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2,4-Diazido-2,4,6-trideoxy-L-hexopyranoses as valuable building units in the synthesis of natural products

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Abstract—Synthesis of five L-enantiomers of 2,4-diazido-2,4,6-trideoxy-pyranoses has been accomplished. These sugars were prepared via the regioselective protection of hydroxyl groups in L-rhamnoside and L-fucoside, followed by triflation and subsequent S_N2 substitution with azido nucleophiles.

1. Introduction

In recent years interest in the 2,4-diamino-2,4,6-trideoxy-hexoses has markedly increased. This has been caused by their direct involvement in biological and immunochemical phenomena. These sugars have been recognized in Gram-negative pathogens as components of O-specific polysaccharides of the different types of *Shigella*[1] as well as of the capsular polysaccharides of *Bacteroides fragilis*[2] and *Streptococus pneumoniae*.[3] In addition, the fragments of 2,4-diamino-2,4,6-trideoxy-hexoses can be found in the structures of bacterial polysaccharides of 5,7-diamino-3,5,7,9-tetradeoxy-non-ulosonic acids[4] and have been used for their synthesis.[5] On the other hand, these aminosugars have also been isolated from kasugamycin[6] and other aminoglycosidic antibiotics.[7]

Most of the syntheses of 2,4-diamino-2,4,6-trideoxy-hexopyranoses concerns the D-enantiomers,[8] which were also utilized for the synthesis of polysaccharides.[9] Syntheses of L-enantiomers are rather rare,[5,10,11] therefore there is a constant need to develop efficient methodologies for their preparation.

As a part of our progress in the synthesis of isomeric 2,4-diamino-2,4,6-trideoxy-hexopyranoses of the defined structure, we present here convenient routes to their precursors that is, L-diazido sugars. The azido sugars are valuable synthons in the synthesis both of disaccharides[12] and glycopeptides,[13] which contain an amino-sugar unit, due to the unique properties of the azido moiety to serve as a protective, nonactive group, easily convertible into amino function.

2. Results and discussion

Previous routes to 2,4-diazido-2,4,6-trideoxyhexopyranosides used commercially available monosaccharides (glucose, mannose, rhamnose, and fucose) as starting materials. Their transformation into the desired 2,4-diazido compounds was performed via epoxide formation/ring opening, or by nucleophilic substitution of sulfonate groups. Our own synthetic sequence, depicted in Schemes 1–3 also utilizes similar reactions for conversion of L-rhamnose and L-fucose derivatives. However, improved processes of displacement of the sulfonate function by azide ion without oxirane ring cleavage or opening of the oxirane ring by azide without displacing the mesyl function, now allow the preparation of 2,4-diazido sugars of the required configuration and in a satisfactory yield.

Approaching the synthesis of methyl 2,4-diazido-2,4,6-trideoxy-α-L-*ido*-pyranoside **6** methyl-α-L-*rhamno*-pyranoside **1** was regioselectively protected at C-3 by a *p*-methoxybenzyl (PMB) residue in a Bu_3SnO mediated reaction,[14] to give **2a** (Scheme 1). Further manipulation with the blocking groups, as shown in Scheme 1, led to methyl 2,4-di-*O*-acetyl-α-L-*rhamno*-pyranoside **2c** in high yield. This was converted to the 3-*O*-triflate derivative **2d** furnishing, after treatment with MeONa

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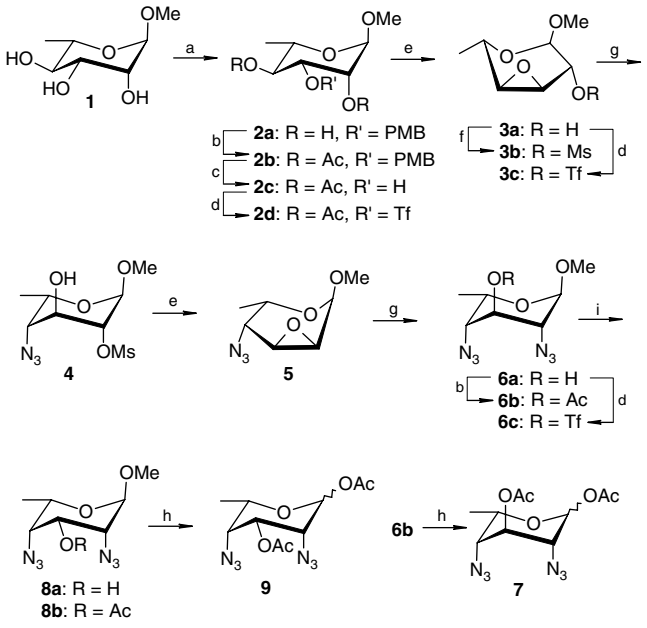
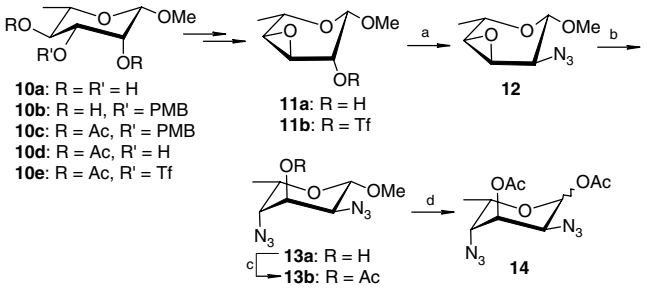
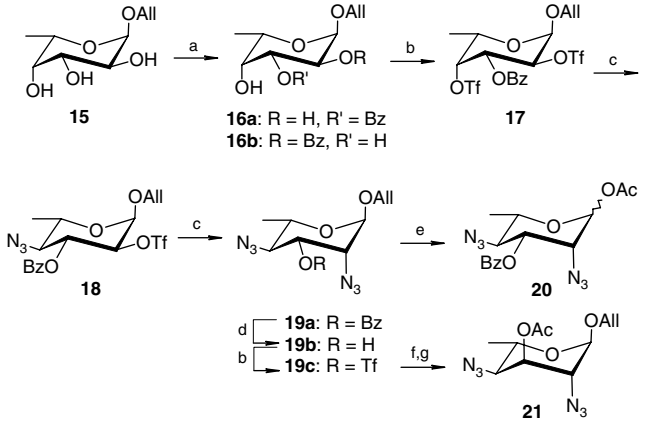


Scheme 1. Reagents and conditions: (a) (1) Bu_2SnO, (2) PMBI; (b) Ac_2O, Py; (c) CAN; (d) Tf_2O, Py; (e) MeONa, MeOH; (f) MsCl, Py; (g) $TMSN_3/BF_3{\cdot}OEt_2$; (h) Ac_2O, AcOH, H_2SO_4; (i) $NaNO_2$, DMF.



Scheme 2. Reagents and conditions: (a) NaN_3, 18-crown-6, DMF; (b) (g) $TMSN_3/BF_3{\cdot}OEt_2$; (c) Ac_2O, Py; (d) Ac_2O, AcOH, H_2SO_4.



Scheme 3. Reagents and conditions: (a) (1) Bu_2SnO, benzene, reflux, (2) BzCl; (b) Tf_2O, Py; (c) NaN_3, 18-crown-6, DMF; (d) MeONa, MeOH; (e) $PdCl_2$, AcOH, H_2O, AcONa; (f) $NaNO_2$, DMF; (g) Ac_2O, Py.

solution, the epoxide **3a**. The 2-OH group in **3a** was sulfonylated (MsCl, TsCl, Tf_2O) to give the corresponding derivatives **3b**,**c**. The oxirane ring in 2-*O*-methyl derivative **3b** was regioselectively cleavaged using $TMSN_3$ in the presence of BF_3 etherate[11b,15] to afford 4-azido sugars **4**. As indicated by the coupling constants ($J_{1,2}$ 3.9, $J_{2,3}$ 5.7, $J_{3,4}$ 5.5, $J_{4,5}$ 3.7 Hz) the conformation of **4** is slightly distorted to $^1C_4$ form due to 1,3-diaxial interaction in $^4C_1$.

