Synthesis of 2-Amino-2-deoxy-D-hexopyranoside-Containing Disaccharides Involving Glycosylation and [3,3] Sigmatropic Rearrangement

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The syntheses of D-mannosamine **15**, D-idosamine **16**, D-altrosamine **19**, and D-tallosamine **20** derivatives of 2-amino-2-deoxy-D-hexopyranoside-containing disaccharides were achieved by [3,3] sigmatropic rearrangement reaction of the disaccharide **13** having a 4-trichloroacetimidate-2-enoside group, prepared in turn by glycosylation of thioglycosyl donors using $Pd(CH_3CN)_2Cl_2$–AgOTf as a promoter.

N-Acetyl-D-mannosamine is known as a constituent in the repeating unit of the capsular polysaccharides of *Streptococcus preunoniae* type 19F bacteria[1] and the group-specific agents of *Neisseria meningitidis* serogroups A and X polysaccharides.[2] Especially, the former polysaccharide derivatives play an important role as substrate for type-specific immunogenity in various bacteria associated with invasive diseases (Scheme 1).

***Streptococcus pneumoniae* 19 F**

[→3)-β-D-Man*p*NAc-(1→4)-α-D-Glc*p*-(1→2)-α-L-Rha*p*-(1-PO_4^-→]$_n$

***Neisseria Meningitidis Serogroups* A *and* X**

[→6)-α-D-Man*p*NAc-1-PO_4^-→]$_n$

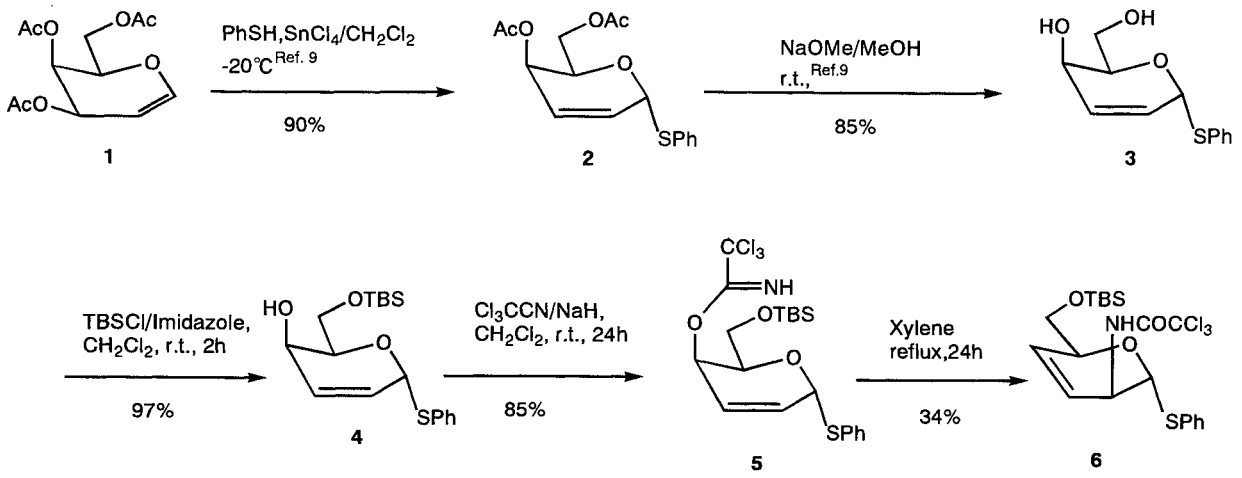
Scheme 1

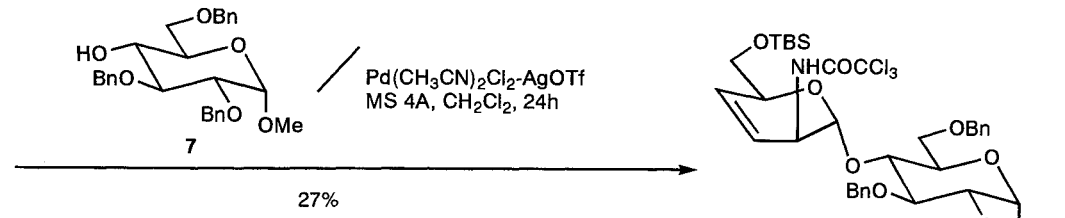
The development of practical methods for laboratory synthesis of amino sugars such as *N*-acetyl-D-mannosamine assumes new importance. Several methods are available for the synthesis of 2-amino-2-deoxy-D-hexopyranosides and their derivatives. For example, mannosamine derivatives have been synthesized by azidonitration of 1-enose[3] and reduction of 2-oxoimino sugar,[4] etc. However, only few syntheses of 2-amino sugars employ the [3,3] sigmatropic rearrangement of a 2-enopyranoside. Although these methods were carried out by [3,3] sigmatropic rearrangement of a 4-azide[5] or 4-thiocyanate group,[6] the yields were not so high and the transformation to the amino sugar from the rearrangement products has not been reported.

Recently, we reported the regio- and stereoselective synthesis of D-mannosamine employing a [3,3] sigmatropic rearrangement as a key step from a 2-enoside having a 4-trichloroacetamide group.[7] In this paper, we wish to report the synthesis of 2-amino-2-deoxy-D-hexopyranoside-containing disaccharides involving the [3,3] sigmatropic rearrangement of a 2-enoside-containing disaccharide which could be prepared from phenylthio-2,3-dideoxyhex-2-enopyranoside **(2)** or pyridylthio-2,3-dideoxyhex-2-enopyranoside **(9)** with methyl 2,3,6-tri-*O*-benzylglucoside by glycosylation using $Pd(CH_3CN)_2Cl_2$–AgOTf as the activator.[8]

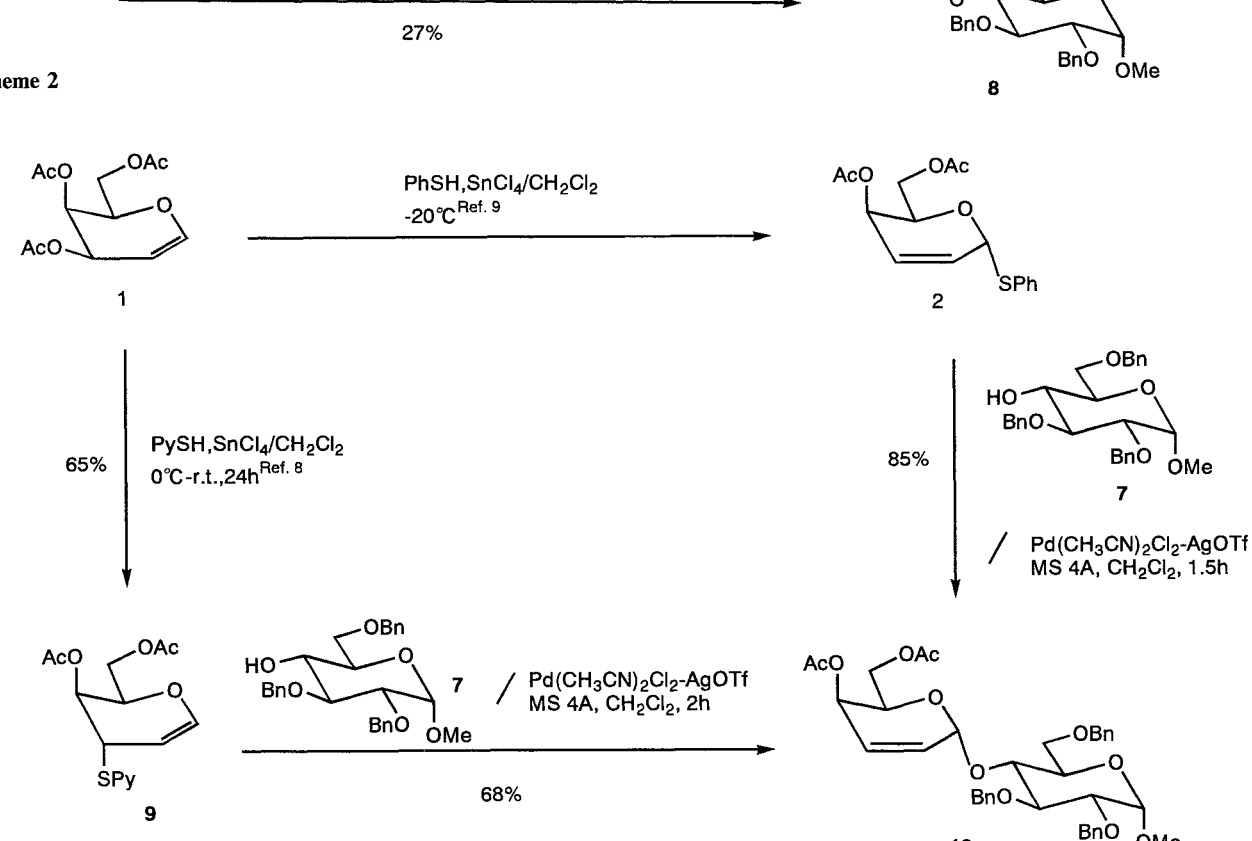
1-Thio-2-enosides like **2**, which can be prepared by Ferrier rearrangement of 1-enose, have been applied in the synthesis of antibiotics such as Esperamicine.[9] These compounds contain a thioallylic function in the molecular structure; therefore, the 1-thio-2-enoside **2** having a thioglycoside function will be applicable to *O*-glycosylation by use of the previously reported method.[8] Furthermore, the allylic alcohol function of this compound also can be used for an allylic rearrangement such as a [3,3] sigmatropic rearrangement. On the basis of above considerations, we describe here a synthesis of 2-amino-D-hexopyranoside-containing disaccharides involving the reactions of *O*-glycosylation and [3,3] sigmatropic rearrangement of 1-thio-2-enoside derivatives.

