.4$ Hz, H-1), 4.77 (d, 1H, $J = 12.5$ Hz, PhCH_2), 4.52 (d, 1H, PhCH_2), 4.39–4.29 (m, 1H, CH_2CH$_3$), 4.20–4.29 (m, 2H, CH_2CH$_3$), 4.16–4.05 (m, 2H, CH_2CH$_3$, H-1′), 3.95 (dt, 1H, $J_{1,2} = 3.4$, $J_{NH,2} = 8.5$, $J_{2,3} = 12.0$ Hz, H-2), 3.85–3.77 (m, 1H, H-6a), 3.75–3.66 (m, 2H, H-5, H-6b), 3.48–3.40 (m, 1H, H-4), 2.98–2.83 (m, 1H, H-4a′), 2.41–2.28 (m, 2H, H-3, H-4b′), 1.97 (s, 3H, NCOCH_3), 1.71(td, 1H, $J_{3,7a} \approx J_{1',7a} = 3.5$, $J_{7a,7b} = 14.5$ Hz, H-7a), 1.47 (s, 3H, CH_3), 1.41 (dt, 1H, $J = 3.4$, $J = 11.5$, $J_{7a,7b} = 14.5$ Hz, H-7b), 1.34 (s, 3H, CH_3), 1.26 (t, 3H, $J = 7.4$ Hz, CH_3), 1.24 (t, 3H, CH_3); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 170.72 (NH*C*OCH$_3$), 168.6 (*C*O$_2$Et), 167.8 (*C*O$_2$Et), 138.0, 128.9 (C-3′), 128.1, 127.3, 127.1, 122.1 (C-2′), 99.3 (CH$_3$*C*O), 96.8 (C-1), 79.7 (C-5′), 74.3 (C-4), 72.0 (C-1′), 69.1 (Ph*C*H$_2$), 65.9 (C-5), 62.8 (C-6), 62.0 (*C*H$_2$), 61.9 (*C*H$_2$), 53.0 (C-2), 36.0 (C-3), 33.2 (C-7), 29.2 (CH$_3$), 29.1 (C-4′), 22.8 (CO*C*H$_3$), 19.2 (CH$_3$), 14.0 (CH$_2$*C*H$_3$), 14.0 (CH$_2$*C*H$_3$). ESIMS *m*/*z*: calcd for $[C_{30}H_{41}NO_{10}+Na]^+$: 598.2628. Found: 598.2620. Anal. Calcd for $C_{30}H_{41}NO_{10}$: C, 62.57; H, 7.18; N, 2.43. Found: C, 62.83; H, 7.25; N, 2.39.

Eluted second was **3** contaminated by **2** (1.07 g). Crystallization from diethyl ether afforded pure **3** (784 mg, 32%) as white crystals. $[\alpha]_D^{30}$ 25 (*c* 1.15, $CHCl_3$); mp 116 °C; IR (KBr, *v* cm^{-1}): 3380, 2982, 2934, 2909, 2869, 2843, 1748, 1732, 1674, 1527, 1386, 1371, 1306, 1291, 1263, 1206, 1190, 1129, 1082, 1054, 1035, 958, 858, 742, 691, 649; ^1H NMR (C_6D_6, 400 MHz): δ 7.41 (d, 1H, $J_{NH,2} = 7.8$ Hz, N*H*), 7.29 (d, 2H, $J = 7.8$ Hz, Ph), 7.20–7.14 (m, 3H, Ph), 5.62–5.50 (m, 2H, H-2′, H-3′), 5.20 (d, 1H, $J_{1,2} = 2.9$ Hz, H-1), 4.62–4.55 (m, 1H, H-1′), 4.58 (d, 1H, $J = 12.7$ Hz, PhCH_2), 4.38 (ddd, 1H, $J_{1,2} = 2.9$, $J_{NH,2} = 7.8$, $J_{2,3} = 11.7$ Hz, H-2), 4.28 (d, 1H, $J = 12.7$ Hz, PhCH_2), 3.97 (dd, 2H, $J = 6.8$, $J = 13.6$ Hz, CH_2CH$_3$), 3.94–3.80 (m, 4H, CH_2CH$_3$, H-5, H-6a), 3.66 (t, 1H, $J_{6a,6b} \approx J_{5,6b} = 10.3$ Hz, H-6b), 3.24 (dd, 1H, $J_{4,5} = 10.3$, $J_{3,4} = 9.3$ Hz, H-4), 2.80 (ddd, 1H, $J = 2.9$, $J = 4.9$, $J_{4a',4b'} = 17.1$ Hz, H-4b′), 2.35–2.25 (m, 2H, H-3, H-4a′), 2.20 (s, 3H, NHCOCH_3), 1.84 (dt, 1H, $J = 4.9$, $J_{7a,7b} = 14.7$ Hz, H-7a), 1.63 (dt, 1H, $J = 2.9$, $J_{7a,7b} = 14.7$ Hz, H-7b), 1.40 (s, 3H, CH_3), 1.23 (s, 3H, CH_3), 0.91 (t, 3H, $J = 6.8$ Hz, CH$_2$CH_3), 0.85 (t, 3H, $J = 6.8$ Hz, CH$_2$CH_3); NMR ^{13}C (C_6D_6, 100 MHz): δ 170.3 (NH*C*OCH$_3$), 169.3 (*C*O$_2$Et), 168.1 (*C*O$_2$Et), 138.8, 129.6, 128.4, 127.6, 127.5, 122.7 (C-2′), 99.3 (2CH$_3$*C*), 97.9 (C-1), 80.0 (C-5′), 74.0 (C-4), 71.0 (C-1′), 69.5 (Ph*C*H$_2$), 66.5 (C-5), 63.1 (C-6), 62.0 (*C*H$_2$), 61.7 (*C*H$_2$), 54.0 (C-2), 36.0 (C-3), 34.2 (C-7), 31.7 (*C*H$_3$), 29.5 (C-4′), 23.0 (CO*C*H$_3$), 19.3 (*C*H$_3$), 14.0 (CH$_2$*C*H$_3$), 13.8 (CH$_2$*C*H$_3$); ESIMS *m*/*z*: calcd for $[C_{30}H_{41}NO_{10}+Na]^+$: 598.2628. Found, 598.2628. Anal. Calcd for $C_{30}H_{41}NO_{10}$: C, 62.57; H, 7.18; N, 2.43. Found: C, 62.83; H, 7.25; N, 2.39.

4.3. Benzyl 2-acetamido-2,3-dideoxy-3-C-(ethyl 2′,3′,4′-trideoxy-α-D-*glycero*-hex-2′-enopyranosyluronate)-methyl-4,6-*O*-isopropylidene-α-D-glucopyranoside (4) and benzyl 2-acetamido-2,3-dideoxy-3-C-(ethyl 2′,3′,4′-trideoxy-β-L-*glycero*-hex-2′-enopyranosyluronate)methyl-4,6-*O*-isopropylidene-α-D-glucopyranoside (5)

To a solution of compound **2** (950 mg, 1.65 mmol) and lithium chloride (210 mg, 4.95 mmol, 3 equiv) in freshly

dried and distilled DMSO (10 mL) was added 35 μL water. The mixture was heated at 170 °C for 3 h, cooled to room temperature, and water was added. The products were extracted into diethyl ether; the extracts were dried by Na_2SO_4 and evaporated to dryness to give 814 mg (98%) of a 20:1 mixture of **4** and **5**. Flash chromatography (1:1 toluene–EtOAc) of the residue led first to 750 mg of compound **4** as a foam (1.49 mmol, 90%). $[\alpha]_D^{25}$ 43 (*c* 1.1, $CHCl_3$); IR (KBr, *v* cm^{-1}): 3331, 2992, 2941, 1738, 1661, 1524, 1456, 1372, 1268, 1207, 1182, 1122, 1080, 1040, 942, 855, 738, 699; ^1H NMR ($CDCl_3$, 400 MHz): δ 7.32–7.20 (m, 5H, Ph), 5.92 (d, 1H, $J_{NH,2} = 9.8$ Hz, N*H*), 5.73–5.64 (m, 1H, H-3′), 5.60–5.53 (m, 1H, H-2′), 4.72 (d, 1H, $J_{1-2} = 2.9$ Hz, H-1), 4.65 (d, 1H, $J = 11.7$ Hz, PhCH_2), 4.44–4.35 (m, 1H, H-1′), 4.39 (d, 1H, $J = 11.7$ Hz, PhCH_2), 4.05–4.18 (m, 3H, H-5′, CH_2CH$_3$), 3.93 (ddd, 1H, $J_{1,2} = 2.9$, $J_{NH,2} = 9.8$, $J_{2,3} = 12.7$ Hz, H-2), 3.75–3.58 (m, 3H, H-5, H-6a, H-6b), 3.41 (t, 1H, $J_{3,4} \approx J_{4,5} = 9.8$ Hz), 2.36–2.26 (m, 1H, H-4a), 2.22–2.09 (m, 2H, H-3, H-4b), 1.83 (s, 3H, NHCOCH_3) 1.63–1.54 (m, 1H, H-7b), 1.40 (s, 1H, CH_3), 1.41–1.32 (m, 1H, H-7a), 1.29 (s, 3H, CH_3), 1.17 (t, 3H, $J = 7.8$ Hz, CH$_2$CH_3); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 171.5 (*C*ONH), 170.0 (*C*O), 137.3 (Ph), 129.9 (Ph), 128.5 (Ph), 128.0 (Ph), 127.9 (Ph), 122.3 (*C*-2′, *C*-3′), 99.3 (CH$_3$O*C*OCH$_3$), 96.4 (*C*-1), 75.1 (*C*-4), 72.8 (*C*-1′), 69.5 (*C*H$_2$Ph), 67.7 (*C*-5′), 65.1 (*C*-5), 62.7 (*C*-6), 61.1 (CH$_3$*C*H$_2$), 51.6 (*C*-2), 36.9 (*C*-3), 33.0 (*C*-7), 29.1 (*C*H$_3$), 26.9 (*C*-4′), 22.9 (NHCO*C*H$_3$), 19.1 (*C*H$_3$), 14.1 (CH$_2$*C*H$_3$); IR (KBr, *v* cm^{-1}): 3331, 2992, 2941, 1738, 1661, 1524, 1456, 1372, 1268, 1207, 1182, 1122, 1080, 1040, 942, 855, 738, 699. ESIMS *m*/*z*: calcd for $[C_{27}H_{37}NO_8+Na]^+$: 526.2417. Found: 526.2420. Anal. Calcd for $C_{27}H_{37}NO_8$: C, 64.40; H, 7.41; N, 2.78. Found: C, 64.19; H, 7.56; N, 2.67.