Assuming that a direct substitution of the mesyl group in **4** by an azide ion could not be efficient enough due to the *axial–axial* arrangement of 1-OMe-2-OMs,[16] compound **4** was converted first into the oxirane derivative **5**. Compound **5** was treated with $TMSN_3/BF_3{\cdot}OEt_2$ species to afford 2,4-diazido sugar of α-L-*ido* configuration **6**. The NMR data ($J_{1,2}$ 6.2, $J_{2,3}$ 9.0, $J_{3,4}$ 8.1, $J_{4,5}$ 5.0 Hz) confirmed high predominance of $^4C_1$ conformation due to 1,3-*diaxial* interaction of 2,4-azido groups, reinforced further by an 1,3-interaction of negative $4N_3$ group with the ring oxygen and are in full agreement with the conclusion of Paulsen and Koebernick regarding 2,4-diazido-α-D-*ido* enantiomer.[8b]

Because 1,2-substituents in **3c** are rather pseudo-*axial* and 3-OTf is a very effective leaving group, it was interesting to check whether it would be possible to displace the 2-OTf group in the epoxide **2c** by an azide ion. For this purpose compound **3c** was treated with NaN_3 (or Bu_4NN_3) in DMF. The reaction mixture was stirred at room temperature, then at 60 °C. Unfortunately, the substrate failed to react and after a long time decomposed.

Compound **6a** was utilized for the preparation of L-talo isomer **8** in a simple triflation of the 3-OH group, followed by reaction with $NaNO_2$.

A very similar reaction sequence was performed with methyl β-L-rhamnoside **10** providing, in the final step, methyl 2,4-diazido-2,4,6-trideoxy-β-L-gulopyranoside **14** (Scheme 2).

For the preparation of starting sugar **10a** the glycosylation procedure of Hodosi and Kovác via 'locked anomeric configuration' was applied.[17] Accordingly, reaction of L-rhamnose with Bu_2SnO gave the 1,2-*O*-*cis*-stannylene acetal, which upon treatment with MeI underwent substitution at C-1 by a methyl group. β-Glycoside **10a** thus obtained in 70% yield was accompanied by the 3-OMe derivative, which resulted from the isomerization of the acetal (1,2 → 1,3). Further synthetic steps, depicted in Scheme 2, were fully analogous to the transformation of the α-anomer. The stability of the epoxide ring in **11a** during introduction of the 2-*O*-triflate group and its displacement by azide allowed **12** containing the 2-N_3 moiety to be produced.[5] Oxirane ring cleavage with $TMSN_3/BF_3{\cdot}OEt_2$ provided required L-*gulo* isomer **13a** in high yield.

Removal of 1-*O*-methyl group in all the 2,4-diazido sugars was readily performed by acetolysis (Ac_2O–AcOH–H_2SO_4) to give the corresponding α,β-1-*O*-acetyl derivatives.

Utilizing L-fucose as the precursor of a synthesis of 2,4-diazido-2,4,6-trideoxy-L-mannose and L-altrose was accomplished. The synthesis begins from allyl α-L-fucoside **15**, which was converted into 3-*O*-benzoyl derivative **16a** via a Bu_2SnO/BzCl reaction. The esterification process was accompanied by the known migration of the benzoyl residue to furnish 2-*O*-benzoyl derivative **16b**. Compound **16a** was readily transformed into the 2,4-di-*O*-triflate derivative **17** in high yield (Scheme 3).

Displacement of *O*-triflate residues by azide was conducted with NaN_3/18-crown-6 or with Bu_4NN_3 in DMF. It was noticed that the displacement of the 4-OTf group proceeds much faster than that of the 2-OTf at temperatures below 40 °C, leading to **18**. To substitute the 2-OTf residue the temperature had to be raised to 60 °C, affording after 2 h diazido derivative **19a**. 1-*O*-Deallylation of **19a** was performed by the use of $PdCl_2$ in MeOH,[18] or $PdCl_2$/AcOH, AcONa,[19] to give after acetylation 1,3-di-*O*-acetyl-2,4-diazido-3-*O*-benzoyl-α,β-L-*manno*-pyranoside **20**.

Inversion of the configuration at C-3 of **19** was accomplished via a reaction sequence involving deblocking of the 3-*O*-Bz, introduction of the 3-OTf and its displacement using $NaNO_2$, thus leading to 2,4-diazido-2,4,6-trideoxy-α-L-*altro*-pyranoside **21**.

The azido sugars presented herein are valuable building blocks in the synthesis of the disaccharide part of glycoproteins and glycolipids. In addition, they can be used as the starting material for different carbohydrate-based mimetics.

3. Experimental

3.1. General

Optical rotations were measured with a JASCO Dip-360 Digital Polarimeter at room temperature. ^{1}H NMR spectra were recorded on Varian-400 (400 MHz) spectrometers with Me_4Si as internal standard. High-resolution mass spectra were taken on a Mariner PerSeptive Biosystems mass spectrometer with time-of-flight (TOF) detector. IR spectra were taken with a Perkin Elmer FT-IR-1600 spectrophotometer. Reactions were controlled using TLC on silica [Merck alu-plates (0.2 mm)]. All reagents and solvents were purified and dried according to common methods. All organic solutions were dried over $MgSO_4$. Reaction products were purified by flash chromatography using Merck's Kieselgel 60 (240–400 mesh or 70–230 mesh).

3.2. Methyl 3-*O*-(*p*-methoxy)benzyl-α-L-hamnopyranoside 2a

A suspension of Bu_2SnO (2.49 g, 10 mmol) in dry MeOH (50 mL) containing methyl α-L-rhamnopyranoside (1.78 g, 10 mmol) was heated under reflux until a clear solution was formed (~1 h). Then CsF (2.28 g, 15 mmol) and toluene (10 mL) were added and the solvents were evaporated. The residue was dried in vacuo for 30 min leaving a white powder. To this, dry DMF (20 mL) was added and the mixture was vigorously stirred. A solution of PMBI (3.72 g, 15 mmol) in DMF (2.5 mL) was added in two portions in 2 h intervals between the additions. After 3 h the mixture was diluted with ether, filtered, and washed with brine. The solvent was evaporated to dryness and the residue was chromatographed on a silica gel column (ether). Eluted first was methyl **2a** (1.26 g, 42%). Colorless oil, R_f 0.5 (ether); $[\alpha]_D = -22.9$ (*c* 0.95, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.3, 6.9 (2d, 4H, Ph), 4.71 (d, 1H, *J* 1.5 Hz, H-1), 4.63, 4.48 (2d, 2H, *J* 11.3 Hz, CH_2Ph), 4.00 (m, 1H, H-2), 3.81 (s, 3H, MeOPh), 3.64 (pq, 1H, *J* 6.6, 9.2 Hz, H-5), 3.60 (dd, 1H, *J* 3.2, 9.2 Hz), 3.52 (t, 1H, *J* 9.2 Hz, H-4), 3.36 (s, 3H, OMe), 2.36 (br s, 1H, OH), 2.12 (br s, 1H, OH), 1.31 (d, 3H, *J* 6.2 Hz, Me); ^{13}C NMR (50 MHz, $CDCl_3$) δ: 129.6, 114.1, 100.4, 71.3, 79.5, 71.5, 67.7, 67.5, 55.3, 54.8, 17.6 (C-6); IR (film, cm^{-1}) *v*: 3440 (br), 1613, 1587, 1515, 1250. HRMS (ESI): exact mass calcd for $C_{15}H_{22}O_6Na$ $[M+Na]^+$ 321.1309, found 321.1326. Eluted with ethyl acetate was **1** (0.78 g, 44%).

3.3. Methyl 2,4-di-*O*-acetyl-3-*O*-(*p*-methoxy)benzyl-α-L-rhamnopyranoside 2b

A solution of **2a** (1.26 g, 4.2 mmol) in the mixture of Ac_2O and pyridine (1:1, 10 mL) was left overnight, then evaporated with toluene (three times) and dried in vacuo to give **2b** (1.62 g, nearly quantitative yield). Colorless oil, R_f 0.8 (ethyl acetate–hexanes, 1:1); $[\alpha]_D = -6.2$ (*c* 2.02, $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$) δ: 7.18, 6.85 (2d, 4H, Ar), 5.32 (dd, 1H, *J* 3.4, 1.7 Hz, H-2), 5.00 (m, 1H, H-4), 4.63 (d, 1H, *J* 1.7 Hz, H-1), 4.3, 4.6 (2d, 2H, *J* 11.7 Hz, CH_2Ph), 4.00 (m, 1H, H-2), 3.80 (s, 3H, MeOPh), 3.8–3.6 (m, 2H, H-3, H-5), 3.35 (s, 3H, MeO), 2.14, 2.01 (2s, 6H, 2 Ac), 1.20 (d, 3H, *J* 6.4 Hz, Me); IR (film, cm^{-1}) *v*: 1748, 1613, 1515, 1231. HRMS (ESI): exact mass calcd for $C_{19}H_{26}O_8Na$ $[M+Na]^+$ 405.1520, found 405.1542.