The thioglycosyl donor, 1-thio-2-enoside **2**, was prepared in two steps from D-galactal **(1)** as described by Danishefsky et al.[9] (Scheme 2). After selective *tert*-butyldimethylsilylation of the 6-position of **2** (97%) using *tert*-butyldimethylsilyl chloride (TBSCl) and 4-dimethylaminopyridine (DMAP) in dichloromethane solution at room temperature, the 6-*O*-TBS compound **4** was treated with trichloroacetonitrile (TCA) in the presence of NaH in dichloromethane and gave the 4-imidate **5** in 85% yield. The 4-imidate **5** was relatively stable and could be isolated by preparative TLC on silica gel. A signal due to the imino proton of **5** was observed at 8.32 ppm as a singlet in the ^{1}H NMR spectrum. The 4-imidate **5** was subjected to [3,3] sigmatropic rearrangement in refluxing xylene for 24 h. The rearrangement product **6** was isolated by preparative TLC from the reaction mixture (34%). The ^{1}H NMR spectrum of **6** showed a signal due to the amide proton at 6.88 ppm ($J_{NH,2eq}$ = 8.5 Hz) as a doublet which coupled the amide group with the 2-equatorial proton. As a coupling constant between the 2-equatorial proton and anomeric proton of $J_{1,2}$ = 1.5 Hz was observed, the amide group was shown to be in the axial configuration. The imino nitrogen of compound **5** may attack the 2-position from the upper side of the pyranose ring by way of a cyclic intermediate. *O*-Glycosylation of the rearranged product **6** was carried out by our reported method,[8] that is, *O*-glycosylation of *S*-glycosyl donors performed by use of $Pd(CH_3CN)_2Cl_2$–AgOTf as a promoter. The reaction of **6** and methyl 2,3,6-tri-*O*-benzyl-α-D-glucoside **(7)** in the presence of $Pd(CH_3CN)_2Cl_2$–AgOTf as promoter gave the α-disaccharide **8** in 27% yield. Since each yield was low in the two key steps, rearrangement reaction and *O*-glycosylation, we tried *O*-glycosylations of the individual *S*-glycosyl donors **2** and **9**[8] followed by [3,3] sigmatropic rearrangement of the disaccharide **10** (Scheme 3).





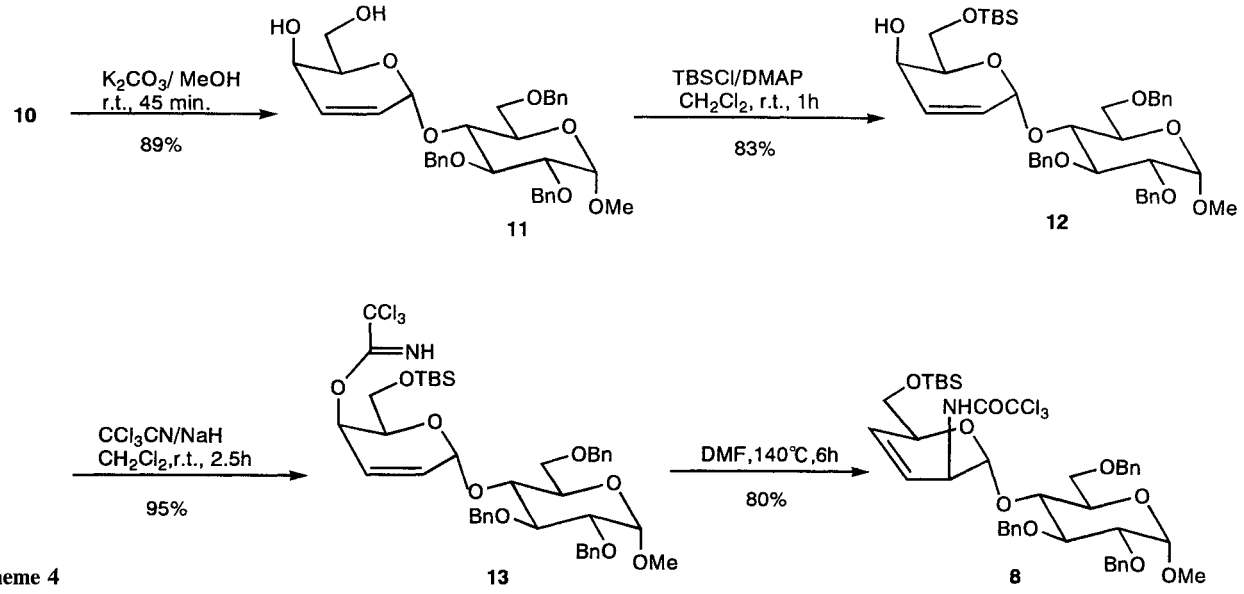
Scheme 2



Scheme 3

Glycosylation of **2** and **7** using $Pd(CH_3CN)_2Cl_2$–AgOTf as promoter gave **10** in good yield. On the other hand, S_N2' glycosylation of compound **9** also proceeded smoothly and the α-compound was preferentially obtained in good yield (68%). Although we have no immediate, accurate explanation for the configuration of the anomeric position in these results, it may be attributed to the anomeric effect as discussed in the preceding paper.[8]

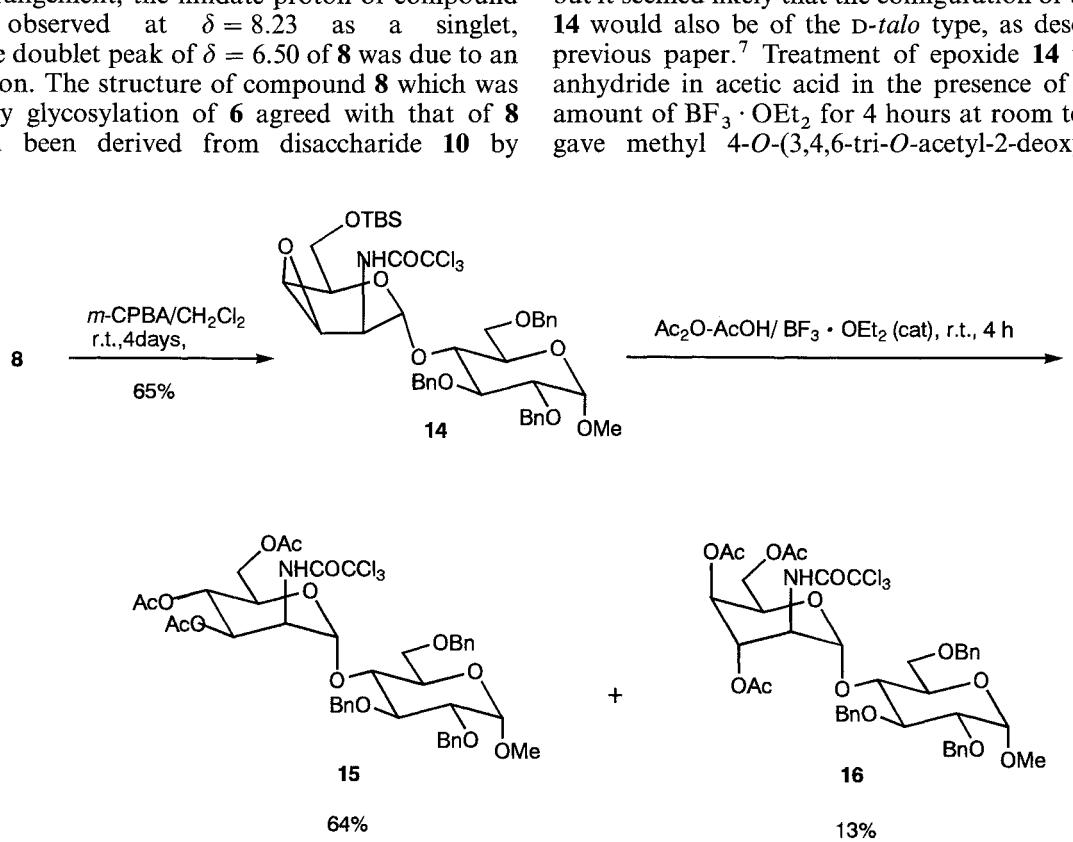
In any case, it is obvious that the anomeric configuration is α in these glycosylations because compound **10** can be converted to disaccharides **15**, **16**, **19**, and **20**. After *O*-deacetylation of disaccharide **10** with potassium carbonate in MeOH, selective *tert*-butyldimethylsilylation of the *O*-6 position was carried out and gave **12** in 83% yield (Scheme 4).



Scheme 4

The 4-OH disaccharide **12** was treated with trichloroacetonitrile in the presence of sodium hydride in dichloromethane to give trichloroacetimidate **13** in 95% yield. The [3,3] sigmatropic rearrangement of **13** was attempted in several solvents, for example, in refluxing octane for 16 hours, and in refluxing xylene for 5.5 hours, and rearranged compound **8** was obtained in 16% and 27% yield, respectively. On the other hand, in DMF solution, the imidate **13** was heated at 140°C for 6 hours to give a rearranged product **8** bearing a trichloroacetamido group at the allylic position in 80% yield. In the process of allylic rearrangement, the imidate proton of compound **13** was observed at $\delta = 8.23$ as a singlet, whereas the doublet peak of $\delta = 6.50$ of **8** was due to an amide proton. The structure of compound **8** which was obtained by glycosylation of **6** agreed with that of **8** which had been derived from disaccharide **10** by ^{1}H NMR examination. Therefore, the glycosylation of **6** using $Pd(CH_3CN)_2Cl_2$–AgOTf was shown to give the α-predominant configuration, as was also the case for **10**. These reactions probably proceeded by a similar mechanism involving the anomeric effect as described above.