Eluted second was **5** contaminated by **4** (60 mg, 7%). ^1H NMR ($CDCl_3$, 250 MHz): δ 7.42–7.22 (m, 5H, Ph), 7.09 (d, 1H, $J_{NH,2} = 8.5$ Hz, N*H*COCH$_3$), 5.83–5.72 (m, 1H, H-3′), 5.66–5.58 (m, 1H, H-2′), 4.94 (d, 1H, $J_{1,2} = 3.5$ Hz, H-1), 4.72 (d, 1H, $J = 12.0$ Hz, PhCH_2), 4.52 (d, 1H, $J = 12.4$ Hz, PhCH_2), 4.36–4.29 (m, 1H, H-1′), 4.30–4.10 (m, 3 H, CH$_3$CH_2, H-5′), 3.89 (ddd, 1H, $J_{1,2} = 3.5$, $J_{NH,2} = 8.5$ Hz, $J_{2,3} = 12.5$ Hz, H-2), 3.83–3.67 (m, 3H, H-6a, H-5, H-6b), 3.43 (t, 1H, $J_{3,4} \approx J_{4,5} = 9.8$ Hz, H-4), 2.40–2.18 (m, 3H, H-4a′, H-4b′, H-3), 1.95 (s, 3 H, NHCOCH_3), 1.72 (td, 1H, $J = 3.5$, $J_{7a,7b} = 14.5$ Hz, H-7a), 1.47 (s, 1H, CH_3), 1.37 (s, 3H, CH_3), 1.35–1.21 (m, 4H, CH$_2$CH_3, H-7b); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 171.5, 169.9, 155.8, 129.8, 128.4, 128.0, 127.9, 122.3, 99.2, 96.3, 75.0, 72.7, 69.4, 67.6, 65.0, 62.6, 61.1, 51.5, 40.8, 36.8, 29.1, 26.8, 22.9, 19.0, 14.1. ESIMS *m*/*z*: calcd for $[C_{27}H_{37}NO_8+Na]^+$: 526.2417. Found: 526.2428.

4.4. Benzyl 2-acetamido-2,3-dideoxy-3-C-(ethyl 2′,3′,4′-trideoxy-α-L-*glycero*-hex-2′-enopyranosyluronate)methyl-4,6-*O*-isopropylidene-α-D-glucopyranoside (6) and benzyl 2-acetamido-2,3-dideoxy-3-C-(ethyl 2′,3′,4′-trideoxy-β-D-*glycero*-hex-2′-enopyranosyluronate)methyl-4,6-*O*-isopropylidene-α-D-glucopyranoside (7)

Compound **3** (820 mg, 1.42 mmol) was treated as described for compound **2** to give 700 mg (98%) of a 20:1 mixture of **6** and **7**. Flash chromatography (1:1 toluene–EtOAc) led first to 30 mg (4%) of **7**. $[\alpha]_D^{26}$ 54 (*c* 1.0, $CHCl_3$); IR (NaCl, *v* cm^{-1}): 3368, 3035, 2990, 2928, 2871, 1747, 1673, 1527, 1498, 1456, 1375, 1288, 1268, 1218, 1190, 1123, 1082, 1045, 944, 859, 734, 698; ^1H NMR ($CDCl_3$, 400 MHz): δ 7.29–7.16 (m, 5H, Ph), 7.05 (d, 1H, $J_{NH,2} = 8.0$ Hz, N*H*COCH$_3$), 5.82–5.73 (m, 1H, H-3′), 5.53–5.46 (m, 1H, H-2′), 4.89 (d, 1H, $J_{1,2} = 3.5$ Hz, H-1), 4.66 (d, 1H, $J = 12.4$ Hz, PhCH_2), 4.41 (d, 1H, $J = 12.4$ Hz, PhCH_2), 4.36–4.29 (m, 1H, H-1′), 4.24–4.10 (m, 3H, CH$_3$CH_2, H-5′), 3.82 (ddd, 1H, $J_{1,2} = 3.5$, $J_{NH,2} = 8.0$, $J_{2,3} = 12.0$ Hz, H-2), 3.77–3.66 (m, 1H, H-6a), 3.65–3.54 (m, 2H, H-5, H-6b), 3.33–3.24 (m, 1H, H-4), 2.21–2.13 (m, 2H, H-4a′, H-4b′), 2.07–1.98 (m, 1H, H-3), 1.96 (s, 3H, NHCOCH_3), 1.68 (td, 1H, $J_{1',7a} = J_{3,7a} = 3.0$, $J_{7a,7b} = 15.0$ Hz, H-7a), 1.60 (td, 1H, $J_{1,7b} = J_{3,7b} = 5.0$, $J_{7a,7b} = 15.0$ Hz, H-7b), 1.39 (s, 3H, CH_3), 1.29 (s, 3H, CH_3), 1.20 (t, 3H, $J = 7.5$ Hz, CH$_2$CH_3); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 171.5, 171.0, 138.1, 130.0, 128.1, 127.3, 127.1, 123.7, 99.2, 96.8, 73.5, 73.0, 71.9, 69.1, 65.8, 62.8, 61.0, 53.7, 33.3, 31.3, 29.2, 27.8, 22.8, 19.1, 14.2. ESIMS *m*/*z*: calcd for $[C_{27}H_{37}NO_8+H]^+$: 504.2597. Found: 504.2599. Anal. Calcd for $C_{27}H_{37}NO_8$: C, 64.40; H, 7.41; N, 2.78. Found: C, 64.24; H, 7.54; N, 2.61.

Eluted second was **6** (620 mg, 1.24 mmol, 87%). $[\alpha]_D^{29}$ 129 (*c* 01.0, $CHCl_3$); mp 142°C; IR (NaCl, *v* cm^{-1}): 3318, 3035, 2992, 2938, 2874, 1739, 1658, 1538, 1456, 1373, 1291, 1267, 1199, 1183, 1118, 1076, 1041, 943, 857, 736, 700; ^1H NMR ($CDCl_3$, 400 MHz): δ 7.40–7.29 (m, 5H, Ph), 5.96 (d, 1H, $J_{NH,2} = 9.4$ Hz, N*H*), 5.82–5.76 (m, 1H, H-3′), 5.73–5.76 (m, 1H, H-2′), 4.76 (d, 1H, $J_{1,2} = 3.7$ Hz, H-1), 4.71 (d, 1H, $J = 11.9$ Hz, PhCH_2), 4.52 (m, 1H, H-1′), 4.45 (d, 1H, $J = 11.9$ Hz, PhCH_2), 4.36 (dd, 1H, $J = 5.3$ Hz, $J = 7.0$ Hz, H-5′), 4.20 (q, 2H, $J = 7.0$ Hz, CH_2CH$_3$), 4.09 (ddd, 1H, $J_{1,2} = 3.7$, $J_{NH,2} = 9.4$, $J_{2,3} = 11.5$ Hz, H-2), 3.81 (dt, 1H, $J = 2.5$, $J = 5.0$ Hz, H-6a), 3.73–3.67 (m, 2H, H-5, H-6b), 3.40 (m, 1H, H-4), 2.35–2.30 (m, 2H, H-4a′, H-4b′), 2.17–2.07 (m, 1H, H-3), 1.92 (s, 3H, NHCOCH_3), 1.80 (ddd, 1H, $J = 4.1$, $J = 9.4$, $J_{7a,7b} = 14.4$ Hz, H-7a), 1.50 (td, 1H, $J_{1',7b} = J_{3,7b} = 6.6$, $J_{7a,7b} = 14.4$ Hz, H-7b), 1.47 (s, 3H, CH_3), 1.36 (t, $J = 7.0$ Hz, CH$_2$CH_3), 1.27 (t, $J = 7.0$ Hz, CH$_2$CH_3); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 171.8 (*C*ONH), 169.9 (*C*O), 137.3 (Ph), 129.8 (Ph), 128.5 (Ph), 128.0 (Ph),