3.4. Methyl 2,4-di-*O*-acetyl-α-L-rhamnopyranoside 2c

A solution of **2b** (1.62 g, 4.2 mmol) and CAN (4.85 g, 8.9 mmol) in the mixture MeCN–H_2O (9:1, 50 mL) was stirred until disappearance of the substrate (~2 h). A two-phase system was carefully poured out into 50 mL of satd aq $NaHCO_3$. The mixture was extracted with CH_2Cl_2. The combined organic extracts were washed with brine and evaporated. The residue was chromatographed on a silica gel (ether) to give **2c** (0.79 g, 71%). Colorless needles, mp 105 °C (hexane); R_f 0.5 (ethyl acetate–hexanes, 1:1); $[\alpha]_D = -38.3$ (*c* 0.95, $CHCl_3$); ^{1}H NMR (200 MHz, $CDCl_3$) δ: 5.04 (dd, 1H, *J* 1.6 Hz, H-2), 4.84 (t, 1H, *J* 9.9, 9.7 Hz, H-4), 4.64 (d, 1H, *J* 1.6 Hz, H-1), 4.0 (ddd, 1H, *J* 9.7, 7.3, 1.6 Hz, H-3), 3.80 (dq, 1H, *J* 9.7, 6.2 Hz, H-5), 3.37 (s, 3H, OMe), 2.16, 2.14 (2 s, 6H, 2Ac), 2.05 (d, 1H, *J* 7.3 Hz, OH), 1.22 (d, 3H, *J* 6.2 Hz, Me); ^{13}C NMR (50 MHz,

$CDCl_3$) δ: 98.1, 74.7, 72.7, 68.6, 65.7, 55.1, 21.0, 17.4; IR (KBr, cm^{-1}) ν: 3537 (sharp), 1737 (Ac), 1250, 1239. Anal. Calcd for $C_{11}H_{18}O_7$: C, 50.38; H, 6.92. Found: C, 50.37; H, 7.07.

3.5. Methyl 2,4-di-*O*-acetyl-3-*O*-trifluoromethanesulfonyl-α-L-rhamnopyranoside 2d

To a solution of **2c** (0.79 g, 3.02 mmol) in dry CH_2Cl_2 (15 mL) a mixture of Tf_2O (0.8 mL, 4.5 mmol) and pyridine (0.8 mL) in CH_2Cl_2 (20 mL) was added at 0 °C and the reaction mixture was stirred for 10 min. Then the solvent was evaporated. Co-evaporation of the residue with toluene left a syrup, which was extracted with hot hexane (3×25 mL), to give **2d** (1.14 g, 96%). Colorless crystals; mp 123–124 °C (with decomp.); R_f 0.5 (ethyl acetate–hexanes, 1:3); $[\alpha]_D = -39.8$ (*c* 0.85, $CHCl_3$); HRMS (ESI): exact mass calcd for $C_{12}H_{17}O_9SF_3Na$ $[M+Na]^+$ 417.0438, found 417.0448.

3.6. Methyl 3,4-anhydro-6-deoxy-α-L-altropyranoside 3a

To a solution of **2d** (1.14 g, 2.89 mmol) in MeOH, (10 mL) 2 M NaOH (3 mL) was added dropwise at rt and the mixture was stirred for 0.5 h. Then it was neutralized with AcOH, evaporated and the residue was extracted with CH_2Cl_2. Removal of the solvent and column chromatography of the residue (hexane–ether, 1:1) gave **3a** as a white solid (0.34 g, 74%), mp 65–66 °C; $[\alpha]_D = -79.5$ (*c* 1.70, $CHCl_3$); ^1H NMR (200 MHz, $CDCl_3$) δ: 4.40 (d, 1H, *J* 4.4 Hz, H-1), 4.29 (q, 1H, *J* 7.1, H-5), 3.80 (dd, 1H, *J* 6.6, 4.4 Hz, H-2), 3.27, 3.03 (2d, 2H, *J* 4.0 Hz, H-3, H-4), 2.07 (d, 1H, *J* 6.6 Hz, OH), 1.42 (d, 3H, *J* 7.1 Hz, Me); ^{13}C NMR (50 MHz, $CDCl_3$) δ: 99.6, 66.0, 65.8, 53.7, 52.9, 56.2, 17.5.

3.7. Methyl 3,4-anhydro-6-deoxy-2-*O*-methanesulfonyl-α-L-altropyranoside 3b

To a solution of **3a** (0.14 g, 0.88 mmol) in dry CH_2Cl_2 (10 mL) pyridine (0.3 mL) and MsCl (0.15 mL, 2.0 mmol) were added. After 12 h a satd aq solution of $NaHCO_3$ (0.5 mL) was added and the mixture was stirred for 0.5 h. The organic layer was separated and the water phase was extracted with dichloromethane. The combined organic solution was washed with brine, filtered through a layer of $MgSO_4$, and concentrated to give a crystalline **3b** (0.21 g, quantitative yield). Mp 106–107 °C (chloroform–hexane); R_f 0.7 (ether–hexanes, 2:1); $[\alpha]_D = -56.5$ (*c* 1.00, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$) δ: 4.62 (d, 1H, *J* 4.3 Hz, H-1), 4.55 (dd, 1H, *J* 4.3, 0.5 Hz, H-2), 4.31 (q, 1H, *J* 7.0 Hz, H-5), 3.42 (pq, 1H, *J* 0.7, 1.4, 3.7 Hz, H-3 or H-4), 3.41 (s, 3H, OMe), 3.11 (s, 3H, $MeSO_3$), 3.08 (dt, 1H, *J* 0.7, 3.7 Hz), 1.44 (d, 3H, *J* 7.0 Hz, H-6); ^{13}C NMR (50 MHz, $CDCl_3$) δ: 96.2, 72.3, 65.9, 53.3, 51.2, 56.2, 38.3, 17.1. Anal. Calcd for $C_8H_{14}O_6S$: C, 40.34; H, 5.88; S, 13.45. Found: C, 40.46; H, 6.03; S, 13.24.

3.8. Methyl 3,4-anhydro-6-deoxy-2-*O*-trifluoromethanesulfonyl-α-L-altropyranoside 3c

Prepared according to the procedure described for **2d**. White solid; $[\alpha]_D = -47.6$ (*c* 0.70, $CHCl_3$).

3.9. Methyl 4-azido-4,6-dideoxy-2-*O*-methanesulfonyl-α-L-idopyranoside 4

To a suspension of **3b** (0.20 g, 0.85 mmol) in $TMSN_3$ (1.0 mL), $BF_3{\cdot}Et_3O$ (0.1 mL) was added and the reaction mixture was stirred at rt until no more starting material was detected by TLC. Then the solution was poured onto ice and extracted with CH_2Cl_2. The extracts were washed with aqueous solution Na_2CO_3, dried, and evaporated. Chromatography on silica gel (ether–hexanes, 1:1) gave **4** (0.15 g, 63%) as a pale yellow oil. R_f 0.8 (ether–hexanes, 2:1); $[\alpha]_D = -50.5$ (*c* 2.00, $CHCl_3$); ^1H NMR (200 MHz, $CDCl_3$) δ: 4.77 (d, 1H, *J* 3.9 Hz, H-1), 4.50 (d, 1H, *J* 3.9 Hz, H-2), 4.28 (dq, 1H, *J* 6.7, 3.7 Hz, H-5), 4.10 (ddd, 1H, *J* 7.2, 5.7, 5.5 Hz, H-3), 3.51 (dd, 1H, *J* 5.5, 3.7 Hz, H-4), 3.46 (s, 3H, MeO), 3.23 (d, 1H, *J* 7.2 Hz, OH), 3.15 (s, 3H, Me-SO_3), 1.32 (d, 3H, *J* 6.7 Hz, Me); ^{13}C NMR (50 MHz, $CDCl_3$) δ: 98.3, 75.6, 68.9, 64.2. 62.4, 56.0, 38.6, 15.5. Anal. Calcd for $C_8H_{15}O_6SN_3$: C, 34.16; H, 5.33; N, 14.95. Found: C, 34.57; H, 5.38; N, 14.34.