Oxidation with *m*-chloroperbenzoic acid (*m*-CPBA) of **8** at ambient temperature furnished an epoxide **14** as a single product in 65% yield (Scheme 5). In this reaction, we could not confirm the configuration of the 3 and 4 positions of the epoxide **14** by ^{1}H NMR examination, but it seemed likely that the configuration of the epoxide **14** would also be of the D-*talo* type, as described in a previous paper.[7] Treatment of epoxide **14** with acetic anhydride in acetic acid in the presence of a catalytic amount of $BF_3 \cdot OEt_2$ for 4 hours at room temperature gave methyl 4-*O*-(3,4,6-tri-*O*-acetyl-2-deoxy-2-trichlo-



Scheme 5

roacetamido-α-D-mannopyranosyl)-2,3,6-tri-*O*-benzyl-α-D-glucopyranoside **(15)** and methyl 4-*O*-(3,4,6-tri-*O*-acetyl-2-deoxy-2-trichloroacetamido-α-D-idopyranosyl)-2,3,6-tri-*O*-benzyl-α-D-glucopyranoside **(16)** (88%, **15:16** = 5.3:1) as a mixture. The ratio of these compounds was determined by the integral value of the C1-H signal of each compound in the ^{1}H NMR spectrum. Further, these isomers were separated by preparative TLC, and each coupling constant of the pyranose ring of **15** and **16** was observed as $J_{1,2} = 2.0$, $J_{2,3} = 4.0$, $J_{3,4} = J_{4,5} = 10.0$ Hz and $J_{1,2} = 2.0$, $J_{2,3} = J_{3,4} = 3.5$, $J_{4,5} = 2.0$ Hz, respectively; therefore, both compounds showed the chair conformation in these results.

On the other hand, oxidation of compound **8** by osmium tetroxide in pyridine followed by hydrolysis of the resulting osmium ester by sodium bisulfite in a mixture of pyridine-H_2O (2:3) afforded methyl 4-*O*-(6-*O*-*tert*-butyldimethylsilyl-2-deoxy-2-trichloroacetamido-α-D-altropyranosyl)-2,3,6-tri-*O*-benzyl-α-D-glucopyranoside **(17)** (68%) and methyl 4-*O*-(6-*O*-*tert*-butyldimethylsilyl-2-deoxy-2-trichloroacetamido-α-D-talopyranosyl)-2,3,6-tri-*O*-benzyl-α-D-glucopyranoside **(18)** (14%) (Scheme 6). From the ^{1}H NMR data of **17** and **18**, each coupling constant of C3-H and C4-H in compounds **17** and **18** could not be confirmed. Therefore, both compounds **17** and **18** were subjected to 3,4,5-tri-*O*-acetylation in order to elucidate the configuration of the C3 and C4-positions, respectively. After desilylation of **17** and **18** had been performed by tetrabutylammonium fluoride (TBAF), the acetylation of each compound was carried out with acetic anhydride–pyridine and gave triacetates **19** and **20** in high yields. From the ^{1}H NMR examination of **19** and **20**, the coupling constants of the amino sugar **19** showed $J_{1,2} = 3.0$, $J_{2,3} = 5.5$, $J_{3,4} = 3.5$, $J_{4,5} = 8.0$ Hz, whereas those of **20** showed $J_{1,2} = 1.0$, $J_{2,3} = 4.5$, $J_{3,4} = 3.5$, $J_{4,5} = 1.5$ Hz. From the $J_{4,5} = 8.0$ Hz in **19**, C4-H was shown to be in an axial configuration, therefore, C3-H was in the equatorial configuration. On the other hand, C3-H and C4-H of counterpart **20** were found to be in the equatorial and axial configurations, respectively. Consequently, from the coupling constants of these compounds, we determined the conformation of both **19** and **20** to be "chair".

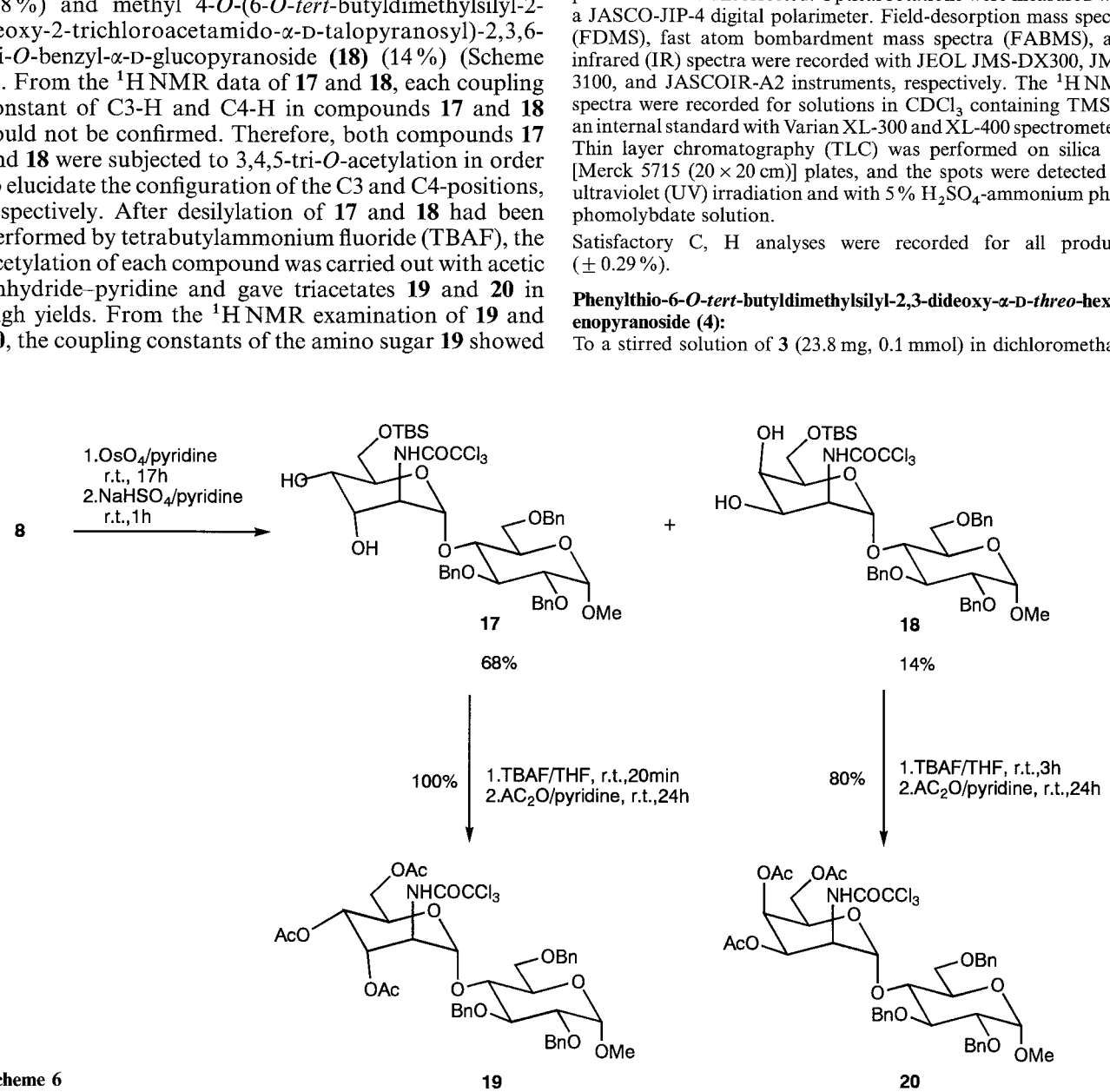
In summary, the [3,3] sigmatropic rearrangement of a disaccharide involving the imidate group was achieved in DMF solution and four kinds of 2-amino-2-deoxy hexopyranoside-containing disaccharide were synthesized. On account of its high efficiency and operational simplicity, the present method should find further practical uses in oligosaccharide syntheses.

Melting points were determined with a Yamato melting point apparatus and are uncorrected. Optical rotations were measured with a JASCO-JIP-4 digital polarimeter. Field-desorption mass spectra (FDMS), fast atom bombardment mass spectra (FABMS), and infrared (IR) spectra were recorded with JEOL JMS-DX300, JMS-3100, and JASCOIR-A2 instruments, respectively. The ^{1}H NMR spectra were recorded for solutions in $CDCl_3$ containing TMS as an internal standard with Varian XL-300 and XL-400 spectrometers. Thin layer chromatography (TLC) was performed on silica gel [Merck 5715 (20 × 20 cm)] plates, and the spots were detected by ultraviolet (UV) irradiation and with 5% H_2SO_4-ammonium phosphomolybdate solution.

Satisfactory C, H analyses were recorded for all products (± 0.29%).

Phenylthio-6-*O*-*tert*-butyldimethylsilyl-2,3-dideoxy-α-D-*threo*-hex-2-enopyranoside (4):

To a stirred solution of **3** (23.8 mg, 0.1 mmol) in dichloromethane



Scheme 6

(1 mL), *tert*-butyldimethylsilyl chloride (TBSCl; 15 mg, 0.1 mmol) and imidazole (24 mg, 0.2 mmol) were added at r.t. After 1 h it was not possible to obtain sufficient product (by TLC analysis); TBSCl (15 mg, 0.1 mmol) was further added to the reaction mixture and stirred for 1 h. After disappearance of the starting material (TLC), the reaction mixture was concentrated and the residue was purified by preparative TLC on silica gel in EtOAc/hexane (1:1) to give **4** as a colorless oil; yield: 34 mg (97%), $[\alpha]_D^{24}$ +121.0 ($c = 0.8$, $CHCl_3$).