122.5 (C-2′, C-3′), 99.4 (2 × CH_3OC), 96.3 (*C*-1), 73.1 (*C*-4), 70.6 (*C*-1′), 69.45 (PhCH_2), 67.5 (*C*-5′), 65.1 (*C*-5), 62.7 (*C*-6), 60.9 (CH_2CH_3), 52.9 (*C*-2), 35.5 (*C*-3), 33.0 (*C*-7), 29.1 (CH_3), 27.3 (*C*-4′), 23.3 ($NHCOCH_3$), 19.1 (CH_3), 14.2 (CH_2CH_3). ESIMS *m*/*z*: calcd for $[C_{27}H_{37}NO_8+Na]^+$: 526.2417, found, 526.2418. Anal. Calcd for $C_{27}H_{37}NO_8$: C, 64.40; H, 7.41; N, 2.78. Found: C, 64.11; H, 7.38; N, 2.58.

4.5. Benzyl 2-acetamido-2,3-dideoxy-3-C-(ethyl 2′,3′-anhydro-4′-deoxy-α-D-*lyxo*-hexopyranosyluronate)-methyl-4,6-*O*-isopropylidene-α-D-glucopyranoside (8) and benzyl 2-acetamido-2,3-dideoxy-3-C-(ethyl 2′,3′-anhydro-4′-deoxy-α-D-*ribo*-hexopyranosyluronate)-methyl-4,6-*O*-isopropylidene-α-D-glucopyranoside (9)

A solution of **4** (78 mg, 0.15 mmol) in CH_2Cl_2 (2 mL) was treated with 3-chloroperoxybenzoic acid (53.5 mg) overnight at room temperature, then additional *m*-CPBA (20 mg) was added. After 3 h, the TLC analysis (6:5 EtOAc–CH_2Cl_2) revealed the complete disappearance of the starting material. The reaction mixture was diluted with CH_2Cl_2, washed with saturated aqueous solution of $NaHCO_3$ and brine, dried ($MgSO_4$) and concentrated. Flash chromatography (1:3 EtOAc–CH_2Cl_2) of the residue gave a 1:4 mixture of the two epoxides **8** and **9** (73 mg, 0.14 mmol, 91%). Pure **9** (56 mg) was obtained by a second flash chromatography (1:4 EtOAc–CH_2Cl_2). $[\alpha]_D^{26}$ 70 (*c* 1.0, CH_2Cl_2); ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.38–7.28 (m, 5H, Ph), 5.87 (d, 1H, $J_{NH,2} = 9.5$ Hz, N*H*COCH$_3$), 4.80 (d, 1H, $J_{1,2} = 3.7$ Hz, H-1), 4.72 (d, 1H, $J = 11.7$ Hz, PhCH_2), 4.45 (d, 1H, $J = 11.7$ Hz, PhCH_2), 4.36 (ddd, 1H, $J_{1',7a} = 10.5$, $J_{1',7b} = 2.5$, $J_{1',2'} = 3.0$ Hz, H-1′), 4.17 ad 4.18 (dq, 2H, $J = 1.5$, $J = 7.3$ Hz, CH_2CH$_3$), 4.11 (dd, 1H, $J_{4a',5'} = 3.7$, $J_{4b',5'} = 9.5$ Hz, H-5′), 4.05 (ddd, 1H, $J_{1,2} = 3.7$, $J_{NH,2} = 9.5$, $J_{2,3} = 11.7$ Hz, H-2), 3.80 (dd, 1H, $J = 3.7$, $J = 8.1$ Hz, H-6a), 3.77–3.66 (m, 2H, H-5, H-6b), 3.58–3.52 (m, 1H, H-4), 3.41 (m, 1H, $J_{3',4a'} = 2.2$ Hz, H-3′), 3.15 (dd, $J_{1',2'} = 3.0$, $J_{2',3'} = 4.0$ Hz, H-2′), 2.24 (ddd, $J_{3',4'a} = 2.2$, $J_{4'a,5'} = 3.7$, $J_{4'a,4'b} = 14.7$ Hz, H-4a′), 2.20–2.07 (m, 2H, H-3, H-4b′), 1.96–1.85 (m, 1H, H-7a), 1.87 (s, 3H, NHCOCH_3), 1.54–1.45 (m, 1H, H-7b), 1.47 (s, 3H, CH_3), 1.37 (s, 3H, CH_3), 1.22 (t, 3H, $J = 7.3$ Hz, CH$_2$CH_3); ^{13}C NMR ($CDCl_3$, 62.9 MHz): δ 171.6, 169.9, 137.3, 128.5, 128.0, 127.9, 99.3, 96.3, 74.8, 70.8, 69.4, 65.2, 62.6, 61.4, 53.2, 51.2, 50.6, 36.5, 29.1, 28.5, 27.2, 22.9, 19.4, 14.0. ESIMS *m*/*z*: calcd for $[C_{27}H_{37}NO_9+Na]^+$: 542.2366. Found: 542.2378.

4.6. Benzyl 2-acetamido-2,3-dideoxy-3-C-(ethyl 2′,3′-anhydro-4′-deoxy-α-L-*ribo*-hexopyranosyluronate)-methyl-4,6-*O*-isopropylidene-α-D-glucopyranoside (11)

A solution of **6** (50 mg, 99 μmol) in CH_2Cl_2 (7.5 mL) was treated at 0 °C for 5 h with a solution of dimethyloxirane in acetone (1.5 mL, 0.09–0.11 M) until complete disappearance of the starting material by TLC analysis (1.2:1 EtOAc–CH_2Cl_2). The reaction mixture was concentrated under reduced pressure to afford pure **11** (51 mg, 100%) as a white solid. $[\alpha]_D^{28}$ 116 (*c* 1.0, $CHCl_3$); mp 143 °C; IR (NaCl, ν cm^{-1}): 3317, 2992, 2926, 1735, 1662, 1533, 1455, 1380, 1267, 1200, 1123, 1071, 1039, 942, 853, 735, 700; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.49–7.29 (m, 5H, Ph), 5.81 (d, 1H, $J_{NH,2} = 9.7$ Hz, N*H*COCH$_3$), 4.75 (d, 1H, $J_{1,2} = 3.7$ Hz, H-1), 4.70 (d, 1H, $J = 12.0$ Hz, PhCH_2), 4.59 (ddd, 1H, $J_{3',5'} = 3.5$, $J_{4'b,5'} = 7.3$, $J_{4'a,5'} = 9.5$ Hz, H-5′), 4.46 (d, 1H, $J = 12.0$ Hz, PhCH_2), 4.20 (q, 2H, $J = 7.1$ Hz, CH$_3$CH_2), 4.13 (dd, 1H, $J_{1,7a} = 3.5$, $J = 10.8$ Hz, H-1′), 4.07 (ddd, 1H, $J = 3.7$, $J = 9.7$ Hz, $J = 11.5$ Hz, H-2), 3.86–3.65 (m, 3H, H-5, H-6a, H-6b), 3.55–3.43 (m, 2H, H-2′, H-4), 3.32 (t, 1H, $J_{3',5'} = 3.5$, $J = 4.0$ Hz, H-3′), 2.29 (ddd, 1H, $J_{3,7a} = 2.5$, $J_{1',7a} = 3.5$ $J_{7a,7b} = 14.5$ Hz, H-7a), 2.04–1.91 (m, 2H, H-7b, H-3), 1.97 (s, 3H, NHCOCH_3), 1.86 (ddd, 1H, $J = 3.5$, $J = 9.5$, $J_{4'a,4'b} = 13.5$ Hz, H-4′a), 1.70 (dt, 1H, $J_{4'b,5'} = 7.3$, $J_{4'a,4'b} = 13.5$ Hz, H-4′b), 1.49 (s, 3H, CH_3), 1.36 (s, 3H, CH_3), 1.27 (t, 3H, $J = 7.1$, CH$_2$CH_3); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 171.6, 170.1, 137.1, 128.6, 128.1, 128.1, 99.4, 96.2, 74.5, 69.6, 69.6, 65.0, 64.7, 62.7, 61.2, 52.5, 52.0, 51.7, 36.1, 29.9, 29.1, 28.3, 23.3, 19.1 14.1. ESIMS *m*/*z*: calcd for $[C_{27}H_{37}NO_9+ Na]^+$: 542.2366. Found: 542.2376. Anal. Calcd for $C_{27}H_{37}NO_9$: C, 62.41; H, 7.18; O, 27.71; N, 2.70. Found: C, 62.64; H, 7.42; O, 27.58; N, 2.73.

