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Synthesis of α-D-glucosyl substituted methyl glycosides of 3-deoxy-α-D-*manno*- and D-*glycero*-α-D-*talo*-oct-2-ulosonic acid (Kdo/Ko) corresponding to inner core fragments of *Acinetobacter* lipopolysaccharide

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ABSTRACT

The α-D-glucopyranosyl-(1→5)-substituted methyl glycosides of 3-deoxy-α-D-*manno*-oct-2-ulosonic acid (Kdo), 3-deoxy-α-D-*lyxo*-hept-2-ulosonic acid (Kdh), and D-*glycero*-α-D-*talo*-oct-2-ulosonic acid (Ko) were prepared using orthogonally protected glycosyl acceptor derivatives via glycosylation with a torsionally disarmed 4,6-*O*-benzylidene protected trifluoroacetimidate glucosyl donor followed by global deprotection. The related 6-*O*-phosphoryl-α-D-glucopyranosyl-(1→5)-substituted Kdo and Kdh derivatives were derived from a benzylidene-protected glucosyl intermediate using phosphoramidite and phosphoryl chloride-based phosphorylation steps, respectively. The deprotected disaccharides serve as ligands to study lectin binding of *Acinetobacter* lipopolysaccharide core oligosaccharides.

1. Introduction

Bacteria of the genus *Acinetobacter* have increasingly been implicated in nosocomial infections which are difficult to eradicate due to resistance against major antimicrobial drugs.[1] Lipopolysaccharide (LPS)—located in the outer leaflet of the bacterial cell membrane—is a major virulence factor contributing to bacterial evasion of adaptive and innate immune responses.[2] A general but not exclusive architecture of LPS comprises a bisphosphorylated acylated diglucosamine backbone, termed lipid A, a core region and an antigenic polysaccharide which is the main target of specific antibodies allowing the distinction of O-serotypes and which is therefore called O-polysaccharide or O-antigen.[3] The first sugar connecting the core region and the lipid A is—in general—3-deoxy-D-*manno*-oct-2-ulosonic acid (Kdo) but it may be partially replaced by the isosteric, acid-stable 3-hydroxy-derivative D-*glycero*-D-*talo*-oct-2-ulosonic acid (Ko).[4–7] In LPS from *Acinetobacter haemolyticus* NCTC 10305 in particular, a large fraction (~80%) contains Ko instead of Kdo (~20%), providing the linkage to the lipid A. In addition, the core oligosaccharide contains several α- and β-configured glucosyl as well as two 3-deoxy-D-*lyxo*-hept-2-ulosaric acid (Dha) residues (Fig. 1).

Previously, a 28 kDa murine serum protein has been described which binds to the inner core region of LPS from this *Acinetobacter* strain but also to oligosaccharides containing L-*glycero*-D-*manno*-heptosyl-Kdo units.[8–10] This "serum factor" has only recently been recognized as mannose binding lectin-A (MBL-A). Most notably this MBL binds to isolated LPS oligosaccharides with an unusual high affinity for the individual binding site (with ELISA IC_{50} values in the mid to low nanomolar range).[11] Extending our previous studies detailing the interaction of the core region with antibodies and lectins[12–15], we have set out to prepare a first series of fragments of the *Acinetobacter haemolyticus* NCTC 10305 inner core region in order to define the binding epitope at the molecular level. Since Smith degradation of the isolated LPS core resulted in ligands which were still bound by the lectin with similar affinity[5], non-natural disaccharides containing 3-deoxy-D-*lyxo*-hept-2-ulosonic acid (Kdh) have been prepared in addition. The synthetic oligosaccharides serve as ligands in forthcoming binding and STD NMR studies with C-type lectins such as human lung surfactant protein D and mannose-binding lectins.

2. Results and discussion

2.1. Preparation of the disaccharides α-Glc-(1→5)-α-Kdo/Kdh

The glycosides were designed as methyl (Me) glycosides since the single ^{1}H NMR signal of the Me group serves as a suitable

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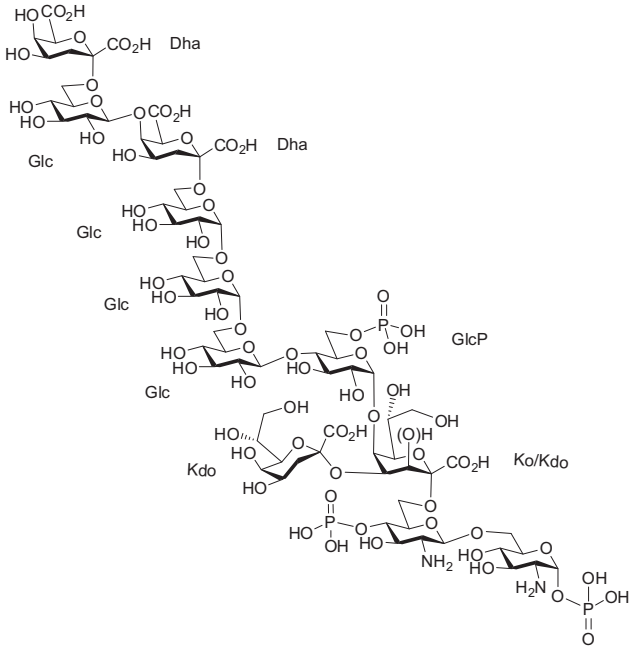
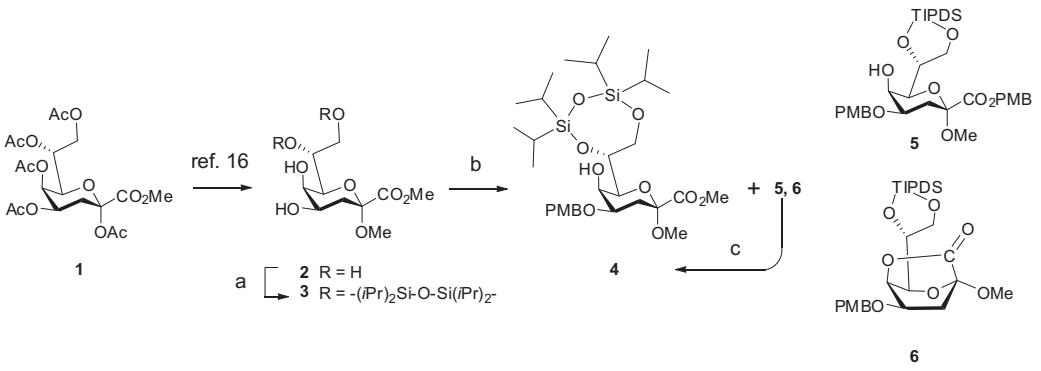


Figure 1. Structure of the deacylated inner core LPS fraction from *Acinetobacter haemolyticus* NCTC 10305.[6]

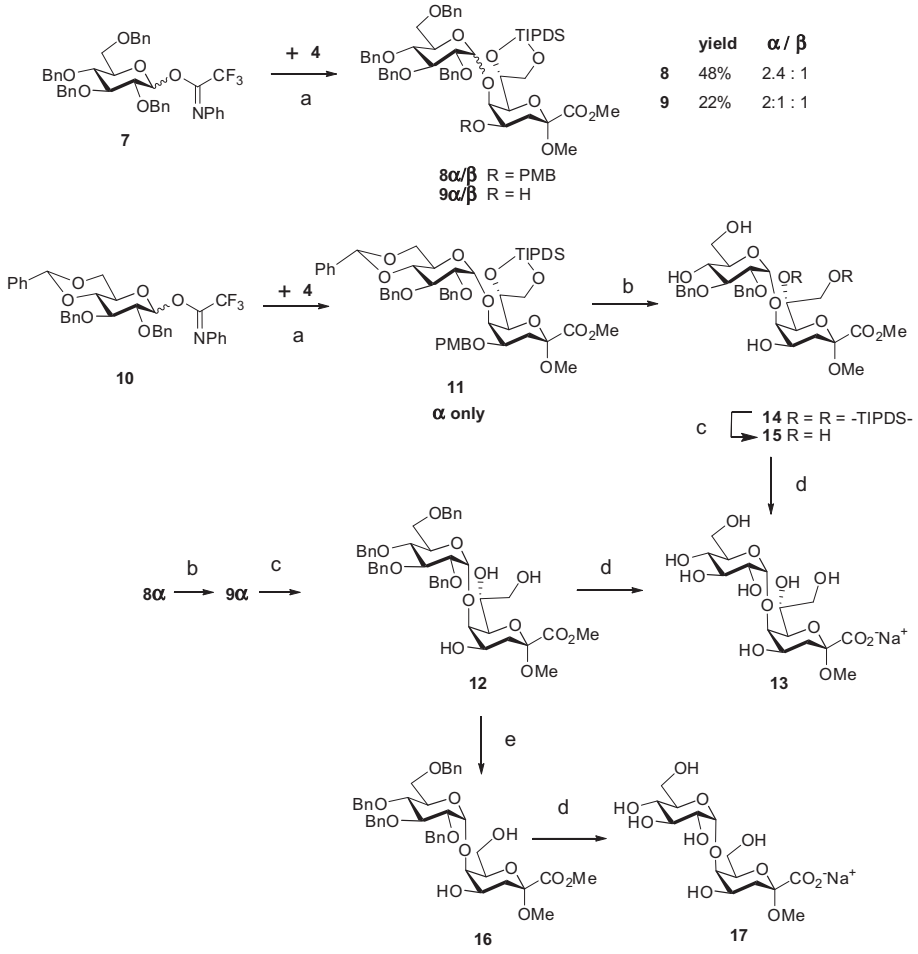
reference for integration of STD effects in binding studies. Thus the previously reported Me α-Kdo glycoside **2**[16] (easily available via the scalable reaction of the peracetate **1** with MeOH, catalyzed by Dowex (H^+) ion-exchange resin) was employed for the preparation of the Kdo glycosyl acceptor derivative. The *exo*cyclic 7,8-*O* positions of **2** were protected by a 1,1,3,3-tetraisopropyldisiloxane-1,3-diyl (TIPDS) group in order to utilize its arming effect and to provide orthogonality of fluoride-induced silyl deprotection.[17] Thus, by using imidazole and $TIPDSCl_2$ in DMF at −40 °C the bis-silyl ether derivative **3** was obtained in 68% yield (Scheme 1). In order to generate an option for eventual attachment of the lateral Kdo unit (Fig. 1) and to also activate the 5-OH group for subsequent glycosylation, a *p*-methoxybenzyl group (PMB) was installed at position 4. The diol derivative **3** was first reacted with dibutyltin oxide to give the intermediate stannylene derivative followed by treatment with PMB-chloride/tetrabutyl ammonium iodide/DMF in toluene. As previously reported, the activated stannylene acetal also induced formation of the corresponding PMB ester **5** and the 1.5-lactone **6** as by-products.[18] Treatment of the mixture with sodium methoxide, however, eventually afforded the methyl ester derivative **4** in 70% yield.

Previously, an α-(1→5)-linked glucosyl residue had been coupled to Kdo using an acetylated 2-*O*-benzyl thioglycoside donor under promotion with DMTST in 85% yield.[19] The use of the known[20] perbenzylated *N*-phenyl trifluoroacetimidate donor (NPTFA) **7α/β** for the TMSOTf-catalyzed glycosylation of **4**, however, resulted in decreased anomeric selectivity and a temperature dependent outcome.[21,22] Glycosylation of acceptor **4** promoted by 10% TMSOTf at −5 °C in CH_2Cl_2 afforded the α-(1→5)-linked disaccharide **8α** as the major anomer (α/β ratio 2.4:1) accompanied by formation of the alcohols **9α** and **9β** (resulting from cleavage of the acid-labile PMB group). By lowering the temperature to −20 °C and reducing the amount of promoter (5% TMSOTf) the PMB cleavage could be largely suppressed. However, under these conditions, the undesired **8β** was formed preferentially (α/β ratio 1:1.4). The change of the solvent to CH_2Cl_2/Et_2O (9:1) resulted in a sluggish reaction with slightly enhanced α/β ratio (1.7:1), albeit in poor yield. Presumably, the formation of an intermediate α-anomeric triflate at a lower temperature leads to an increased contribution of an S_N2-type glycosylation pathway.[23] Alternatively, the torsionally disarmed 4,6-*O*-benzylidene trifluoroacetimidate donor **10** was prepared from its hemiacetal precursor[24] as a separable anomeric mixture.[25] The glycosylation of acceptor **4** with donor **10** in CH_2Cl_2 at −5 °C provided the disaccharide **11** in 80% yield as the α-anomer only, irrespective of the anomeric configuration of the donor (Scheme 2). Due to milder reaction conditions (lower temperature and promoter concentration) PMB cleavage could be completely suppressed without affecting the stereochemical outcome. The PMB group of the α-linked disaccharide derivative **8α** was selectively removed by treatment with trifluoroacetic acid (TFA) affording **9α**, followed by cleavage of the silyl ether group in order to generate the triol derivative **12**. Treatment of **9α** with tetrabutylammonium fluoride (TBAF) produced compound **12** in near quantitative yield, which was then fully deprotected by catalytic hydrogenation followed by alkaline hydrolysis of the methyl ester group to furnish disaccharide **13** as sodium salt in 90% yield. Global deprotection of the benzylidene protected disaccharide **11** provided disaccharide **13** in an excellent overall yield of 65% (based on acceptor **4**). TFA-treatment of **11** simultaneously cleaved the benzylidene and the PMB group, respectively, to give triol **14** in 88% yield, followed by TIPDS removal and ensuing full deprotection of the resulting derivative **15** to give disaccharide **13**.

In addition, the side-chain shortened analog was prepared by oxidative cleavage of the *exo*cyclic diol of **12** with sodium *meta*periodate generating the heptulosonic glycoside **16**. The intermediate aldehyde formed upon oxidation could be analyzed by NMR, but proved to be rather labile upon attempted purification on silica gel. The ensuing borohydride reduction was accompanied by concomitant ester reduction. The reaction was therefore not allowed to run until completion, but was stopped when ester reduction



Scheme 1. Reagents and conditions: (a) $TIPDSCl_2$, 1*H*-imidazole, DMF, −40 °C, 68%; (b) Bu_2SnO, toluene, reflux, then DMF, PMBCl, Bu_4NI, toluene, 60 °C; mixture of **4**, **5** and **6**; then (c) 0.1 M NaOMe, MeOH, rt, 70% for **4**.



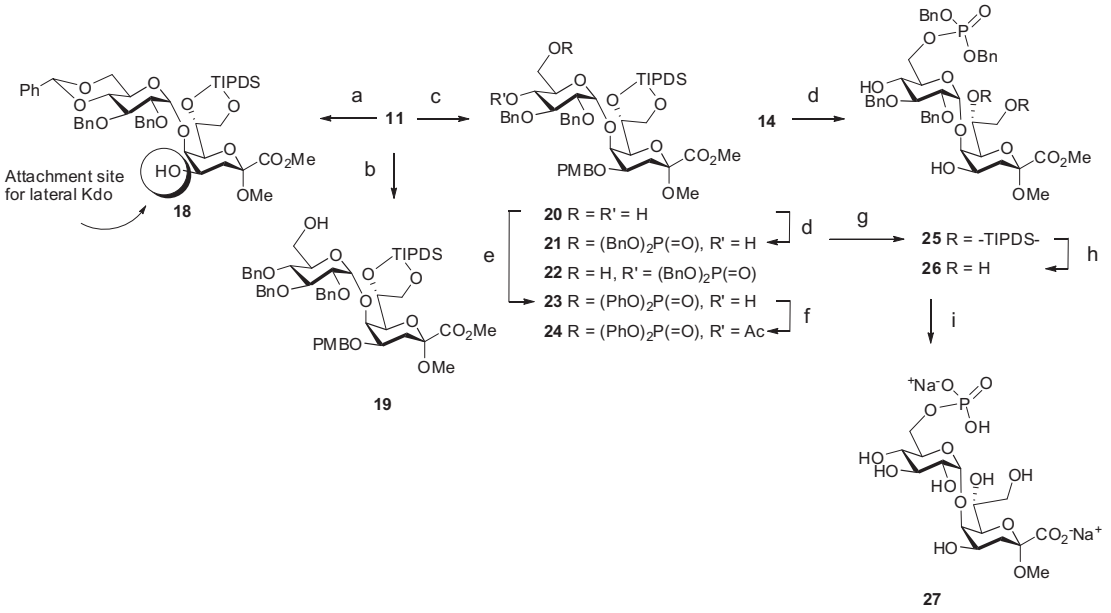
Scheme 2. Reagents and conditions: (a) TMSOTf, CH_2Cl_2, molecular sieves 4 Å, −5 °C, 34% for **8α**, 14% for **8β**, 15% for **9α**, 7% for **9β**, 80% for **11**; (b) 99% TFA, CH_2Cl_2, 0 °C, 83% for **9α**, 88% for **14**; (c) TBAF, THF, rt, 98% for **12**, 97% for **15**; (d) H_2 (1 atm), 10% Pd–C, MeOH, then 0.01 M aq NaOH, rt, 90% for **12**→**13**, 95% for **15**→**13**, 79% for **16**→**17**; (e) $NaIO_4$–SiO_2, CH_2Cl_2, −10 °C, then $NaBH_4$, MeOH, 0 °C, 34%.

was first detected on TLC. Global deprotection of **16** eventually afforded disaccharide **17** in 79% yield.

2.2. Preparation of the disaccharides α-Glc6*P*-(1→5)-α-Kdo/Kdh

Selective cleavage of the PMB-group of the benzylidene-protected disaccharide derivative **11** via DDQ-promoted oxidation afforded the glycosyl acceptor **18** (suitable for attachment of the lateral Kdo unit) in 83% yield (Scheme 3). The orthogonal protecting group pattern also allows for the selective introduction of the 6-phosphoester group as well as for additional glucosyl extension at position 4 of the glucosyl unit upon reductive opening of the benzylidene group (cf. Fig. 1). Reductive opening of the benzylidene toward the 6-OH derivative **19**, however, met with difficulties when applying various combinations of Lewis acids and hydride sources ($CoCl_2/BH_3$.THF, TMSCl/$NaCNBH_3$, TMSOTf/BH_3, Bu_2BOTf/BH_3·THF). Lack of reactivity, loss of the PMB group or cleavage of the benzylidene group with formation of additional by-products were observed under these conditions. A modest conversion of compound **11** into the 4-*O*-benzyl ether **19** could eventually be accomplished in the presence of $PhBCl_2/Et_3SiH$ in 43% yield. Thus, it was envisaged to introduce the 6-*O*-phosphate group at the 4,6-diol intermediate, with the additional option to utilize the remaining 4-hydroxyl group as an acceptor site for future extension by glucosyl residues. Hence, the benzylidene group of **11** was selectively removed—without cleavage of the PMB group—using *p*-toluenesulfonic acid in dry MeOH to afford the diol **20** in 91% yield. Short reaction times at 40 °C gave better and reproducible yields compared to prolonged reaction times at ambient temperature. Phosphorylation of the diol **20** was first approached using the phosphoramidite chemistry. Thus, treatment of **20** with dibenzyl *N*,*N*-diisopropylphosphoramidite/1*H*-tetrazole in the presence of ground molecular sieves (4 Å) in CH_2Cl_2 followed by oxidation with *m*CPBA gave the 6-*O*-phosphotriester derivative **21** in 67% yield and the corresponding 4-*O*-regioisomer **22** (10%). The phosphoramidite protocol also proved to be appropriate for the phosphorylation of the triol **14** and furnished the 6-*O*-phosphotriester derivative **25** in 63% yield. The assignment of the phosphate substitution at *O*-6 was based on the downfield shift of the ^1H NMR signals of the H-6 protons and the ^{13}C–^{31}P coupling interaction leading to splitting of ^{13}C NMR signals of C-6 and C-5, respectively. To increase the selectivity in the phosphorylation step, a more reactive phosphoryl halide was used at a low temperature. Indeed, reaction of the diol **20** with diphenyl phosphoryl chloride at 0 °C in the presence of 4-*N*,*N*-dimethylaminopyridine afforded the corresponding 6-*O*-phosphotriester derivative **23** in 96% yield.