IR (neat): ν_{max} = 3420 (OH), 2950 (CH), 1585 cm^{-1} (Ph).

^1H NMR (300 MHz, $CDCl_3$): δ = 0.10 [6 H, s, $Si(CH_3)_2$], 0.91 (9 H, s, *t*-butyl), 2.17 (1 H, d, J = 8.0 Hz, 4-OH), 3.90, 3.95 (1 H, each, dd, J = 6.0, 10.5 Hz, 6-H_2), 4.04 (1 H, ddd, J = 2.0, 5.0, 8.0 Hz, 4-H), 4.36 (1 H, dt, J = 2.0, 6.0 Hz, 5-H), 5.81 (1 H, dd, J = 1.5, 3.0 Hz, 1-H), 6.09 (1 H, dd, J = 3.0, 10.0 Hz, 2-H), 6.16 (1 H, ddd, J = 1.5, 5.0, 10.0 Hz, 3-H), 7.25 (5 H, m, C_6H_5).

^{13}C NMR (75.0 MHz, $CDCl_3$): δ = −5.47, −5.38 [$Si(CH_3)_2$], 18.20 [$C(CH_3)_3$], 25.88 [$C(CH_3)_3$], 62.31 (C4), 62.71 (C6), 71.07 (C5), 84.04 (C1), 128.71 (C3), 129.26 (C2), 127.29, 128.83, 131.61 (Ph).

FABMS: m/z = 353 $[M + 1]^+$.

Phenylthio-6-*O*-*tert*-butyldimethylsilyl-2,3-dideoxy-4-*O*-(1-imino-1-trichloromethyl)-α-D-*threo*-hex-2-enopyranoside (5):

60% NaH (29 mg, 0.63 mmol) was added to a dichloromethane solution (1 mL) of **4** (106 mg, 0.3 mmol); then, trichloroacetonitrile (65 mg, 0.45 mmol) was added to the reaction mixture. The mixture was stirred for 1 h at r.t. At this point, it was not possible to obtain sufficient product by TLC analysis, 60% NaH (6 mg, 0.13 mmol) and trichloroacetonitrile (38 mg, 0.26 mmol) were further added to the reaction mixture. After 24 h, insoluble materials were removed by filtration, the filtrate was concentrated, and the residue was purified by preparative TLC on silica gel in EtOAc/hexane (1:8) to give **5** as a colorless oil; yield: 126.8 mg (85%), $[\alpha]_D^{20}$ −8.3 ($c = 0.12$, $CHCl_3$).

IR (neat): ν_{max} = 3350 (NH), 2950 (CH), 1670 (C=N), 1580 cm^{-1} (Ph).

^1H NMR (300 MHz, $CDCl_3$): δ = 0.05, 0.07 [3 H each, s, $Si(CH_3)_2$], 0.87 (9 H, s, *t*-butyl), 3.87, 3.94 (1 H each, dd, J = 6.5, 10.0 Hz, 6-H_2), 4.58 (1 H, dt, J = 2.5, 6.5 Hz, 5-H), 5.29 (1 H, dd, J = 2.5, 5.0 Hz, 4-H), 5.88 (1 H, dd, J = 1.0, 3.0 Hz, 1-H), 6.26 (1 H, dd, J = 3.0, 10.0 Hz, 2-H), 6.31 (1 H, ddd, J = 1.0, 5.0, 10.0 Hz, 3-H), 7.27–7.34, 7.57–7.61 (5 H, m, C_6H_5), 8.32 (1 H, s, NH).

^{13}C NMR (75.0 MHz, $CDCl_3$): δ = −5.26, −5.27 [$Si(CH_3)_2$], 18.23 [$C(CH_3)_3$], 25.84 [$C(CH_3)_3$], 61.65 (C6), 67.78 (C4), 70.47 (C5), 83.82 (C1), 97.17 (CCl_3), 123.43 (C3), 127.42, 128.85, 131.84, 135.09 (Ph), 132.16 (C2), 161.86 (C=N).

FABMS: m/z = 494 $[M - 1]^+$.

Phenylthio-6-*O*-*tert*-butyldimethylsilyl-2,3,4-trideoxy-2-trichloroacetamido-α-D-3-enomannoside (6):

A xylene solution (5 mL) of **5** (50 mg, 0.1 mmol) was heated under reflux for 24 h. After the reaction mixture was evaporated, the residue was purified by preparative TLC on silica gel in EtOAc/hexane (1:4) to give **6** as colorless needles; yield: 17 mg (34%), mp 73–75 °C (EtOAc), $[\alpha]_D^{24}$ +114.28 ($c = 0.42$, $CHCl_3$).

IR (film): ν_{max} 3400 (NH), 2950 (CH), 1720 (C=O), 1595 cm^{-1} (Ph).

^1H NMR (400 MHz, $CDCl_3$): δ = 0.08 [6 H, s, $Si(CH_3)_2$], 0.90 (9 H, s, *t*-butyl), 3.81, 3.84 (1 H, dd, J = 4.5, 12.0 Hz, 6-H_2), 4.57 (1 H, dddd, J = 1.0, 1.5, 6.0, 8.5 Hz, 2-H), 4.68 (1 H, m, 5-H), 5.45 (1 H, dd, J = 1.0, 1.5 Hz, 1-H), 6.01 (1 H, dddd, J = 1.5, 2.0, 6.0, 10.0 Hz, 3-H), 6.10 (1 H, dd, J = 1.5, 10.0 Hz, 4-H), 6.88 (1 H, d, J = 8.5 Hz, NH), 7.24–7.55 (5 H, m, C_6H_5).

^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 5.27 [$Si(CH_3)_2$], 18.48 [$C(CH_3)_3$], 25.93 [$C(CH_3)_3$], 48.25 (C2), 64.74 (C6), 70.11 (C5), 86.02 (C1), 92.20 (CCl_3), 122.10 (C3), 127.45, 129.04, 131.41, 134.34 (SPh), 132.98 (C4), 161.13 (NHCO).

FAB-HR-MS: $C_{20}H_{28}{}^{35}Cl_3NO_3SSi(+Na)$: calc. 518.0504; found m/z: 518.0524 $[M + Na]^+$.

Methyl 4-*O*-(6-*O*-*tert*-Butyldimethylsilyl-2,3,4-trideoxy-2-trichloroacetamido-α-D-3-enomannopyranosyl)-2,3,6-tri-*O*-benzyl-α-D-glucopyranoside (8):

To a stirred mixture of $Pd(CH_3CN)_2Cl_2$ (17 mg, 0.06 mmol) and powdered molecular sieves 4 Å (120 mg) in dichloromethane (1 mL) was added, under an argon atmosphere, AgOTf (16 mg, 0.06 mmol) at r.t. The mixture was stirred for 15 min, to afford a solution of activator, which was used directly for glycosylation reactions. To this solution was added a dichloromethane solution (1 mL) of **7** (19 mg, 0.04 mmol) followed immediately by addition of **6** (32 mg, 0.06 mmol) in dichloromethane solution (1 mL) by use of a syringe at r.t., respectively. After 24 h, the reaction mixture was quenched by triethylamine (10 mg, 0.1 mmol) and the insoluble materials were removed by filtration through celite. The filtrate was concentrated, and the residue was purified by preparative TLC on silica gel in EtOAc/hexane (1:4) to give **8** as a colorless oil; yield: 9.3 mg (27%), $[\alpha]_D^{25}$ +60.5 ($c = 0.8$, $CHCl_3$).

IR (neat): ν_{max} = 3400 (NH), 3040 (CH=CH), 1720 cm^{-1} (C=O).

^1H NMR (400 MHz, $CDCl_3$): δ = 0.01, 0.02 [3 H, each, s, $Si(CH_3)_2$], 0.86 (9 H, s, *t*-butyl), 3.38 (3 H, s, CH_3), 3.54 (1 H, dd, J = 2.5, 12.0 Hz, 6-Ha), 3.55 (1 H, dd, J = 3.5, 9.0 Hz, 2′-H), 3.58 (1 H, dd, J = 4.0, 12.0 Hz, 6-Hb), 3.64 (1 H, dd, J = 2.0, 11.0 Hz, 6′-Ha), 3.70 (1 H, dd, J = 4.0, 11.0 Hz, 6′-Hb), 3.75 (1 H, ddd, J = 2.0, 4.0, 9.0 Hz, 5′-H), 3.91 (1 H, t, J = 9.0 Hz, 4′-H), 3.97 (1 H, t, J = 9.0 Hz, 3′-H), 4.17 (1 H, m, 5-H), 4.34 (1 H, dddd, J = 1.5, 2.0, 5.5, 9.0 Hz, 2-H), 4.59 (1 H, d, J = 3.5 Hz, 1′-H), 4.55–5.00 (6 H, $PhCH_2 \times 3$), 5.46 (1 H, dd, J = 1.0, 1.5 Hz, 1-H), 5.81 (1 H, dddd, J = 1.0, 1.5, 5.5, 10.0 Hz, 3-H), 5.87 (1 H, dd, J = 1.5, 10.0 Hz, 4-H), 7.25–7.35 (15 H, m, $C_6H_5 \times 3$), 6.50 (1 H, d, J = 9.0 Hz, NH).