3.10. Methyl 2,3-anhydro-4-azido-4,6-dideoxy-α-L-gulopyranoside 5

To a solution of **4** (90 mg, 0.33 mmol) in dry MeOH (2 mL) 1 M MeONa (0.3 mL) was added. After 1 h the reaction mixture was worked up as described for **3a** to give **5** (60 mg, quantitative yield). Colorless oil; R_f 0.6 (ether–hexanes, 1:1); $[\alpha]_D = -64.5$ (*c* 0.67, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$) δ: 4.93 (d, 1H, *J* 3.0 Hz, H-1), 4.10 (dq, 1H, *J* 6.6, 1.8 Hz, H-5), 3.54 (dd, 1H, *J* 3.7, 2.2 Hz, H-3), 3.46 (s, 3H, MeO), 3.45–3.35 (m, 1H, H-2), 3.36 (t, 1H, *J* 1.8 Hz, H-4), 1.27 (d, 3H, *J* 6.6 Hz, Me); ^1H NMR (400 MHz, C_6D_6) δ: 4.46 (d, 1H, *J* 3.1 Hz, H-1), 3.96 (dq, 1H, *J* 6.6, 1.8 Hz, H-5), 3.12 (s, 3H, MeO), 2.86 (dd, 1H, *J* 3.7, 2.2 Hz, H-3), 2.81 (ddd, 1H, *J* 3.7, 3.11, 0.5 Hz, H-2), 1.37 (m, 1H, H-4), 1.00 (d, 3H, *J* 6.6 Hz, Me); ^{13}C NMR (50 MHz, C_6D_6) δ: 95.2, 63.5, 57.8, 55.1, 50.7, 50.5, 16.8.

3.11. Methyl 2,4-diazido-2,4,6-trideoxy-α-L-idopyranoside 6a

A suspension of **5** (0.63 g, 3.41 mmol) in $TMSN_3$ (3.0 mL) was treated with $BF_3{\cdot}OEt_2$ (0.5 mL). Further proceeding—analogous to that described for **4**, to give 0.69 g of **6a**. Yield 89%; colorless oil; R_f 0.65 (ether–hexanes, 1:1); $[\alpha]_D = -41.1$ (*c* 0.19, $CHCl_3$); ^1H NMR (200 MHz, $CDCl_3$) δ: 4.57 (d, 1H, *J* 5.0 Hz, H-1), 4.26 (dq, 1H, *J* 6.8, 4.4 Hz, H-5), 3.82 (dt, 1H, *J* 6.7 Hz, H-3), 3.55 (dd, 1H, *J* 6.7, 4.4 Hz, H-4), 3.47 (s, 3H, OMe), 3.45 (dd, 1H, *J* 6.7, 5.0 Hz, H-2), 2.98 (d, 1H, *J* 6.0 Hz, OH), 1.29 (d, 3H, *J* 6.8 Hz, Me); ^{13}C NMR (50 MHz, $CDCl_3$)

δ: 99.2, 69.9, 65.6, 63.5, 62.9, 56.2, 15.1; IR (film, cm^{-1}) ν: 3446 (OH), 2111 (N_3), 1260.

3.12. Methyl 3-*O*-acetyl-2,4-diazido-2,4,6-trideoxy-α-L-idopyranoside 6b

Usual acetylation of **6a** gave **6b** as a syrup. $[\alpha]_D = -61.1$ (c 0.90, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$) δ: 5.10 (t, 1H, J 8.1 Hz, H-3), 4.53 (d, 1H, J 6.2 Hz, H-1), 4.30 (pq, 1H, J 5.0, 6.9 Hz H-5), 3.64 (dd, 1H, J 5.0, 8.1 Hz, H-4), 3.49 (s, 3H, OMe), 3.45 (dd, 1H, J 6.2, 8.9 Hz, H-2), 2.16 (s, 3H, OAc), 1.29 (d, 3H, J 6.9 Hz, Me); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 98.9, 70.3, 67.4, 62.6, 62.1, 56.4, 20.8, 14.4; HRMS (ESI): exact mass calcd for $C_9H_{14}O_4N_6Na$ $[M+Na]^+$ 293.0969, found 293.0986.

3.13. 1,3 Di-*O*-acetyl-2,4-diazido-2,4,6-trideoxy-α-L-idopyranose 7

Compound **6b** (0.135 g, 0.5 mmol) was dissolved in Ac_2O (4 mL), AcOH (2 mL), and the solution was cooled to −20 °C. 1 M H_2SO_4 in Ac_2O (0.4 mL) was added. The reaction was monitored by TLC (CH_2Cl_2–acetone, 9:1), raising the temperature to 25 °C. After finishing of the reaction AcONa (0.2 g) was added and the mixture was concentrated, then subjected to column chromatography. Eluted first (CH_2Cl_2–acetone, 7:3) was the α anomer (59 mg, 39%) **7**: $[\alpha]_D = -18.6$ (c 0.83, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$) δ: 5.84 (d, 1H, J 6.7 Hz, H-1), 5.19 (t, 1H, J 8.3, 8.5 Hz, H-3), 4.34 (pq, 1H, J 5.0, 6.9 Hz, H-5), 3.70 (dd, 1H, J 5.0, 8.3 Hz, H-4), 3.60 (dd, 1H, J 6.7, 8.5 Hz, H-2), 2.19, 2.16 (2s, 2×3H, 2×Ac), 1.34 (d, 3H, J 6.9 Hz, Me); IR (KBr, cm^{-1}) ν: 2109, 1760; HRMS (ESI): exact mass calcd for $C_{10}H_{14}O_5N_6Na$ $[M+Na]^+$ 321.0918, found 321.0934. Eluted second was the β anomer (42 mg, 28%): $[\alpha]_D = +116.3$ (c 0.59, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$) δ: 6.10 (d, 1H, J 3.0 Hz, H-1), 5.40 (t, 1H, J 6.2 Hz, H-3), 4.22 (pq, 1H, J 4.1, 6.7 Hz, H-5), 3.58 (dd, 1H, J 4.1, 6.2 Hz, H-4), 3.56 (dd, 1H, J 3.0, 6.2 Hz, H-2), 2.18, 2.17 (2s, 2×3H, 2×Ac), 1.40 (d, 3H, J 6.7 Hz, Me); HRMS (ESI): exact mass calcd for $C_{10}H_{14}O_5N_6Na$ $[M+Na]^+$ 321.0918, found 321.0933.

3.14. Methyl 2,4-diazido-2,4,6-trideoxy-α-L-talopyranoside 8a

To a solution of **6a** (0.65 g, 2.85 mmol) in dry CH_2Cl_2 (15 mL) a mixture of Tf_2O (0.70 mL, 4.28 mmol) and pyridine (0.8 mL) in CH_2Cl_2 (70 mL) was added at −10 °C and the reaction mixture was allowed to stay for 10 min. Then it was diluted with CH_2Cl_2, washed with brine, filtered through a layer of $MgSO_4$, and concentrated. The residue was dried by three times evaporation with toluene, then the crude tiflate (1.0 g) was dissolved in DMF (30 mL). To this solution, sodium nitrite (0.3 g, 4.4 mmol) was added and the mixture was stirred overnight at rt. The solvent was evaporated in vacuo and the residue was taken into CH_2Cl_2, washed with water and brine, dried over $MgSO_4$ and concentrated. Crystallization from chloroform–hexane afforded **8a** (0.51 g). Yield 78%; mp 166–167 °C; $[\alpha]_D = -53.2$ (c 0.74, $CHCl_3$). Anal. Calcd for $C_7H_{12}O_3N_6$: C, 36.83; H, 5.26; N, 36.85. Found: C, 36.97; H, 5.41; N, 37.01.