4.7. Benzyl 2-acetamido-2,3-dideoxy-3-C-(ethyl 2′-*t*butyldimethylsilyl-3′,4′-dideoxy-α-D-erythro-hex-3′-enopyranosyluronate)methyl-4,6-*O*-isopropylidene-α-D-glucopyranoside (13)

To a solution of *t*-butyldimethylsilyl trifluoromethanesulfonate (244 mg, 212 μL, 0.924 mmol) in dry toluene (0.6 mL) was added a solution of epoxide **9** (200 mg, 0.385 mmol) and dry pyridine (61 mg, 62 μL, 0.77 mmol) in dry toluene (1.5 mL). After 10 min at room temperature, an additional 31 μL of pyridine was added. The solution was stirred for 1 h until disappearance of the starting material by TLC analysis (3:2 toluene–EtOAc), then diluted with pyridine (10.0 mL), and heated at 55 °C for 1 h. The solution was concentrated and the residue purified by flash chromatography (95:5→80:20 CH_2Cl_2–Et_2O) to give **13** (192 mg, 0.303 mmol, 90%). $[\alpha]_D^{27}$ 128 ($c = 0.7$, $CHCl_3$); IR (KBr, ν cm^{-1}): 3300, 2928, 1731, 1664, 1535, 1462, 1370, 1255, 1188, 1120, 1074, 1036.4, 936, 836, 775, 736, 699; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.37–7.28 (m, 5H, Ph), 6.25 (d, 1H, $J_{NH,2} = 8.5$ Hz, N*H*), 6.05 (dd, 1H, $J_{4',5'} = 3.7$, $J_{3',4'} = 10.1$ Hz, H-4′), 5.98 (ddd, 1H, $J_{3',5'} = 2.3$, $J_{2',3'} = 5.1$, $J_{3',4'} = 10.1$ Hz, H-3′), 4.93 (d, 1H, $J_{1,2} = 3.5$ Hz, H-1), 4.76 (dd, 1H, $J_{3',5'} = 2.3$,

$J_{4',5'} = 3.7$ Hz, H-5′), 4.74 (d, 1H, $J = 11.8$ Hz, PhCH_2), 4.48 (d, 1H, $J = 11.8$ Hz, PhCH_2), 4.18 (m, 2H, CH_3CH_2), 4.06 (ddd, 1H, $J_{1,2} = 3.5$, $J_{NH,2} = 8.5$, $J_{2,3} = 12.0$ Hz, H-2), 3.91 (m, 1H, H-1′), 3.84–3.66 (m, 4H, H-4, H-5, H-6a, H-6b), 3.77 (dd, 1H, $J_{1',2'} = 2.5$, $J_{2',3'} = 5.1$ Hz, H-2′), 2.26–2.16 (m, 1H, H-3), 1.91 (s, 3H, NHCOCH_3), 1.78 (ddd, 1H, $J = 3.5$, $J_{7a,7b} = 15.0$, $J = 10.0$ Hz, H-7a), 1.51 (dd, $J = 3.5$, $J = 15.0$ Hz, H-7b), 1.46 (s, 3H, CH_3), 1.36 (s, 3H, CH_3), 1.25 (t, 3H, $J = 7.2$ Hz, CH_2CH_3), 0.88 (s, 9H, $3 \times CH_3$), 0.06 (s, 6H, $2 \times CH_3$); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 170.5, 169.9, 137.6, 128.8, 128.4, 127.8, 127.8, 126.1, 99.5, 96.7, 75.2, 73.3, 72.7, 69.5, 65.6, 64.5, 62.9, 61.4, 52.0, 37.8, 19.7, 29.2, 28.9, 25.9, 23.2, 19.1, 18.3, 14.2, −4.2, −4.6. ESIMS *m*/*z*: calcd for $[C_{33}H_{51}NO_9Si+Na]^+$: 656.3231. Found: 656.3234. Anal. Calcd for $C_{33}H_{51}NO_9Si$: C, 62.53; H, 8.11; N, 2.21. Found: C, 62.56; H, 8.23; N, 2.11.

4.8. Benzyl 2-acetamido-2,3-dideoxy-3-C-(ethyl 2′-*t*butyldimethylsilyl-3′,4′-dideoxy-α-L-erythro-hex-3′-enopyranosyluronate)methyl-4,6-*O*-isopropylidene-α-D-glucopyranoside (14)

Epoxide **11** (32 mg, 0.06 mmol) was treated as described for **9** to give, after flash chromatography (19:1→4:1 CH_2Cl_2–Et_2O), 35 mg of **14** (92%). $[\alpha]_D^{27}$ 129 (*c* 0.7, $CHCl_3$); IR (KBr, *v* cm^{-1}): 3376, 2930, 2905, 2858, 1738, 1677, 1531, 1463, 1373, 1261, 1191, 1143, 1122, 1059, 1025, 939, 858, 837, 776, 735, 698; ^{1}H NMR ($CDCl_3$, 400 MHz): δ 7.39–7.25 (m, 5H, Ph), 7.23 (d, 1H, $J_{NH,2} = 9.8$ Hz, N*H*Ac), 6.04–5.94 (m, 2H, H-3′, H-4′), 4.87–4.84 (m, 1H, H-5′), 4.76 (d, 1H, $J = 11.7$ Hz, PhCH_2), 4.74 (d, 1H, $J_{1,2} = 2.9$ Hz, H-1), 4.50 (d, 1H, $J = 11.7$ Hz, PhCH_2), 4.23 (dq, 2H, $J = 6.8$, $J = 3.9$ Hz, CH_3CH_2), 4.10 (ddd, 1H, $J_{1,2} = 2.9$, $J_{2,3} = 12.5$, $J_{NH,2} = 9.8$ Hz, H-2), 4.06 (m, 1H, H-1′), 3.85–3.78 (m, 1H, H-6a), 3.70–3.65 (m, 3H, H-5, H-2′, H-6b), 3.37 (dd, 1H, $J_{3,4} \approx J_{4,5} = 9.5$ Hz, H-4), 2.63–2.42 (m, 2H, H-3, H-7a), 1.85 (s, 3H, NHCOCH_3), 1.45, 1.37 ($2 \times$ s, 6H, CH_3), 1.30 (t, 3H, $J = 6.8$ Hz, CH_2CH_3), 1.08 (ddd, 1H, $J_{1',7b} = 2.9$, $J_{3,7b} = 9.7$, $J_{7a,7b} = 12.7$ Hz, H-7b), 0.89 (s, 9H, $3 \times CH_3$), 0.064, 0.059 ($2 \times$ S, 6H, SiCH_3); ^{1}H NMR (C_6D_6, 400 MHz): δ 7.33 (d, 1H, $J_{NH,2} = 9.3$ Hz, N*H*Ac), 7.29–7.26 (m, 1H, Ph), 7.20–7.08 (m, 4H, Ph), 5.83 (ddd, 1H, $J = 2.5$, $J_{2',3'} = 5.0$, $J_{3',4'} = 10.3$ Hz, H-3′), 5.77 (dd, 1H, $J_{3',4'} = 10.3$, $J = 3.3$ Hz, H-4′), 5.01 (d, 1H, $J_{1,2} = 3.5$ Hz, H-1), 4.60 (d, 1H, $J = 12.2$ Hz, PhCH_2), 4.55 (ddd, 1H, $J_{1,2} = 3.5$, $J_{NH,2} = 9.3$, $J_{2,3} = 12.5$ Hz), 4.48 (t, 1H, $J = 2.5$ Hz, H-5′), 4.31 (d, 1H, $J = 12.2$ Hz, PhCH_2), 4.28 (m, 1H, $J = 12.5$ Hz, $J = 1.4$ Hz, H-1′), 3.98 (ddd, 1H, $J_{5,6a} = 5.0$, $J_{5,6b} = 9.0$, $J_{4,5} = 10.0$ Hz, H-5), 3.88 (dd, 1H, $J_{5,6a} = 5.0$, $J_{6a,6b} = 10.3$ Hz, H-6a), 3.76–3.68 (m, 3H, CH_3CH_2, H-6b), 3.56 (dd, 1H, $J = 2.0$, $J_{2',3'} = 5.0$ Hz, H-2′), 3.37 (t, 1H, $J_{3,4} \approx J_{4,5} = 10.0$ Hz, H-4), 2.95 (m, 1H, H-3), 2.75 (m, 1H, H-7a), 1.94 (s, 3H, NHCOCH_3), 1.50, 1.35 ($2 \times$ s, 6H, CH_3), 1.22 (m, 1H, H-7b), 0.99 (s, 9H, $3 \times CH_3$), 0.81 (t, $J = 7.3$ Hz, CH_2CH_3), 0.05, 0.04 ($2 \times$ s, 6H, CH_3); ^{13}C NMR (C_6D_6, 100 MHz): δ 171.7 (NH*C*O), 169.0 (O*C*OCH$_3$), 138.8 (Ph), 129.6 (C-3′), 128.5 (Ph), 127.8 (Ph), 127.6 (Ph), 126.5 (C-4′), 99.7 ((CH$_3$)$_2$*C*O$_2$), 99.7 (*C*-1), 73.27 (*C*-4′), 72.90 (*C*-1′), 72.42 (C′-5), 69.6 (Ph*C*H$_2$), 66.1 (C′-5), 64.5 (C′-2), 63.4 (C-6), 61.0 (CH$_3$*C*H$_2$), 54.9 (C-2), 34.1 (C-3), 30.5 (C-7), 29.7 (CH$_3$), 26.1 (Si(*C*H$_3$)$_3$), 23.0 (NHCO*C*H$_3$), 19.3 (CH$_3$), 14.0 (*C*H$_3$CH$_2$), −3.6, −4.5 (Si*C*H$_3$); ESIMS *m*/*z*: calcd for $[C_{33}H_{51}NO_9Si+Na]^+$: 656.3231. Found, 656.3231. Anal. Calcd for $C_{33}H_{51}NO_9Si$: C, 62.53; H, 8.11; N, 2.21. Found: C, 62.55; H, 8.35; N, 2.15.