^{13}C NMR (100.6 MHz, $CDCl_3$): δ = −5.29 [$Si(CH_3)_2$], 18.48 [$C(CH_3)_3$], 25.96 [$C(CH_3)_3$], 46.94 (C2), 55.21 (CH_3), 64.95 (C6), 68.92 (C′6), 69.56 (C5), 69.66 (C′5), 73.35, 75.01 ($PhCH_2 \times 3$), 73.42 (C′4), 80.18 (C′2), 81.6 (C′3), 92.27 (CCl_3), 97.63 (Cl), 97.90 (C′1), 121.15 (C3), 131.45 (C4), 127.30, 127.43, 127.49, 127.55, 127.90, 128.15, 128.28, 128.42, 137.97, 138.06, 138.50 ($C_6H_5 \times 3$), 161.05 (NHCO).

FABMS: m/z = 874 $[M + Na]^+$.

Methyl 4-*O*-(4,6-Di-*O*-acetyl-2,3-dideoxy-α-D-*threo*-hex-2-enopyranosyl)-2,3,6-tri-*O*-benzyl-α-D-glucopyranoside (10) [Reaction of 2-Phenylmercapto-4,6-*O*-diacetyl-2,3-dideoxy-α-D-galactoside (2) with 7]:

To a stirred solution of $Pd(CH_3CN)_2Cl_2$ (259.4 mg, 1.0 mmol) and powdered 4Å molecular sieves (1 g) in dichloromethane (5 mL) was added, under an argon atmosphere, AgOTf (257 mg, 1.0 mmol) at r.t. After the reaction mixture had been stirred for 15 min, to this solution was added a dichloromethane solution (1 mL) of **7** (232 mg, 0.5 mmol) followed immediately by 2-phenylmercapto-4,6-*O*-diacetyl-2,3-dideoxy-α-D-glactoside (**2**; 322 mg, 1.0 mmol) in dichloromethane solution (1 mL) by use of a syringe at r.t. After 1.5 h, the reaction mixture was quenched by triethylamine (118 mg, 1.1 mmol), and the insoluble materials were removed by filtration through celite. The filtrate was concentrated and residue was purified by preparative TLC on silica gel in EtOAc/hexane (1:5) to give **10** (288.2 mg, 85%, α/β = 99: ≧ 1) as colorless needles; yield: 288.2 mg (85%), mp 122–123 °C (EtOAc), $[\alpha]_D^{25}$ −62.4 ($c = 1.0$, $CHCl_3$).

IR (film): ν_{max} = 2860 (CH) 1740 cm^{-1} (C=O).

^1H NMR (400 MHz, $CDCl_3$): δ = 2.01, 2.05 (3 H, each, s, $COCH_3$), 3.41 (3 H, s, OCH_3), 3.55 (1 H, dd, J = 3.5, 9.5 Hz, 2′-H), 3.66 (1 H, dd, J = 9.0, 9.5 Hz, 4′-H), 3.69 (1 H, dd, J = 6.5, 11.0 Hz, 6′-Ha), 3.79 (1 H, dd, J = 1.5, 11.0 Hz, 6′-Hb), 3.83 (1 H, ddd, J = 1.5, 6.5, 9.0 Hz, 5′-H), 3.96 (1 H, t, J = 9.5 Hz, 3′-H), 4.06–4.10 (3 H, m, 5-H, 6-H_2), 4.54–4.76, 5.05 (6 H, $PhCH_2 \times 3$), 4.63 (1 H, d, J = 3.5 Hz, 1′-H), 4.91 (1 H, br d, J = 5.5 Hz, 4-H), 5.50 (1 H, dd, J = 1.0, 3.0 Hz, 1-H), 5.69 (1, dd, J = 3.0, 10.0 Hz, 2-H), 6.00 (1 H, ddd, J = 1.0, 5.5, 10.0 Hz, 3-H), 7.27–7.35 (15 H, m, $C_6H_5 \times 3$).

^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 20.74, 20.79 ($COCH_3$), 55.17 (OCH_3), 62.37 (C4), 62.59 (C6), 66.83 (C5), 69.51 (C′6), 69.55 (C′5), 72.99, 73.19, 75.52 ($PhCH_2 \times 3$), 76.12 (C′4), 80.16 (C′2), 81.86 (C′3), 95.10 (C1), 97.64 (C′1), 124.44 (C3), 127.46, 127.51, 127.58,

127.96, 128.12, 128.26, 128.45 (Ph), 130.49 (C2), 137.86, 138.28, 138.51 (Ph), 170.28, 170.41 ($COCH_3$).

FAB-MS: $m/z = 675$ $[M-1]^+$.

Methyl 4-*O*-(4,6-Di-*O*-acetyl-2,3-dideoxy-α-D-*threo*-hex-2-enopyranosyl)-2,3,6-tri-*O*-benzyl-α-D-glucopyranoside (10) [Reaction of 3-β-Pyridylthio-4,6-*O*-diacetyl-2,3-dideoxy-D-galactal (9) with 7]:

To a stirred solution of $Pd(CH_3CN)_2Cl_2$ (130 mg, 0.5 mmol) and powdered 4Å molecular sieves (1 g) in dichloromethane (4 mL) was added, under an argon atmosphere, AgOTf (129 mg, 0.5 mmol) at r.t. After the reaction mixture had been stirred for 15 min, to this solution was added a dichloromethane solution (1 mL) of **7** (232 mg, 0.5 mmol) followed immediately by 3-β-pyridylthio-4,6-*O*-diacetyl-2,3-dideoxy-D-galactal (**9**; 162 mg, 0.5 mmol) in dichloromethane solution (0.5 mL) by use of a syringe at r.t. After 2 h, the reaction mixture was quenched by triethylamine (56 mg, 0.55 mmol), and the insoluble materials were removed by filtration through celite. The filtrate was concentrated and residue was purified by preparative TLC on silica gel in EtOAc/hexane (1:5) to give **10** as colorless needles; yield: 228.5 mg (68%), $\alpha > 99$, mp 122–123°C (EtOAc), $[\alpha]_D^{25}$ −65.0 ($c = 1.0$, $CHCl_3$).

^{1}H NMR of this compound **10** agreed with **10** which was obtained by reaction of **2** and **7**.

Methyl 4-*O*-(2,3-Dideoxy-α-D-*threo*-hex-2-enopyranosyl)-2,3,6-tri-*O*-benzyl-α-D-glucopyranoside (11):

To a stirred solution of **10** (566.2 mg, 0.838 mmol) in dry MeOH (2 mL) was added K_2CO_3 (522 mg, 3.78 mmol) at r.t. After 45 min, insoluble materials were filtered. The filtrate was purified by preparative TLC on silica gel in EtOAc/hexane/MeOH (25:25:1) to give **11** as a colorless oil; yield: 442.6 mg (89%), $R_f = 0.34$ (EtOAc/hexane/MeOH = 25:25:1), $[\alpha]_D^{24}$ −3.3 ($c = 0.30$, $CHCl_3$).

IR (neat): $\nu_{max} = 3400$ (OH), 3040 cm^{-1} (CH=CH).

^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 1.86$ (1H, br d, $J = 8.0$ Hz, 4-OH), 2.74 (1H, br, 6-OH), 3.40 (3H, s, OCH_3), 3.57 (1H, dd, $J = 3.5$, 9.5 Hz, 2′-H), 3.65–3.84 (8H, m, 4-H, 5-H, 6-H_2, 4′-H, 5′-H, 6′-H_2), 3.96 (1H, dd, $J = 8.5$, 9.5 Hz, 3′-H), 4.65 (1H, d, $J = 3.5$ Hz, 1′-H), 4.62–4.75, 5.05 (6H, $PhCH_2 \times 3$), 5.52 (1H, dd, $J = 1.0$, 3.0 Hz, 1-H), 5.60 (1H, dd, $J = 3.0$, 10.0 Hz, 2-H), 6.04 (1H, ddd, $J = 1.0$, 5.5, 10.0 Hz, 3-H), 7.28–7.39 (15H, m, $C_6H_5 \times 3$).

^{13}C NMR (100.6 MHz, $CDCl_3$): $\delta = 55.18$ (CH_3), 62.38 (C′5), 62.92 (C′6), 68.55 (C6), 70.29 (C5), 71.35 (C4), 73.22, 73.61, 75.60 ($PhCH_2 \times 3$), 75.20 (C′4), 80.29 (C′2), 82.08 (C′3), 95.35 (C1), 97.68 (C′1), 128.42 (C2), 128.99 (C3), 127.53, 127.62, 127.96, 128.06, 128.33, 128.48, 137.92, 138.30, 138.53 ($C_6H_5 \times 3$).

FAB-MS: $m/z = 615$ $[M + Na]^+$.

Methyl 4-*O*-(6-*O*-*tert*-Butyldimethylsilyl-2,3-dideoxy-α-D-*threo*-hex-2-enopyranosyl)-2,3,6-tri-*O*-benzyl-α-D-glucopyranoside (12):

To a stirred solution of **11** in dry CH_2Cl_2 (10 mL) were added 4-dimethylaminopyridine (DMAP; 150 mg, 0.25 mmol) and *t*-butyldimethylsilyl chloride (TBSCl; 115 mg, 0.76 mmol) at r.t. After 1 h, the reaction mixture was quenched with sat. $NaHCO_3$ solution and extracted with dichloromethane (10 mL × 3) and washed with H_2O (30 mL × 2) and brine (30 mL). After drying (Na_2SO_4), the organic layer was evaporated under vacuum and the residue was purified by preparative TLC on silica gel in EtOAc/hexane (1:3) to give **12** as colorless prisms; yield: 147.5 mg (83%), mp 113–114°C (EtOAc), $[\alpha]_D^{20}$ −23.1 ($c = 0.26$, $CHCl_3$).