Usual acetylation of **8a** afforded **8b**. $[\alpha]_D = -94.8$ (c 0.77, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$) δ: 5.37 (t, 1H, J 4.1 Hz, H-3), 4.69 (d, 1H, J 1.1 Hz, H-1), 4.00 (pq, 1H, J 1.9, 6.5 Hz H-5), 3.88 (td, 1H, J 1.1, 4.1 Hz, H-2), 3.80 (ddd, 1H, J 1.0, 1.9, 2.9 Hz, H-4), 2.21 (s, 3H, OAc), 1.32 (d, 3H, J 6.5 Hz, Me); HRMS (ESI): exact mass calcd for $C_9H_{14}O_4N_6Na$ $[M+Na]^+$ 293.0969, found 293.0969.

3.15. 1,3-Di-*O*-acetyl-2,4-diazido-2,4,6-trideoxy-α-L-talopyranose 9

Acetolysis of **8b** was performed according to the procedure described for **7**, to give **9** as α/β mixture in 72% yield. Chromatography on silica gel (hexane–ether, 7:3) gave the α anomer in the first fraction: $[\alpha]_D = -73.5$ (c 0.46, $CHCl_3$); ^1H NMR (400 MHz, C_6D_6) δ: 6.11 (d, 1H, J 1.6 Hz), 5.08 (t, 1H, J 4.1 Hz, H-3), 3.52 (pq, 1H, J 2.1, 6.3 Hz H-5), 3.29 (dq, 1H, J 1.6, 4.1 Hz, H-2), 3.14 (m, 1H, H-4), 1.74, 1.55 (2s, 2×3H, 2×Ac), 0.99 (d, 3H, J 6.3 Hz, Me); HRMS (ESI): exact mass calcd for $C_{10}H_{14}O_5N_6Na$ $[M+Na]^+$ 321.0918, found 321.0934.

β-Anomer: $[\alpha]_D = +84.2$ (c 0.33, $CHCl_3$); ^1H NMR (400 MHz, C_6D_6) δ: 5.32 (d, 1H, J 1.6 Hz, H-1), 4.52 (t, 1H, J 4.1 Hz, H-3), 3.36 (ddd, 1H, J 0.8, 1.8, 4.1 Hz H-2), 2.83 (ddd, 1H, J 0.8, 1.8, 4.1 Hz, H-4), 2.78 (pq, 1H, J 1.8, 6.4 Hz, H-5), 1.74, 1.57 (2s, 2×3H, 2×Ac), 1.00 (d, 3H, J 6.4 Hz, Me); HRMS (ESI): exact mass calcd for $C_{10}H_{14}O_5N_6Na$ $[M+Na]^+$ 321.0918, found 321.0934.

3.16. Methyl β-L-rhamnopyranoside 10a and methyl 3-*O*-methyl-β-L-rhamnopyranoside

A suspension of Bu_2SnO (2.05 g, 8.2 mmol) in dry MeOH (30 mL) containing L-rhamnose hydrate (1,82 g, 10 mmol) was heated to reflux until a clear solution was formed (30 min). Then CsF (1.90 g, 12 mmol) and toluene (10 mL) were added and the solvents were evaporated in vacuo. The residue was dried in vacuo for 10 min leaving a white powder. To this, dry DMF (35 mL) was added and the mixture was vigorously stirred. After 10 min a solution of MeI (0.77 mL, 1.2 mmol) in DMF (2.5 mL) was slowly added 10 min and the mixture was stirred for 3 h. Then the solvent was evaporated and the residue was chromatographed on a silica gel column (CH_2Cl_2–MeOH, 9:1 > 1:1). Eluted first was methyl 3-methyl-β-L-rhamnopyranoside (0.44 g, 28%). White solid; mp 114–115 °C (CH_2Cl_2–hexane) characterized as its 2,4-di-*O*-acetyl derivative: mp 122–123 °C; $[\alpha]_D = +84.0$ (c 0.25, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$) δ: 5.58 (dd, 1H, J 1.1, 3.3 Hz, H-2), 4.93 (t, 1H, J 9.6, 9.8 Hz, H-4), 4.43 (d, 1H, J 1.1 Hz, H-1), 3.53 (s, 3H, CH_3Ph), 3.46 (pq, 1H, J 6.3, 9.6 Hz, H-5), 3.35 (s, 3H, Me), 3.31 (dd, 1H, J 3.3, 9.8 Hz, H-3), 2.10, 2.18 (2s, 2×3H, 2×Ac), 1.28 (d, 3H, J 6.3 Hz, Me). Anal. Calcd for $C_{12}H_{20}O_7$: C, 52.17; H, 7.25. Found: C,

52.16; H, 7.35. Eluted second was **10a** (1.03 g, 70%). Colorless oil; mp 155–156 °C; $[\alpha]_D = +84.4$ (*c* 0.74, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$) δ: 5.47 (dd, 1H, *J* 3.2, 1.1 Hz, H-2), 5.07 (t, 1H, *J* 10.1 Hz, H-4), 5.02 (dd, 1H, *J* 3.2, 10.0 Hz, H-3), 4.50 (d, 1H, H-1), 3.54 (pq, 1H, *J* 6.3, 10.0 Hz, H-5), 3.52 (s, 3H, Me), 2.16, 2.03, 1.97 (3s, 3×3H, 3×Ac), 1.28 (d, 3H, *J* 6.3 Hz, Me). Anal. Calcd for $C_{13}H_{20}O_8$: C, 51.32; H, 6.58. Found: C, 50.99; H, 6.85. Eluted third was substrate (0.37 g).

3.17. Methyl 3-*O*-(*p*-methoxy)benzyl-β-L-rhamnopyranoside 10b

Prepared from **10a**. Yield 84%; colorless crystals; mp 130 °C; $[\alpha]_D = +95.2$ (*c* 0.42, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$) δ: 6.88–7.29 (m, 4H, Ph), 4.71–4.45 (2d, 2H, *J* 11.6 Hz, CH_2Ph), 4.31 (d, 1H, *J* 1.1 Hz, H-1), 4.10 (t, 1H, *J* 1.1 Hz, H-2), 3.60 (t, 1H, *J* 9.1 Hz, H-4), 3.55 (s, 3H, CH_3), 3.28 (m, 2H, H-3, H-5), 2.28, 2.22 (2bs, 2×OH), 1.36 (d, 3H, *J* 6.1 Hz, Me); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 129.5, 114.0, 100.7, 80.7, 71.7, 71.3, 70.6, 67.6, 56.9, 17.7. Anal. Calcd for $C_{15}H_{22}O_6$: C, 60.39; H, 7.43. Found: C, 60.24; H, 7.51. Eluted second was the substrate (0.41 g).

3.18. Methyl 2,4-di-*O*-acetyl-3-*O*-(*p*-methoxy)benzyl-β-L-rhamnopyranoside 10c

Prepared from **10b** in theoretical yield; mp 140 °C (ether–hexane); $[\alpha]_D = +87.0$ (*c* 0.95, $CHCl_3$); ^1H NMR (200 MHz, $CDCl_3$) δ: 7.22, 6.80 (2d, 4H, Ph), 5.57 (dd, 1H, *J* 1.1, 3.3 Hz, H-2), 4.95 (t, 1H, *J* 9.7 Hz, H-4), 4.38 (d, 1H, *J* 1.1 Hz, H-1), 4.60, 4.35 (2d, 2H, *J* 11.9 Hz, CH_2Ph), 3.80 (s, 3H, MeOPh), 3.50 (s, 3H, OMe), 3.45 (dd, 1H, *J* 3.3, 9.7 Hz, H-3), 3.40–3.30 (dq, 1H, *J* 6.2, 9.7 Hz, H-5), 2.20, 2.00 (2s, 2×3H, 2×Ac), 1.25 (d, 3H, Me); ^{13}C NMR (50 MHz, $CDCl_3$) δ: 129.4, 113.7, 99.9, 75.9, 72.3, 70.5, 70.4, 67.5, 57.2, 55.2, 21.0, 20.9, 17.4. Anal. Calcd for $C_{19}H_{26}O_6$: C, 59.68; H, 6.85. Found: C, 60.04; H, 7.23.