4.9. Benzyl 2-acetamido-2,3-dideoxy-3-C-(ethyl 2′-*t*butyldimethylsilyl-α-L-galactopyranosyluronate)methyl-4,6-*O*-isopropylidene-α-D-glucopyranoside (16)

To a solution of **14** (80 mg, 126 μmol) and NMO (35 mg, 258 μmol) in 8:1 acetone–water (4 mL) was added a solution of OsO_4 (3.1 μmol, 15.5 μL, 0.025 equiv) in THF (0.2 M). The mixture was stirred at room temperature for 48 h and then concentrated. Flash chromatography of the residue (2:100 MeOH–CH_2Cl_2) gave **16** (82 mg, 123 μmol, 97%) as a white solid; mp 88 °C; $[\alpha]_D^{27}$ 12 (*c* 0.7, $CHCl_3$); IR (NaCl, *v* cm^{-1}): 3357, 2951, 1737, 1654, 1379, 1254, 1207, 116, 1049, 941, 837, 777; ^{1}H NMR (C_6D_6, 400 MHz): δ 7.66 (d, 1H, $J_{NH,2} = 9.5$ Hz, N*H*COCH$_3$), 7.27–7.23 (m, 2H, Ph), 7.17–7.10 (m, 3H, Ph), 4.90 (d, 1H, $J_{1,2} = 3.5$ Hz, H-1), 4.80 (s, 1H, O*H*), 4.64 (m, 1H, H-1′), 4.56 (d, 1H, $J = 12.5$ Hz, PhCH_2), 4.55–4.49 (m, 1H, H-4′), 4.45 (ddd, 1H, $J_{1,2} = 3.5$, $J_{NH,2} = 9.5$, $J_{2,3} = 12.5$ Hz, H-2), 4.30 (d, 1H, $J = 12.5$ Hz, PhCH_2), 4.27 (d, 1H, $J_{4',OH} = 6.0$ Hz, O*H*), 4.10 (dd, 1H, $J_{2',3'} = 2.5$, $J = 3.5$ Hz, H-3′), 3.97 (ddd, 1H, $J_{5,6a} = 5.0$, $J_{4,5} = 10.1$, $J_{5,6b} = 10.3$ Hz, H-5), 3.95 (dd, 1H, $J = 7.0$, $J = 10.0$ Hz, CH_3CH_2), 3.92–3.78 (m, 3H, H-6a, H-2′, CH_3CH_2), 3.78–3.70 (m, 2H, H-5′, H-6b), 3.47 (t, 1H, $J_{3,4} = J_{4,5} = 10.1$ Hz, H-4), 2.92 (dddd, $J_{3,7b} = 2.5$, $J_{3,4} = 10.1$, $J_{2,3} = 12.5$, $J_{3,7a} = 13.0$ Hz, H-3), 2.75 (t, 1H, $J = 13.0$ Hz, H-7a), 2.0 (s, 3H, NHCOCH_3), 1.50, 1.41 (2s, 6H, 2CH_3), 1.2–1.06 (m, 1H, H-7b), 1.03 (s, 9H, 3CH_3), 0.90 (t, $J = 7.0$ Hz, CH_2CH_3), 0.24, 0.21 (2s, 6H, 2CH_3); ^{13}C NMR (C_6D_6, 62.9 MHz): δ 172.9, 170.9, 138.3, 128.5, 127.9, 127.0, 99.7, 97.2, 74.5, 73.4, 73.0, 72.8, 69.4, 68.3, 68.0, 66.0, 63.3, 61.0, 55.2, 34.2, 30.4, 29.6, 26.0, 22.8, 19.2, 18.4, 13.9, −4.0, −4.7. ESIMS *m*/*z*: calcd for $[C_{33}H_{53}NO_{11}Si+Na]^+$: 690.3286. Found: 690.3286. Anal. Calcd for $C_{33}H_{53}NO_{11}Si$: C, 59.35; H, 8.00; N, 2.10. Found: C, 59.44; H, 8.04; N, 1.94

4.10. Benzyl 2-acetamido-2,3-dideoxy-3-C-(ethyl 2′-*t*butyldimethylsilyl-α-D-galactopyranosyluronate)methyl-4,6-*O*-isopropylidene-α-D-glucopyranoside (15)

Compound **13** (80 mg, 126 μmol) was treated as described for **14**. Flash chromatography of the residue (2:100 MeOH–CH_2Cl_2) gave **15** (82 mg, 123 μmol, 97%) as a white solid. $[\alpha]_D^{28}$ 74 (*c* 0.1, $CHCl_3$); ^1H NMR ($CDCl_3$, 400 MHz): δ 7.40–7.28 (m, 5H, Ph), 5.97 (d, 1H, $J_{NH,2} = 9.0$ Hz, N*H*COCH$_3$), 4.86 (d, 1H, $J_{1,2} = 3.5$ Hz, H-1), 4.73 (d, 1H, $J = 12.0$ Hz, PhC*H*$_2$), 4.46 (d, 1H, J = 12.0 Hz, PhC*H*$_2$), 4.34–4.18 (m, 5H, H-1′, H-5′, H-4′, CH_3CH_2), 4.13–3.99 (m, 2H, H-2, H-3′), 3.88–3.60 (m, 6H, H-2′, H-5, H-6a, H-6b, H-4, H-4′), 3.00 (s, 1H, O*H*), 2.20–2.08 (m, 2H, H-3, OH), 1.90 (s, 3H, NHCOC*H*$_3$), 1.70 (ddd, 1H, $J = 2.5$, $J = 11.0$, $J = 14.5$ Hz, H-7a), 1.45 (s, 3H, C*H*$_3$), 1.37–1.30 (m, 1H, H-7b), 1.38 (s, 3H, CH_3), 1.31 (t, 3H, $J = 7.0$ Hz, C*H*$_3$CH$_2$), 0.88 (s, 9H, C(C*H*$_3$)$_3$), 0.06, 0.03 (2s, 6H, 2SiC*H*$_3$); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 172.8, 169.9, 137.4, 128.4, 127.9, 99.4, 96.5, 73.6, 72.5, 71.8, 71.4, 71.0, 70.4, 69.4, 67.2, 65.4, 62.7, 61.6, 51.6, 37.1, 29.1, 28.0, 25.7, 23.0, 19.0, 17.9, 13.9, −4.7, −4.9. ESIMS *m*/*z*: calcd for $[C_{33}H_{53}NO_{11}Si+Na]^+$: 690.32856. Found: 690.3283. Anal. Calcd for $C_{33}H_{53}NO_{11}Si$: C, 59.35; H, 8.00; N, 2.10. Found: C, 59.42; H, 8.05; N, 2.04.