IR (film): $\nu_{max} = 3450$ (OH), 2930 cm^{-1} (CH).

^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 0.05, 0.06$ [3H, each, s, $Si(CH_3)_2$], 0.88 (9H, s, *t*-butyl), 2.34 (1H, d, $J = 7.0$ Hz, 4-OH), 3.40 (3H, s, CH_3), 3.53 (1H, dd, $J = 3.5$, 9.5 Hz, 2′-H), 3.67 (1H, dd, $J = 9.0$, 10.0 Hz, 4′-H), 3.70–3.86 (6H, m, 6-H_2, 5-H, 6′-H_2, 5′-H), 3.90 (1H, ddd, $J = 2.0$, 5.5, 7.0 Hz, 4-H), 3.95 (1H, dd, $J = 9.0$, 9.5 Hz, 3′-H), 4.53–4.75, 5.03 (6H, $PhCH_2 \times 3$), 4.63 (1H, d, $J = 3.5$ Hz, 1′-H), 5.46 (1H, dd, $J = 1.0$, 3.0 Hz, 1-H), 5.65 (1H, dd, $J = 3.0$, 10.0 Hz, 2-H), 6.09 (1H, ddd, $J = 1.0$, 5.5, 10.0 Hz, 3-H), 7.27–7.35 (15H, $C_6H_5 \times 3$).

^{13}C NMR (75.0 MHz $CDCl_3$): $\delta = -5.46, -5.42$ [$Si(CH_3)_2$], 18.25 [$C(CH_3)_3$], 25.86 [$C(CH_3)_3$], 55.14 (CH_3), 61.60 (C4), 62.62, 69.60 (C6, C′6), 69.83, 70.30 (C5, C′5), 73.24, 75.67 ($PhCH_2 \times 3$), 75.82 (C′4), 80.20 (C′2), 82.01 (C′3), 95.65 (C1), 97.71 (C′1), 127.35, 127.44, 127.65, 127.95, 128.13, 128.29, 128.47, 128.51 ($C_6H_5 \times 3$), 128.26 (C2), 129.16 (C3).

FAB-MS: $m/z = 706$ $[M]^+$.

Methyl 4-*O*-[6-*O*-*tert*-Butyldimethylsilyl-2,3-dideoxy-4-*O*-(1-imino-1-trichloromethyl]-α-D-*threo*-hex-2-enopyranosyl)-2,3,6-tri-*O*-benzyl-α-D-glucopyranoside (13):

To a stirred solution of **12** (374.3 mg, 0.53 mmol) in dry dichloromethane (5 mL) were added trichloroacetonitrile (230 mg, 1.59 mmol) and 60% NaH (20 mg, 0.5 mmol) at r.t. After 2 h, it was not possible to obtain sufficient product by TLC analysis; trichloroacetonitrile (184 mg, 1.27 mmol) and 60% NaH (20 mg, 0.5 mmol) were added again to the reaction mixture. After 30 min, the organic solvent was evaporated and the residue was purified by preparative TLC on silica gel in EtOAc/hexane (1:4) to give **13** as a colorless oil; yield: 185 mg (95%), $[\alpha]_D^{25}$ −54.1 ($c = 0.54$, $CHCl_3$).

IR (neat): $\nu_{max} = 3340$ (NH), 2950 (CH), 1660 cm^{-1} (C=N).

^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 0.00, 0.02$ [3H, each, s, $Si(CH_3)_2$], 0.85 [9H, s, $SiC(CH_3)_3$], 3.39 (3H, s, CH_3), 3.53 (1H, dd, $J = 3.5$, 9.0 Hz, 2′-H), 3.71 (1H, t, $J = 9.0$ Hz, 4′-H), 3.77 (1H, dd, $J = 6.0$, 9.5 Hz, 6-Ha), 3.79 (3H, m, 5′-H, 6′-H_2), 3.86 (1H, dd, $J = 8.5$, 9.5 Hz, 6-Hb), 3.95 (1H, t, $J = 9.0$ Hz, 3′-H), 4.12 (1H, ddd, $J = 2.0$, 6.0, 8.5 Hz, 5-H), 4.50–4.75, 5.03 (6H, $PhCH_2 \times 3$), 4.63 (1H, d, $J = 3.5$ Hz, 1′-H), 5.15 (1H, dd, $J = 2.0$, 5.5 Hz, 4-H), 5.51 (1H, dd, $J = 1.0$, 3.0 Hz, 1-H), 5.78 (1H, dd, $J = 3.0$, 10.0 Hz, 2-H), 6.25 (1H, ddd, $J = 1.0$, 5.5, 10.0 Hz, 3-H), 7.24 (15H, m, $C_6H_5 \times 3$), 8.28 (1H, s, NH).

^{13}C NMR (75.0 MHz, $CDCl_3$): $\delta = -5.44, -5.37$ [$Si(CH_3)_2$], 18.16 [$C(CH_3)_3$], 25.82 [$C(CH_3)_3$], 55.13 (CH_3), 61.27, 69.73 (C6, C′6), 66.63 (C4), 69.88 (C′5), 70.08 (C5), 73.23, 73.38, 75.54 ($PhCH_2 \times 3$), 76.11 (C′4), 80.20 (C′2), 81.95 (C′3), 91.44 (CCl_3), 95.37 (C1), 97.71 (C′1), 123.81 (C3), 127.42, 127.49, 127.57, 127.93, 128.12, 128.24, 128.44 ($C_6H_5 \times 3$), 131.30 (C2), 137.98, 138.36, 138.63 ($C_6H_5 \times 3$), 161.82 (C=N).

FAB-MS: $m/z = 872$ $[M + Na]^+$.

Methyl 4-*O*-(6-*O*-*tert*-Butyldimethylsilyl-2,3,4-trideoxy-2-trichloroacetamido-α-D-3-enopyranosyl)-2,3,6-tri-*O*-benzyl-α-D-glucopyranoside (8) (from 13):

A DMF solution of **13** (207.8 mg, 0.244 mmol) was heated at 140°C for 6 h. The reaction mixture was evaporated and the residue was purified by preparative TLC on silica gel in EtOAc/hexane (1:4) to give **8** as a colorless oil; yield: 165 mg (80%), $[\alpha]_D^{25}$ +61.51 ($c = 0.8$, $CHCl_3$).

^{1}H NMR of the compound **8** agreed with **8** which was prepared from **6**.

Methyl 4-*O*-(3,4-Anhydro-6-*O*-*tert*-butyldimethylsilyl-2-deoxy-2-trichloroacetamido-α-D-tallopyranosyl)-2,3,6-tri-*O*-benzyl-α-D-glucopyranoside (14):

To a stirred solution of **8** (65.5 mg, 0.077 mmol) in chloroform (5 mL) was added *m*-chloroperbenzoic acid (531.5 mg, 3.08 mmol) at r.t. After 4 days (reaction was monitored by TLC), the reaction mixture was washed with sat. $NaHCO_3$ solution (10 mL × 2), water (10 mL) and brine (10 mL). After drying, the organic layer was evaporated and the residue was purified by preparative TLC on silica gel in EtOAc/hexane (1:4) to give **14** as a colorless oil; yield: 43.2 mg (65%), $[\alpha]_D^{23}$ +27.0 ($c = 0.67$, $CHCl_3$).

IR (neat): $\nu_{max} = 3440$ (NH), 1720 (C=O), 1250 cm^{-1} (epoxy).

^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 0.04, 0.06$ [3H each, s, $Si(CH_3)_2$], 0.89 [9H, s, $SiC(CH_3)_3$], 3.23 (1H, ddd, $J = 1.0$, 4.0, 5.5 Hz, 3-H), 3.30 (1H, dd, $J = 1.5$, 4.0 Hz, 4-H), 3.38 (3H, s, CH_3), 3.56 (1H, dd, $J = 3.5$, 9.0 Hz, 2′-H), 3.62–3.76 (5H, m, 6-H_2, 6′-H_2, 5′-H), 3.86 (1H, t, $J = 9.0$ Hz, 4′-H), 3.93 (1H, t, $J = 9.0$ Hz, 3′-H), 4.12 (1H, ddd, $J = 1.5$, 6.0, 7.0 Hz, 5-H), 4.26 (1H, ddd, $J = 1.5$, 5.5, 8.5 Hz, 2-H), 4.49–4.77 (6H, $PhCH_2 \times 3$), 4.58 (1H, d, $J = 3.5$ Hz, 1′-H), 5.02 (1H, dd, $J = 1.0$, 1.5 Hz, 1-H), 6.92 (1H, d, $J = 8.5$ Hz, NH), 7.25–7.36 (15H, $C_6H_5 \times 3$).

^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 18.16 [$C(CH_3)_3$], 25.83 [$C(CH_3)_3$], 46.26 (C2), 48.98 (C3), 51.09 (C4), 55.29 (OCH_3), 62.74, 68.57 (C6, C'6), 66.37 (C5), 69.68 (C'5), 73.34, 73.40, 74.73 ($PhCH_2 \times 3$), 74.02 (C'4), 80.25 (C'2), 81.05 (C'3), 92.20 (CCl_3), 96.25 (C1), 97.90 (C'1), 127.07, 127.27, 127.52, 127.57, 127.94, 128.14, 128.30, 128.43, 137.89, 138.64 ($C_6H_5 \times 3$), 161.53 (NHCO).