3.19. Methyl 2,4-di-*O*-acetyl-β-L-rhamnopyranoside 10d

Prepared from **10c** in 72% yield; colorless crystals; mp 165 °C (ether–hexane); $[\alpha]_D = +20.0$ (*c* 0.13, $CHCl_3$); ^1H NMR (200 MHz, $CDCl_3$) δ: 5.40 (dd, 1H, *J* 1.0, 3.6 Hz, H-2), 4.82 (t, 1H, *J* 9.5, 9.7 Hz, H-4), 4.45 (d, 1H, *J* 1.0 Hz, H-1), 4.78 (ddd, 1H, *J* 3.6, 7.3, 9.7 Hz, H-3), 3.51 (s, 3H, OMe), 3.55–3.40 (dq, 1H, *J* 6.2, 9.5 Hz, H-5), 2.38 (d, 1H, *J* 7.3 Hz, OH), 2.19, 2.13 (2s, 2×3H, 2×Ac), 1.30 (d, 3H, *J* 6.2 Hz, Me); ^{13}C NMR (50 MHz, $CDCl_3$) δ: 99.8, 74.6, 71.4, 71.2, 70.2, 57.2, 21.0, 17.5; IR (KBr, cm^{-1}) *v*: 3424, 1738, 1723. Anal. Calcd for $C_{11}H_{18}O_7$: C, 50.38; H, 6.92. Found: C, 50.04; H, 7.20.

3.20. Methyl 2,4-di-*O*-acetyl-3-*O*-trifluoromethanesulfonyl-β-L-rhamnopyranoside 10e

Prepared from **10d** in 96% yield; colorless crystals, mp 100–101 °C; $[\alpha]_D = +45.0$ (*c* 0.95, $CHCl_3$); ^1H NMR (200 MHz, $CDCl_3$) δ: 5.67 (dd, 1H, *J* 1.0, 3.5 Hz, H-2), 5.18 (t, 1H, *J* 9.7 Hz, H-4), 4.90 (dd, 1H, *J* 3.5, 9.9 Hz, H-3), 4.50 (d, 1H, *J* 1.0 Hz, H-1), 3.52 (s, 3H, OMe), 3.58 (dq, 1H, *J* 6.2, 9.7 Hz, H-5), 2.20, 2.13 (2s, 2×3H, 2×Ac), 1.33 (d, 3H, *J* 6.2 Hz, Me); IR (KBr, cm^{-1}) *v*: 1756. Anal. Calcd for $C_{12}H_{17}O_9SF_3$: C, 36.55; H, 4.35. Found: 36.72; H, 4.64.

3.21. Methyl 3,4-anhydro-6-deoxy-β-L-altropyranoside 11a

Pale yellow oil; $[\alpha]_D = +61.0$ (*c* 1.60, $CHCl_3$); ^1H NMR (200 MHz, $CDCl_3$) δ: 4.40 (d, 1H, *J* 1.8 Hz, H-1), 4.08 (q, 1H, *J* 6.9 Hz, H-5), 4.02 (t, 1H, *J* 1.8, 2.0 Hz, H-2), 3.50 (s, 3H, OMe), 3.43 (ddd, 1H, *J* 1.0, 2.0, 3.9 Hz, H-3), 3.05 (d, 1H, *J* 3.9 Hz, H-4), 2.35 (d, 1H, OH), 1.44 (d, 3H, *J* 6.9 Hz, Me); ^{13}C NMR (50 MHz, $CDCl_3$) δ: 97.9, 70.2, 64.8, 55.1, 54.9, 56.8, 19.1.

3.22. Methyl 3,4-anhydro-6-deoxy-2-*O*-trifluoromethanesulfonyl-β-L-altropyranoside 11b

Prepared from **11a** in 89% yield; colorless oil; $[\alpha]_D = +39.0$ (*c* 0.60, $CHCl_3$). Anal. Calcd for $C_8H_{11}O_6SF_3$: C, 32.88; H, 3.79. Found: 32.77; H, 4.07.

3.23. Methyl 3,4-anhydro-2-azido-2,6-dideoxy-β-L-allopyranoside 12

A suspension of NaN_3 (0.29 g, 4.5 mmol), **11b** (0.46 g, 1.60 mmol) and 18-crown-6 (1.15 g, 4.4 mmol) in toluene (10 mL) was stirred at rt overnight, then it was diluted with toluene, filtered, washed with water and brine to give, after drying over $MgSO_4$ and evaporation of the solvent **12** (0.23 g, 78%). White solid, mp 65 °C (hexanes); $[\alpha]_D = +108.0$ (*c* 1.00, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$) δ: 4.40 (d, 1H, *J* 7.6 Hz, H-1), 4.10 (q, 1H, *J* 6.8 Hz, H-5), 3.58 (dd, 1H, *J* 2.0, 7.6 Hz, H-2), 3.50 (s, 3H, OMe), 3.44 (ddd, 1H, *J* 2.0, 4.2, 1.0 Hz, H-3), 3.15 (d, 1H, *J* 4.2 Hz, H-4), 1.41 (d, 3H, *J* 6.2 Hz, Me); ^{13}C NMR (50 MHz, $CDCl_3$) δ: 100.1, 57.1, 70.4, 60.3, 58.1, 54.5, 18.9; IR (KBr, cm^{-1}) *v*: 2130, 2108. Anal. Calcd for $C_7H_{11}O_3N_3$: C, 45.40; H, 5.99; N, 22.69. Found: 45.32; H, 6.28; N, 22.15.

3.24. Methyl 2,4-diazido-2,4,6-trideoxy-β-L-gulopyranoside 13a

Prepared from **12** in 88% yield; colorless oil; ^1H NMR (400 MHz, C_6D_6) δ: 4.38 (d, 1H, *J* 8.1 Hz, H-1), 3.78 (dq, 1H, *J* 1.7, 6.5 Hz, H-5), 3.55 (t, 1H, *J* 3.7 Hz, H-3), 3.41 (dd, 1H, *J* 3.0, 8.1 Hz, H-2), 2.88 (dd, 1H, *J* 1.7, 3.4 Hz, H-4), 1.66 (br s, 1H, OH), 1.02 (d, 3H, *J* 6.5 Hz, Me); ^{13}C NMR (50 MHz, $CDCl_3$) δ: 100.9, 69.6, 68.0, 63.8, 61.0, 56.7, 16.8.

13a was converted further into 3-*O*-acetyl derivative **13b**: $[\alpha]_D = +25.5$ (*c* 0.80, $CHCl_3$); ^1H NMR (400 MHz,

$CDCl_3$) δ: 5.28 (t, 1H, J 3.6 Hz, H-3), 4.58 (d, 1H, J 8.1 Hz, H-1), 4.02 (pq, 1H, J 1.7, 6.5 Hz, H-5), 3.59 (dd, 1H, J 8.1, 3.4 Hz, H-2), 3.47 (dd, 1H, J 1.7, 3.6 Hz, H-4), 3.45 (s, 3H, OMe), 3.47 (dd, 1H, J 1.7, 3.6 Hz, H-4), 2.14 (s, 3H, OAc), 1.35 (d, 3H, J 6.5 Hz, Me). HRMS (ESI): exact mass calcd for $C_9H_{14}O_4N_6Na$ $[M+Na]^+$ 293.0969, found 293.0985.

3.25. 1,3-Di-*O*-acetyl-2,4-diazido-2,4,6-trideoxy-α/β-L-gulopyranose 14

Acetolysis of **13b** was performed according to the procedure described for **6b**, to give **14** in 68% yield. Chromatography (hexane–ether, 7:3) gave β-anomer as a sole product: $[\alpha]_D = -12.7$ (c 0.91, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 5.88 (d, 1H, J 8.7 Hz, H-1), 5.88 (t, 1H, J 3.3 Hz, H-3), 4.17 (pq, 1H, J 1.7, 6.5 Hz, H-5), 3.77 (dd, 1H, J 3.3, 8.7 Hz, H-2), 3.52 (dd, 1H, J 1.7, 3.7 Hz, H-4), 2.16, 2.18 (2s, 2×3H, 2×Ac), 1.34 (d, 3H, J 6.5 Hz, Me); ^{13}C NMR (50 MHz, $CDCl_3$) δ: 16.6, 20.7, 20.9, 57.1, 61.7, 69.7, 69.9, 91.4, 169.0, 169.3, 169.2. HRMS (ESI): exact mass calcd for $C_{10}H_{14}O_5N_6Na$ $[M+Na]^+$ 321.0918, found 321.0931.