TFA-treatment of the dibenzylphosphate derivative **21** proved to be selective for the removal of the PMB group and gave the diol derivative **25** in 88% yield. Subsequent reaction of **25** with TBAF afforded the tetraol derivative **26** (92%), which was subjected to hydrogenation on 10% Pd–C followed by alkaline hydrolysis to

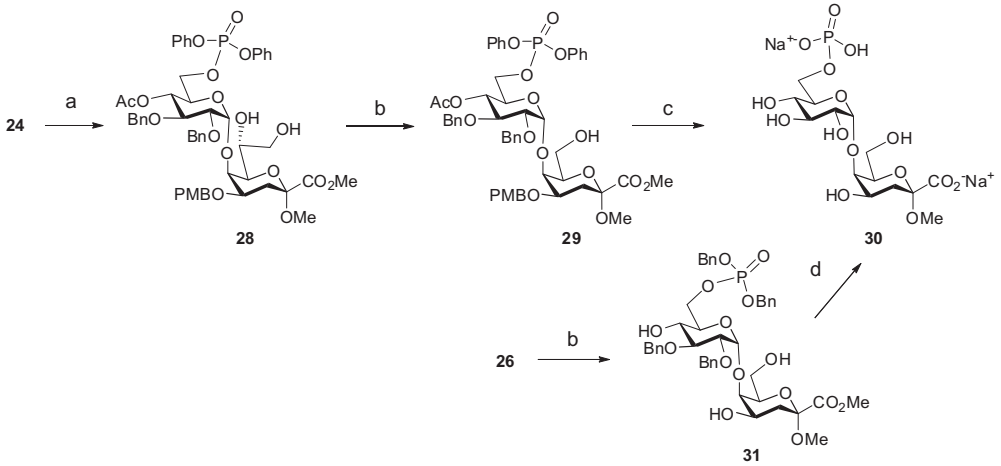


Scheme 3. Reagents and conditions: (a) DDQ, CH_2Cl_2/MeOH (3:1), rt, 83%; (b) $PhBCl_2$, Et_3SiH, CH_2Cl_2, −70 °C, 43%; (c) *p*TosOH, MeOH, 40 °C, 91%; (d) $(BnO)_2PN(iPr)_2$, 1*H*-tetrazole, CH_2Cl_2, −5 °C/0 °C, molecular sieves 4 Å, then *m*CPBA, 67% for **21**, 10% for **22**, 63% for **25**; (e) $(PhO)_2P(=O)Cl$, DMAP, CH_2Cl_2, molecular sieves 4 Å, 0 °C, 96%; (f) Ac_2O, pyr., DMAP, 0 °C, 96%; (g) TFA, CH_2Cl_2, 0 °C, 88%; (h) 1 M TBAF, THF, rt, 92%; (i) H_2 (1 atm), 10% Pd–C, MeOH, then 0.01 M aq NaOH, rt, 98%.

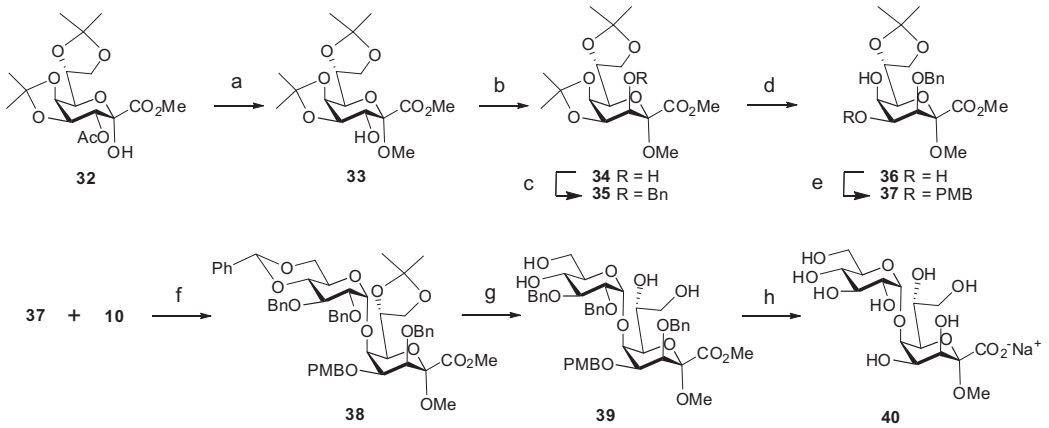
furnish the target disaccharide phosphate **27** as sodium salt in 98% yield. Deprotection of the silyl group of diphenylphosphate **23**, however, required a modified protocol, since treatment with TBAF resulted in fluoride-induced nucleophilic displacement of the phenoxy groups on the phosphoester.[26] The 4-OH group of **23** was thus acetylated to give compound **24** in order to prevent intramolecular phosphate migration or cyclization, respectively. The silyl ether groups of **24** were then removed by the action of triethylamine trihydrogen fluoride (TREAT), which afforded **28** in 82% yield with only minor (~10%) phosphate cleavage (Scheme 4). Compound **28** was used for the preparation of the side-chain-shortened analog **29** by periodate oxidation (36%) followed by successive hydrogenolysis on Pd-C and PtO_2, and saponification to afford the heptulosonic glycoside **30** in 52% yield. The poor yield was due to formation of an unidentified side product, which had to be separated on a HILIC column. Alternatively, dibenzylphosphate **26** was subjected to the oxidative degradation protocol affording **31** (47%), which reacted cleanly to target compound **30** upon hydrogenolysis with Pd–C and subsequent saponification.

2.3. Preparation of the disaccharide α-Glc-(1→5)-α-Ko

The previously reported intermediate **32** was employed for the preparation of a suitably protected methyl glycoside of D-*glycero*-α-D-*talo*-oct-2-ulopyranosylonic acid (Ko).[27] The epimeric 3-*O*-acetate **32** was subjected to base-induced anomeric methylation followed by de-*O*-acetylation to produce **33**. Ensuing Dess–Martin periodinane oxidation and reduction with ammonia–borane complex gave the alcohol **34** in 65% overall yield (Scheme 5). Reaction of **34** with benzyl bromide/NaH in DMF afforded the 3-*O*-benzyl derivative **35** in 94% yield. The reaction had to be performed in high dilution at 0 °C in order to prevent formation of the



Scheme 4. Reagents and conditions: (a) TREAT, CH_2Cl_2, rt, 82%; (b) $NaIO_4$–SiO_2, CH_2Cl_2, 0 °C → rt, then $NaBH_4$, MeOH, 0 °C, 36% for **29**, 47% for **31**; (c) H_2 (1 atm), 10% Pd–C, MeOH, then H_2 (1 atm), PtO_2, MeOH, then 0.01 M aq NaOH, rt, 52%; (d) H_2 (1 atm), 10% Pd–C, MeOH, then 0.01 M aq NaOH, rt, 87%.



Scheme 5. Reagents and conditions: (a) NaH, MeI, DMF, 0°C, then NaOMe, rt, 86%; (b) Dess–Martin reagent, CH_2Cl_2, rt, then $NH_3{\cdot}BH_3$, MeOH, 0 °C, 75%; (c) NaH, BnBr, DMF, 0 °C, 94%; (d) *p*TosOH, wet acetone, rt, 71%; (e) Bu_2SnO, toluene, reflux, then DMF, PMBCl, Bu_4NI, toluene, 60 °C, 81%; (f) TMSOTf, CH_2Cl_2, molecular sieves 4 Å, −30 °C, 42%; (g) *p*TosOH, MeOH, 0 °C → rt, 70%; (h) H_2 (1 atm), 10% Pd–C, MeOH, then 0.01 M aq NaOH, rt, 92%.

corresponding benzyl ester derivative. Next, the 4,5-*O*-isopropylidene ketal was selectively cleaved by the action of *p*-toluenesulfonic acid in wet acetone under equilibrating conditions.

The use of a defined amount of water was critical in order to prevent additional loss of the 7,8-*O*-acetonide. This way diol **36** was obtained in 71% yield ready for further processing into suitable glycosyl acceptor derivatives. Similar to the corresponding Kdo acceptor **4**, the 4-*O*-PMB group was installed via the respective stannylidene acetal intermediate and ensuing treatment with PMBCl/Bu_4NI/DMF in toluene affording the orthogonally protected acceptor **37** in 81% yield. Coupling of **37** with the benzylidene-protected NPTFA donor **10** promoted by TMSOTf in CH_2Cl_2 at −5 °C afforded the α-linked disaccharide **38** in 42% yield. The reduced yield of the coupling step was due to the concomitant cleavage of the acetonide during the glycosylation reaction. Deprotection of **38** was achieved by treatment with *p*-toluenesulfonic acid hydrate in methanol for 24 h which furnished the tetraol **39** in 70% yield. Hydrogenation of **39** with 10% Pd–C in methanol and final purification on Bio-Gel PD10 afforded the glucosyl-Ko disaccharide **40** as sodium salt in 92% yield. ^{13}C NMR data of the deprotected target disaccharides **13**, **17**, **27**, **30**, and **40** were fully assigned and confirmed the respective structures (Table 1).

2.4. Conclusions and outlook

A benzylidene-protected glucosyl NPTFA donor proved as an efficient and α-selective glycosyl donor for the glycosylation of OH-5 of orthogonally protected Kdo and Ko glycosides and allowed for the regioselective introduction of the 6-*O*-phosphoryl group. Oxidative cleavage of the *exo*cyclic side chain of Kdo provided the Kdh containing fragments. Global deprotection gave the disaccharide ligands related to the inner core region of *Acinetobacter* LPS which are suited to perform various binding assays to elucidate structural details of the interaction with MBL which are serum components and important in innate first-line immune reactions such as complement activation. The synthesis of larger fragments is currently in progress.

3. Experimental

3.1. General

All purchased chemicals were used without further purification unless stated otherwise. Solvents were dried over activated

Table 1
^{13}C NMR chemical shifts (δ) of disaccharide derivatives **13**, **17**, **27**, **30**, and **40**

Atom position	Compound				
	13	**17**	**27**	**30**	**40**
OCH_3	51.42	51.31	51.42	51.31	51.64
Kdo/Kdh/Ko					
1	176.03	175.93	176.06	175.95	174.16
2	101.29	100.98	101.30	100.99	103.26
3	35.47	35.36	35.22	35.16	72.76
4	66.60	66.45	66.42	66.31	66.95
5	75.95	76.73	75.48	76.46	77.19
6	72.35	73.90	72.35	73.95	71.75
7	69.24	61.67	69.01	61.63	68.96
8	63.94	—	64.07	—	63.87
Glc					
1	100.71	100.67	100.61	100.60	100.98
2	72.80	72.74	72.99	72.79	72.49
3	73.70	73.60	73.23	73.30	73.88
4	70.05	70.03	69.50	69.61	69.86
5	72.51	72.45	72.25	71.84	72.82
			$J_{C,P}$ 7.5 Hz	$J_{C,P}$ 7.7 Hz	
6	60.77	60.73	62.93	63.73	60.77
			$J_{C,P}$ 4.1 Hz	$J_{C,P}$ 4.5 Hz	

3 Å (acetone) or 4 Å (CH_2Cl_2, DMF, pyridine, toluene) molecular sieves. THF was distilled on 4 Å molecular sieves shortly before use. Dry MeOH (secco solv) was purchased from Merck. Cation exchange resin DOWEX 50 H^+ was regenerated by consecutive washing with HCl (3 M), water, and dry MeOH. Aqueous solutions of salts were saturated unless stated otherwise. Concentration of organic solutions was performed under reduced pressure <40 °C. Optical rotations were measured with a Perkin–Elmer 243 B polarimeter. $[\alpha]_D^{20}$ values are given in units of 10^{-1} deg cm^2 g^{-1}. Thin layer chromatography was performed on Merck precoated plates: generally on 5 × 10 cm, layer thickness 0.25 mm, silica gel $60F_{254}$; alternatively on HPTLC plates with 2.5 cm concentration zone (Merck). Spots were detected by dipping reagent (anisaldehyde–H_2SO_4). For column chromatography silica gel (0.040–0.063 mm) was used. HP-column chromatography was performed on pre-packed columns (YMC-Pack SIL-06, 0.005 mm, 250 × 10 mm and 250 × 20 mm). Size exclusion chromatography was performed on Bio-Gel® P-2 Gel extra fine <45 μm (wet) (Bio-Rad, 45–90 μm) or on pre-packed PD-10 columns (GE Healthcare, Sephadex™ G-25 M). NMR spectra were recorded with a Bruker Avance III 600 instrument (600.22 MHz for ^1H, 150.93 MHz for ^{13}C and 242.97 MHz for ^{31}P) using standard Bruker NMR software. ^1H spectra were referenced to 7.26 ($CDCl_3$), 5.32 (CD_2Cl_2), 3.31 (MeOD), and 0.00 (D_2O, external calibration to 2,2-dimethyl-2-silapentane-5-sulfonic acid) ppm unless stated otherwise. ^{13}C spectra were referenced to 77.00 ($CDCl_3$), 53.84 (CD_2Cl_2), 49.00 (MeOD), and 67.40 (D_2O, external calibration to 1,4-dioxane) ppm. ^{31}P spectra in D_2O were referenced to external *ortho*-phosphoric acid (0.00 ppm). ESI-MS data were obtained on a Waters Micromass Q-TOF Ultima Global instrument.

3.2. Methyl [methyl 3-deoxy-7,8-*O*-(1,1,3,3-tetraisopropyldisiloxane-1,3-diyl)-α-D-*manno*-oct-2-ulopyranosid]onate (3)

A cooled mixture of 1*H*-imidazole (0.22 g, 3.228 mmol) and TIPDSCl$_2$ (0.46 mL, 1.412 mmol) in dry DMF (7.4 mL) was added dropwise to a solution of **2** (0.36 g, 1.345 mmol) in dry DMF (8.6 mL) at −40 °C. After 2 h at −40 °C another portion of 1*H*-imidazole (22 mg, 0.323 mmol) and TIPDSCl$_2$ (46 μL, 0.141 mmol) in dry DMF (0.74 mL) was slowly added and after 30 min excessive reagent was scavenged by addition of dry MeOH (2 mL). The mixture was allowed to warm up to ambient temperature, solid $NaHCO_3$ (0.4 g) was added, and the suspension was concentrated. The residue was partitioned between EtOAc and aq $NaHCO_3$, the aqueous phase was extracted with EtOAc (2 × 10 mL) and the combined organic layers were dried over $MgSO_4$, filtered, and concentrated. The residual oil was purified by column chromatography (toluene/EtOAc 4:1 → 1:1) affording **3** (0.46 g, 68%) as a colorless amorphous solid: $[\alpha]_D^{20}$ +36.4 (*c* 0.85, $CHCl_3$); R_f 0.38 (toluene/EtOAc 1:1); ^1H NMR ($CDCl_3$): δ 4.30–4.26 (m, 1H, H-7), 4.18 (dd, 1H, $J_{8a,8b}$ 12.1, $J_{8a,7}$ 1.7 Hz, H-8a), 4.06–4.04 (m, 1H, H-5), 4.03–3.98 (m, 1H, H-4), 3.84 (dd, 1H, $J_{8b,7}$ 7.0 Hz, H-8b), 3.78 (s, 3H, CO_2CH_3), 3.50 (dd, $J_{6,7}$ 8.0, $J_{6,5}$ 1.0 Hz, H-6), 3.22 (s, 3 H, OCH_3), 2.15 (dd, 1H, $J_{3eq,3ax}$ 13.0, $J_{3eq,4}$ 5.1 Hz, H-3*eq*), 1.86 (dd, 1H, $J_{3ax,4}$ 11.5 Hz, H-3*ax*), 1.12–0.93 (m, 28 H, TIPDS); ^{13}C NMR ($CDCl_3$): δ 168.53 (s, C-1), 99.36 (s, C-2), 74.08 (d, C-7), 71.35 (d, C-6), 66.81 (t, C-8), 66.67 (d, C-5), 66.17 (d, C-4), 52.52 (q, CO_2CH_3), 51.17 (q, OCH_3), 35.10 (t, C-3), 17.40, 17.35, 17.33, 17.23, 17.21 [q, 8C, Si-CH-$(CH_3)_2$], 13.31, 12.77, 12.48 [d, 4C, Si-CH-$(CH_3)_2$]; ESI-TOF HRMS: m/z = 531.2409; calcd for $C_{22}H_{44}O_9Si_2Na^+$: 531.2416.

3.3. Methyl [methyl 3-deoxy-4-*O*-(4-methoxybenzyl)-7,8-*O*-(1,1,3,3-tetraisopropyldisiloxane-1,3-diyl)-α-D-*manno*-oct-2-ulopyranosid]onate (4)

A mixture of **3** (91 mg, 0.179 mmol) and dibutyltin oxide (49 mg, 0.197 mmol) in dry toluene (4.0 mL) was heated to reflux on a Dean–Stark apparatus for 2 h. To the cooled solution dry DMF (166 μL, 2.146 mmol), 4-methoxybenzyl chloride (73 μL, 0.537 mmol) and tetrabutylammonium iodide (73 mg, 0.197 mmol) were added successively. After 16 h at 60 °C the solution was allowed to cool to ambient temperature. The solution was diluted with EtOAc and consecutively washed with HCl (1 M), aq $NaHCO_3$, aq $Na_2S_2O_3$ (50 g/L) and brine. The organic phase was dried ($MgSO_4$), filtered, and concentrated. The residual oil was taken up in dry MeOH (4.0 mL) and treated with 0.1 M NaOMe in dry MeOH (0.179 mmol, 1.8 mL) at 0 °C. After 1 h at ambient temperature the solution was made neutral by adding DOWEX 50 H^+ resin, the suspension was filtered, and the filtrate was concentrated. Column chromatography of the residue (toluene/EtOAc 19:1 → 9:1) provided **4** (79 mg, 70%) as a colorless oil: $[\alpha]_D^{20}$ +24.5 (*c* 1.07, $CHCl_3$); R_f 0.66 (toluene/EtOAc 3:1); ^1H NMR ($CDCl_3$): δ 7.27–7.24 (m, 2H, Ar), 6.89–6.86 (m, 2H, Ar), 4.56 (d, 1H, *J* 11.5 Hz, C*H*HPh), 4.50 (d, 1H, *J* 11.4 Hz, CH*H*Ph), 4.36–4.32 (m, 1H, H-7), 4.25 (dd, 1H, $J_{8a,8b}$ 11.9, $J_{8a,7}$ 1.6 Hz, H-8a), 4.14–4.12 (m, 1H, H-5), 3.84 (ddd, 1H, $J_{4,3ax}$ 11.5, $J_{4,3eq}$ 5.2, $J_{4,5}$ 2.9, H-4), 3.80–3.75 (m, 7H, H-8b, PhOCH_3, CO_2CH_3), 3.38 (dd, 1H, $J_{6,7}$ 8.6, $J_{6,5}$ 1.0 Hz, H-6), 3.20 (s, 3H, OCH_3), 2.21 (bs, 1H, O*H*), 2.18 (dd, 1H, $J_{3eq,3ax}$ 12.8, H-3*eq*), 2.01 (dd, 1H, H-3*ax*), 1.18–0.91 (m, 28H, TIPDS); ^{13}C NMR ($CDCl_3$): δ 168.60 (s, C=O), 159.38, 130.03 (s, 2C, Ar), 129.28, 113.96 (d, 4C, Ar), 99.36 (s, C-2), 72.97 (d, 2C, C-4, C-7), 71.88 (d, C-6), 69.99 (t, CH_2Ph), 67.16 (t, C-8), 63.77 (d, C-5), 55.26 (q, PhOCH_3), 52.50 (q, CO_2CH_3), 50.99 (q, OCH_3), 32.09 (t, C-3), 17.47, 17.41, 17.37, 17.27 [q, 8C, Si-CH-$(CH_3)_2$], 13.29, 12.82, 12.54, 12.49 [d, 4C, Si-CH-$(CH_3)_2$]; ESI-TOF HRMS: m/z = 651.2995; calcd for $C_{30}H_{52}O_{10}Si_2Na^+$: 651.2991.

Data for **5**: colorless oil; $[\alpha]_D^{20}$ +18.2 (*c* 0.72, $CHCl_3$), R_f 0.76 (toluene/EtOAc 3:1); ^1H NMR ($CDCl_3$): δ 7.32–7.29 (m, 2H, Ar), 7.26–7.22 (m, 2H, Ar), 6.89–6.85 (m, 4H, Ar), 5.15 (s, 2H, CH_2Ph), 4.53 (d, 1H, *J* 11.6 Hz, C*H*HPh), 4.49 (d, 1H, *J* 11.4 Hz, CH*H*Ph), 4.33 (ddd, 1H, $J_{7,6}$ 8.6, $J_{7,8b}$ 7.2, $J_{7,8a}$ 1.5 Hz, H-7), 4.24 (dd, 1H, $J_{8a,8b}$ 11.8 Hz, H-8a), 4.13–4.11 (m, 1H, H-5), 3.84–3.79 (m, 7H, H-4, 2 × PhOCH_3), 3.76 (dd, 1H, H-8b), 3.37 (d, 1H, H-6), 3.13 (s, 3H, OCH_3), 2.21 (d, 1H, $J_{OH,5}$ 2.6 Hz, O*H*), 2.15 (dd, 1H, $J_{3eq,3ax}$ 12.9, $J_{3eq,4}$ 4.9 Hz, H-3*eq*), 1.97 (dd, 1H, $J_{3ax,4}$ 11.7 Hz, H-3*ax*), 1.10–0.90 (m, 28H, TIPDS); ^{13}C NMR ($CDCl_3$): δ 167.77 (s, C=O), 159.74, 159.37 (s, 2C, Ar), 130.26 (d, 2C, Ar), 130.03 (s, Ar), 129.29 (d, 2C, Ar), 127.57 (s, Ar), 113.94 (d, 4C, Ar), 99.18 (s, C-2), 73.06 (d, 2C, C-4, C-7), 71.84 (d, C-6), 69.98 (t, CH_2Ph), 67.10 (t, C-8), 66.98 (t, CH_2Ph), 63.75 (d, C-5), 55.26 (q, 2C, 2 × PhOCH_3), 50.94 (q, OCH_3), 31.99 (t, C-3), 17.47, 17.40, 17.38, 17.27 [q, 8C, Si-CH-$(CH_3)_2$], 13.29, 12.81, 12.54, 12.51 [d, 4C, Si-CH-$(CH_3)_2$]; ESI-TOF HRMS: m/z = 757.3414; calcd for $C_{37}H_{58}O_{11}Si_2Na^+$: 757.3410.