FAB-MS: m/z = 890 $[M + Na]^+$.

Methyl 4-*O*-(3,4,6-Tri-*O*-acetyl-2-deoxy-2-trichloroacetamido-α-D-mannopyranosyl)-2,3,6-tri-*O*-benzyl-α-D-glucopyranoside (15) and Methyl 4-*O*-(3,4,6-Tri-*O*-acetyl-2-deoxy-2-trichloroacetamido-α-D-idopyranosyl)-2,3,6-tri-*O*-benzyl-α-D-glucopyranoside (16):

To a stirred solution of **14** (43.2 mg, 0.05 mmol) in 20% acetic anhydride–acetic acid (1 mL) was added one drop of boron trifluoride–diethyl ether complex (ca. 2.5 mg, 0.017 mmol) using a 10 μL micro syringe at r.t. After 24 h, EtOAc (10 mL) was added to the reaction mixture which was then quenched with sat. $NaHCO_3$ solution (10 mL). The aqueous layer was extracted with EtOAc (10 mL × 2), and the combined organic layers were washed with brine (15 mL), dried (Na_2SO_4), and the solvent was evaporated under vacuum. The residue was purified by preparative TLC on silica gel in EtOAc/hexane (1:1) to afford a mixture of **15** and **16** as a colorless oil (39.1 mg, 88%). The ratio of this mixture was observed to be **15**/**16** = 5.3:1 by ^{1}H-NMR examination (based on the integral value of C1-H). Furthermore, the separation of compounds **15** and **16** was carried out by preparative TLC with multiple development on silica gel in acetone/benzene (1:150) to afford compound **15** (28.7 mg, 64%) and compound **16** (5.6 mg, 13%) as colorless oils, respectively.

15: $[\alpha]_D^{27}$ + 42.17 (c = 0.46, $CHCl_3$).

IR (neat): ν_{max} = 3430 (NH), 1760, 1730 cm^{-1} (C=O).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.98, 2.02, 2.03 (3H, each s, $COCH_3 \times 3$), 3.41 (3H, s, OCH_3), 3.55 (1H, dd, J = 3.5, 9.5 Hz, 2'-H), 3.67 (1H, dd, J = 2.0, 11.0 Hz, 6'-Ha), 3.75 (1H, dd, J = 3.0, 11.0 Hz, 6'-Hb), 3.78 (1H, ddd, J = 2.0, 3.0, 9.0 Hz, 5'-H), 3.81 (1H, dd, J = 5.5, 10.0 Hz, 6-Ha), 3.85 (1H, dd, J = 8.0, 9.0 Hz, 4'-H), 3.95 (1H, ddd, J = 3.0, 5.5, 10.0 Hz, 5-H), 3.97 (1H, dd, J = 3.0, 10.0 Hz, 6-Hb), 4.40 (1H, dd, J = 8.0, 9.5 Hz, 3'-H), 4.53 (1H, ddd, J = 2.0, 4.0, 9.5 Hz, 2-H), 4.61 (1H, d, J = 3.5 Hz, 1'-H), 4.56–4.77, 5.06 (6H, $PhCH_2 \times 3$), 5.18 (1H, t, J = 10.0 Hz, 4-H), 5.29 (1H, dd, J = 4.0, 10.0 Hz, 3-H), 5.41 (1H, d, J = 2.0 Hz, 1-H), 6.59 (1H, d, J = 9.5 Hz, NH), 7.20–7.40 (15H, m, $C_6H_5 \times 3$).

^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 20.59 ($COCH_3 \times 3$), 52.19 (C2), 55.40 (OCH_3), 61.71 (C6), 64.90 (C4), 68.73 (C5), 68.89 (C'6), 69.34 (C'5), 69.41 (C3), 73.22, 73.54, 75.54 ($PhCH_2 \times 3$), 75.66 (C'4), 80.28 (C'2), 81.22 (C'3), 92.20 (CCl_3), 97.79 (C'1), 98.69 (C1), 127.35, 127.71, 127.77, 127.89, 128.02, 128.10, 128.40, 128.48, 128.51, 137.79, 137.83 ($C_6H_5 \times 3$), 161.48 (NHCO), 169.30, 170.15, 170.25 ($COCH_3$).

FAB-MS: m/z = 896 $[M]^+$.

16: $[\alpha]_D^{26}$ + 53.66 (c = 0.41, $CHCl_3$).

IR (neat): ν_{max} = 3430 (NH), 1750, 1730 cm^{-1} (C=O).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.98, 2.04, 2.11 (3H each, s, $COCH_3 \times 3$), 3.40 (3H, s, OCH_3), 3.55 (1H, dd, J = 3.5, 9.5 Hz, 2'-H), 3.70–3.82 (3H, m, 5'-H, 6'-H_2), 3.86 (1H, br d, J = 9.5 Hz, 4'-H), 3.92, 4.09 (1H each, dd, J = 6.5, 11.5 Hz, 6-H_2), 3.98 (1H, t, J = 9.5 Hz, 3'-H), 4.23 (1H, ddd, J = 2.0, 3.5, 10.0 Hz, 2-H), 4.39 (1H, dt, J = 2.0, 6.5 Hz, 5-H), 4.60 (1H, d, J = 3.5 Hz, 1'-H), 4.56–4.73, 5.01 (6H, $PhCH_2 \times 3$), 4.83 (1H, t, J = 3.5, 3-H), 4.99 (1H, dd, J = 2.0, 3.5 Hz, 4-H), 5.48 (1H, br d, J = 2.0 Hz, 1-H), 7.16 (1H, d, J = 10.0 Hz, NH), 7.26–7.32 (15H, m, $C_6H_5 \times 3$).

^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 20.67, 20.73, 20.83 ($COCH_3 \times 3$), 48.80 (C2), 55.42 (OCH_3), 61.74 (C6), 64.08 (C5), 66.12 (C4), 66.78 (C3), 69.07 (C'6), 69.71 (C'5), 73.28, 73.64, 74.78 ($PhCH_2 \times 3$), 73.43 (C'4), 80.27 (C'2), 81.74 (C'3), 92.17 (CCl_3), 97.78 (C'1), 98.06 (C1), 127.35, 127.43, 127.53, 127.73, 127.95, 127.99, 128.08, 128.13, 128.35, 128.42, 128.46, 128.55, 129.63, 137.82, 138.02, 138.28 ($C_6H_5 \times 3$), 160.75 (NHCO), 168.52, 168.76, 170.15 ($COCH_3 \times 3$).

FAB-MS: m/z = 919 $[M + Na]^+$.

Methyl 4-*O*-(6-*O*-*tert*-Butyldimethylsilyl-2-deoxy-2-trichloroacetamido-α-D-altropyranosyl)-2,3,6-tri-*O*-benzyl-α-D-glucopyranoside (17) and Methyl 4-*O*-(6-*O*-*tert*-Butyldimethylsilyl-2-deoxy-2-trichloroacetamido-α-D-talopyranosyl)-2,3,6-tri-*O*-benzyl-α-D-glucopyranoside (18):

To a stirred solution of **8** (100 mg, 0.118 mmol) in pyridine (3 mL) was added dropwise a pyridine solution (1 mL) of OsO_4 (445 mg, 0.18 mmol) at r.t. After 17 h, 2.5 mL of $NaHSO_3$ (60 mg) in pyridine/water (2:3) were added to the reaction mixture and stirring was continued for 1 h. This solution was extracted with dichloromethane (5 mL × 7) and the combined organic layers were washed with 10% citric acid solution (10 mL × 2), H_2O (10 mL), and brine (10 mL), dried (Na_2SO_4), and the solvent was evaporated under vacuum. The residue was purified by preparative TLC on silica gel in EtOAc/hexane (1:3) to afford a mixture of **17** (70.6 mg, 68%) and **18** (14.5 mg, 14%) as colorless oils, respectively.

17: ^{1}H NMR (400 MHz, $CDCl_3 + D_2O$): δ = 0.03 [6H, s, $Si(CH_3)_2$], 0.87 (9H, s, t-butyl), 2.50 (1H, d, J = 9.0 Hz, 4-OH), 3.32 (1H, d, J = 9.5 Hz, 3 OH), 3.39 (3H, s, OCH_3), 3.54 (1H, dd, J = 3.5, 9.5 Hz, 2'-H), 3.66 (1H, dd, J = 2.0, 11.0 Hz, 6-Ha or 6'-Ha), 3.68 (2H, m, 5-H, 5'-H), 3.71 (1H, m, 4-H), 3.79 (1H, dd, J = 3.0, 11.0 Hz, 6-Hb or 6'-Hb), 3.70–3.80 (2H, m, 6'-Ha or 6-Ha, 6'-Hb or 6-Hb), 3.82 (1H, dd, J = 8.0, 10.0 Hz, 4'-H), 3.99 (1H, ddt, J = 1.5, 3.5, 9.5 Hz, 3-H), 4.00 (1H, dd, J = 8.0, 9.5 Hz, 3'-H), 4.27 (1H, ddd, J = 1.5, 3.5, 8.5 Hz, 2-H), 4.53–4.76, 5.05 (6H, $PhCH_2 \times 3$), 4.59 (1H, d, J = 3.5 Hz, 1'-H), 5.42 (1H, t, J = 1.5 Hz, 1-H), 6.50 (1H, d, J = 8.5 Hz, NH), 7.26–7.36 (15H, m, $C_6H_5 \times 3$).