α-Anomer was not isolated.

3.26. Allyl α-L-fucopyranoside 15

Prepared according to the procedure described in Ref. 20: mp 156–157 °C; $[\alpha]_D = -191.6$ (c 0.76, MeOH). Lit.[21]: mp 154–158 °C; $[\alpha]_D = -190$ (MeOH).

3.27. Allyl 3-*O*-benzoyl-α-L-fucopyranoside 16a and allyl 2-*O*-benzoyl-α-L-fucopyranoside 16b

A suspension of **15α** (2.04 g, 10 mmol) and Bu_2SnO (2.74 g, 11 mmol) in benzene (50 mL) was heated under reflux with azeotropic removal of water for 3 h. After cooling to 0 °C BzCl (1.28 mL, 11 mmol) was added dropwise and the mixture was stirred for 15 min at ambient temperature. Then it was diluted with benzene and poured into ice-cold aq $NaHCO_3$ solution. The organic layer was separated and the aqueous layer was extracted with CH_2Cl_2. Concentration of extracts and chromatography (hexane–AcOEt, 7:3) gave in the first fraction **16b** (0.83 g, 27%). Mp 115–116 °C; $[\alpha]_D = -191.7$ (c 0.99, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.10–7.50 (m, 5H, Ph), 5.97–5.88 (m, 1H, All), 5.47 (dd, 1H, J 3.0, 10.4 Hz, H-2), 5.38–5.26 (m, 1H, All), 5.20 (d, 1H, J 3.0 Hz, H-1), 5.07 (dd, 1H, J 7.7, 10.4 Hz, H-3), 4.75 (d, 1H, J 7.7, H-4), 4.03 (q, 1H, J 6.5 Hz, H-5), 1.43 (d, 3H, J 6.5 Hz, Me). HRMS (ESI): exact mass calcd for $C_{16}H_{20}O_6Na$ $[M+Na]^+$ 331.1149, found 331.1149. Eluted second was **16a** (1.45 g, 47%). Mp 123–124 °C; $[\alpha]_D = -218.8$ (c 0.82, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.10–7.42 (m, 5H, Ph), 5.94 (m, 1H, All), 5.35 (m, 1H, All), 5.31 (dd, 1H, J 3.2, 10.2 Hz, H-3), 5.23 (m, 1H, All), 4.99 (d, 1H, J 4.0 Hz, H-1), 4.26 (m, 1H, All), 4.16–4.10 (m, 2H, H-2, H-5), 3.99 (d, 1H, J 2.5 Hz, H-4), 2.10 (m, 2H, 2OH), 1.29 (d, 3H, J 6.6 Hz, Me); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 15.9, 65.9, 67.0, 68.7, 70.8, 74.5, 97.9, 117.9, 128.4, 129.7, 129.8, 138.3, 133.2, 133.5, 166.4. HRMS (ESI): exact mass calcd for $C_{16}H_{20}O_6Na$ $[M+Na]^+$ 331.1149, found 331.1157.

3.28. Allyl 3-*O*-benzoyl-2,4-di-*O*-trifluoromethanesulfonyl-α-L-fucopyranoside 17

A solution of **16a** (0.7 g, 2.27 mmol) in CH_2Cl_2 (15 mL) pyridine (2.5 mL) then Tf_2O (1.12 mL, 6.81 mmol) was added dropwise at −15 °C. The temperature was allowed to attain 0 °C. THL (hexane–ether, 1:1) showed complete conversion of **16a** into the corresponding di-*O*-triflyl derivative. Solid $NaHCO_3$ was added and the mixture was evaporated to dryness. Flash chromatography gave **17** (1.2 g, 92%) as white solid. $[\alpha]_D = -148.5$ (c 0.68, $CHCl_3$. HRMS (ESI): exact mass calcd for $C_{18}H_{18}O_{10}F_6S_2Na$ $[M+Na]^+$ 595.0138, found 595.0162.

3.29. Allyl 4-azido-3-*O*-benzoyl-2,6-dideoxy-2-*O*-trifluoromethanesulfonyl-α-L-glucopyranoside 18

To a solution of **17** (1.0 g, 1.75 mmol) in DMF (15 mL) NaN_3 (0.34 g, 5.25 mmol) or Bu_4NN_3 (3 g, 4.75 mmol) was added and the mixture was stirred below 40 °C. TLC (hexane–ether, 7:3) revealed a single spot. The suspension was poured into ice-cold water and extracted with ether. Evaporation of the solvent followed by flash chromatography afforded **18** (0.62 g, 77%). White solid; mp 43–43 °C; $[\alpha]_D = -149.2$ (c 1.10, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 8.10–7.50 (m, 5H, Ph), 5.90 (m, 1H, All), 5.84 (t, 1H, J 9.9 Hz, H-3), 5.28–5.38 (m, 1H, All), 5.13 (d, 1H, J 3.7 Hz, H-1), 4.87 (dd, 1H, J 3.7, 9.9 Hz, H-2), 3.88 (dq, 1H, J 6.2, 9.9 Hz, H-5), 3.37 (t, 1H, J 9.9 Hz, H-4), 1.39 (d, 3H, J 6.2 Hz, Me); IR (KBr, cm^{-1}) ν: 2113, 1732, 1648, 1602.

3.30. Allyl 2,4-diazido-3-*O*-benzoyl-2,4,6-trideoxy-α-L-mannopyranoside 19a

A suspension of **19a** (1.3 g, 2.27 mmol) in DMF was added NaN_3 (0.44 g, 6.80 mmol) and 18-crown-6 (1 g) and the mixture was heated at 60 °C. TLC (hexane–ether, 7:3) indicated complete reaction (2 h). The mixture was poured into ice-cold water and extracted with ether. Evaporation of the solvent followed by the filtration through a short column of silica gel yielded **19a** (0.63 g, 77%). Colorless oil; $[\alpha]_D = -156.0$ (c 1.41, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$) δ: 7.49–8.13 (m, 5H, Ph), 5.90 (m, 1H, All), 5.54 (dd, 1H, J 3.7, 9.9 Hz, H-3), 5.24–5.34 (m, 1H, All), 4.85 (d, 1H, J 1.0 Hz, H-1), 4.17 (dd, 2H, J 1.0, 3.7 Hz, H-2), 3.98–4.04 (m, 1H, All), 3.72 (pq, 1H, J 6.0, 9.9 Hz, H-4), 1.40 (d, 3H, J 6.0 Hz, Me); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 18.3, 61.4, 63.2, 67.2, 68.4, 72.6, 96.9, 118.2, 128.6, 128.7, 130.0, 133.0, 133.7, 165.5; IR (KBr, cm^{-1}) ν: 2113, 1755. HRMS (ESI): exact mass calcd for $C_{16}H_{19}O_4N_6$ $[M]^+$ 359.1468, found 359.1473.

3.31. 1-*O*-Acetyl-2,4-diazido-3-*O*-benzoyl-2,4,6-trideoxy-α-L-mannopyranose 20a and 20b

A suspension of **19a** (0.179 g, 0.5 mmol) and $PdCl_2$ (0.18 g, 0.5 mmol) in Ac_2O–H_2O (20:1, 10 mL) containing AcONa (0.18 g) was stirred overnight at rt. Removal of the solvents, then filtration through a short column of silica gel (hexane–ether, 7:3) gave a mixture of two products. Usual acetylation followed by chromatography (hexane–ether, 3:1) yielded β-anomer **20b** in the first fraction (51 mg, 28%). $[\alpha]_D = -2.7$ (*c* 0.47, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$) δ: 7.48–8.12 (m, 5H, Ph), 5.85 (d, 1H, *J* 1.3 Hz, H-1), 5.14 (dd, 1H, *J* 3.5, 10.1 Hz, H-3), 4.33 (dd, 1H, *J* 1.1, 3.5 Hz, H-2), 3.66 (t, 1H, *J* 9.9 Hz, H-4), 3.47 (pq, 1H, *J* 6.1, 9.9 Hz, H-5), 2.18 (s, 3H, Ac), 1.45 (d, 3H, *J* 6.1 Hz, Me); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 18.4, 20.9, 60.3, 62.5, 69.7, 72.2, 91.4, 128.4, 130.0, 133.9, 165.5, 168.6. HRMS (ESI): exact mass calcd for $C_{15}H_{16}O_5N_6Na$ $[M+Na]^+$ 383.1074, found 383.1087. Eluted second was **20a** (77 mg, 42%). Mp 63–64 °C; $[\alpha]_D = -136.4$ (*c* 0.45, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$) δ: 7.45–8.13 (m, 5H, Ph), 6.10 (d, 1H, *J* 1.9 Hz, H-1), 5.49 (dd, 1H, *J* 3.7, 9.9 Hz, H-3), 4.19 (dd, 1H, *J* 1.9, 3.7 Hz, H-2), 3.72–3.80 (m, 2H, H-4, H-5), 2.18 (s, 3H, Ac), 1.41 (d, 3H, *J* 6.6 Hz, Me); HRMS (ESI): exact mass calcd for $C_{15}H_{16}O_5N_6Na$ $[M+Na]^+$ 383.1074, found 383.1092.