Data for **6**: colorless amorphous solid; $[\alpha]_D^{20}$ −13.8 (*c* 0.82, $CHCl_3$); R_f 0.59 (toluene/EtOAc 9:1); ^1H NMR ($CDCl_3$): δ 7.26–7.23 (m, 2H, Ar), 6.89–6.86 (m, 2H, Ar), 5.00–4.99 (m, 1H, H-5), 4.54 (d, 1H, *J* 11.9 Hz, C*H*HPh), 4.49 (d, 1H, *J* 11.8 Hz, CH*H*Ph), 4.16 (dd, 1H, $J_{8a,8b}$ 12.1, $J_{8a,7}$ 1.7 Hz, H-8a), 3.93 (ddd, 1H, $J_{7,6}$ 9.5, $J_{7,8b}$ 7.6 Hz, H-7), 3.89 (app. td, 1H, $J_{4,3ax}$ 8.8, $J_{4,3eq} = J_{4,5}$ 2.2 Hz, H-4), 3.80 (s, 3H, PhOCH_3), 3.69 (dd, 1H, H-8b), 3.58 (s, 3H, OCH_3), 3.57 (d, 1H, H-6), 2.50 (dd, 1H, $J_{3ax,3eq}$ 14.7 Hz, H-3*ax*), 2.00–1.97 (m, 1H, H-3*eq*), 1.12–0.91 (m, 28H, TIPDS); ^{13}C NMR ($CDCl_3$): δ 168.24 (s, C=O), 159.54 (s, Ar), 129.36 (d, 2C, Ar), 128.92 (s, Ar), 114.03 (d, 2C, Ar), 94.91 (s, C-2), 73.37 (d, C-6), 72.71, 72.68 (d, 2C, C-5, C-7), 71.93 (d, C-4), 70.05 (t, CH_2Ph), 66.64 (t, C-8), 55.25 (q, PhOCH_3), 52.71 (q, OCH_3), 38.72 (t, C-3), 17.40, 17.35, 17.32,

17.27, 17.20, 17.18 [q, 8C, Si-CH-(CH_3)$_2$], 13.20, 12.64, 12.45, 12.39 [d, 4C, Si-CH-(CH_3)$_2$].

3.4. 2,3,4,6-Tetra-*O*-benzyl-α-D-*gluco*pyranosyl-(1→5)-methyl [methyl 3-deoxy-4-*O*-(4-methoxybenzyl)-7,8-*O*-(1,1,3,3-tetra isopropyldisiloxane-1,3-diyl)-α-D-*manno*-oct-2-ulopyranosid] onate (8α), 2,3,4,6-tetra-*O*-benzyl-β-D-*gluco*pyranosyl-(1→5)-methyl [methyl 3-deoxy-4-*O*-(4-methoxybenzyl)-7,8-*O*-(1,1,3,3-tetraisopropyldisiloxane-1,3-diyl)-α-D-*manno*-oct-2-ulopyranosid]onate (8β), 2,3,4,6-tetra-*O*-benzyl-α-D-*gluco*pyranosyl-(1→5)-methyl [methyl 3-deoxy-7,8-*O*-(1,1,3,3-tetraisopropyl disiloxane-1,3-diyl)-α-D-*manno*-oct-2-ulopyranosid]onate (9α), and 2,3,4,6-tetra-*O*-benzyl-β-D-*gluco*pyranosyl-(1→5)-methyl [methyl 3-deoxy-7,8-*O*-(1,1,3,3-tetraisopropyl disiloxane-1,3-diyl)-α-D-*manno*-oct-2-ulopyranosid] onate (9β)

A solution of glycosyl acceptor **4** (50 mg, 0.080 mmol) in dry CH_2Cl_2 (0.6 mL) containing 4 Å molecular sieves (75 mg) was stirred for 20 min followed by addition of glycosyl donor **7**[22] (85 mg, 0.120 mmol) in dry CH_2Cl_2 (0.6 mL) under Ar. TMSOTf (1.4 μL, 0.008 mmol) in dry CH_2Cl_2 (50 μL) was added dropwise to the cold (−5 °C) mixture and after 5 min the reaction was quenched by adding a solution of Et_3N (23 μL, 0.160 mmol) in dry CH_2Cl_2 (0.3 mL). Filtration of the suspension over Celite®, concentration of the filtrate, and purification of the residue by HP-column chromatography (*n*-hexane/EtOAc 9:1 → 2:1) provided target compound **8α** (31 mg, 34%) together with **8β** (13 mg, 14%) and disaccharide alcohols **9α** (14 mg, 15%) and **9β** (6 mg, 7%) as colorless syrups.

Data for **8α**: $[\alpha]_D^{20}$ +68.4 (*c* 0.53, $CHCl_3$); R_f 0.62 (*n*-hexane/EtOAc 3:1); ^{1}H NMR ($CDCl_3$): δ 7.36–7.20 (m, 20H, Ar), 7.10–7.07 (m, 2H, Ar), 6.85–6.81 (m, 2H, Ar), 5.28 (d, 1H, $J_{1',2'}$ 3.7 Hz, H-1′), 4.94 (d, 1H, *J* 12.0 Hz, C*H*HPh), 4.86 (d, 1H, *J* 11.7 Hz, C*H*HPh), 4.83 (d, 1H, *J* 11.1 Hz, CH*H*Ph), 4.75 (d, 1H, *J* 10.7 Hz, C*H*HPh), 4.68 (d, 1H, *J* 12.0 Hz, CH*H*Ph), 4.54 (d, 1H, *J* 11.5 Hz, C*H*HPh), 4.51 (d, 1H, *J* 12.3 Hz, C*H*HPh), 4.50–4.45 (m, 2H, H-7, CH*H*Ph), 4.41 (d, 1H, *J* 11.0 Hz, CH*H*Ph), 4.27 (d, 1H, $J_{5,4}$ 2.2 Hz, H-5), 4.24–4.19 (m, 2H, H-5′, CH*H*Ph), 4.06 (app. t, 1H, $J_{3',2'} = J_{3',4'}$ 9.5 Hz, H-3′), 4.01 (dd, 1H, $J_{8a,8b}$ 13.1, $J_{8a,7}$ 1.9 Hz, H-8a), 3.86–3.80 (m, 4H, H-4, CO_2CH_3), 3.79 (s, 3H, PhOCH_3), 3.72 (app. t, 1H, $J_{4',5'}$ 9.4 Hz, H-4′), 3.64–3.60 (m, 3H, H-2′, H-6, H-8b), 3.40 (dd, 1H, $J_{6'a,6'b}$ 10.7, $J_{6'a,5'}$ 2.1 Hz, H-6′a), 3.29 (s, 3H, OCH_3), 3.12 (dd, 1H, $J_{6'b,5'}$ 1.9 Hz, H-6′b), 2.21 (dd, 1H, $J_{3eq,3ax}$ 12.5, $J_{3eq,4}$ 4.4 Hz, H-3*eq*), 2.16 (app. t, 1H, $J_{3ax,4}$ 12.2 Hz, H-3*ax*), 1.06–0.87 (m, 28H, TIPDS); ^{13}C NMR ($CDCl_3$): δ 168.80 (s, C=O), 159.07, 138.86, 138.78, 138.57, 138.11, 130.52 (s, 6C, Ar), 129.01, 128.25, 128.23, 128.21, 128.09, 127.98, 127.85, 127.82, 127.50, 127.48, 127.36, 127.00, 126.77, 113.70 (d, 24C, Ar), 99.13 (s, C-2), 98.66 (d, C-1′), 81.82 (d, C-3′), 80.19 (d, C-2′), 77.95 (d, C-4′), 75.10 (t, CH_2Ph), 74.78 (t, CH_2Ph), 73.62 (d, C-4), 73.29 (t, CH_2Ph), 72.53 (t, CH_2Ph), 71.82 (d, C-5), 71.75 (d, C-7), 71.39 (d, C-6), 70.23 (d, C-5′), 69.94 (t, CH_2Ph), 67.79 (t, C-6′), 63.00 (t, C-8), 55.22 (q, PhOCH_3), 52.34 (q, CO_2CH_3), 51.12 (q, OCH_3), 33.21 (t, C-3), 17.60, 17.54, 17.50, 17.49, 17.29, 17.17, 17.09 [q, 8C, Si-CH-(CH_3)$_2$], 14.18, 13.55, 12.99, 12.75 [d, 4C, Si-CH-(CH_3)$_2$]; ESI-TOF HRMS: *m*/*z* = 1168.5848; calcd for $C_{64}H_{86}O_{15}Si_2NH_4^+$: 1168.5844.

Data for **8β**: $[\alpha]_D^{20}$ +14.4 (*c* 0.94, $CHCl_3$); R_f 0.60 (*n*-hexane/EtOAc 3:1); ^{1}H NMR ($CDCl_3$): δ 7.37–7.34 (m, 2H, Ar), 7.29–7.22 (m, 16H, Ar), 7.18–7.13 (m, 4H, Ar), 6.83–6.80 (m, 2H, Ar), 5.31 (d, 1H, $J_{1',2'}$ 7.8 Hz, H-1′), 5.08 (d, 1H, *J* 11.6 Hz, C*H*HPh), 4.89 (d, 1H, *J* 10.9 Hz, C*H*HPh), 4.81 (d, 1H, *J* 11.0 Hz, C*H*HPh), 4.78–4.76 (m, 1H, H-5), 4.74–4.71 (m, 2H, 2 × CH*H*Ph), 4.62 (d, 1H, *J* 11.8 Hz, C*H*HPh), 4.52–4.45 (m, 4H, 1 × C*H*HPh, 3 × CH*H*Ph), 4.35–4.31 (m, 1H, H-7), 4.27 (dd, 1H, $J_{8a,8b}$ 12.0, $J_{8a,7}$ 2.0 Hz, H-8a), 3.94 (ddd, 1H, $J_{4,3ax}$ 11.7, $J_{4,3eq}$ 4.6, $J_{4,5}$ 1.8 Hz, H-4), 3.81 (dd, 1H, $J_{8b,7}$ 6.4 Hz, H-8b), 3.78 (s, 3H, PhOCH_3), 3.73–3.69 (m, 1H, H-6′a), 3.65–3.55 (m, 2H, H-3′, H-6′b), 3.49 (s, 3H, CO_2CH_3), 3.46–3.39 (m, 3H, H-4′, H-5′, H-6), 3.34 (dd, 1H, $J_{2',3'}$ 9.1 Hz, H-2′), 3.20 (s, 3H, OCH_3), 2.26 (app. t, 1H, $J_{3ax,3eq}$ 12.7 Hz, H-3*ax*), 2.20 (dd, 1H, H-3*eq*), 1.11–0.87 (m, 28H, TIPDS); ^{13}C NMR ($CDCl_3$): δ 168.52 (s, C=O), 159.00, 138.95, 138.67, 138.22, 138.19, 130.32 (s, 6C, Ar), 128.66, 128.35, 128.29, 128.25, 128.15, 128.01, 127.96, 127.89, 127.68, 127.56, 127.51, 127.45, 127.19, 113.79 (d, 24C, Ar), 100.49 (d, C-1′), 99.36 (s, C-2), 84.73 (d, C-3′), 82.31 (d, C-2′), 78.36 (d, C-4′), 75.81 (d, C-4), 75.75 (t, CH_2Ph), 74.94 (t, CH_2Ph), 74.57 (d, C-6), 74.09 (t, CH_2Ph), 73.28 (d, C-5′), 73.24 (t, CH_2Ph), 72.69 (d, C-7), 69.86, 69.83 (t, 2C, CH_2Ph, C6′), 66.57 (t, C-8), 64.98 (d, C-5), 55.24 (q, PhOCH_3), 52.19 (q, CO_2CH_3), 50.94 (q, OCH_3), 33.30 (t, C-3), 17.81, 17.79, 17.57, 17.48, 17.42, 17.34, 17.28 [q, 8C, Si-CH-(CH_3)$_2$], 13.38, 12.79, 12.74 [d, 4C, Si-CH-(CH_3)$_2$]; ESI-TOF HRMS: *m*/*z* = 1168.5854; calcd for $C_{64}H_{86}O_{15}Si_2NH_4^+$: 1168.5844.

Data for **9α**: $[\alpha]_D^{20}$ +34.3 (*c* 0.64, $CHCl_3$); R_f 0.39 (*n*-hexane/EtOAc 3:1); ^{1}H NMR ($CDCl_3$): δ 7.33–7.24 (m, 18H, Ar), 7.13–7.10 (m, 2H, Ar), 5.04 (d, 1H, $J_{1',2'}$ 3.4 Hz, H-1′), 4.93 (d, 1H, *J* 11.0 Hz, C*H*HPh), 4.82 (d, 1H, *J* 11.0 Hz, CH*H*Ph), 4.79 (d, 1H, *J* 10.7 Hz, C*H*HPh), 4.75 (s, 2H, CH_2Ph), 4.54 (d, 1H, *J* 12.2 Hz, C*H*HPh), 4.52 (m, 1H, H-7), 4.45 (d, 1H, *J* 12.2 Hz, CH*H*Ph), 4.44 (d, 1H, *J* 10.5 Hz, CH*H*Ph), 4.16 (dd, 1H, $J_{8a,8b}$ 12.9, $J_{8a,7}$ 2.9 Hz, H-8a), 4.09–3.99 (m, 5H, H-3′, H-5′, H-4, H-5, H-8b), 3.79–3.77 (m, 4H, H-6, CO_2CH_3), 3.61–3.56 (m, 2H, H-6′a, H-6′b), 3.54 (dd, 1H, $J_{2',3'}$ 9.6 Hz, H-2′), 3.48 (dd, 1H, *J* 9.9, *J* 8.9 Hz, H-4′), 3.44 (d, 1H, $J_{OH,4}$ 9.6 Hz, O*H*), 3.31 (s, 3H, OCH_3), 2.13 (dd, 1H, $J_{3eq,3ax}$ 12.8, $J_{3eq,4}$ 4.4 Hz, H-3*eq*), 1.86 (app. t, 1H, $J_{3ax,4}$ 12.5 Hz, H-3*ax*), 1.06–0.82 (m, 28H, TIPDS); ^{13}C NMR ($CDCl_3$): δ 168.57 (s, C=O), 138.67, 138.30, 137.96, 137.69 (s, 4C, Ar), 128.39, 128.38, 128.35, 138.33, 127.99, 127.89, 127.87, 127.80, 127.73, 127.58, 127.53, 127.45 (d, 20C, Ar), 99.46 (d, C-1′), 99.03 (s, C-2), 81.42 (d, C-3′), 78.74 (d, C-2′), 78.60 (d, C-5), 77.87 (d, C-4′), 75.37 (t, CH_2Ph), 75.08 (t, CH_2Ph), 73.50 (t, CH_2Ph), 73.08 (d, C-7), 72.56 (t, CH_2Ph), 72.05 (d, C-6), 71.39 (d, C-5′), 68.67 (t, C-6′), 66.79 (d, C-4), 63.87 (t, C-8), 52.37 (q, CO_2CH_3), 51.19 (q, OCH_3), 36.13 (t, C-3), 17.63, 17.54, 17.53, 17.50, 17.35, 17.22, 17.14 [q, 8C, Si-CH-(CH_3)$_2$], 13.98, 13.60, 12.96, 12.77 [d, 4C, Si-CH-(CH_3)$_2$]; ESI-TOF HRMS: *m*/*z* = 1048.5273; calcd for $C_{56}H_{78}O_{14}Si_2NH_4^+$: 1048.5268.

Data for **9β**: $[\alpha]_D^{20}$ +19.7 (*c* 0.85, $CHCl_3$); R_f 0.27 (*n*-hexane/EtOAc 3:1); ^{1}H NMR ($CDCl_3$): δ 7.33–7.23 (m, 18H, Ar), 7.17–7.13 (m, 2H, Ar), 5.00 (d, 1H, *J* 11.0 Hz, C*H*HPh), 4.90 (d, 1H, *J* 10.9 Hz, C*H*HPh), 4.83 (d, 1H, *J* 10.7 Hz, CH*H*Ph), 4.78 (2d, 2H, *J* 10.7 Hz, C*H*HPh, CH*H*Ph), 4.70 (d, 1H, $J_{1',2'}$ 7.9 Hz, H-1′), 4.62 (d, 1H, *J* 11.9 Hz, C*H*HPh), 4.57 (d, 1H, *J* 10.7 Hz, CH*H*Ph), 4.41 (d, 1H, *J* 11.9 Hz, CH*H*Ph), 4.38 (app. dt, 1H, $J_{7,6} = J_{7,8a}$ 8.7, $J_{7,8b}$ 2.5 Hz, H-7), 4.17–4.09 (m, 3H, H-5, H-8a, H-8b), 3.90 (app. ddt, 1H, $J_{4,3ax} = J_{4,OH}$ 11.6, $J_{4,3eq}$ 4.8, $J_{4,5}$ 2.6 Hz, H-4), 3.81 (dd, 1H, $J_{6'a,6'b}$ 10.9, $J_{6'a,5'}$ 3.2 Hz, H-6′a), 3.80 (app. t, 1H, $J_{4',3'} = J_{4',5'}$ 9.4 Hz, H-4′), 3.78 (s, 3H, CO_2CH_3), 3.72–3.68 (m, 3H, H-3′, H-6′b, O*H*), 3.63 (d, 1H, H-6), 3.55 (dd, 1H, $J_{2',3'}$ 9.1 Hz, H-2′), 3.41–3.37 (m, 1H, H-5′), 3.26 (s, 3H, OCH_3), 1.82 (dd, 1H, $J_{3eq,3ax}$ 12.7 Hz, H-3*eq*), 1.64 (app. t, 1H, H-3*ax*), 1.08–0.85 (m, 28H, TIPDS); ^{13}C NMR ($CDCl_3$): δ 168.73 (s, C=O), 138.15, 137.16 (s, 4C, Ar), 128.47, 128.44, 128.39, 128.34, 127.96, 127.94, 127.8, 127.71, 127.69, 127.67, 127.60 (d, 20C, Ar), 103.86 (d, C-1′), 99.21 (s, C-2), 85.57 (d, C-3′), 82.12 (d, C-2′), 78.06 (d, C-4′), 77.23 (d, C-5), 75.53 (t, CH_2Ph), 75.50 (t, CH_2Ph), 75.13 (d, C-5′), 74.90 (t, CH_2Ph), 73.43 (t, CH_2Ph), 72.73 (d, C-7), 71.12 (d, C-6), 68.75 (t, C-6′), 67.43 (d, C-4), 63.88 (t, C-8), 52.33 (q, CO_2CH_3), 51.20 (q, OCH_3), 35.88 (t, C-3), 17.83, 17.74, 17.54, 17.47, 17.37, 17.34, 17.21, 17.15 [q, 8C, Si-CH-(CH_3)$_2$], 13.77, 13.67, 12.95, 12.84 [d, 4C, Si-CH-(CH_3)$_2$]; ESI-TOF HRMS: *m*/*z* = 1053.4818; calcd for $C_{56}H_{78}O_{14}Si_2Na^+$: 1053.4822.

Alternatively compound **9α** was obtained by acid treatment of **8α**:

A solution of **8α** (17.6 mg, 0.015 mmol) in CH_2Cl_2 (14.2 mL) was treated with 99% TFA (3.6 mL) at 0 °C for 10 min. The solution was

concentrated and coevaporated with toluene. Subsequent column chromatography of the residue (*n*-hexane/EtOAc 5:1) yielded **9α** (13.0 mg, 83%) as a colorless oil.

3.5. 2,3-Di-*O*-benzyl-4,6-*O*-benzylidene-α,β-D-*gluco*pyranosyl (*N*-phenyl)trifluoroacetimidate (10α/β)

2,3-Di-*O*-benzyl-4,6-*O*-benzylidene-α,β-D-glucopyranose[28] (128 mg, 0.285 mmol) was dissolved in a mixture of dry CH_2Cl_2 (2.0 mL) and dry acetone (0.9 mL) followed by successive addition of K_2CO_3 (79 mg, 0.570 mmol) and 2,2,2-trifluoro-*N*-phenylacetimidoyl chloride (92 μL, 0.570 mmol). The heterogenous mixture was stirred at ambient temperature for 16 h, filtered through a pad of Celite®, and rinsed with CH_2Cl_2. After addition of one drop of Et_3N the filtrate was concentrated and the crude residue was purified by chromatography (*n*-hexane/EtOAc 10:1) affording an anomeric mixture ($\alpha/\beta \sim 1{:}8$) of **10** (169 mg, 96%).