4.11. Benzyl 2-acetamido-3-C-(3′,4′,6′-tri-*O*-acetyl-2′-*t*butyldimethylsilyl-α-L-galactopyranosyl)methyl-2,3-dideoxy-4,6-*O*-isopropylidene-α-D-glucopyranoside (18)

To a stirred, cooled (0 °C) solution of **16** (125 mg, 188 μmol) in dry THF (15 mL) was added a 1 M solution of $LiAlH_4$ in THF (374 μL). The mixture was stirred at 0 °C for 3 h, diluted with a saturated aqueous solution of NH_4Cl, and extracted with EtOAc three times. The combined organic phases were dried (Na_2SO_4) and concentrated. The residue was purified by flash chromatography (1:99→5:95 MeOH–CH_2Cl_2) to give benzyl 2-acetamido-3-*C*-(2′-*t*-butyldimethylsilyl-α-L-galactopyranosyl)methyl-2,3-dideoxy-4,6-*O*-isopropylidene-α-D-glucopyranoside (**17**) (98 mg, 157 μmol, 84%). ^1H NMR (MeOD, 400 MHz): δ 7.39–7.26 (m, 5H, Ph), 4.71 (d, 1H, $J = 12.2$ Hz, PhC*H*$_2$), 4.68 (d, 1H, $J_{1,2} = 3.5$ Hz, H-1), 4.50 (d, 1H, $J = 12.2$ Hz, PhC*H*$_2$), 4.145 (td, 1H, $J = 4.0$, $J = 12.5$ Hz, H-1′), 4.07 (dd, 1H, $J_{1,2} = 3.5$, $J_{2,3} = 11.8$ Hz, H-2), 3.94–3.86 (m, 2H, H-4′, H-6a), 3.84 (dd, $J_{1',2'} = 4.6$, $J_{2',3'} = 7.8$ Hz, H-2′), 3.78–3.65 (m, 5H, H-5, H-5′, H-6b, H-6a′, H-6b′), 3.63 (dd, 1H, $J_{2',3'} = 7.8$, $J_{3',4'} = 3.4$ Hz, H-3′), 3.58 (dd, 1H, $J = 9.0$, $J = 10.3$ Hz, H-4), 2.30–2.20 (m, 1H, H-3), 2.15–2.05 (m, 1H, H-7a), 1.92 (s, 3H, NHCOC*H*$_3$), 1.51 (s, 3H, C*H*$_3$), 1.45 (ddd, 1H, H-7b), 1.36 (s, 3H, C*H*$_3$), 0.91 (s, 9H, 3 × C*H*$_3$), 0.11 (s, 3H, C*H*$_3$), 0.09 (s, 3H, C*H*$_3$); ^{13}C NMR (MeOD, 100 MHz): δ 173.1 (NH*C*OCH$_3$), 139.0 (Ph), 129.4, 129.2, 128.8 (Ph), 100.8 ((CH$_3$)$_2$*C*O$_2$), 96.9 (C-1), 74.0, 73.4 (C-4), 72.8 (C-2′), 71.9 (C-3′), 71.7 (C-1′), 70.2 (Ph*C*H$_2$), 69.8 (C-4′), 66.4, 63.8 (C-6′), 61.4 (C-6), 54.7 (C-2), 35.6 (C-3), 29.6 (O*C*H$_3$), 26.5 (C(*C*H$_3$)$_3$), 25.8 (C-7), 22.7 (NHCO*C*H$_3$), 19.5 (O*C*H$_3$), −4.3, −4.6 (Si*C*H$_3$). ESIMS *m*/*z*: calcd for $[C_{31}H_{51}NO_{10}Si+Na]^+$: 648.31807. Found: 648.31827. Anal. Calcd for $C_{31}H_{51}NO_{10}Si$: C, 59.49; H, 8.21; N, 2.24. Found: C, 59.43; H, 8.34; N, 2.09.

A solution of triol **17** (29 mg, 46 μmol) in pyridine (1.5 mL) and acetic anhydride (0.5 mL) was kept at room temperature overnight, then concentrated. Flash chromatography of the residue (1:3 EtOAc–toluene) gave **18** (34 mg, 100%) as a colorless oil. $[\alpha]_D^{29}$ 70.0 (*c* 1.0, $CHCl_3$); IR (NaCl, *ν* cm^{-1}): 3373, 2930, 2858, 1751, 1681, 1660, 1535, 1463, 1372, 1234, 1121, 1080, 1053, 942, 909, 864, 839, 780, 739 and 700; ^1H NMR (C_6D_6, 400 MHz): δ 7.24–7.02 (m, 5H, Ph), 6.31 (d, 1H, $J_{NH,2} = 9.8$ Hz, N*H*), 5.73 (dd, 1H, $J_{4',5'} = 4.1$, $J_{3',4'} = 3.4$ Hz, H-4′), 5.51 (dd, 1H, $J_{3',4'} = 3.4$, $J_{2',3'} = 6.8$ Hz, H-3′), 4.98 (dd, 1H, $J_{5',6a'} = 9.3$ Hz, H-6a′), 4.76 (d, 1H, $J_{1,2} = 3.5$ Hz, H-1), 4.50 (ddd, 1H, $J_{1,2} = 3.5$, $J_{2,3} = 11.6$, $J_{NH,2} = 9.8$ Hz, H-2), 4.49 (d, 1H, $J = 11.7$ Hz, PhC*H*$_2$), 4.33 (td, 1H, $J = 11.5$, $J_{1',2'} = 3.5$ Hz, H-1′), 4.21 (ddd, 1H, $J_{4',5'} \approx J_{5',6b'} = 4.1$, $J_{5',6a'} = 9.3$ Hz, *H*-5′, 4.20 (d, 1H, $J =$ 11.7 Hz, PhC*H*$_2$), 4.06 (dd, 1H, $J_{2',3'} = 6.8$, $J_{1',2'} =$ 3.5 Hz, H-2′), 3.97 (dd, 1H, $J_{5',6'b} = 4.1$, $J_{6'a,6'b} =$ 11.5 Hz, H-6b′), 3.95–3.85 (m, 2H, H-5, H-6a), 3.72–3.63 (m, 1H, H-6b), 3.28 (m, 1H, H-4), 2.47–2.37 (m, 1H, H-7a), 2.33–2.23 (m, 1H, H-3), 1.88 (s, 3H, NHCOC*H*$_3$), 1.74 (s, 3H, COC*H*$_3$), 1.63–1.58 (m, 1H, H-7b), 1.61 (s, 3H, COC*H*$_3$), 1.60 (s, 3H, COC*H*$_3$), 1.43 (s, 3H, C*H*$_3$), 1.23 (s, 3H, C*H*$_3$), 1.0 (s, 9H, 3 × C*H*$_3$), 0.18 (s, 3H, C*H*$_3$), 0.10 (s, 3H, C*H*$_3$); ^{13}C NMR (C_6D_6, 100 MHz): δ 171.1, 169.2, 169.2, 169.1, 137.9, 128.6, 128.6, 128.2, 128.1, 99.8, 97.4, 73.2, 70.6, 70.1, 69.7, 67.4, 65.8, 63.1, 60.6, 53.9, 35.4, 29.4, 28.4, 25.9, 22.9, 20.5, 20.3, 20.1, 19.1, 18.3, −4.7, −4.9. ESIMS *m*/*z*: calcd for $[C_{37}H_{58}NO_{13}Si]^+$: 752.3677. Found: 752.3673. Anal. Calcd for $C_{37}H_{57}NO_{13}Si$: C, 59.10; H, 7.64; N, 1.86. Found: C, 59.32; H, 7.66; N, 1.74.

4.12. Benzyl 2-acetamido-3-C-(2′,3′,4′,6′-tetra-*O*-acetyl-α-L-galactopyranosyl)methyl-2,3-dideoxy-4,6-*O*-isopropylidene-α-D-glucopyranoside (19)

To a solution of **18** (12 mg, 16 μmol) in THF (1 mL) was added a 1 M solution of Bu_4NF in THF (16 μL, 1 equiv). After 10 min at room temperature, the solution was concentrated and the residue was partitioned between H_2O and CH_2Cl_2. The organic phase was dried (phase separator filter) and concentrated. A solution of the residue in pyridine (1 mL) and acetic anhy-