^{13}C NMR (100.6 MHz, $CDCl_3 + D_2O$): δ = −5.44, −5.36 [$Si(CH_3)_2$], 18.39 [$SiC(CH_3)_3$], 25.96 [$SiC(CH_3)_3$], 52.55 (C2), 55.41 (OCH_3), 62.16, 69.04 (C6, C'6), 63.42 (C4), 67.82 (C3), 69.70, 69.78 (C'5, C5), 73.24, 73.51, 75.49 ($PhCH_2 \times 3$), 76.08 (C'4), 80.27 (C'2) 81.30 (C'3), 91.98 (CCl_3), 97.72 (C'1), 99.11 (C1), 127.49, 127.81, 127.83, 127.87, 128.07, 128.12, 128.43, 128.53, 128.56, 137.65, 137.73, 137.76 ($C_6H_5 \times 3$), 160.83 (NHCO).

FAB-MS: m/z = 908 $[M + Na]^+$.

18: ^{1}H NMR (400 MHz, $CDCl_3 + D_2O$): δ = −0.01, 0.00 [3H each, s, $Si(CH_3)_2$], 0.84 (9H, s, t-butyl), 1.60 (1H, br, 4-OH), 2.20 (1H, br d, J = 8.0 Hz, 3-OH), 3.40 (3H, s, OCH_3), 3.56 (1H, dd, J = 3.5, 9.5 Hz, 2'-H), 3.61 (2H, m, 5-H, 6'-Ha), 3.67, 3.75 (1H each, m, 6-H_2), 3.71 (1H, m, 6'-Hb), 3.73 (1H, m, 5'-H), 3.86 (1H, m, 3-H), 3.88 (1H, dd, J = 9.0, 9.5 Hz, 4'-H), 3.98 (1H, dd, J = 9.0, 9.5 Hz, 3'-H), 4.11 (1H, d, J = 2.5 Hz, 4-H), 4.28 (1H, ddd, J = 1.0, 4.5, 9.0 Hz, 2-H), 4.52–5.01 (6H, $PhCH_2 \times 3$), 4.58 (1H, d, J = 3.5 Hz, 1'-H), 5.50 (1H, d, J = 1.0 Hz, 1-H), 7.27–7.36 (15H, m, $C_6H_5 \times 3$), 8.47 (1H, d, J = 9.0 Hz, NH).

^{13}C NMR (100.6 MHz, $CDCl_3 + D_2O$): δ = −5.73, −5.59 [$Si(CH_3)_2$], 18.00 [$SiC(CH_3)_3$], 25.64 [$SiC(CH_3)_3$], 53.20 (C2), 55.32 (OCH_3), 64.83 (C3), 65.59 (C6), 68.54 (C5), 69.02 (C'6), 69.62 (C'5), 71.81 (C4), 73.06 (C'4), 73.34, 73.55, 74.96 ($PhCH_2 \times 3$), 80.45 (C'2), 81.58 (C'3), 92.64 (CCl_3), 97.86 (C'1), 99.18 (C1), 127.30, 127.42, 127.70, 127.77, 127.93, 128.11, 128.24, 128.38, 128.44, 137.92, 137.95, 138.48 ($C_6H_5 \times 3$), 162.37 (NHCO).

FAB-MS: m/z = 908 $[M + Na]^+$.

Methyl 4-*O*-(3,4,6-Tri-*O*-acetyl-2-deoxy-2-trichloroacetamido-α-D-altropyranosyl)-2,3,6-tri-*O*-benzyl-α-D-glucopyranoside (19):

To a solution of **17** (70.6 mg, 0.0798 mmol) in THF (2 mL) was added 1 M TBAF–THF solution (0.159 mL, 0.159 mmol) at r.t. The mixture was stirred for 20 min. After the organic solvent was evaporated under vacuum, pyridine/Ac_2O (1:1) (4 mL) was added to the residue and stirring was continued for 24 h at r.t. The pyridine/Ac_2O solution was evaporated under vacuum, and the residue was purified by preparative TLC on silica gel in EtOAc/hexane (1:2) to afford **19** as a colorless oil; yield: 71.2 mg (100%), $[\alpha]_D^{24}$ + 53.2 (c = 1.47, $CHCl_3$).

IR (neat): ν_{max} = 3420 (NH), 1750, 1720 cm^{-1} (C=O).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 2.01, 2.03, 2.04 (3H each, s, $COCH_3$), 3.41 (3H, s, OCH_3), 3.55 (1H, dd, J = 3.5, 9.5 Hz, 2'-H), 3.71–3.80 (3H, m, 6'-H_2, 5'-H), 3.84 (1H, t, J = 9.5 Hz, 4'-H), 3.92 (1H, dd, J = 3.0, 12.0 Hz, 6-Ha), 3.98 (1H, t, J = 9.5 Hz, 3'-H),

4.12 (1 H, dd, J = 7.5, 12.0 Hz, 6-Hb), 4.16 (1 H, m, 5-H), 4.21 (1 H, ddd, J = 3.0, 5.5, 8.5 Hz, 2-H), 4.56–4.74, 5.06 (6 H, PhCH_2 × 3), 4.63 (1 H, d, J = 3.5 Hz, 1′-H), 5.06 (1 H, dd, J = 3.5, 8.0 Hz, 4-H), 5.23 (1 H, dd, J = 3.5, 5.5 Hz, 3-H), 5.40 (1 H, d, J = 3.0 Hz, 1-H), 6.48 (1 H, d, J = 8.5 Hz, NH), 7.25–7.34 (15 H, m, C_6H_5 × 3).

^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 20.62, 20.75 (CO*C*H$_3$ × 3), 52.18 (C2), 55.42 (O*C*H$_3$), 62.19 (C6), 64.96 (C4), 66.47 (C3), 67.10 (C5), 68.92 (C′6), 69.67 (C′5), 73.16, 73.71, 74.99 (PhCH$_2$ × 3), 73.77 (C′4), 80.24 (C′2), 81.77 (C′3), 97.73 (C′1), 98.41 (C1), 127.27, 127.55, 127.68, 127.73, 128.03, 128.12, 128.38 128.50, 128.54, 137.73, 138.01, 138.16 (*C*$_6$H$_5$ × 3), 161.11 (NH*C*O), 169.37, 169.65, 170.30 (*C*OCH$_3$ × 3).

FAB-MS: m/z = 896 $[M]^+$.

Methyl 4-*O*-(3,4,6-Tri-*O*-acetyl-2-deoxy-2-trichloroacetamido-α-D-talopyranosyl)-2,3,6-tri-*O*-benzyl-α-D-glucopyranoside (20):

To a solution of **18** (14.5 mg, 0.0164 mmol) 1 M TBAF–THF solution (0.033 mL, 0.033 mmol) was added at r.t. The mixture was stirred for 3 h. After the organic layer had been evaporated under vacuum, pyridine–Ac_2O (3:2) (2.5 mL) was added to the residue and stirring was continued for 24 h at r.t. The pyridine–Ac_2O solution was evaporated under vacuum, and the residue was purified by preparative TLC on silica gel in EtOAc/hexane (1:2) to afford **20** as a colorless oil; yield: 11.8 mg (80%), $[\alpha]_D^{26}$ + 54.5 (c = 0.61, $CHCl_3$).

IR (neat): ν_{max} = 3430 (NH), 1760, 1720 cm^{-1} (C=O).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.96, 2.14 (3 H, each, s, COCH_3 × 3), 3.40 (3 H, s, OCH_3), 3.56 (1 H, dd, J = 3.5, 9.5 Hz, 2′-H), 3.66 (1 H, dd, J = 1.5, 11.0 Hz, 6′-Ha), 3.75 (1 H, dd, J = 3.5, 11.0 Hz, 6′-Hb), 3.78 (1 H, ddd, J = 1.5, 3.5, 9.5 Hz, 5′-H), 3.85 (1 H, dd, J = 8.5, 9.5 Hz, 4′-H), 3.86, 4.03 (1 H each, dd, J = 7.0, 11.5 Hz, 6-H$_2$), 4.00 (1 H, dd, J = 8.5, 9.5 Hz, 3′-H), 4.21 (1 H, dt, J = 1.5, 7.0 Hz, 5-H), 4.45 (1 H, ddt, J = 1.0, 4.5, 10.0 Hz, 2-H), 4.56–4.75, 5.03 (6 H, PhCH_2 × 3), 4.58 (1 H, d, J = 3.5 Hz, 1′-H), 5.24 (1 H, dd, J = 3.5, 4.5 Hz, 3-H), 5.30 (1 H, ddd, J = 1.0, 1.5, 3.5 Hz, 4-H), 5.51 (1 H, d, J = 1.0 Hz, 1-H), 7.27–7.33 (15 H, m, C_6H_5 × 3), 7.35 (1 H, d, J = 10.0 Hz, NH).

^{13}C NMR (100.6 MHz, $CDCl_3$): δ = 20.43, 20.59, 20.77 (COCH_3 × 3), 50.72 (C2), 55.37 (O*C*H$_3$), 61.30 (C6), 64.58 (C3), 66.95 (C5), 66.98 (C4), 69.00 (C′6), 69.35 (C′5), 73.28, 73.43, 75.10 (Ph*C*H$_2$ × 3), 75.24 (C′4), 80.28 (C′2), 81.22 (C′3), 97.79 (C′1), 99.69 (C1), 127.40, 127.49, 127.55, 127.70, 127.99, 128.13, 128.30, 128.38, 128.47, 137.82, 137.89, 138.17 (*C*$_6$H$_5$ × 3), 161.42 (NH*C*O), 169.12, 169.25, 170.09 (*C*OCH$_3$ × 3).

FAB-MS: m/z = 897 $[M + 1]^+$.

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