Data for **10β**: colorless amorphous solid; $[\alpha]_D^{20}$ +49.1 (*c* 2.57, $CHCl_3$); R_f 0.75 (*n*-hexane/EtOAc 4:1); ^{1}H NMR (CD_2Cl_2): δ 7.54–7.46 (m, 2H, Ar), 7.42–7.27 (m, 15H, Ar), 7.17–7.13 (m, 1H, Ar), 6.88–6.75 (m, 2H, Ar), 5.83 (bs, 1H, H-1), 5.60 (s, 1H, C*H*Ph), 4.92 (d, 1H, *J* 11.4 Hz, C*H*HPh), 4.84 (d, 1H, *J* 11.0 Hz, C*H*HPh), 4.81 (2d, 2H, *J* 11.1 Hz, 2 × CH*H*Ph), 4.38–4.29 (m, 1H, H-6a), 3.88–3.65 (m, 4H, H-2, H-3, H-4, H-6b), 3.45 (bs, 1H, H-5); ^{13}C NMR (CD_2Cl_2): δ 143.78, 138.94, 138.41, 137.84 (s, 4C, Ar), 129.37, 129.20, 128.75, 128.67, 128.59, 128.49, 128.41, 128.27, 128.06, 126.49, 124.88, 119.63 (d, 20C, Ar), 101.69 (d, C*H*Ph), 81.50, 81.13, 81.11 (d, 3C, C-2, C-3, C-4), 75.71, 75.21 (t, 2C, 2 × *C*H$_2$Ph), 68.91 (t, C-6), 67.06 (d, C-5).

Data for **10α**: colorless oil; $[\alpha]_D^{20}$ +43.0 (*c* 1.92, $CHCl_3$); R_f 0.61 (*n*-hexane/EtOAc, 4:1); ^{1}H NMR (CD_2Cl_2): δ 7.53–7.49 (m, 2H, Ar), 4.42–7.27 (m, 15H, Ar), 7.15–7.11 (m, 1H, Ar), 6.80–6.74 (m, 2H, Ar), 6.45 (bs, 1H, H-1), 5.61 (s, 1H, C*H*Ph), 4.94 (d, *J* 11.4 Hz, C*H*HPh), 4.85 (d, *J* 11.3 Hz, CH*H*Ph), 4.84 (d, *J* 11.8 Hz, C*H*HPh), 4.76 (d, *J* 11.9 Hz, CH*H*Ph), 4.36 (dd, 1H, $J_{6a,6b}$ 10.2, $J_{6a,5}$ 4.8 Hz, H-6a), 4.09 (app. t, 1H, $J_{3,2} = J_{3,4}$ 9.5 Hz, H-3), 4.03–3.96 (m, 1H, H-5), 3.81–3.70 (m, 3H, H-2, H-4, H-6b); ^{13}C NMR (CD_2Cl_2): δ 144.06, 139.23, 138.46, 137.89 (s, 4C, Ar), 129.37, 129.20, 128.83, 128.63, 128.60, 128.30, 128.27, 128.12, 127.96, 126.52, 124.69, 119.75 (d, 20C, Ar), 101.82 (d, C*H*Ph), 81.77 (d, C-4), 79.14 (d, C-2), 78.62 (d, C-3), 75.50, 74.29 (t, 2C, 2 × *C*H$_2$Ph), 69.07 (t, C-6), 65.52 (d, C-5).

3.6. 2,3-Di-*O*-benzyl-4,6-*O*-benzylidene-α-D-*gluco*pyranosyl-(1→5)-methyl [methyl 3-deoxy-4-*O*-(4-methoxybenzyl)-7,8-*O*-(1,1,3,3-tetraisopropyldisiloxane-1,3-diyl)-α-D-*manno*-oct-2-ulopyranosid]onate (11)

A solution of donor **10α/β** (74 mg, 0.119 mmol) in dry CH_2Cl_2 (1.0 mL) was added to dry acceptor **4** (50 mg, 0.080 mmol) under Ar followed by addition of 4 Å molecular sieves. After stirring for 2.5 h at ambient temperature a solution of TMSOTf (0.4 μL, 0.002 mmol) in dry CH_2Cl_2 (0.1 mL) was added dropwise at −5 °C. The reaction was quenched after 15 min by addition of Et_3N (23 μL, 0.159 mmol) in dry CH_2Cl_2 (0.7 mL). The mixture was allowed to warm to ambient temperature and was filtered through a pad of Celite®. The filtrate was concentrated and the residue was purified by chromatography (*n*-hexane/EtOAc 8:1→3:1, with 0.1% TEA) to give **11** (67 mg, 80%) as a coloress oil: $[\alpha]_D^{20}$ +59.7 (*c* 0.53, $CHCl_3$); R_f 0.63 (*n*-hexane/EtOAc 3:1), ^{1}H NMR ($CDCl_3$): δ 7.51–7.47 (m, 2H, Ar), 7.42–7.21 (m, 15H, Ar), 6.88–6.84 (m, 2H, Ar), 5.51 (s, 1H, C*H*Ph), 5.28 (d, 1H, $J_{1',2'}$ 3.8 Hz, H-1′), 5.08 (d, 1H, *J* 11.8 Hz, C*H*HPh), 4.96 (d, 1H, *J* 11.3 Hz, C*H*HPh), 4.75 (d, 1H, *J* 11.0 Hz, CH*H*Ph), 4.66 (d, 1H, *J* 11.5 Hz, CH*H*Ph), 4.57 (s, 2H, C*H*$_2$Ph), 4.42–4.39 (m, 1H, H-7), 4.35 (app. dt, 1H, $J_{5',4'} = J_{5',6'b}$ 9.9, $J_{5',6'a}$ 5.1 Hz, H-5′), 4.25 (d, 1H, $J_{5,4}$ 2.3 Hz, H-5), 4.19 (app. t, 1H, $J_{3',2'} = J_{3',4'}$ 9.5 Hz, H-3′), 3.96 (dd, 1H, $J_{8a,8b}$ 13.2, $J_{8a,7}$ 1.6 Hz, H-8a), 3.89 (dd, 1H, $J_{6'a,6'b}$ 10.1 Hz, H-6′a), 3.85 (ddd, 1H, $J_{4,3ax}$ 11.6, $J_{4,3eq}$ 4.7, H-4), 3.81 (s, 3H, CO_2CH_3), 3.77 (s, 3H, PhOCH_3), 3.67 (dd, 1H, H-2′), 3.64–3.59 (m, 3H, H-4′, H-6, H-8b), 3.55 (app. t, 1H, $J_{6'b,5'}$ 10.2 Hz, H-6′b), 3.28 (s, 3H, OCH_3), 2.23 (dd, 1H, $J_{3eq,3ax}$ 12.5, H-3*eq*), 2.17 (app. t, 1H, H-3*ax*), 1.14–0.77 (m, 28H, TIPDS); ^{13}C NMR ($CDCl_3$): δ 168.76 (s, C═O), 159.08, 138.93, 138.78, 137.79, 130.34 (s, 5C, Ar), 129.01, 128.69, 128.23, 128.10, 128.05, 127.91, 127.43, 126.96, 126.08, 113.85 (d, 19C, Ar), 100.99 (d, C*H*Ph), 99.24 (d, C-1′), 99.16 (s, C-2), 82.96 (d, C-4′), 79.28 (d, C-2′), 78.04 (d, C-3′), 74.70 (t, *C*H$_2$Ph), 73.09 (d, C-4), 71.99 (t, *C*H$_2$Ph), 71.65 (d, C-5), 71.54 (d, C-7), 71.23 (d, C-6), 70.11 (t, *C*H$_2$Ph), 69.08 (t, C-6′), 62.79 (t, C-8), 62.37 (d, C-5′), 55.19 (q, PhO*C*H$_3$), 52.34 (q, CO_2CH_3), 51.06 (q, OCH_3), 33.20 (t, C-3), 17.55, 17.49, 17.47, 17.44, 17.27, 17.16, 17.07 [q, 8C, Si-CH-(*C*H$_3$)$_2$], 14.22, 13.44, 12.99, 12.79 [d, 4C, Si-*C*H-(CH$_3$)$_2$]; ESI-TOF HRMS: *m*/*z* = 1076.5210; calcd for $C_{57}H_{78}O_{15}Si_2NH_4^+$: 1076.5218.

3.7. 2,3,4,6-*O*-benzyl-α-D-*gluco*pyranosyl-(1→5)-methyl (methyl 3-deoxy-α-D-*manno*-oct-2-ulopyranosid)onate (12)

Compound **9α** (16.0 mg, 0.016 mmol) was dissolved in dry THF (3.3 mL) and was treated with TBAF (1 M in THF, 23 μL, 0.023 mmol) at ambient temperature for 20 min. After addition of dry MeOH (1.7 mL) the solvent was removed in vacuo. Purification of the residue by chromatography (toluene/EtOAc 1:1) afforded **12** (12.0 mg, 98%) as a colorless oil; $[\alpha]_D^{20}$ +36.0 (*c* 0.53, $CHCl_3$); R_f 0.18 (toluene/EtOAc 1:1); ^{1}H NMR ($CDCl_3$): δ 7.39–7.24 (m, 18H, Ar), 7.18–7.15 (m, 2H, Ar), 4.96 (d, 1H, *J* 11.1 Hz, C*H*HPh), 4.93 (d, 1H, *J* 11.1 Hz, CH*H*Ph), 4.89 (d, 1H, *J* 11.6 Hz, C*H*HPh), 4.83 (d, 1H, *J* 10.7 Hz, C*H*HPh), 4.73 (d, 1H, $J_{1',2'}$ 3.7 Hz, H-1′), 4.64 (d, 1H, *J* 11.8 Hz, CH*H*Ph), 4.52 (d, 1H, *J* 12.3 Hz, C*H*HPh), 4.49 (d, 1H, *J* 10.7 Hz, CH*H*Ph), 4.45 (d, 1H, *J* 12.1 Hz, CH*H*Ph), 4.28 (d, 1H, *J* 5.6 Hz, O*H*), 4.07 (app. t, 1H, $J_{3',2'} = J_{3',4'}$ 9.5 Hz, H-3′), 4.03–3.95 (m, 4H, H-5′, H-4, H-5, H-7), 3.86–3.81 (m, 1H, H-8a), 3.79 (s, 3H, CO_2CH_3), 3.68 (dd, 1H, $J_{6,7}$ 8.9, $J_{6,5}$ 1.6 Hz, H-6), 3.66–3.61 (m, 1H, H-8b), 3.60 (dd, 1H, $J_{6'a,6'b}$ 10.4, $J_{6'a,5'}$ 2.2 Hz, H-6′a), 3.58 (dd, 1H, H-2′), 3.55 (dd, 1H, $J_{6'b,5'}$ 5.6 Hz, H-6′b), 3.54 (d, 1H, *J* 12.5 Hz, O*H*), 3.51 (app. t, 1H, $J_{4',5'}$ 9.6 Hz, H-4′), 3.18 (s, 3H, OCH_3), 2.16–2.11 (m, 1H, H-3*eq*), 2.08–2.00 (m, 1H, O*H*), 1.68 (app. t, 1H, $J_{3ax,3eq} = J_{3ax,4}$ 12.3 Hz, H-3*ax*); ^{13}C NMR ($CDCl_3$): δ 168.20 (s, C═O), 138.15, 137.55, 137.48, 136.60 (s, 4C, Ar), 128.85, 128.72, 128.61, 128.54, 128.53, 128.40, 128.03, 128.01, 127.89, 127.86, 127.83 (d, 20C, Ar), 100.65 (d, C-1′), 98.99 (s, C-2), 81.83 (d, C-3′), 80.06 (d, C-5), 78.83 (d, C-2′), 78.31 (d, C-4′), 75.77 (t, *C*H$_2$Ph), 75.37 (t, *C*H$_2$Ph), 74.96 (t, *C*H$_2$Ph), 73.51 (t, *C*H$_2$Ph), 71.98 (d, C-6), 71.75 (d, C-5′), 69.06 (d, C-7), 68.44 (t, C-6′), 65.85 (d, C-4), 64.32 (t, C-8), 52.46 (q, CO_2CH_3), 51.02 (q, OCH_3), 36.12 (t, C-3); ESI-TOF HRMS: *m*/*z* = 811.3299; calcd for $C_{44}H_{52}O_{13}Na^+$: 811.3300.

3.8. α-D-*Gluco*pyranosyl-(1→5)-sodium (methyl 3-deoxy-α-D-*manno*-2-oct-2-ulopyranosid)onate (13)

Compound **12** (11.2 mg, 0.014 mmol) was dissolved in dry MeOH (0.5 mL). The atmosphere was exchanged to argon by alternating evacuation and flushing with argon. Then, palladium on active charcoal (10%, 1 mg) was added to the flask followed by successive exchange of the atmosphere to argon and hydrogen using the same method described before. The mixture was stirred intensively for 3 h, diluted with MeOH, and passed through a 0.45 μm syringe filter. Concentration of the filtrate afforded debenzylated methyl ester which was saponified with aq NaOH (0.01 M, 2.0 mL) at ambient temperature for 1.5 h. The solution was neutralized by addition of freshly regenerated DOWEX 50 H^+, the ion-exchange resin was filtered off, and the filtrate was lyophilized. Purification by SEC (Bio-Gel P2 gel, 5% aq EtOH) and freeze-drying

of pooled fractions provided **13** (5.6 mg, 90%) as a colorless amorphous solid; $[\alpha]_D^{20}$ +99.9 (*c* 0.56, D_2O); ^{1}H NMR (D_2O): 5.11 (d, 1H, $J_{1',2'}$ 4.0 Hz, H-1′), 4.12–4.03 (m, 4H, H-4, H-5, H-7, H-5′), 3.89 (dd, 1H, $J_{8a,8b}$ 11.8, $J_{8a,7}$ 2.8 Hz, H-8a), 3.79–3.68 (m, 3H, H-3′, H-6′a, H-6′b), 3.62 (dd, 1H, $J_{8b,7}$ 6.1 Hz, H-8b), 3.56–3.54 (m, 1H, H-6), 3.49 (dd, 1H, $J_{2',3'}$ 10.0 Hz, H-2′), 3.41 (dd, 1H, *J* 10.0, *J* 9.0 Hz, H-4′), 3.11 (s, 3H, OCH_3), 1.99–1.95 (m, 1H, H-3*eq*), 1.82 (app. t, 1H, $J_{3ax,3eq} = J_{3ax,4}$ 12.5 Hz, H-3*ax*); ^{13}C NMR data: see Table 1; ESI-TOF HRMS: *m*/*z* = 413.1296; calcd for $C_{15}H_{25}O_{13}^-$: 413.1301.

3.9. 2,3-Di-*O*-benzyl-α-D-*gluco*pyranosyl-(1→5)-methyl [methyl 3-deoxy-7,8-*O*-(1,1,3,3-tetraisopropyldisiloxane-1,3-diyl)-α-D-*manno*-oct-2-ulopyranosid]onate (14)

Compound **11** (50.0 mg, 0.047 mmol) was treated with trifluoroacetic acid (99%, 1.0 mL) in CH_2Cl_2 (8.0 mL) at 0 °C for 10 min. The solution was concentrated, coevaporated with toluene, and the crude product was purified by chromatography (*n*-hexane/EtOAc 3:1, then 1:2) yielding **14** (40.2 mg, 88%) as a colorless oil; $[\alpha]_D^{20}$ +79.6 (*c* 0.52, $CHCl_3$); R_f 0.24 (*n*-hexane/EtOAc 1:2); ^{1}H NMR ($CDCl_3$): δ 7.36–7.26 (m, 10H, Ar), 5.09 (d, 1H, $J_{1',2'}$ 3.4 Hz, H-1′), 4.91 (d, 1H, *J* 11.6 Hz, C*H*HPh), 4.79 (d, 1H, *J* 12.4 Hz, C*H*HPh), 4.75 (d, 1H, *J* 12.5 Hz, CH*H*Ph), 4.71 (d, 1H, *J* 11.5 Hz, CH*H*Ph), 4.44 (app. td, 1H, $J_{7,6}$ 8.3, $J_{7,8a} = J_{7,8b}$ 2.3 Hz, H-7), 4.14 (dd, 1H, $J_{8a,8b}$ 12.8 Hz, H-8a), 4.10–4.05 (m, 2H, H-4, H-5), 4.03–3.97 (m, 2H, H-5′, H-8b), 3.85 (app. t, 1H, $J_{3',2'} = J_{3',4'}$ 8.6 Hz, H-3′), 3.81–3.76 (m, 5H, CO_2CH_3, H-6, H-6′a), 3.73 (dd, 1H, $J_{6'b,6'a}$ 11.7, $J_{6'b,5'}$ 5.6 Hz, H-6′b), 3.53 (dd, 1H, H-2′), 3.49 (app. t, 1H, $J_{4',5'}$ 8.7 Hz, H-4′), 3.31 (s, 3H, OCH_3), 2.17 (m, 1H, H-3*eq*), 1.90 (app. t, 1H, $J_{3ax,3eq} = J_{3ax,4}$ 12.2 Hz, H-3*ax*), 1.07–0.81 (m, 28H, TIPDS); ^{13}C NMR ($CDCl_3$): δ 168.62 (s, C=O), 138.38, 138.02 (s, 2C, Ar), 128.58, 128.41, 127.96, 127.91, 127.67, 127.42 (d, 10C, Ar), 99.07 (s, C-2), 98.90 (d, C-1′), 80.20 (d, C-3′), 78.39 (d, C-2′), 77.62 (d, C-5), 74.73 (t, CH_2Ph), 73.12 (d, C-5′), 72.91 (d, C-7), 72.55 (t, CH_2-Ph), 71.79 (d, C-6), 69.91 (d, C-4′), 66.60 (d, C-4), 63.70 (t, C-8), 62.19 (t, C-6′), 52.42 (q, CO_2CH_3), 51.20 (q, OCH_3), 36.15 (t, C-3), 17.56, 17.52, 17.50, 17.44, 17.31, 17.20, 17.12 [q, 8C, Si-CH-(CH_3)$_2$], 14.00, 13.57, 12.93, 12.77 [d, 4C, Si-C*H*-(CH$_3$)$_2$]; ESI-TOF HRMS: *m*/*z* = 873.3880; calcd for $C_{42}H_{66}O_{14}Si_2Na^+$: 873.3883.

3.10. 2,3-Di-*O*-benzyl-α-D-*gluco*pyranosyl-(1→5)-methyl (methyl 3-deoxy-α-D-*manno*-oct-2-ulopyranosid)onate (15)

TBAF (1 M in THF, 28 μL, 0.028 mmol) was added to a solution of **14** (15.9 mg, 0.019 mmol) in dry THF (1.0 mL) at ambient temperature and stirred for 5 min. Dry MeOH (2.0 mL) was added followed by concentration. The residue was purified by chromatography (EtOAc, then EtOAc/methanol 19:1) to provide **15** (11.0 mg, 97%) as a colorless oil; $[\alpha]_D^{20}$ +50.6 (*c* 0.52, $CHCl_3$); R_f 0.22 (EtOAc); ^{1}H NMR ($CDCl_3$): δ 7.41–7.30 (m, 10H, Ar), 4.98 (d, 1H, *J* 11.4 Hz, C*H*HPh), 4.91 (d, 1H, *J* 11.6 Hz, C*H*HPh), 4.85 (d, 1H, *J* 11.4 Hz, CH*H*Ph), 4.77 (d, 1H, $J_{1',2'}$ 3.6 Hz, H-1′), 4.66 (d, 1H, *J* 11.5 Hz, CH*H*Ph), 4.20 (d, 1H, *J* 5.8 Hz, O*H*), 4.06–3.97 (m, 3H, H-4, H-5, H-7), 3.92 (app. t, 1H, $J_{3',2'} = J_{3',4'}$ 9.3 Hz, H-3′), 3.86–3.78 (m, 6H, CO_2CH_3, H-5′, H-6′a, H-8a), 3.75–3.68 (m, 2H, H-6′b, H-6), 3.66–3.61 (m, 1 H, H-8b), 3.57 (app. dt, 1H, $J_{4',5'}$ 9.3, $J_{4',OH}$ 3.2 Hz, H-4′), 3.54 (dd, 1H, H-2′), 3.44 (d, 1H, *J* 11.7 Hz, O*H*), 3.19 (s, 3H, OCH_3), 2.63 (d, 1H, $J_{OH,4'}$ 3.7 Hz, O*H*), 2.20 (dd, 1H, $J_{3eq,3ax}$ 12.6, $J_{3eq,4}$ 4.3 Hz, H-3*eq*), 2.14–2.07 (m, 2H, 2 × O*H*), 1.73–1.65 (m, 1H, H-3*ax*); ^{13}C NMR ($CDCl_3$): δ 168.40 (s, C=O), 138.17, 136.48 (s, 2C, Ar), 128.89, 128.80, 128.73, 128.63, 128.11, 127.90 (d, 10C, Ar), 100.72 (d, C-1′), 99.04 (s, C-2), 81.33 (d, C-3′), 79.78 (d, C-5), 78.97 (d, C-2′), 75.60 (t, CH_2Ph), 74.86 (t, CH_2Ph), 73.01 (d, C-5′), 71.90 (d, C-6), 70.69 (d, C-4′), 69.06 (d, C-7), 65.87 (d, C-4), 64.19 (t, C-8), 62.01 (t, C-6′), 52.62 (q, CO_2CH_3), 51.10 (q, OCH_3), 36.20 (t, C-3); ESI-TOF HRMS: *m*/*z* = 626.2804; calcd for $C_{30}H_{40}O_{13}NH_4^+$: 626.2807.