3.32. Allyl 2,4-diazido-2,4,6-trideoxy-α-L-mannopyranose 19b

Prepared by usual deprotection of 3-*O*-Bz in **19a** using 2 M MeONa in MeOH. $[\alpha]_D = -136.7$ (*c* 0.78, $CHCl_3$). HRMS (ESI): exact mass calcd for $C_9H_{14}O_3N_6Na$ $[M+Na]^+$ 277.1020, found 277.1038.

3.33. Allyl 2,4-diazido-2,4,6-trideoxy-3-*O*-trifluoromethanesulfonyl-α-L-mannopyranoside 19c

Prepared according to the procedure described for **17** was used in a crude state for epimerization reaction.

3.34. Allyl 3-*O*-acetyl-2,4-diazido-2,4,6-trideoxy-α-L-altropyranoside 21

Triflate **19c** (0.4 g, 1.0 mmol) was stirred with $NaNO_2$ (0.2 g, 3 mmol) and 18-crown-6 (0.3 g) at 40 °C until the reaction was completed TLC (hexane–ether, 7:3). Then the mixture was poured into ice-cold water and extracted with ether. Evaporation of the solvent and subsequent acetylation of the residue afforded **21**, which was purified by flash chromatography to yield white solid (0.21 g, 71%). $[\alpha]_D = -91.9$ (*c* 0.42, $CHCl_3$); ^1H NMR (400 MHz, $CDCl_3$) δ: 5.85–5.95 (m, 1H, All), 5.21–5.34 (m, 1H, All), 5.07 (dd, 1H, *J* 3.7, 6.2 Hz, H-3), 4.71 (d, 1H, *J* 3.3 Hz, H-1), 4.14 (q, 1H, *J* 6.6 Hz, H-5), 3.87 (dd, 1H, *J* 3.3, 6.2 Hz, H-2), 3.49 (dd, 1H, *J* 3.7, 7.8 Hz, H-4), 2.17 (s, 3H, Ac), 1.36 (d, 3H, *J* 6.6 Hz, Me); ^{13}C NMR (100 MHz, $CDCl_3$) δ: 18.0, 20.7, 59.7, 60.4, 65.4, 68.8, 70.0, 97.1, 117.4, 133.4, 170.1. HRMS (ESI): exact mass calcd for $C_{11}H_{16}O_4N_6Na$ $[M+Na]^+$ 319.1125, found 319.1144.

References and notes

1. (a) Cohen, D.; Block, C.; Green, M. S.; Lowell, G.; Ofek, I. *J. Clin. Microbiol.* **1989**, *27*, 162–167; (b) Cohen, D.; Green, M. S.; Block, C.; Roauch, T.; Ofek, I. *J. Infect. Dis.* **1988**, *157*, 1068–1071; (c) Taylor, D. N.; Trofa, A. C.; Sadoff, J.; Chu, C.; Bryla, D.; Shiloach, J.; Cohen, D.; Ashkenazi, S.; Lerman, Y.; Egan, W.; Schneerson, R.; Robbins, J. B. *Infect. Immun.* **1993**, *61*, 3678–3687.
2. (a) Kontrohr, T. *Carbohydr. Res.* **1977**, *58*, 498–500; (b) Baumann, H.; Tziabanos, A. O.; Brisson, J.-R.; Kasper, D. L.; Jennings, H. J. *Biochemistry* **1992**, *31*, 4081–4089.
3. Jennings, H. J.; Lugowski, C.; Young, N. M. *Biochemistry* **1980**, *19*, 4712–4719.
4. (a) Knirel, Y. A.; Kochetkov, N. K. *Biochemistry (Moscow)* **1994**, *59*, 1325–1383; (b) Castric, P.; Cassels, F. J.; Carlson, R. W. *J. Biol. Chem.* **2001**, *276*, 26479–26485.
5. Tsvetkov, Y. E.; Shashkov, A. S.; Knirel, Y. A.; Zähringer, U. *Carbohydr. Res.* **2001**, *335*, 221–243.
6. Suhara, T.; Maeda, K.; Umezawa, H. *Tetrahedron Lett.* **1966**, *7*, 1239–1244.
7. Umezawa, S. *Adv. Carbohydr. Chem. Biochem.* **1974**, *30*, 111–182.
8. (a) Čapek, K.; Čapková, J.; Jarý, J.; Knirel, Y. A.; Shashkov, A. S. *Collection Czechoslovak Chem. Commun.* **1987**, *52*, 2248–2259; (b) Paulsen, H.; Koebernick, H. *Chem. Ber.* **1976**, *109*, 90–103; (c) Smid, P.; Jorning, W. P. A.; van Duuren, A. M. G.; Boons, G. J. P. H.; van der Marel, G. A.; van Boom, J. H. *J. Carbohydr. Chem.* **1992**, *11*, 849–865, and references cited therein.
9. (a) Paulsen, H.; Lockhoff, O.; Schröder, B.; Stenzel, W. *Carbohydr. Res.* **1979**, *68*, 239–255; (b) Medgyes, A.; Farkas, E.; Liptak, A.; Pozsgay, V. *Tetrahedron* **1997**, *53*, 4159–4178.
10. (a) Zehavi, U.; Sharon, N. *J. Org. Chem.* **1972**, *37*, 2141–2145; (b) Jeanloz, R. W.; Rapin, A. M. C. *J. Org. Chem.* **1963**, *28*, 2978–2983.
11. (a) Banaszek, A.; Pakulski, Z.; Zamojski, A. *Carbohydr. Res.* **1995**, *279*, 173–182; (b) Banaszek, A.; Janisz, B. *Tetrahedron: Asymmetry* **2000**, *11*, 4693–4700.
12. Paulsen, H. *Angew. Chem., Int. Ed. Engl.* **1982**, *21*, 155–173.
13. (a) Jiaang, W.-T.; Chang, M.-X.; Tseng, P.-H.; Chen, S.-T. *Tetrahedron Lett.* **2000**, *41*, 3127–3130; (b) Wong, C.-H.; Hendrix, M.; Manning, D. D.; Rosenbohm, C.; Greenberg, W. A. *J. Am. Chem. Soc.* **1998**, *120*, 8319–8327.
14. Izumi, M.; Suhara, Y.; Ichikawa, Y. *J. Org. Chem.* **1998**, *63*, 4811–4816.
15. Janairo, G.; Kowolik, W.; Voelter, W. *Liebigs Ann. Chem.* **1987**, 165–167.
16. Karpiesiuk, W.; Banaszek, A.; Zamojski, A. *Carbohydr. Res.* **1989**, *186*, 156–162, and references cited therein.
17. (a) Hodosi, G.; Kováč, P. *J. Am. Chem. Soc.* **1997**, *119*, 2335–2336; (b) Srivastava, V. K.; Schuerch, C. *Tetrahedron Lett.* **1979**, 3269–3273.
18. Yu, B.; Yu, H.; Han, X. *Synlett* **1999**, 753–755.
19. Iuima, H.; Ogawa, T. *Carbohydr. Res.* **1988**, *172*, 183–193.
20. Vermeer, J. H.; van Dijk, C. M.; Kamerling, J. P.; Vliegenthart, J. F. G. *Eur. J. Org. Chem.* **2001**, 193–209.
21. Garegg, P. J.; Norberg, T. *Carbohydr. Res.* **1976**, *52*, 235–240.