dride (0.5 mL) was kept at room temperature overnight, then concentrated. Flash chromatography of the residue (step gradient from 100:0.5→100:2 CH_2Cl_2–MeOH) afforded **19** (10.4 mg, 96%). $[\alpha]_D^{29}$ 81.0 (*c* 1.0, $CHCl_3$); ^1H NMR (CD_3CN, 400 MHz): δ 7.36–7.24 (m, 5H, Ph), 6.46 (d, 1H, $J_{NH,2} = 9.8$ Hz, N*H*), 5.36 (dd, 1H, $J_{4',5'} = 2.0$, $J_{3',4'} = 3.5$ Hz, H-4′), 5.20 (dd, 1H, $J_{3',4'} = 3.5$, $J_{2',3'} = 10.0$ Hz, H-3′), 5.06 (dd, 1H, $J_{2',3'} = 10.0$, $J_{1',2'} = 5.5$ Hz, H-2′), 4.78 (dd, 1H, $J_{5,6a} = 5.0$, $J_{6a,6b} = 11.3$ Hz, H-6a), 4.74 (d, 1H, $J = 12.0$ Hz, PhCH_2), 4.71 (ddd, 1H, $J_{5,6b} = J_{6a,6b} = 11.3$ Hz, H-6b), 4.69 (d, 1H, $J_{1,2} = 3.5$ Hz, H-1), 4.53 (d, 1H, $J = 12.0$ Hz, PhCH_2), 4.29–4.21 (m, 2H, H-1′, H-5′), 4.16–4.08 (m, 2H, H-2, H-6′a), 4.06 (dd, 1H, $J_{5',6'b} = 6.0$, $J_{6'a,6'b} = 11.5$ Hz, H-6′b), 3.60 (ddd, 1H, $J_{4,5} = 10.0$ Hz, H-5), 3.52 (dd, 1H, $J_{3,4} = 10.0$ Hz, H-4), 1.92–1.79 (m, 2H, H-3, H-7a), 1.99, 1.94, 1.87, 1.85, 1.75 (5s, 15H, $5CH_3$), 1.34 (ddd, 1H, $J = 2.5$ Hz, $J = 7.0$ Hz, $J_{7a,7b} = 15.0$ Hz, H-7b), 1.42, 1.24 (2s, 6H, $2CH_3$); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 170.4, 170.2, 170.1, 136.9, 128.6, 128.3, 128.2, 99.7, 96.5, 72.6, 71.7, 69.6, 68.1, 67.7, 67.5, 66.8, 65.5, 62.5, 61.2, 53.1, 35.9, 29.6, 29.2, 28.9, 23.3, 23.1, 20.8, 20.7, 20.6, 19.1. ESIMS *m/z*: calcd for $[C_{33}H_{45}NO_{14}+Na]^+$: 702.2732. Found: 702.2749. Anal. Calcd for $C_{33}H_{45}NO_{14}$: C, 58.31; H, 6.67; N, 2.06. Found: C, 58.22; H, 6.81; N, 1.94.

4.13. Benzyl 2-acetamido-3-C-(2′,3′,4′,6′-tetra-*O*-acetyl-α-D-galactopyranosyl)methyl-2,3-dideoxy-4,6-*O*-isopropylidene-α-D-glucopyranoside (20)

To a stirred, cooled (0 °C) solution of **15** (80 mg, 0.12 mmol) in dry THF (10 mL) was added a 2 M solution of $LiBH_4$ in THF (70 μL). After 2 d at room temperature, a 1 M solution of Bu_4NF in THF (480 μL, 4 equiv) was added. After 4 min at room temperature, the solution was concentrated and the residue was partitioned between H_2O and CH_2Cl_2. The organic phase was dried (phase separator filter) and concentrated. A solution of the residue in pyridine (3 mL) and acetic anhydride (1.5 mL) was kept at room temperature overnight, then concentrated. Flash chromatography of the residue (step gradient from 100:1→100:3 CH_2Cl_2–MeOH,) afforded **20** (67.5 mg, 83%). $[\alpha]_D^{29}$ 63.0 (*c* 1.0, $CHCl_3$); ^1H NMR ($CDCl_3$, 400 MHz): δ 7.29–7.40 (m, 5H, Ph), 5.93 (d, 1H, $J_{NH,2} = 10.0$ Hz, N*H*), 5.15 (dd, 1H, $J_{2',3'} = 9.5$, $J_{1',2'} = 5.5$ Hz, H-2′), 5.07 (dd, 1H, $J_{3',4'} = 3.5$, $J_{2',3'} = 9.5$ Hz, H-3′), 4.78 (d, 1H, $J_{1,2} = 3.5$ Hz, H-1), 4.72 (d, 1H, $J = 12.0$ Hz, PhCH_2), 4.66–4.60 (m, 1H, H-1′), 4.46 (d, 1H, $J = 12.0$ Hz, PhCH_2), 4.78 (dd, 1H, $J_{5',6'a} = 8.5$, $J_{6'a,6'b} = 12.0$ Hz, H-6′a), 4.13–3.90 (m, 3H, H-5, H-2, H-6′b), 3.88–3.80 (m, 1H, H-6a), 3.76–3.65 (m, 2H, H-5, H-6b), 3.48 (dd, 1H,

Table 1. Crystallographic data for **3**, **2**, **6**, and **11**

	6	**11**	**3**	**2**
Formula	$C_{27}H_{37}N_1O_8$	$C_{27}H_{37}N_1O_9$	$C_{30}H_{41}N_1O_{10}$	$C_{30}H_{41}N_1O_{10}$
Fw	503.58	519.58	575.64	575.64
Crystal system	Monoclinic	Monoclinic	Orthorhombic	Orthorhombic
Space group	$P2_1$	$P2_1$	$P2_12_12_1$	$P2_12_12_1$
a (Å)	10.9963(3)	11.1060(4)	11.8525(11)	10.4979(14)
b (Å)	9.3926(3)	9.3810(3)	14.1706(15)	17.996(3)
c (Å)	14.4351(4)	14.3592(7)	18.5722(15)	16.512(2)
α (°)	90	90	90	90
β (°)	112.017(2)	112.552(2)	90	90
γ (°)	90	90	90	90
V (Å^3)	1382.18(7)	1381.62(9)	3119.3(5)	3119.4(7)
Z	2	2	4	4
F(000)	540	556	1232	1232
λ (Å)	0.71075	0.71075	0.71075	0.71075
T (K)	293(2)	293(2)	293(2)	293(2)
ρ_{calcd} (Mg m^{-3})	1.210	1.249	1.226	1.226
μ(Mo Kα) (mm^{-1})	0.089	0.093	0.092	0.092
θ Range (° min–max)	2.93–27.56	1.54–27.38	1.81–23.27	1.81–23.27
No. of data collected	5921	6015	14929	15018
No. of unique data	5921	6015	4488	4496
R(int)	0.0	0.0	0.0358	0.0263
No. of variable parameters	383	394	423	423
No. of obsd Refl ($I > 2\sigma(I)$)	4064	3925	4119	3928
R obsd, all	0.0472, 0.0813	0.0502, 0.0887	0.0535, 0.0594	0.0337, 0.0425
Rw obsd, all	0.0753, 0.1204	0.1268, 0.1483	0.1152, 0.1177	0.0846, 0.0908
S	1.011	1.029	1.155	1.066
$(\Delta/\sigma)_{max}$	0.010	0.009	0.000	0.002
$(\Delta/\rho)_{max,min}$ (e Å^{-3})	0.140, −0.144	0.151, −0.210	0.221, −0.179	0.165, −0.130

$J_{3,4} = J_{4,5} = 10.0$ Hz, H-4), 2.12 (s, 3H, CH_3), 2.10–2.00 (m, 1H, H-3), 2.06, 2.02, 1.98, 1.87 (4s, 12H, $4CH_3$), 1.84–1.73 (m, 1H, H-7a), 1.43, 1.39 (2s, 6H, $2CH_3$), 1.38–1.25 (m, 1H, H-7b); ^{13}C NMR ($CDCl_3$, 100 MHz): δ 170.9, 170.2, 170.1, 169.8, 169.5, 136.9, 128.5, 128.2, 128.1, 99.2, 96.2, 75.7, 70.9, 69.5, 68.6, 67.8, 67.3, 67.1, 64.9, 62.6, 62.0, 51.0, 35.7, 28.9, 25.2, 23.0, 20.7, 20.6, 20.4, 18.9. ESIMS *m/z*: calcd for $[C_{33}H_{45}NO_{14}+Na]^+$: 702.2732. Found: 702.2743. Anal. Calcd for $C_{33}H_{45}NO_{14}$: C, 58.31; H, 6.67; N, 2.06. Found: C, 58.64, H, 6.48; N, 1.96.

4.14. X-ray crystallography

X-ray diffraction data were collected by using a Kappa CCD Nonius diffractometer with graphite-monochromated Mo Kα radiation ($\lambda = 0.71073$ Å). The data were corrected for Lorentz polarization, and absorption effects. The structures were solved by direct methods using SHELXS-97[21] and refined against F^2 by full-matrix least-squares techniques using SHELXL-97[22] with anisotropic displacement parameters for all non-hydrogen atoms. Hydrogen atoms were located on a difference Fourier map and introduced into the calculations as a riding model with isotropic thermal parameters. All calculations were performed by using the Crystal Structure crystallographic software package WINGX.[23]

CCDC 676261, CCDC 676262, CCDC 676263, and CCDC 676264 contain the Supplementary data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via http://www.ccdc.cam.ac.uk/data_request/cif. The crystallographic data are summarized in Table 1.

Acknowledgments

This work was supported by the CNRS and the Ministère de l'Education Nationale, de l'Enseignement Supérieur et de la Recherche. Q. W. thanks the Ministère des Affaires étrangères for an Eiffel fellowship. We thank Professor N. Ghermani for some X-ray analysis.

Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.carres.2008.03.015.