*Deprotection of **15**:* A solution of **15** (5.6 mg, 0.009 mmol) in dry MeOH (1.0 mL) was hydrogenated for 4 h with 10% Pd–C (1 mg) as described for **13**. The suspension was diluted with MeOH and passed through a 0.45 μm syringe filter. Concentration of the filtrate afforded the debenzylated methyl ester which was treated with 0.01 M aq NaOH (1.0 mL) at ambient temperature for 12 h. The solution was made neutral by addition of DOWEX 50 H^+ resin. The ion-exchange resin was filtered off and the filtrate was lyophilized. Purification of the residue on Bio-Gel PD10 column (H_2O) and freeze-drying of pooled fractions provided **13** (3.8 mg, 95%) as a colorless amorphous solid.

3.11. 2,3,4,6-Tetra-*O*-benzyl-α-D-*gluco*pyranosyl-(1→5)-methyl (methyl 3-deoxy-α-D-*lyxo*-2-hept-2-ulopyranosid)onate (16)

A solution of **12** (32.0 mg, 0.041 mmol) in dry CH_2Cl_2 (3.5 mL) was cooled to −10 °C. Sodium *meta*periodate on silica (15 w%, 116 mg, 0.082 mmol) was added and the suspension was stirred for 1 h at −10 °C with exclusion of light. The excess of reagent was destroyed by addition of ethylene glycol (3 w% in water, 84 μL, 0.041 mmol). The mixture was diluted with $CHCl_3$ and extracted with distilled water. The aqueous phase was further extracted with CH_2Cl_2 (3 × 5 mL) and the combined organic extracts were dried (Na_2SO_4), filtered, and concentrated. The crude material was dissolved in dry MeOH (1.0 mL), cooled to 0 °C, and treated with sodium borohydride (2.5 mg, 0.065 mmol) for 1 h. Another portion of sodium borohydride (1.0 mg, 0.026 mmol) was added at 0 °C and after 5 min the solution was diluted with EtOAc and aq NH_4Cl. The aqueous phase was extracted with EtOAc (3 × 5 mL) and the combined organic layers were dried (Na_2SO_4). Concentration of the solution gave a crude product which was purified by HP-column chromatography (*n*-hexane/EtOAc 4:1 → 3:2) to afford **16** (10.4 mg, 34%) as a colorless oil; $[\alpha]_D^{20}$ +40.4 (*c* 0.96, $CHCl_3$); R_f 0.54 (toluene/EtOAc 1:2); ^{1}H NMR ($CDCl_3$): δ 7.39–7.26 (m, 18H, Ar), 7.18–7.15 (m, 2H, Ar), 4.95–4.91 (m, 2H, CH_2Ph), 4.85 (d, 1H, *J* 11.8 Hz, C*H*HPh), 4.84 (d, 1H, *J* 10.6 Hz, C*H*HPh), 4.74 (d, 1H, $J_{1',2'}$ 3.5 Hz, H-1′), 4.64 (d, 1H, *J* 11.9 Hz, CH*H*Ph), 4.52 (d, 1H, *J* 11.8 Hz, C*H*HPh), 4.49 (d, 1H, *J* 10.7 Hz, CH*H*Ph), 4.45 (d, 1H, *J* 12.4 Hz, CH*H*Ph), 4.06 (app. t, 1H, $J_{3',2'} = J_{3',4'}$ 9.4 Hz, H-3′), 4.04–3.98 (m, 2H, H-5′, H-4), 3.92–3.86 (m, 2H, H-5, H-7a), 3.86–3.83 (m, 1H, H-6), 3.82–3.78 (m, 4H, H-7b, CO_2CH_3), 3.60 (dd, 1H, $J_{6'a,6'b}$ 10.3, $J_{6'a,5'}$ 2.1 Hz, H-6′a), 3.58–3.54 (m, 2H, H-2′, H-6′b), 3.54–3.48 (m, 2H, H-4′, O*H*), 3.21 (s, 3H, OCH_3), 2.15 (dd, 1H, $J_{3eq,3ax}$ 12.2, $J_{3eq,4}$ 4.5 Hz, H-3*eq*), 1.71 (app. t, 1H, $J_{3ax,4}$ 12.5 Hz, H-3*ax*); ^{13}C NMR ($CDCl_3$): δ 168.28 (s, C=O), 138.25, 137.63, 137.53, 136.83 (s, 4C, Ar), 128.82, 128.62, 128.51, 128.40, 128.02, 127.99, 127.88, 127.83, 127.80 (d, 20C, Ar), 100.47 (d, C-1′), 99.03 (s, C-2), 81.74 (d, C-3′), 79.80 (d, C-5), 79.22 (d, C-2′), 78.11 (d, C-4′), 75.80 (t, CH_2Ph), 75.36 (t, CH_2Ph), 74.77 (t, CH_2Ph), 73.49 (t, CH_2Ph), 71.77 (d, C-5′), 71.59 (d, C-6), 68.49 (t, C-6′), 65.95 (d, C-4), 60.64 (t, C-7), 52.50 (q, CO_2CH_3), 51.01 (q, OCH_3), 36.27 (t, C-3); ESI-TOF HRMS: *m*/*z* = 781.3198; calcd for $C_{43}H_{50}O_{12}Na^+$: 781.3194.

3.12. α-D-*Gluco*pyranosyl-(1→5)-sodium (methyl 3-deoxy-α-D-*lyxo*-hept-2-ulopyranosid)onate (17)

A solution of **16** (8.0 mg, 0.011 mmol) in dry MeOH (0.5 mL) was hydrogenated for 4 h with 10% Pd–C (1 mg) as described for **13**. Another portion of catalyst (1 mg) was added and stirring under H_2 was continued for 19 h. The suspension was diluted with MeOH and passed through a 0.45 μm syringe filter. Concentration of the filtrate afforded the debenzylated methyl ester which was treated with 0.01 M aq NaOH (1.5 mL) at ambient temperature

for 1 h. The solution was made neutral by addition of DOWEX 50 H^+ resin. The ion-exchange resin was filtered off and the filtrate was lyophilized. Purification of the residue on Bio-Gel P2 (5% aq EtOH) and freeze-drying of pooled fractions provided **17** (3.4 mg, 79%) as a colorless amorphous solid; $[\alpha]_D^{20}$ +170.7 (*c* 0.28, D_2O); ^{1}H NMR (D_2O): 4.89 (d, 1H, $J_{1',2'}$ 3.8 Hz, H-1′), 4.10 (ddd, 1H, $J_{3ax,4}$ 12.3, $J_{3eq,4}$ 4.8, $J_{5,4}$ 3.0 Hz, H-4), 4.06 (ddd, 1H, $J_{6'a,5'}$ 3.5, $J_{6'b,5'}$ 2.6, $J_{4',5'}$ 10.3 Hz, H-5′), 3.96 (dd, 1H, $J_{7a,7b}$ 11.4, $J_{7a,6}$ 8.2 Hz, H-7a), 3.88 (br d, 1H, H-5), 3.81 (dd, 1H, $J_{7b,6}$ 4.7 Hz, H-7b), 3.76-3.68 (m, 4H, H-6, H-3′, H-6′a, H-6′b), 3.48 (dd, 1H, $J_{2',3'}$ 10.0 Hz, H-2′), 3.41 (app. t, 1H, $J_{4',3'}$ 9.1 Hz, H-4′), 3.14 (s, 3H, OC*H*$_3$), 2.01–1.99 (m, 1H, H-3*eq*), 1.82 (app. t, 1H, $J_{3ax,3eq}$ 12.6 Hz, H-3*ax*); ^{13}C NMR data: see Table 1; ESI-TOF HRMS: *m*/*z* = 383.1193; calcd for $C_{14}H_{23}O_{12}^-$: 383.1195.

3.13. 2,3-Di-*O*-benzyl-4,6-*O*-benzylidene-α-D-*gluco*pyranosyl-(1→5)-methyl [methyl 3-deoxy-7,8-*O*-(1,1,3,3-tetraisopropyl disiloxane-1,3-diyl)-α-D-*manno*-oct-2-ulopyranosid] onate (18)

2,3-Dichloro-4,5-dicyano-*p*-benzoquinone (26.2 mg, 0.116 mmol) was added in four portions during 1 h to a solution of **11** (15.3 mg, 0.014 mmol) in dry CH_2Cl_2 (0.9 mL) and dry MeOH (0.3 mL). After complete addition the mixture was stirred at ambient temperature for 1.5 h, diluted with $CHCl_3$, and washed with aq $NaHCO_3$. The aqueous phase was extracted with CH_2Cl_2 (2 × 5 mL) and the combined organic phases were washed with aq $NaHCO_3$, dried ($MgSO_4$), filtered, and concentrated. To remove aromatic impurities the crude product was dissolved in toluene and subjected to chromatography (toluene→toluene/EtOAc 9:1) to afford **18** (11.2 mg, 83%) as a colorless oil; $[\alpha]_D^{20}$ +52.2 (*c* 0.54, $CHCl_3$); R_f 0.30 (*n*-hexane/EtOAc 3:1); ^{1}H NMR ($CDCl_3$): δ 7.49–7.47 (m, 2H, Ar), 7.39–7.24 (m, 13H, Ar), 5.54 (s, 1H, C*H*Ph), 5.11 (d, 1H, $J_{1',2'}$ 3.9 Hz, H-1′), 4.93 (d, 1H, *J* 11.2 Hz, C*H*HPh), 4.90 (d, 1H, *J* 12.2 Hz, C*H*HPh), 4.79 (d, 1H, *J* 11.2 Hz, CH*H*Ph), 4.75 (d, 1H, *J* 12.5 Hz, CH*H*Ph), 4.47 (app. dt, 1H, $J_{7,6} = J_{7,8a}$ 8.7, $J_{7,8b}$ 2.1 Hz, H-7), 4.24 (dd, 1H, $J_{6'a,6'b}$ 10.4, $J_{6'a,5'}$ 4.9 Hz, H-6′a), 4.15–4.07 (m, 5H, H-3′, H-5′, H-4, H-5, H-8a), 3.90 (dd, 1H, $J_{8b,8a}$ 12.9 Hz, H-8b), 3.80 (s, 3H, CO_2CH_3), 3.75 (d, 1H, H-6), 3.69 (app. t, 1H, $J_{6'b,5'}$ 10.4 Hz, H-6′b), 3.65 (app. t, 1H, $J_{4',3'} = J_{4',5'}$ 9.5 Hz, H-4′), 3.62 (dd, 1H, $J_{2',3'}$ 9.0 Hz, H-2′), 3.32 (s, 3H, OC*H*$_3$), 2.85 (bs, 1H, O*H*), 2.20–2.16 (m, 1H, H-3*eq*), 1.92 (app. t, 1H, $J_{3ax,3eq} = J_{3ax,4}$ 12.2 Hz, H-3*ax*), 1.05–0.81 (m, 28H, TIPDS); ^{13}C NMR ($CDCl_3$): δ 168.53 (s, C=O), 138.59, 138.39, 137.28 (s, 3C, Ar), 128.90, 128.27, 128.22, 127.96, 127.56, 127.46, 127.41, 125.97 (d, 15C, Ar), 101.13 (d, C*H*Ph), 100.05 (d, C-1′), 99.07 (s, C-2), 82.09 (d, C-4′), 78.26 (d, C-2′), 78.18 (d, C-3′), 77.25 (d, C-5), 74.84 (t, *C*H$_2$Ph), 72.57 (t, *C*H$_2$Ph), 72.32 (d, C-7), 71.49 (d, C-6), 68.75 (t, C-6′), 66.50 (d, C-4), 63.37 (d, C-5′), 63.33 (t, C-8), 52.46 (q, CO_2CH_3), 51.22 (q, OCH_3), 36.28 (t, C-3), 17.62, 17.53, 17.52, 17.49, 17.32, 17.18, 17.11 [q, 8C, Si-CH-(*C*H$_3$)$_2$], 14.12, 13.58, 12.96, 12.81 [d, 4C, Si-*C*H-(CH$_3$)$_2$]; ESI-TOF HRMS: *m*/*z* = 961.4190; calcd for $C_{49}H_{70}O_{14}Si_2Na^+$: 961.4196.

3.14. 2,3,4-Tri-*O*-benzyl-α-D-*gluco*pyranosyl-(1→5)-methyl [methyl 3-deoxy-4-*O*-(4-methoxybenzyl)-7,8-*O*-(1,1,3,3-tetraisopropyldisiloxane-1,3-diyl)-α-D-*manno*-oct-2-ulopyranosid]onate (19)

A suspension of compound **11** (20.0 mg, 0.019 mmol) and 4 Å molecular sieves (70 mg) in dry CH_2Cl_2 (0.8 mL) was cooled to −70 °C followed by consecutive addition of triethylsilane (9.8 μL, 0.061 mmol) and dichlorophenylborane (7.2 μL, 0.055 mmol). After 1 h Et_3N (44 μL) and dry MeOH (44 μL) were added to the cold solution. The mixture was diluted with $CHCl_3$, allowed to warm up to ambient temperature and washed with aq $NaHCO_3$. The aqueous layer was extracted with CH_2Cl_2 (3 × 5 mL), the combined organic layers were dried (Na_2SO_4) and concentrated. The residue was purified by column chromatography (*n*-hexane/EtOAc 9:1 → 3:1) to give **19** (8.6 mg, 43%) as a colorless oil; $[\alpha]_D^{20}$ +87.6 (*c* 0.78, $CHCl_3$); R_f 0.31 (*n*-hexane/EtOAc 3:1); ^{1}H NMR ($CDCl_3$): δ 7.36–7.21 (m, 17H, Ar), 6.84–6.81 (m, 2H, Ar), 5.25 (d, 1H, $J_{1',2'}$ 3.7 Hz, H-1′), 4.93 (d, 1H, *J* 12.0 Hz, C*H*HPh), 4.88–4.82 (m, 3H, C*H*HPh, C*H*$_2$Ph), 4.68 (d, 1H, *J* 12.0 Hz, CH*H*Ph), 4.63 (d, 1H, *J* 11.0 Hz, CH*H*Ph), 4.51 (d, 1H, *J* 11.6 Hz, C*H*HPh), 4.49 (d, 1H, *J* 11.8 Hz, CH*H*Ph), 4.40 (app. td, 1H, $J_{7,6}$ 9.3, $J_{7,8a} = J_{7,8b}$ 1.9 Hz, H-7), 4.23–4.21 (m, 1H, H-5), 4.20 (app. td, 1H, $J_{5',4'}$ 10.1, $J_{5',6'a} = J_{5',6'b}$ 2.8 Hz, H-5′), 4.09 (app. t, 1H, $J_{3',2'} = J_{3',4'}$ 9.4 Hz, H-3′), 4.01 (dd, 1H, $J_{8a,8b}$ 13.0 Hz, H-8a), 3.83 (ddd, 1H, $J_{4,3ax}$ 11.8, $J_{4,3eq}$ 4.6, $J_{4,5}$ 2.4 Hz, H-4), 3.81 (s, 3H, CO_2CH_3), 3.77 (s, 3H, PhOC*H*$_3$), 3.67 (dd, 1H, H-8b), 3.61 (d, 1H, H-6), 3.57–3.51 (m, 2H, H-2′, H-4′), 3.45–3.41 (m, 2H, H-6′a, H-6′b), 3.27 (s, 3H, OC*H*$_3$), 2.22 (dd, 1H, $J_{3eq,3ax}$ 12.5, H-3*eq*), 2.15 (app. t, 1H, H-3*ax*), 1.57–1.53 (m, 1H, O*H*), 1.04–0.78 (m, 28H, TIPDS); ^{13}C NMR ($CDCl_3$): δ 168.79 (s, C=O), 159.14, 138.77, 138.72, 138.42, 130.22 (s, 5C, Ar), 129.05, 128.40, 128.29, 128.14, 127.98, 127.86, 127.73, 127.44, 127.09, 126.82, 113.77 (d, 19C, Ar), 99.15 (s, C-2), 98.09 (d, C-1′), 81.52 (d, C-3′), 80.24 (d, C-4′), 77.79 (d, C-2′), 75.12 (t, *C*H$_2$Ph), 74.84 (t, *C*H$_2$Ph), 73.22 (d, C-4), 72.52 (t, *C*H$_2$Ph), 71.86 (d, C-7), 71.57 (d, C-5), 71.37 (d, C-6), 70.73 (d, C-5′), 69.81 (t, *C*H$_2$Ph), 63.02 (t, C-8), 61.43 (t, C-6′), 55.23 (q, PhO*C*H$_3$), 52.38 (q, CO_2CH_3), 51.10 (q, OCH_3), 33.02 (t, C-3), 17.53, 17.50, 17.49, 17.46, 17.28, 17.17, 17.08 [q, 8C, Si-CH-(*C*H$_3$)$_2$], 14.17, 13.59, 12.98, 12.78 [d, 4C, Si-*C*H-(CH$_3$)$_2$]; ESI-TOF HRMS: *m*/*z* = 1078.5373; calcd for $C_{57}H_{80}O_{15}Si_2NH_4^+$: 1078.5374.

3.15. 2,3-Di-*O*-benzyl-α-D-*gluco*pyranosyl-(1→5)-methyl [methyl 3-deoxy-4-*O*-(4-methoxybenzyl)-7,8-*O*-(1,1,3,3-tetraisopropyldisiloxane-1,3-diyl)-α-D-*manno*-oct-2-ulopyranosid]onate (20)

A solution of **11** (59 mg, 0.056 mmol) and *p*-toluenesulfonic acid monohydrate (1 mg, 0.006 mmol) in dry MeOH (2.5 mL) was stirred at 40 °C for 2 h. The solution was allowed to cool to ambient temperature followed by treatment with solid $NaHCO_3$ (25 mg) for 2 min. After removal of the solvent, the residue was partitioned between EtOAc and aq $NaHCO_3$, the aqueous layer was washed with EtOAc (2 × 10 mL) and the combined organic phases were dried (Na_2SO_4), filtered, and concentrated. The residue was purified by chromatography (*n*-hexane/EtOAc 7:3) providing **20** (49 mg, 91%) as a colorless oil; $[\alpha]_D^{20}$ +86.0 (*c* 0.44, $CHCl_3$); R_f 0.70 (*n*-hexane/EtOAc 1:1); ^{1}H NMR ($CDCl_3$): δ 7.38–7.35 (m, 2H, Ar), 7.34–7.22 (m, 10H, Ar), 6.87–6.84 (m, 2H, Ar), 5.27 (d, 1H, $J_{1',2'}$ 3.4 Hz, H-1′), 4.89 (d, 1H, *J* 11.9 Hz, C*H*HPh), 4.88 (d, 1H, *J* 11.8 Hz, C*H*HPh), 4.74 (d, 1H, *J* 11.3 Hz, CH*H*Ph), 4.71 (d, 1H, *J* 12.0 Hz, CH*H*Ph), 4.52 (s, 2H, C*H*$_2$Ph), 4.40–4.37 (m, 1H, H-7), 4.25–4.23 (m, 1H, H-5), 4.14 (app. td, 1H, $J_{5',4'}$ 9.9, $J_{5',6'a} = J_{5',6'b}$ 3.8 Hz, H-5′), 4.02 (dd, 1H, $J_{8a,8b}$ 13.1, $J_{8a,7}$ 1.9 Hz, H-8a), 3.91 (app. t, 1H, $J_{3',2'} = J_{3',4'}$ 9.5 Hz, H-3′), 3.86–3.82 (m, 4H, H-4, CO_2CH_3), 3.80 (s, 3H, PhOC*H*$_3$), 3.69 (dd, 1H, $J_{8b,7}$ 2.1 Hz, H-8b), 3.63 (d, 1H, $J_{6,7}$ 9.6 Hz, H-6), 3.57 (app. dt, 1H, $J_{4',OH}$ 2.8 Hz, H-4′), 3.53–3.45 (m, 3H, H-2′, H-6′a, H-6′b), 3.28 (s, 3H, OC*H*$_3$), 2.25–2.20 (m, 2H, H-3*eq*, O*H*), 2.15 (app. t, 1H, $J_{3ax,3eq} = J_{3ax,4}$ 12.1 Hz, H-3*ax*), 1.67–1.63 (m, 1H, O*H*), 1.05–0.79 (m, 28H, TIPDS); ^{13}C NMR ($CDCl_3$): δ 168.84 (s, C=O), 159.20, 138.70, 138.51, 130.20 (s, 4C, Ar), 129.05, 128.50, 128.21, 127.99, 127.75, 127.22, 126.89, 113.81 (d, 14C, Ar), 99.18 (s, C-2), 98.06 (d, C-1′), 80.72 (d, C-3′), 79.87 (d, C-2′), 74.68 (t, *C*H$_2$Ph), 73.19 (d, C-4), 72.30 (t, *C*H$_2$Ph), 71.96 (d, C-7), 71.50 (d, C-5), 71.38 (d, C-6), 70.94 (d, C-4′), 70.76 (d, C-5′), 69.84 (t, *C*H$_2$Ph), 63.07 (t, C-8), 62.44 (t, C-6′), 55.26 (q, PhO*C*H$_3$), 52.40 (q, CO_2CH_3), 51.14 (q, OCH_3), 33.11 (t, C-3), 17.51, 17.48, 17.44, 17.27, 17.17, 17.08 [q, 8C, Si-CH-(*C*H$_3$)$_2$], 14.14, 13.61, 12.97, 12.78 [d, 4C,

Si-CH-$(CH_3)_2$]; ESI-TOF HRMS: m/z = 988.4917; calcd for $C_{50}H_{74}O_{15}Si_2NH_4^+$: 988.4905.

3.16. 2,3-Di-*O*-benzyl-6-*O*-(dibenzylphosphoryl)-α-D-*gluco*pyranosyl-(1→5)-methyl [methyl 3-deoxy-4-*O*-(4-methoxybenzyl)-7,8-*O*-(1,1,3,3-tetraisopropyldisiloxane-1,3-diyl)-α-D-*manno*-oct-2-ulopyranosid]onate (21) and 2,3-di-*O*-benzyl-4-*O*-(dibenzyl phosphoryl)-α-D-*gluco*pyranosyl-(1→5)-methyl [methyl 3-deoxy-4-*O*-(4-methoxybenzyl)-7,8-*O*-(1,1,3,3-tetra isopropyldisiloxane-1,3-diyl)-α-D-*manno*-oct-2-ulopyranosid] onate (22)

A solution of **20** (47.0 mg, 0.048 mmol) in dry CH_2Cl_2 (3.0 mL) was flushed with Ar before 1*H*-tetrazole (6.8 mg, 0.097 mmol) and 4 Å molecular sieves (50 mg) were added. The suspension was stirred for 30 min at ambient temperature and cooled to −5 °C. Dibenzyl *N*,*N*-diisopropylphosphoramidite (15.9 μL, 0.048 mmol) in dry CH_2Cl_2 (1.0 mL) was added dropwise at −5 °C. After 30 min another portion of dibenzyl *N*,*N*-diisopropylphosphoramidite (4.0 μL, 0.012 mmol) in dry CH_2Cl_2 (0.25 mL) was added at −5 °C and after 15 min the solution was treated with *m*-chloroperbenzoic acid (70 w%, 23.9 mg, 0.097 mmol) for 5 min. The reaction mixture was partitioned between aq $NaHCO_3$ and CH_2Cl_2, the aqueous phase was extracted with $CHCl_3$ (2 × 10 mL) and the combined organic phases were dried ($MgSO_4$), filtered, and concentrated. Purification by HP-column chromatography (*n*-hexane/EtOAc 3:1 → 3:2) provided **21** (39.6 mg, 67%) and **22** (5.8 mg, 10%) as colorless oils.

Data for **21**: $[\alpha]_D^{20}$ +96.7 (*c* 0.32, $CHCl_3$); R_f 0.19 (*n*-hexane/EtOAc 2:1, HPTLC); ^{1}H NMR ($CDCl_3$): δ 7.37–7.19 (m, 22H, Ar), 6.84–6.81 (d, 2H, Ar), 5.21 (d, 1H, $J_{1',2'}$ 3.6 Hz, H-1′), 5.03–4.89 (m, 6H, 2 × C*H*HPh, 2 × POC*H*HPh, 2 × POCH*H*Ph), 4.80 (d, 1H, *J* 11.2 Hz, CH*H*Ph), 4.64 (d, 1H, *J* 11.9 Hz, CH*H*Ph), 4.47 (d, 1H, *J* 11.4 Hz, C*H*HPh), 4.44 (d, 1H, *J* 11.4 Hz, CH*H*Ph), 4.42 (app. td, 1H, $J_{7,6}$ 9.8, $J_{7,8a} = J_{7,8b}$ 1.7 Hz, H-7), 4.22–4.20 (m, 1H, H-5), 4.17–4.14 (m, 1H, H-5′), 4.00–3.92 (m, 3H, H-3′, H-6′a, H-8a), 3.85–3.81 (m, 4H, H4, CO_2CH_3), 3.70 (s, 3H, PhOCH_3), 3.66–3.53 (m, 4H, H-4′, H-6′b, H-6, H-8b), 3.49 (dd, 1H, $J_{2',3'}$ 9.7 Hz, H-2′), 3.45–3.41 (m, 1H, O*H*), 3.28 (s, 3H, OCH_3), 2.23 (dd, 1H, $J_{3eq,3ax}$ 12.5, $J_{3eq,4}$ 4.1 Hz, H-3*eq*), 2.11 (app. t, 1H, $J_{3ax,4}$ 12.2 Hz, H-3*ax*), 1.02–0.72 (m, 28H, TIPDS); ^{13}C NMR ($CDCl_3$): δ 168.79 (s, C═O), 159.20, 138.95, 138.77 (s, 3C, Ar), 135.72 (s, $J_{C,P}$ 6.7 Hz, Ar), 135.62 (s, $J_{C,P}$ 7.3 Hz, Ar), 130.14 (s, Ar), 129.22, 128.52, 128.49, 128.27, 128.07, 127.96, 127.93, 127.88, 127.44, 127.01, 126.81, 113.79 (d, 24C, Ar), 99.11 (s, C-2), 98.76 (d, C-1′), 80.47 (d, C-3′), 79.46 (d, C-2′), 74.89 (t, CH_2-Ph), 73.32 (d, C-4), 72.22 (t, CH_2Ph), 71.94 (d, C-5), 71.58 (d, C-7), 71.30 (d, C-6), 70.24 (d, $J_{C,P}$ 4.8 Hz, C-5′), 69.96 (t, CH_2Ph), 69.64 (d, C-4′), 69.47 (t, $J_{C,P}$ 5.4 Hz, POCH_2Ph), 69.32 (t, $J_{C,P}$ 5.8 Hz, POCH_2-Ph), 66.00 (t, $J_{C,P}$ 5.4 Hz, C-6′), 62.83 (t, C-8), 55.14 (q, PhOCH_3), 52.37 (q, CO_2CH_3), 51.10 (q, OCH_3), 33.02 (t, C-3), 17.54, 17.48, 17.44, 17.26, 17.14, 17.06 [q, 8C, Si-CH-(CH_3)$_2$], 14.16, 13.40, 12.98, 12.74 [d, 4C, Si-C*H*-$(CH_3)_2$]; ^{31}P NMR ($CDCl_3$): δ 0.81; ESI-TOF HRMS: m/z = 1253.5072; calcd for $C_{64}H_{87}O_{18}PSi_2Na^+$: 1253.5061.

Data for **22**: colorless oil; $[\alpha]_D^{20}$ +72.4 (*c* 0.53, $CHCl_3$); R_f 0.26 (*n*-hexane/EtOAc 2:1, HPTLC); ^{1}H NMR ($CDCl_3$): δ 7.35–7.08 (m, 22H, Ar), 6.84–6.81 (m, 2H, Ar), 5.30 (d, 1H, $J_{1',2'}$ 3.8 Hz, H-1′), 5.00 (dd, 1H, *J* 11.8, $J_{H,P}$ 7.9 Hz, POC*H*HPh), 4.94–4.87 (m, 3H, C*H*HPh, POCH_2Ph), 4.84 (dd, 1H, *J* 11.9, $J_{H,P}$ 9.8 Hz, POCH*H*Ph), 4.81 (d, 1H, *J* 12.2 Hz, C*H*HPh), 4.79 (d, 1H, *J* 11.9 Hz, CH*H*Ph), 4.65 (d, 1H, *J* 11.9 Hz, CH*H*Ph), 4.54 (d, 1H, *J* 11.9 Hz, C*H*HPh), 4.50 (d, 1H, *J* 11.8 Hz, CH*H*Ph), 4.44 (app. q, 1H, $J_{4',3'} = J_{4',5'} = J_{4',P}$ 9.5 Hz, H-4′), 4.37–4.34 (m, 1H, H-7), 4.27–4.25 (m, 1H, H-5), 4.24–4.20 (m, 1H, H-5′), 4.07 (app. t, 1H, $J_{3',2'}$ 9.5 Hz, H-3′), 3.97 (dd, 1H, $J_{8a,8b}$ 13.1, $J_{8a,7}$ 1.7 Hz, H-8a), 3.86–3.78 (m, 5H, CO_2CH_3, H-4, O*H*), 3.74 (s, 3H, PhOCH_3), 3.62–3.56 (m, 4H, H-2′, H-6′a, H-6, H-8b), 3.46–3.41 (m, 1H, H-6′b), 3.28 (s, 3H, OCH_3), 2.23 (dd, 1H, $J_{3eq,3ax}$ 12.4, $J_{3eq,4}$ 4.5 Hz, H-3*eq*), 2.14 (app. t, $J_{3ax,4}$ 12.2 Hz, H-3*ax*), 1.03–0.75 (m, 28H, TIPDS); ^{13}C NMR ($CDCl_3$): δ 168.91 (s, C═O), 159.17, 138.38 (s, 3C, Ar), 135.65 (s, $J_{C,P}$ 6.4 Hz, Ar), 135.42 (s, $J_{C,P}$ 7.5 Hz, Ar), 130.08 (s, Ar), 128.93, 128.58, 128.55, 128.43, 128.39, 128.14, 128.10, 127.97, 127.87, 127.81, 127.32, 127.13, 126.77, 113.83 (d, 24C, Ar), 99.12 (s, C-2), 97.92 (d, C-1′), 79.85 (d, C-2′), 79.12 (d, $J_{C,P}$ 4.2 Hz, C-3′), 75.04 (d, $J_{C,P}$ 5.8 Hz, C-4′), 74.85 (t, CH_2Ph), 73.08 (d, C-4), 72.71 (t, CH_2Ph), 71.73 (d, C-7), 71.32 (d, C-5), 71.20 (d, C-6), 70.65 (d, $J_{C,P}$ 3.3 Hz, C-5′), 69.91, 69.86 (t, 2C, CH_2Ph, POCH_2Ph), 69.55 (t, $J_{C,P}$ 5.5 Hz, POCH_2Ph), 62.90 (t, C-8), 60.24 (t, C-6′), 55.19 (q, PhOCH_3), 52.37 (q, CO_2CH_3), 51.14 (q, OCH_3), 33.27 (t, C-3), 17.56, 17.49, 17.27, 17.15, 17.07 [q, 8C, Si-CH-(CH_3)$_2$], 14.19, 13.51, 12.98, 12.77 [d, 4C, Si-C*H*-$(CH_3)_2$]; ^{31}P NMR ($CDCl_3$): δ 0.67; ESI-TOF HRMS: m/z = 1253.5067; calcd for $C_{64}H_{87}O_{18}PSi_2Na^+$: 1253.5061.

3.17. 2,3-Di-*O*-benzyl-6-*O*-(diphenylphosphoryl)-α-D-*gluco* pyranosyl-(1→5)-methyl [methyl 3-deoxy-4-*O*-(4-methoxy benzyl)-7,8-*O*-(1,1,3,3-tetraisopropyldisiloxane-1,3-diyl)-α-D-*manno*-oct-2-ulopyranosid]onate (23)

A suspension of compound **20** (34.0 mg, 0.035 mmol) and 4-*N*,*N*-dimethylaminopyridine (8.6 mg, 0.070 mmol) in dry CH_2Cl_2 (1.0 mL) containing 4 Å molecular sieves (50 mg) was stirred for 30 min at 0 °C. Diphenyl phosphoryl chloride (7.6 μL, 0.037 mmol) dissolved in dry CH_2Cl_2 (0.1 mL) was added dropwise to the cold solution. After stirring for 20 min the reactive species was destroyed with dry MeOH (0.1 mL). The solution was stirred for 10 min, filtered over a pad of Celite®, rinsed with CH_2Cl_2, and concentrated. The residue was purified by chromatography (*n*-hexane/EtOAc 5:2) to provide **23** (40.6 mg, 96%) as a colorless oil; $[\alpha]_D^{20}$ +76.5 (*c* 0.81, $CHCl_3$); R_f 0.42 (*n*-hexane/EtOAc 3:2); ^{1}H NMR ($CDCl_3$): δ 7.36–7.21 (m, 16H, Ar), 7.19–7.11 (m, 6H, Ar), 6.85–6.82 (m, 2H, Ar), 5.21 (d, 1H, $J_{1',2'}$ 3.7 Hz, H-1′), 4.92 (d, 1H, *J* 11.9 Hz, C*H*HPh), 4.82 (d, 1H, *J* 11.2 Hz, C*H*HPh), 4.77 (d, 1H, *J* 11.3 Hz, CH*H*Ph), 4.64 (d, 1H, *J* 12.0 Hz, CH*H*Ph), 4.49 (d, 1H, *J* 11.2 Hz, C*H*HPh), 4.46 (d, 1H, *J* 11.2 Hz, CH*H*Ph), 4.42–4.39 (m, 1H, H-7), 4.22 (d, 1H, $J_{5,4}$ 2.3 Hz, H-5), 4.20–4.16 (m, 1H, H-5′), 4.13–4.08 (m, 1H, H-6′a), 3.99 (dd, 1H, $J_{8a,8b}$ 13.1, $J_{8a,7}$ 1.6 Hz, H-8a), 3.91 (app. t, 1H, $J_{3',2'} = J_{3',4'}$ 9.4 Hz, H-3′), 3.85 (ddd, 1H, $J_{4,3ax}$ 11.9, $J_{4,3eq}$ 4.5, H-4), 3.83 (s, 3H, CO_2CH_3), 3.76–3.71 (m, 1H, H-6′b), 3.70 (s, 3H, PhOCH_3), 3.64–3.61 (m, 2H, H-6, H-8b), 3.52 (app. t, 1H, $J_{4',5'}$ 9.7 Hz, H-4′), 3.39 (dd, 1H, H-2′), 3.29 (s, 3H, OCH_3), 2.25 (dd, 1H, $J_{3eq,3ax}$ 12.4 Hz, H-3*eq*), 2.11 (app. t, 1H, H-3*ax*), 1.04–0.75 (m, 28 H, TIPDS); ^{13}C NMR ($CDCl_3$): δ 168.78 (s, C═O), 159.24 (s, Ar), 150.51 (s, $J_{C,P}$ 7.0 Hz, Ar), 150.38 (s, $J_{C,P}$ 7.3 Hz, Ar), 138.93, 138.73, 130.11 (s, 3C, Ar), 129.68, 129.21, 128.28, 128.09, 127.84, 127.46, 127.04, 126.82, 125.43, 125.29 (d, 18C, Ar), 120.25 (d, $J_{C,P}$ 4.6 Hz, 2C, Ar), 120.05 (d, $J_{C,P}$ 5.2 Hz, 2C, Ar), 113.82 (d, 2C, Ar), 99.12 (s, C-2), 98.59 (d, C-1′), 80.30 (d, C-3′), 79.36 (d, C-2′), 74.58 (t, CH_2Ph), 73.55 (d, C-4), 72.11 (t, CH_2Ph), 71.86 (d, C-5), 71.64 (d, C-7), 71.30 (d, C-6), 70.09 (t, CH_2Ph), 70.03 (d, $J_{C,P}$ 4.9 Hz, C-5′), 69.30 (d, C-4′), 67.25 (t, $J_{C,P}$ 5.9 Hz, C-6′), 62.87 (t, C-8), 55.13 (q, PhOCH_3), 52.37 (q, CO_2CH_3), 51.12 (q, OCH_3), 33.00 (t, C-3), 17.54, 17.50, 17.48, 17.46, 17.27, 17.16, 17.07 [q, 8C, Si-CH-(CH_3)$_2$], 14.17, 13.47, 12.99, 12.76 [d, 4C, Si-C*H*-$(CH_3)_2$]; ^{31}P NMR ($CDCl_3$): δ—10.34; ESI-TOF HRMS: m/z = 1225.4760; calcd for $C_{62}H_{83}O_{18}PSi_2Na^+$: 1225.4748.

3.18. 4-*O*-Acetyl-2,3-di-*O*-benzyl-6-*O*-(diphenylphosphoryl)-α-D-*gluco*pyranosyl-(1→5)-methyl [methyl 3-deoxy-4-*O*-(4-methoxybenzyl)-7,8-*O*-(1,1,3,3-tetraisopropyldisiloxane-1,3-diyl)-α-D-*manno*-oct-2-ulopyranosid]onate (24)

Distilled acetic anhydride (9.4 μL, 0.100 mmol) and 4-*N*,*N*-dimethylaminopyridine (0.3 mg, 0.003 mmol) were added

successively at 0 °C to a solution of **23** (30.0 mg, 0.025 mmol) in dry pyridine (1.0 mL). After stirring for 2 h at 0 °C the reaction was quenched with dry MeOH (100 μL). Concentration of the solution and coevaporation with toluene gave a residue which was purified by chromatography (*n*-hexane/EtOAc 2:1) to furnish **24** (29.8 mg, 96%) as a colorless oil; $[\alpha]_D^{20}$ +72.8 (*c* 0.47, $CHCl_3$); R_f 0.25 (*n*-hexane/EtOAc 2:1); ^{1}H NMR ($CDCl_3$): δ 7.35–7.12 (m, 22H, Ar), 6.82–6.79 (m, 2H, Ar), 5.26 (d, 1H, $J_{1',2'}$ 3.7 Hz, H-1′), 5.07 (app. t, 1H, $J_{4',3'} = J_{4',5'}$ 9.9 Hz, H-4′), 4.90 (d, 1H, *J* 11.7 Hz, C*H*HPh), 4.73 (d, 1H, *J* 11.3 Hz, C*H*HPh), 4.64 (d, 1H, *J* 11.8 Hz, CH*H*Ph), 4.60 (d, 1H, *J* 11.3 Hz, CH*H*Ph), 4.50 (d, 1H, *J* 11.5 Hz, C*H*HPh), 4.47 (d, 1H, *J* 11.5 Hz, CH*H*Ph), 4.42–4.38 (m, 1H, H-5′), 4.38–4.34 (m, 1H, H-7), 4.25 (d, 1H, $J_{5,4}$ 2.2 Hz, H-5), 4.03 (app. t, 1H, $J_{3',2'}$ 9.7 Hz, H-3′), 4.01 (dd, 1H, $J_{8a,8b}$ 13.0, $J_{8a,7}$ 1.6 Hz, H-8a), 3.97 (ddd, 1H, $J_{6'a,6'b}$ 11.3, $J_{6'a,P}$ 5.4, $J_{6'a,5'}$ 2.3 Hz, H-6′a), 3.88–3.83 (m, 4H, CO_2CH_3, H-4), 3.74–3.69 (m, 4H, H-6′b, $PhOCH_3$), 3.67 (dd, 1H, $J_{8b,7}$ 1.9 Hz, H-8b), 3.64 (d, 1H, $J_{6,7}$ 9.4 Hz, H-6), 3.50 (dd, 1H, H-2′), 3.29 (s, 3H, OCH_3), 2.27 (dd, 1H, $J_{3eq,3ax}$ 12.5, $J_{3eq,4}$ 4.6 Hz, H-3*eq*), 2.13 (app. t, 1H, $J_{3ax,4}$ 12.2 Hz, H-3*ax*), 1.86 (s, 3H, $COCH_3$), 1.03–0.78 (m, 28H, TIPDS); ^{13}C NMR ($CDCl_3$): δ 169.18 (s, $COCH_3$), 168.94 (s, C-1), 159.23 (s, Ar), 150.70 (s, $J_{C,P}$ 7.2 Hz, Ar), 150.54 (s, $J_{C,P}$ 7.4 Hz, Ar), 138.51, 138.34, 129.97 (s, 3C, Ar), 129.62, 129.57, 129.28, 128.27, 128.16, 128.05, 127.53, 127.16, 126.76, 125.11, 125.02 (d, 18C, Ar), 120.21 (d, $J_{C,P}$ 5.1 Hz, 2C, Ar), 120.11 (d, $J_{C,P}$ 5.1 Hz, 2C, Ar), 113.82 (d, 2C, Ar), 99.15 (s, C-2), 97.84 (d, C-1′), 79.60 (d, C-2′), 78.36 (d, C-3′), 74.19 (t, CH_2Ph), 72.99 (d, C-4), 72.59 (t, CH_2Ph), 71.73 (d, C-7), 71.19 (d, C-5), 71.17 (d, C-6), 69.95 (t, CH_2Ph), 69.25 (d, C-4′), 67.91 (d, $J_{C,P}$ 8.1 Hz, C-5′), 66.64 (t, $J_{C,P}$ 5.5 Hz, C-6′), 62.91 (t, C-8), 55.18 (q, $PhOCH_3$), 52.42 (q, CO_2CH_3), 51.16 (q, OCH_3), 33.11 (t, C-3), 20.83 (q, $COCH_3$), 17.52, 17.48, 17.45, 17.26, 17.15, 17.07 [q, 8C, Si-CH-$(CH_3)_2$], 14.21, 13.55, 12.96, 12.79 [d, 4C, Si-CH-$(CH_3)_2$]; ^{31}P NMR ($CDCl_3$): δ–12.14; ESI-TOF HRMS: *m*/*z* = 1262.5295; calcd for $C_{64}H_{85}O_{19}PSi_2NH_4^+$: 1262.5299.