References

1. Reviews: (a) Postema, M. H. D. *C-Glycosides Synthesis*; CRC Press: Boca Raton, 1995; (b) Levy, D. E.; Tang, C. *The Chemistry of C-Glycosides*; Elsevier: Oxford, 1995; (c) Beau, J.-M.; Gallagher, T. *Top. Curr. Chem.* **1997**, *187*, 1; (d) Beau, J.-M.; Vauzeilles, B.; Skrydstrup, T. In *Glycoscience. Chemistry and Chemical Biology*; Fraser-Reid, B., Tatsuta, K., Thiem, J., Eds.; Springer: Heidelberg, 2001; Vol. 3, p 2679.
2. For recent synthesis of C-disaccharides, see: (a) Stichler-Bonaparte, J.; Vasella, A. *Helv. Chim. Acta* **2001**, *84*, 2355–2367; (b) Dondoni, A.; Marra, A.; Mamoru, M.; Giovannini, P. P. *J. Org. Chem.* **2002**, *67*, 4186–4199; (c) Paterson, D. E.; Griffin, F. K.; Alcaraz, M.-L.; Taylor, R. J. K. *Eur. J. Org. Chem.* **2002**, 1323–1326; (d) Postema, M. H. D.; Piper, J. L.; Liu, L.; Shen, J.; Faust, M.; Andreana, P. *J. Org. Chem.* **2003**, *68*, 4748–4754; (e) Mikkelsen, L. M.; Skrydstrup, T. *J. Org. Chem.* **2003**, *68*, 2123–2128; (f) Kuberan, B.; Sikkander, S. A.; Tomiyama, H.; Linhardt, R. J. *Angew. Chem., Int. Ed.* **2003**, *42*, 2073–2075; (g) Abdallah, Z.; Doisneau, G.; Beau, J.-M. *Angew. Chem., Int. Ed.* **2003**, *42*, 5209–5212; (h) Dondoni, A.; Marra, A. *Tetrahedron Lett.* **2003**, *44*, 4067–4071; (i) Demange, R.; Awad, L.; Vogel, P. *Tetrahedron: Asymmetry* **2004**, *15*, 3573–3585; (j) Li, X.; Takahashi, H.; Ohtake, H.; Ikegami, S. *Tetrahedron Lett.* **2004**, *45*, 4123–4126; (k) Chambers, D. J.; Evans, G. R.; Fairbanks, A. J. *Tetrahedron* **2005**, *61*, 7184–7192; (l) Ress, D. K.; Baytas, S. N.; Wang, Q.; Munoz, E. M.; Tokuzoki, K.; Tomiyama, H.; Lindhardt, R. J. *J. Org. Chem.* **2005**, *70*, 8197–8200; (m) Steunenberg, P.; Jeanneret, V.; Zhu, Y.-H.; Vogel, P. *Tetrahedron: Asymmetry* **2005**, *16*, 337–346; (n) Cheshev, P.; Marra, A.; Dondoni, A. *Org. Biomol. Chem.* **2006**, *4*, 3225–3227; (o) Ren, Z.-X.; Yang, Q.; Price, K. N.; Chen, T.; Nygren, C.; Turner, J. F. C.; Baker, D. C. *Carbohydr. Res.* **2007**, *342*, 1668–1679.
3. (a) Xin, Y.-C.; Zhang, Y.-M.; Mallet, J.-M.; Glaudemans, C. P. J.; Sinaÿ, P. *Eur. J. Org. Chem.* **1999**, 471–476; (b) Glaudemans, C. P. J. *Chem. Rev.* **1991**, *91*, 25–33.
4. Yang, G.; Schmieg, J.; Tsuji, M.; Franck, R. W. *Angew. Chem., Int. Ed.* **2004**, *43*, 3818–3822.
5. (a) Rodrigues, F.; Canac, Y.; Lubineau, A. *Chem. Commun.* **2000**, 2049–2050; (b) Hersant, Y.; Abou-Jneid, R.; Canac, Y.; Lubineau, A.; Philippe, M.; Semeria, D.; Radisson, X.; Scherrmann, M.-C. *Carbohydr. Res.* **2004**, *339*, 741–745; (c) Bragnier, N.; Scherrmann, M.-C. *Synthesis* **2005**, *5*, 814–818.
6. (a) Canac, Y.; Levoirier, E.; Lubineau, A. *J. Org. Chem.* **2001**, *66*, 3206–3210; (b) Lubineau, A.; Canac, Y.; Le Goff, N. *Adv. Synth. Catal.* **2002**, *344*, 319–327; (c) Levoirier, E.; Canac, Y.; Norsikian, S.; Lubineau, A. *Carbohydr. Res.* **2004**, *339*, 2737–2747.
7. (a) Zeitouni, J.; Norsikian, S.; Merlet, D.; Lubineau, A. *Adv. Synth. Catal.* **2006**, *348*, 1662–1670; (b) For a corrigendum, see: *Adv. Synth. Catal.* **2006**, *348*, 2009.
8. Dmitriev, B. A.; Knirel, Y. A.; Kochetkov, N. K. *J. Biochem.* **1976**, *66*, 559–566.
9. (a) Kovác, P.; Edgar, K. J. *J. Org. Chem.* **1992**, *57*, 2455–2467; (b) Pozsgay, V.; Coxon, B. *Carbohydr. Res.* **1995**, *277*, 171–178; (c) Pozsgay, V. *J. Org. Chem.* **1998**, *63*, 5983–5999; (d) Pozsgay, V.; Kubler-Kielb, J.; Schneerson, R.; Robbins, J. B. *Proc. Natl. Acad. Sci. U.S.A.* **2007**, *104*, 14478–14482.
10. Wan, Q.; Lubineau, A.; Scherrmann, M.-C. *J. Carbohydr. Chem.* **2004**, *23*, 83–93.
11. (a) Ruden, R. A.; Bonjouklian, R. *J. Am. Chem. Soc.* **1975**, *97*, 6892–6893; (b) Achmatowicz, O.; Jurczak, J.; Pyrek, J. S. *Tetrahedron* **1976**, *32*, 2113–2116; (c) Bonjouklian, R.; Ruden, R. A. *J. Org. Chem.* **1977**, *42*, 4095–4103; (d) Schmidt, R.; Wagner, A. *Synthesis* **1981**, 273–275; (e) Salomon, R. G.; Roy, S.; Salomon, M. F.

Tetrahedron Lett. **1988**, *29*, 769–772; (f) Robert, H.; Garrigues, B.; Dubac, J. *Tetrahedron Lett.* **1998**, *39*, 1161–1164; (g) Yao, S.; Roberson, M.; Reichel, F.; Hazell, R. G.; Jørgensen, K. A. *J. Org. Chem.* **1999**, *64*, 6677–6687.

12. (a) David, S.; Eustache, J.; Lubineau, A. *J. Chem. Soc., Perkin Trans. 1* **1979**, 1795–1798; (b) Knapp, S.; Levorse, A. T.; Potenza, J. A. *J. Org. Chem.* **1988**, *53*, 4773–4779; (c) Bataille, C.; Bégin, G.; Guillam, A.; Lemiègre, L.; Lys, C.; Maddaluno, J.; Toupet, L. *J. Org. Chem.* **2002**, *67*, 8054–8062.
13. Krapcho, A. P. *Synthesis* **1982**, *805*, 893–914.
14. Sharpless, K. B.; Lauer, R. F. *J. Am. Chem. Soc.* **1973**, *95*, 2697–2699.
15. O'Brien, P. *J. Chem. Soc., Perkin Trans. 1* **1998**, 1439–1457.
16. Inoue, T.; Uchimaru, T.; Mukaiyama, T. *Chem. Lett.* **1977**, 1215–1218.
17. Detty, M. R. *J. Org. Chem.* **1980**, *45*, 924–926.
18. (a) Murata, S.; Suzuki, M.; Noyori, R. *J. Am. Chem. Soc.* **1979**, *101*, 2738–2739; (b) Murata, S.; Suzuki, M.; Noyori, R. *Bull. Chem. Soc. Jpn.* **1982**, *55*, 247–254.
19. Mosset, P.; Mana, S.; Viala, J.; Falk, J. R. *Tetrahedron Lett.* **1986**, *27*, 299–302.
20. (a) Cha, J. K.; Christ, W. J.; Kishi, Y. *Tetrahedron Lett.* **1983**, *24*, 3943–3946; (b) Christ, W. J.; Cha, J. K.; Kishi, Y. *Tetrahedron Lett.* **1983**, *24*, 3947–3950; (c) Cha, J. K.; Christ, W. J.; Kishi, Y. *Tetrahedron* **1984**, *40*, 2247–2255; For a review see: (d) Cha, J. K.; Kim, N. S. *Chem. Rev.* **1995**, *95*, 1761–1795.
21. Sheldrick, G. M. SHELXS-97, Program for Crystal Structure Solution, University of Göttingen, Göttingen, Germany, 1997.
22. Sheldrick, G. M. SHELXL-97, Program for the refinement of crystal structures from diffraction data, University of Göttingen, Göttingen, Germany, 1997.
23. Farrugia, L. J. *J. Appl. Crystallogr.* **1999**, *32*, 837–838.