3.19. 2,3-Di-*O*-benzyl-6-*O*-(dibenzylphosphoryl)-α-D-*gluco*pyranosyl-(1→5)-methyl [methyl 3-deoxy-7,8-*O*-(1,1,3,3-tetraisopropyldisiloxane-1,3-diyl)-α-D-*manno*-oct-2-ulopyranosid]onate (25)

A solution of dibenzyl *N*,*N*-diisopropylphosphoramidite (22.0 μL, 0.066 mmol) in dry CH_2Cl_2 (1.0 mL) was added under Ar in two portions to an ice-cold solution of **14** (28.4 mg, 0.033 mmol) and 1*H*-tetrazole (7.9 mg, 0.113 mmol) in dry CH_2Cl_2 (2.1 mL) and stirred for 30 min at 0 °C. *m*-Chloroperbenzoic acid (70 w%, 28.8 mg, 0.117 mmol) was added, and the solution was stirred for 15 min. The solution was diluted with CH_2Cl_2 and extracted with aq $NaHCO_3$. The aqueous layer was extracted with CH_2Cl_2 (2 × 5 mL) and the combined organic phases were dried (Na_2SO_4) and concentrated. The residue was purified by chromatography (1:1 *n*-hexane/EtOAc containing 0.1% MeOH and 0.1% Et_3N) to give **25** (23.4 mg, 63%) as a colorless oil: $[\alpha]_D^{20}$ +56.0 (*c* 0.72, $CHCl_3$); R_f 0.49 (*n*-hexane/EtOAc 1:2); ^{1}H NMR ($CDCl_3$): δ 7.35–7.26 (m, 20H, Ar), 5.10 (d, 1H, $J_{1',2'}$ 3.5 Hz, H-1′), 5.04–4.96 (m, 4H, 2 × $POCH_2Ph$), 4.87 (d, 1H, *J* 11.4 Hz, C*H*HPh), 4.80 (d, 1H, *J* 12.2 Hz, C*H*HPh), 4.78 (d, 1H, *J* 11.5 Hz, CH*H*Ph), 4.74 (d, 1H, *J* 12.4 Hz, CH*H*Ph), 4.45–4.42 (m, 1H, H-7), 4.25–4.20 (m, 1H, H-6′a), 4.16–4.04 (m, 5H, H-5′, H-6′b, H-4, H-5, H-8a), 3.96 (dd, 1H, $J_{8b,8a}$ 12.8, $J_{8b,7}$ 1.9 Hz, H-8b), 3.87 (app. t, 1H, $J_{3',2'} = J_{3',4'}$ 9.0 Hz, H-3′), 3.79 (s, 3H, CO_2CH_3), 3.75 (d, 1H, $J_{6,7}$ 8.3 Hz, H-6), 3.50–3.45 (m, 2H, H-2′, H-4′), 3.31 (s, 3H, OCH_3), 2.98 (bs, 1H, O*H*), 2.14 (dd, 1H, $J_{3eq,3ax}$ 12.8, $J_{3eq,4}$ 4.9 Hz, H-3*eq*), 1.87 (app. t, $J_{3ax,4}$ 12.3 Hz, H-3*ax*), 1.04–0.80 (m, 28 H, TIPDS); ^{13}C NMR ($CDCl_3$): δ 168.63 (s, C═O), 138.56, 138.23, (s, 2C, Ar), 135.66 (s, $J_{C,P}$ 6.5 Hz, 2C, Ar), 128.58, 128.55, 128.48, 128.35, 128.02, 127.99, 127.97, 127.78, 127.56, 127.32 (d, 20C, Ar), 99.04 (s, C-2), 99.01 (d, C-1′), 80.05 (d, C-3′), 78.41 (d, C-2′), 77.30 (d, C-5), 74.93 (t, CH_2Ph), 72.76 (d, C-7), 72.49 (t, CH_2Ph), 71.69, 71.63 (d, 2C, C-5′, C-6), 69.60 (t, $J_{C,P}$ 6.1 Hz, $POCH_2Ph$), 69.56 (t, $J_{C,P}$ 7.0 Hz, $POCH_2Ph$), 69.50 (d, C-4′), 66.61 (t, $J_{C,P}$ 7.7 Hz, C-6′), 66.54 (d, C-4), 63.62 (t, C-8), 52.39 (q, CO_2CH_3), 51.18 (q, OCH_3), 35.93 (t, C-3), 17.57, 17.53, 17.50, 17.47, 17.31, 17.20, 17.12 [q, 8C, Si-CH-$(CH_3)_2$], 14.03, 13.52, 12.95, 12.78 [d, 4C, Si-CH-$(CH_3)_2$]; ^{31}P NMR ($CDCl_3$): δ—0.08; ESI-TOF HRMS: *m*/*z* = 1133.4487; calcd for $C_{56}H_{79}O_{17}PSi_2Na^+$: 1133.4486.

Alternatively, a solution of **21** (39.9 mg, 0.032 mmol) in CH_2Cl_2 (2.0 mL) was treated with trifluoroacetic acid (99%, 0.25 mL) at 0 °C for 10 min. Dilution with toluene and azeotropic distillation afforded a crude product which was immediately purified by chromatography (*n*-hexane/EtOAc 1:1) providing **25** (31.8 mg, 88%) as a colorless oil.

3.20. 2,3-Di-*O*-benzyl-6-*O*-(dibenzylphosphoryl)-α-D-*gluco* pyranosyl-(1→5)-methyl (methyl 3-deoxy-α-D-*manno*-2-octulopyranosid)onate (26)

A solution of **25** (6.4 mg, 0.006 mmol) in dry THF (1.2 mL) was treated with TBAF (1 M in THF, 9 μL, 0.009 mmol) at ambient temperature for 15 min. Addition of dry MeOH (1 mL) and concentration provided a crude product which was purified by chromatography (EtOAc) yielding **26** (4.6 mg, 92%) as a colorless oil; $[\alpha]_D^{20}$ +96.0 (*c* 0.37, MeOH); R_f 0.34 (EtOAc); ^{1}H NMR (MeOD): δ 7.40–7.25 (m, 20H, Ar), 5.18 (d, 1H, $J_{1',2'}$ 3.5 Hz, H-1′), 5.07–5.04 (m, 4H, 2 × $POCH_2Ph$), 4.91 (d, 1H, *J* 11.2 Hz, C*H*HPh), 4.84–4.82 (m, 1H, CH*H*Ph), 4.75 (d, 1H, *J* 11.6 Hz, C*H*HPh), 4.72 (d, 1H, *J* 11.7 Hz, CH*H*Ph), 4.30–4.27 (m, 1H, H-6′a), 4.26–4.18 (m, 2H, H-5′, H-6′b), 4.10–4.02 (m, 3H, H-4, H-5, H-7), 3.86 (dd, 1H, $J_{3',2'}$ 9.6, $J_{3',4'}$ 9.0 Hz, H-3′), 3.74 (s, 3H, CO_2CH_3), 3.70 (dd, 1H, $J_{8a,8b}$ 11.2, $J_{8a,7}$ 2.9 Hz, H-8a), 3.67 (dd, 1H, $J_{6,7}$ 9.3, $J_{6,5}$ 1.1 Hz, H-6), 3.64 (dd, 1H, $J_{8b,7}$ 4.4 Hz, H-8b), 3.51 (app. t, 1H, $J_{4',5'}$ 9.3 Hz, H-4′), 3.43 (dd, 1H, H-2′), 3.21 (s, 3H, OCH_3), 2.06–2.01 (m, 1H, H-3*eq*), 1.96 (app. t, 1H, $J_{3ax,3eq} = J_{3ax,4}$ 12.3 Hz, H-3*ax*); ^{13}C NMR (MeOD): δ 170.39 (s, C═O), 140.30, 139.34 (s, 2C, Ar), 135.82 (s, $J_{C,P}$ 6.6 Hz, Ar), 135.81 (s, $J_{C,P}$ 6.6 Hz, Ar), 129.67, 129.66, 129.43, 129.38, 129.24, 129.17, 129.09, 129.07, 128.87, 128.52 (d, 20C, Ar), 100.44 (s, C-2), 100.10 (d, C-1′), 82.37 (d, C-3′), 81.07 (d, C-2′), 77.55 (d, C-5), 76.26 (t, CH_2Ph), 74.63 (t, CH_2Ph), 73.18 (d, C-6), 72.47 (d, $J_{C,P}$ 7.3 Hz, C-5′), 71.18 (d, C-4′), 70.82 (t, $J_{C,P}$ 5.9 Hz, 2C, 2 × $POCH_2Ph$), 69.98 (d, C-7), 68.23 (t, $J_{C,P}$ 5.5 Hz, C-6′), 67.25 (d, C-4), 64.13 (t, C-8), 52.94 (q, CO_2CH_3), 51.55 (q, OCH_3), 36.47 (t, C-3); ^{31}P NMR (MeOD): δ—1.20; ESI-TOF HRMS: *m*/*z* = 891.2966; calcd for $C_{44}H_{53}O_{16}PNa^+$: 891.2963.

3.21. 6-*O*-Phosphono-α-D-*gluco*pyranosyl-(1→5)-methyl 3-deoxy-α-D-*manno*-oct-2-ulopyranosidonic acid (sodium salt) (27)

A solution of **26** (8.2 mg, 0.009 mmol) in dry MeOH (1.0 mL) was hydrogenated for 1 h in the presence of 10% Pd–C (1 mg) as described for **13.** The suspension was diluted with MeOH and passed through a 0.45 μm syringe filter. The filtrate was made neutral by adding 0.1 M NaOMe (0.1 M in MeOH, 200 μL). Concentration of the filtrate afforded the debenzylated methyl ester which was saponified with 0.01 M aq NaOH (1.5 mL) at ambient temperature for 1 h. The solution was made neutral by addition of DOWEX 50 H^+ resin. The ion exchange resin was filtered off and the filtrate was lyophilized. Purification of the residue on a Bio-Gel PD10 column (H_2O) and freeze-drying of pooled fractions provided **27** (5.2 mg, 98%) as a colorless amorphous solid; $[\alpha]_D^{20}$ +97.5 (*c* 0.49, H_2O); ^{1}H NMR (D_2O): δ 5.11 (d, 1H, $J_{1',2'}$ 4.1 Hz, H-1′), 4.15–4.06 (m, 3H, H-4, H-7, H-5′), 4.05–4.00 (m, 2H, H-5, H-6′a), 3.90 (dd, 1H, $J_{8a,8b}$ 11.8, $J_{8a,7}$ 2.8 Hz, H-8a), 3.78–3.68 (ddd, 1H, $J_{6'b,6'a}$ 12.1, *J*

4.7, *J* 1.9 Hz, H-6′b), 3.73 (app. t, 1H, $J_{3',2'} = J_{3',4'}$ 9.6 Hz, H-3′), 3.62 (dd, 1H, $J_{8b,7}$ 6.1 Hz, H-8b), 3.59 (app. t, 1H, $J_{4',5'}$ 9.7 Hz, H-4′), 3.55–3.52 (m, 2H, H-6, H-2′), 3.11 (s, 3H, OCH_3), 1.96 (ddd, 1H, $J_{3eq,3ax}$ 12.9, $J_{3eq,4}$ 4.9, $J_{3eq,5}$ 0.7 Hz, H-3*eq*), 1.82 (app. t, 1H, $J_{3ax,4}$ 12.5 Hz, H-3*ax*); ^{13}C NMR data: see Table 1; ^{31}P NMR (D_2O): δ 4.65; ESI-TOF HRMS: m/z = 493.0966; calcd for $C_{15}H_{26}O_{16}P^-$: 493.0964.

3.22. 4-*O*-Acetyl-2,3-di-*O*-benzyl-6-*O*-(diphenylphosphoryl)-α-D-*gluco*pyranosyl-(1→5)-methyl [methyl 3-deoxy-4-*O*-(4-methoxybenzyl)-α-D-*manno*-oct-2-ulopyranosid]onate (28)

A solution of **24** (17.9 mg, 0.014 mmol) in dry CH_2Cl_2 was treated with triethylamine trihydrofluoride (117 μL, 0.719 mmol) for 4 h at ambient temperature. Another portion of triethylamine trihydrofluoride (117 μL, 0.719 mmol) was added and stirring was continued for 12 h. The colorless solution was added dropwise into ice-cold aq $NaHCO_3$ and extracted with CH_2Cl_2 (4 × 10 mL). The combined organic layers were dried ($MgSO_4$), filtered, and concentrated. The residue was purified by chromatography (toluene/EtOAc 1:1) which afforded **28** (11.8 mg, 82%) as a colorless oil; $[\alpha]_D^{20}$ +51.6 (*c* 1.13, $CHCl_3$); R_f 0.24 (toluene/EtOAc 1:1); ^{1}H NMR ($CDCl_3$, ref. to TMS at 0.00 ppm): δ 7.37–7.10 (m, 22H, Ar), 6.84–6.80 (m, 2H, Ar), 5.05 (app. t, 1H, $J_{4',3'} = J_{4',5'}$ 9.5 Hz, H-4′), 5.04 (d, 1H, $J_{1',2'}$ 3.5 Hz, H-1′), 4.83 (d, 1H, *J* 11.8 Hz, C*H*HPh), 4.82 (d, 1H, *J* 11.5 Hz, C*H*HPh), 4.69 (d, 1H, *J* 11.5 Hz, CH*H*Ph), 4.61 (d, 1H, *J* 11.7 Hz, CH*H*Ph), 4.44 (d, 1H, *J* 11.9 Hz, C*H*HPh), 4.37 (d, 1H, *J* 11.8 Hz, CH*H*Ph), 4.19–4.15 (m, 2H, H-5′, H-6′a), 4.12 (bs, 1H, H-5), 4.09–4.03 (m, 2H, H-6′b, H-7), 4.00 (app. t, 1H, $J_{3',2'}$ 9.5 Hz, H-3′), 3.85 (ddd, 1H, $J_{4,3ax}$ 11.9, $J_{4,3eq}$ 4.5, $J_{4,5}$ 2.4 Hz, H-4), 3.79 (dd, 1H, $J_{8a,8b}$ 11.1, $J_{8a,7}$ 3.4 Hz, H-8a), 3.76 (s, 3H, CO_2CH_3), 3.73 (s, 3H, PhOCH_3), 3.63 (dd, 1H, $J_{8b,7}$ 4.9 Hz, H-8b), 3.59 (d, 1H, $J_{6,7}$ 9.2 Hz, H-6), 3.52 (dd, 1H, H-2′), 3.18 (s, 3H, OCH_3), 2.19 (dd, 1H, $J_{3eq,3ax}$ 12.7 Hz, H-3*eq*), 1.98 (app. t, 1H, H-3*ax*), 1.92 (s, 3H, COCH_3); ^{13}C NMR ($CDCl_3$): δ 169.44 (s, *C*OCH$_3$), 168.46 (s, C-1), 159.13 (s, Ar), 150.57 (s, $J_{C,P}$ 6.9 Hz, Ar), 150.45 (s, $J_{C,P}$ 6.5 Hz, Ar), 138.04, 136.99, 130.15 (s, 3C, Ar), 129.69, 129.64, 128.85, 128.75, 128.52, 128.49, 128.01, 127.83, 125.22, 125.14 (d, 18C, Ar), 120.16 (d, $J_{C,P}$ 4.6 Hz, 2C, Ar), 120.10 (d, $J_{C,P}$ 4.9 Hz, 2C, Ar), 113.85 (d, 2C, Ar), 99.15 (s, C-2), 98.49 (d, C-1′), 80.60 (d, C-2′), 79.04 (d, C-3′), 75.20 (t, *C*H$_2$Ph), 74.74 (t, *C*H$_2$Ph), 73.98 (d, C-5), 72.95 (d, C-4), 72.39 (d, C-6), 69.89 (t, *C*H$_2$Ph), 69.82 (d, C-4′), 69.02 (d, $J_{C,P}$ 8.3 Hz, C-5′), 68.59 (d, C-7), 67.07 (t, $J_{C,P}$ 5.5 Hz, C-6′), 63.96 (t, C-8), 55.19 (q, PhO*C*H$_3$), 52.55 (q, CO_2CH_3), 51.01 (q, O*C*H$_3$), 32.66 (t, C-3), 20.84 (q, CO*C*H$_3$); ^{31}P NMR ($CDCl_3$): δ–11.95; ESI-TOF HRMS: m/z = 1020.3773; calcd for $C_{52}H_{59}O_{18}PNH_4^+$: 1020.3777.

3.23. 4-*O*-Acetyl-2,3-di-*O*-benzyl-6-*O*-(diphenylphosphoryl)-α-D-*gluco*pyranosyl-(1→5)-methyl [methyl 3-deoxy-4-*O*-(4-methoxybenzyl)-α-D-*lyxo*-hept-2-ulopyranosid]onate (29)

A solution of **28** (27.0 mg, 0.027 mmol) in dry CH_2Cl_2 (3.5 mL) was treated with sodium periodinate on silica (15 w%, 77 mg, 0.054 mmol) for 1.5 h at −10 °C under light protection. Excessive reagent was destroyed with ethylene glycol (3 w% in water, 56 μL, 0.027 mmol). The mixture was diluted with $CHCl_3$ and water, the phases were separated and the aqueous phase was extracted with CH_2Cl_2 (3 × 10 mL). The combined organic phases were dried ($MgSO_4$), filtered, and concentrated. The residue was treated with sodium borohydride (3.1 mg, 0.081 mmol) in dry MeOH (3.5 mL) at −5 °C for 30 min. The mixture was partitioned between EtOAc and aq NH_4Cl, the aqueous phase was extracted with EtOAc (3 × 5 mL) and the combined organic phases were dried ($MgSO_4$). Filtration and concentration afforded a crude product which was purified by HP-column chromatography (toluene/EtOAc 2:1) providing **29** (9.5 mg, 36%) as a colorless oil: $[\alpha]_D^{20}$ +48.0 (*c* 0.42, $CHCl_3$); R_f 0.32 (toluene/EtOAc 1:1); ^{1}H NMR ($CDCl_3$, ref. to TMS at 0.00 ppm): δ 7.36–7.19 (m, 16H, Ar), 7.18–7.10 (m, 6H, Ar), 6.84–6.81 (m, 2H, Ar), 5.03 (app. t, 1H, $J_{4',3'} = J_{4',5'}$ 9.8 Hz, H-4′), 4.98 (d, 1H, $J_{1',2'}$ 3.4 Hz, H-1′), 4.83 (d, 1H, *J* 11.5 Hz, C*H*HPh), 4.79 (d, 1H, *J* 11.5 Hz, C*H*HPh), 4.66 (d, 1H, *J* 11.5 Hz, CH*H*Ph), 4.61 (d, 1H, *J* 11.8 Hz, CH*H*Ph), 4.47 (d, 1H, *J* 11.8 Hz, C*H*HPh), 4.38 (d, 1H, *J* 11.6 Hz, CH*H*Ph), 4.22–4.18 (m, 1H, H-5′), 4.15 (ddd, $J_{6'a,6'b}$ 11.1, $J_{6'a,P}$ 6.1, $J_{6'a,5'}$ 2.4 Hz, H-6′a), 4.03–3.96 (m, 3H, H-3′, H-6′b, H-5), 3.90–3.84 (m, 2H, H-4, H-7a), 3.82–3.76 (m, 4H, H-7b, CO_2CH_3), 3.74–3.70 (m, 4H, H-6, PhOCH_3), 3.49 (dd, 1H, $J_{2',3'}$ 9.6, H-2′), 3.20 (s, 3H, OCH_3), 2.99 (bs, 1H, O*H*), 2.23 (dd, 1H, $J_{3eq,3ax}$ 12.7, $J_{3eq,4}$ 4.3 Hz, H-3*eq*), 2.02 (app. t, 1H, $J_{3ax,4}$ 12.2 Hz, H-3*ax*), 1.90 (s, 3H, COCH_3); ^{13}C NMR ($CDCl_3$): δ 169.41 (s, *C*OCH$_3$), 168.56 (s, C-1), 159.16 (s, Ar), 150.60 (s, $J_{C,P}$ 7.5 Hz, Ar), 150.47 (s, $J_{C,P}$ 6.6 Hz, Ar), 138.15, 137.11, 130.14 (s, 3C, Ar), 129.68, 129.63, 128.92, 128.69, 128.47, 128.45, 128.40, 127.95, 127.75, 125.20, 125.12 (d, 18C, Ar), 120.15 (d, 2C, $J_{C,P}$ 5.1 Hz, Ar), 120.09 (d, 2C, $J_{C,P}$ 5.3 Hz, Ar), 113.85 (d, 2C, Ar), 99.15 (s, C-2), 98.22 (d, C-1′), 80.54 (d, C-2′), 78.95 (d, C-3′), 75.20 (t, *C*H$_2$Ph), 74.56 (t, *C*H$_2$Ph), 73.59 (d, C-5), 73.09 (d, C-4), 72.70 (d, C-6), 69.99 (t, *C*H$_2$Ph), 69.66 (d, C-4′), 68.97 (d, $J_{C,P}$ 7.8 Hz, C-5′), 67.04 (t, $J_{C,P}$ 5.5 Hz, C-6′), 60.68 (t, C-7), 55.19 (q, PhO*C*H$_3$), 52.60 (q, CO_2CH_3), 51.01 (q, OCH$_3$), 32.71 (t, C-3), 20.81 (q, COCH$_3$); ^{31}P NMR ($CDCl_3$): δ −11.96; ESI-TOF HRMS m/z: 990.3668; calcd for $C_{51}H_{57}O_{17}PNH_4^+$: 990.3672.

3.24. 6-*O*-Phosphono-α-D-*gluco*pyranosyl-(1→5)-(methyl 3-deoxy-α-D-*lyxo*-hept-2-ulopyranosid)onic acid (sodium salt) (30)

A suspension of compound **29** (8.0 mg, 0.008 mmol) in dry MeOH was hydrogenated for 36 h and processed as described for **13**. The solution obtained upon removal of the catalyst was concentrated. The residue was dried and dissolved in dry MeOH (1.0 mL). PtO_2 (1 mg) was added under an Ar atmosphere and hydrogenation was continued for 4 h at rt. The suspension was diluted with MeOH and passed through a 0.45 μm syringe filter. The filtrate was concentrated, and the residue was stirred with 0.01 M aq. NaOH (3.0 mL) at ambient temperature for 3 h. The solution was neutralized by addition of DOWEX 50 H^+ resin, the ion-exchange resin was filtered off and the filtrate was lyophilized. Purification of the residue by HILIC (SeQuant ZIC®-HILIC, 5 μm, 250 × 10 mm pre-packed from Merck, 5:1 → 2:3 acetonitrile/water) followed by desalting on a PD10 column (H_2O) afforded **30** (2.2 mg, 52%) as an amorphous colorless solid: $[\alpha]_D^{20}$ +69.2 (*c* 0.39, D_2O); ^{1}H NMR (D_2O): δ 4.88 (d, 1H, $J_{1',2'}$ 4.0 Hz, H-1′), 4.19–4.15 (m, 1H, H-5′), 4.12 (ddd, 1H, $J_{4,3ax}$ 12.3, $J_{4,3eq}$ 4.8, $J_{4,5}$ 3.0 Hz, H-4), 4.05 (ddd, 1H, $J_{6'a,6'b}$ 11.6, *J* 6.2, *J* 3.2 Hz, H-6′a), 3.96 (dd, 1H, $J_{7a,7b}$ 11.5, $J_{7a,6}$ 8.3 Hz, H-7a), 3.89–3.85 (m, 2H, H-5, H-6′b), 3.81 (dd, 1H, $J_{7b,6}$ 4.4 Hz, H-7b), 3.75 (br dd, 1H, H-6), 3.72 (app. t, 1H, $J_{3',2'} = J_{3',4'}$ 9.7 Hz, H-3′), 3.53 (app. t, 1H, $J_{4',5'}$ 9.7 Hz, H-4′), 3.51 (dd, 1H, H-2′), 3.14 (s, 3H, OCH_3), 2.01 (dd, 1H, $J_{3eq,3ax}$ 13.0, H-3*eq*), 1.83 (app. t, 1H, H-3*ax*); ^{13}C NMR data: see Table 1; ^{31}P NMR (D_2O): δ 2.40; ESI-TOF HRMS: m/z = 463.0857; calcd for $C_{14}H_{24}O_{15}P^-$: 463.0858.

3.25. 2,3-Di-*O*-benzyl-6-*O*-(dibenzylphosphoryl)-α-D-*gluco*pyranosyl-(1→5)-methyl (methyl 3-deoxy-α-D-*lyxo*-hept-2-ulopyranosid)onate (31)

Sodium *meta*periodinate on silica (15 w%, 70 mg, 0.049 mmol) was added to a solution of **26** (21.4 mg, 0.025 mmol) in dry CH_2Cl_2 (3.0 mL) at 0 °C under light protection. The suspension was allowed to warm up to ambient temperature during 1.5 h. Excessive reagent was destroyed by addition of aq ethylene glycol (3 w%, 51 μL, 0.025 mmol). The product was partitioned between

$CHCl_3$ and brine, the aqueous phase extracted with CH_2Cl_2 (2×5 mL), and the combined organic layers were dried ($MgSO_4$) and concentrated. The crude aldehyde was dissolved in dry MeOH (3.0 mL) and treated with sodium borohydride (2.8 mg, 0.074 mmol) at 0 °C for 10 min. The solution was extracted with CH_2Cl_2 (3×10 mL) and aq NH_4Cl, and the organic phase was dried ($MgSO_4$), and concentrated. The crude material was purified by HP-column chromatography (*n*-hexane/EtOAc 1:4 → 0:1) to yield **31** (9.6 mg, 47%) as a colorless oil; $[\alpha]_D^{20}$ +29.2 (*c* 0.99, $CHCl_3$); R_f 0.59 (EtOAc); ^{1}H NMR ($CDCl_3$): δ 7.42–7.28 (m, 20H, Ar), 5.03–4.95 (m, 4H, $2 \times POCH_2Ph$), 4.93 (d, 1H, *J* 11.6 Hz, C*H*HPh), 4.88 (d, 1H, *J* 11.3 Hz, CH*H*Ph), 4.85 (d, 1H, *J* 11.7 Hz, C*H*HPh), 4.81 (d, 1H, $J_{1',2'}$ 3.5 Hz, H-1′), 4.65 (d, 1H, *J* 11.9 Hz, CH*H*Ph), 4.23 (ddd, 1H, $J_{6'a,6'b}$ 11.8, *J* 8.1, *J* 5.0 Hz, H-6′a), 4.09 (ddd, 1H, *J* 9.2, *J* 2.1 Hz, H-6′b), 4.06–4.00 (m, 1H, H-4), 3.94–3.76 (m, 9H, H-3′, H-5′, H-5, H-6, H-7a, H-7b, CO_2CH_3), 3.52–3.36 (m, 4H, H-2′, H-4′, $2 \times OH$), 3.21 (s, 3H, OCH_3), 3.21–3.18 (m, 1H, O*H*), 2.19 (ddd, 1H, $J_{3eq,3ax}$ 12.5, $J_{3eq,4}$ 4.6, $J_{3eq,5}$ 0.6 Hz, H-3*eq*), 1.72–1.62 (m, 1H, H-3*ax*); ^{13}C NMR ($CDCl_3$): δ 168.34 (s, C=O), 138.35, 136.76 (s, 2C, Ar), 135.53 (s, $J_{C,P}$ 6.5 Hz, Ar), 135.51 (s, $J_{C,P}$ 6.8 Hz, Ar), 128.85, 128.67, 128.63, 128.60, 128.52, 128.03, 128.02, 127.99 (d, 20C, Ar), 100.37 (d, C-1′), 99.02 (s, C-2), 80.50 (d, C-3′), 79.22 (d, C-5), 79.06 (d, C-2′), 75.61 (t, CH_2Ph), 74.77 (t, CH_2Ph), 72.03 (d, $J_{C,P}$ 5.7 Hz, C-5′), 71.66 (d, C-6), 69.87 (d, C-4′), 69.75 (t, $J_{C,P}$ 5.4 Hz, $POCH_2Ph$), 69.69 (t, $J_{C,P}$ 5.6 Hz, $POCH_2Ph$), 66.27 (t, $J_{C,P}$ 5.1 Hz, C-6′), 66.03 (d, C-4), 60.59 (t, C-7), 52.58 (q, CO_2CH_3), 51.06 (q, OCH_3), 36.32 (t, C-3); ^{31}P NMR ($CDCl_3$): δ 0.04; ESI-TOF HRMS: m/z = 861.2855; calcd for $C_{43}H_{51}O_{15}PNa^+$: 861.2858.

*Deprotection of **31**:* A suspension of compound **31** (7.4 mg, 0.009 mmol) and 10% Pd–C (1 mg) in dry MeOH (1.0 mL) was hydrogenated for 1 h at room temperature as described for **13**. The suspension was diluted with MeOH, passed through a 0.45 μm syringe filter and the filtrate was made neutral by addition of 0.1 M NaOMe in MeOH (100 μL). Concentration afforded the debenzylated methyl ester which was saponified with 0.01 M NaOH (1.5 mL) at ambient temperature for 8 h. The solution was neutralized by addition of DOWEX 50 H^+ ion-exchange resin. The resin was filtered off and the filtrate was lyophilized. Purification of the residue on BioGel PD10 (H_2O) and freeze-drying of pooled fractions provided **30** (3.9 mg, 87%) as a colorless amorphous solid.

3.26. Methyl (methyl 4,5;7,8-di-*O*-isopropylidene-D-*glycero*-α-D-*talo*-oct-2-ulopyranosid)onate (34)

Sodium hydride (0.13 g, 3.28 mmol) was added in small portions to an ice-cold solution of methyl (3-*O*-acetyl-4,5;7,8-di-*O*-isopropylidene-D-*glycero*-α-D-*galacto*-oct-2-ulopyranosyl)onate **32** (0.85 g, 2.19 mmol) and iodomethane (0.16 mL, 2.63 mmol) in dry DMF (10 mL). After vigorous stirring at 0 °C for 45 min, cleavage of the 3-*O*-acetyl group was induced by addition of dry MeOH (15 mL) forming NaOMe in situ. After 15 h at ambient temperature the solution was partitioned between EtOAc and aq NH_4Cl. The aqueous phase was extracted with EtOAc (3×50 mL) and the combined organic phases were dried ($MgSO_4$), filtered, and concentrated. The crude product was purified by chromatography (toluene/EtOAc 2:1) affording **33** (680 mg, 86%) as a colorless oil with minor impurities.

A solution of **33** (0.67 g, 1.85 mmol) in dry CH_2Cl_2 (15 mL) was treated with Dess-Martin periodinane (1.57 g, 3.70 mmol) at ambient temperature for 17 h. The mixture was dissolved in Et_2O (150 mL) and aq $NaHCO_3$ (50 mL) containing $Na_2S_2O_3$ (5 g) and was stirred for 30 min. The organic phase was washed with aq $NaHCO_3$, dried ($MgSO_4$), filtered, and concentrated. The residue was dissolved in dry MeOH (15 mL) and treated with borane ammonia complex (0.08 g, 2.50 mmol) at 0 °C for 15 min. After dilution with dry MeOH the solvent was removed. The residue was partitioned between CH_2Cl_2 and aq NH_4Cl and the aqueous layer was extracted with CH_2Cl_2 (2×50 mL). The combined organic phases were dried ($MgSO_4$), filtered, and concentrated. Chromatography of the residue (2:1 toluene/EtOAc) gave **34** (0.50 g, 75% based on **33**) as a colorless oil; $[\alpha]_D^{20}$ +57.0 (*c* 1.19, $CHCl_3$); R_f 0.40 (toluene/EtOAc 1:1); ^{1}H NMR ($CDCl_3$): δ 4.46 (dd, 1H, $J_{4,5}$ 6.7, $J_{4,3}$ 4.2 Hz, H-4), 4.44 (ddd, 1H $J_{7,6}$ 7.8, $J_{7,8a}$ 6.1, $J_{7,8b}$ 4.6 Hz, H-7), 4.33 (dd, 1H, $J_{5,6}$ 2.6 Hz, H-5), 4.16 (dd, 1H, $J_{8a,8b}$ 8.8, H-8a), 4.10 (dd, 1H, H-8b), 3.92 (dd, 1H, $J_{3,OH}$ 7.8, H-3), 3.82 (s, 3H, CO_2CH_3), 3.72 (dd, 1H, H-6), 3.25 (s, 3 H, OCH_3), 3.01 (d, 1H, O*H*), 1.51 [s, 3H, $C(CH_3)$], 1.44 [s, 3H, $C(CH_3)$], 1.38 [s, 6H, $2 \times C(CH_3)$]; ^{13}C NMR ($CDCl_3$): δ 167.98 (s, C=O), 109.95 [s, $C(CH_3)_2$], 109.41 [s, $C(CH_3)_2$], 99.92 (s, C-2), 73.90 (d, C-7), 72.40 (d, C-4), 71.44 (d, C-5), 69.75 (d, C-6), 68.84 (d, C-3), 66.77 (t, C-8), 52.62 (q, CO_2CH_3), 51.22 (q, OCH_3), 26.90, 25.37, 25.33, 25.18 [q, 4C, $4 \times C(CH_3)$]; ESI-TOF HRMS: m/z = 385.1464; calcd for $C_{16}H_{26}O_9Na^+$: 385.1469.

3.27. Methyl (methyl 3-*O*-benzyl-4,5;7,8-di-*O*-isopropylidene-D-*glycero*-α-D-*talo*-oct-2-ulopyranosid)onate (35)

A solution of **34** (184 mg, 0.508 mmol) in dry DMF (8.5 mL) was treated with sodium hydride (41 mg, 1.016 mmol) and stirred for 5 min at 0 °C. Benzyl bromide (121 μL, 1.016 mmol) was added dropwise and the solution was stirred for 40 min at 0 °C. Dry MeOH (1.1 mL) was added to the cold mixture and after 5 min the solution was neutralized with DOWEX 50 H^+ resin. The resin was filtered off and washed thoroughly with EtOAc. The filtrate was washed successively with aq $NaHCO_3$ and brine, dried ($MgSO_4$), and concentrated. The crude product was purified by chromatography (toluene/EtOAc 5:1) providing **35** (217 mg, 94%) as a colorless oil: $[\alpha]_D^{20}$ −18.5 (*c* 1.04, $CHCl_3$); R_f 0.29 (toluene/EtOAc 4:1); ^{1}H NMR ($CDCl_3$): δ 7.37–7.26 (m, 5H, Ar), 4.80 (s, 2H, CH_2Ph), 4.42 (dd, 1H, $J_{4,5}$ 7.7, $J_{4,3}$ 3.6 Hz, H-4), 4.40 (ddd, 1H, $J_{7,6}$ 7.3, $J_{7,8a}$ 6.3, $J_{7,8b}$ 4.9 Hz, H-7), 4.30 (dd, 1H, $J_{5,6}$ 2.2 Hz, H-5), 4.12 (dd, 1H, $J_{8a,8b}$ 8.9, Hz, H-8a), 4.02 (dd, 1H, H-8b), 3.77 (s, 3H, CO_2CH_3), 3.61 (d, 1H, H-3), 3.55 (dd, 1H, H-6), 3.30 (s, 3H, OCH_3), 1.54 [s, 3H, $C(CH_3)$], 1.41 [s, 3H, $C(CH_3)$], 1.36 [s, 3H, $C(CH_3)$], 1.34 [s, 3H, $C(CH_3)$]; ^{13}C NMR ($CDCl_3$): δ 167.04 (s, C=O), 137.62 (s, Ar), 128.43, 128.30, 127.72 (d, 5C, Ar), 110.60 [s, $C(CH_3)_2$], 109.11 [s, $C(CH_3)_2$], 101.90 (s, C-2), 75.91 (d, C-3), 73.90 (d, C-4), 73.62 (t, CH_2Ph), 73.42 (d, C-7), 72.38 (d, C-5), 70.06 (d, C-6), 66.78 (t, C-8), 52.36 (q, CO_2CH_3), 50.83 (q, OCH_3), 26.84, 25.28, 25.26, 25.07 [q, 4C, $4 \times C(CH_3)$]; ESI-TOF HRMS: m/z = 470.2389; calcd for $C_{23}H_{32}O_9NH_4^+$: 470.2385.

3.28. Methyl (methyl 3-*O*-benzyl-7,8-*O*-isopropylidene-D-*glycero*-α-D-*talo*-oct-2-ulopyranosid)onate (36)

A solution of **35** (101 mg, 0.223 mmol), *p*-toluenesulfonic acid monohydrate (42 mg, 0.223 mmol) and distilled water (84 μL, 4.460 mmol) in dry acetone (3.0 mL) was stirred at ambient temperature for 15 min. Et_3N (160 μL) was added, the solution was stirred for 30 min, and concentrated. The crude product was purified by chromatography (toluene/EtOAc 2:1) affording **36** (65 mg, 71%) as a colorless amorphous solid; $[\alpha]_D^{20}$ +36.8 (*c* 0.80, $CHCl_3$); R_f 0.41 (toluene/EtOAc 1:1); ^{1}H NMR ($CDCl_3$): δ 7.35–7.27 (m, 3H, Ar), 7.24–7.21 (m, 2H, Ar), 4.81 (d, 1H, *J* 10.9 Hz, C*H*HPh), 4.56 (d, 1H, *J* 11.0 Hz, CH*H*Ph), 4.48 (ddd, 1H, $J_{7,6}$ 7.9, $J_{7,8a}$ 6.3, $J_{7,8b}$ 5.1 Hz, H-7), 4.18 (dd, 1H, $J_{8a,8b}$ 8.8 Hz, H-8a), 4.08 (dd, 1H, $J_{3,4}$ 3.3, $J_{3,5}$ 1.2 Hz, H-3), 4.05 (dd, 1H, H-8b), 3.96 (app. td, 1H, $J_{4,OH}$ 9.8, $J_{4,5}$ 3.4 Hz, H-4), 3.93–3.89 (m, 1H, H-5), 3.71 (s, 3H, CO_2CH_3), 3.55 (dd, 1H, $J_{6,5}$ 1.2 Hz, H-6), 3.22 (s, 3H, OCH_3), 3.06 (d, 1H, $J_{OH,5}$ 11.8 Hz, O*H*), 2.92 (d, 1H, $J_{OH,4}$ 9.8 Hz, O*H*), 1.42 [s, 3H, $C(CH_3)$], 1.37 [s, 3H, $C(CH_3)$]; ^{13}C NMR ($CDCl_3$): δ 167.36 (s, C=O), 136.93 (s, Ar), 128.55, 128.15, 127.78 (d, 5C, Ar), 109.19 [s, $C(CH_3)_2$], 100.70 (s, C-2), 79.86 (d, C-3), 76.55 (t, CH_2Ph), 73.35 (d, C-7),

73.28 (d, C-6), 68.69 (d, C-5), 66.96 (d, C-4), 66.77 (t, C-8), 52.44 (q, CO_2CH_3), 51.09 (q, OCH_3), 26.73, 25.31 [q, 2C, 2 × C(CH_3)]; ESI-TOF HRMS: m/z = 435.1624; calcd for $C_{20}H_{28}O_9Na^+$: 435.1626.

3.29. Methyl [methyl 3-*O*-benzyl-7,8-*O*-isopropylidene-4-*O*-(4-methoxybenzyl)-D-*glycero*-α-D-*talo*-oct-2-ulopyranosid]onate (37)

A mixture of **36** (64 mg, 0.155 mmol) and dibutyltin oxide (42 mg, 0.171 mmol) in dry toluene (3.5 mL) was heated to reflux using a Dean-Stark apparatus for 3 h. The solution was allowed to cool to ambient temperature followed by consecutive addition of dry DMF (144 μL, 1.862 mmol), 4-methoxybenzyl chloride (105 μL, 0.776 mmol), and tetrabutylammonium iodide (63 mg, 0.171 mmol). After stirring at 60 °C for 16 h the mixture was diluted with EtOAc and washed successively with HCl (1 M), aq $NaHCO_3$, aq $Na_2S_2O_3$ (50 g/L), and brine. The organic phase was dried ($MgSO_4$), filtered, and concentrated. Chromatography of the residue (toluene/EtOAc 5:1) gave **37** (67 mg, 81%) as a colorless oil; $[\alpha]_D^{20}$ +28.0 (c 0.90, $CHCl_3$); R_f 0.51 (toluene/EtOAc 2:1); ^{1}H NMR ($CDCl_3$): δ 7.35–7.24 (m, 5H, Ar), 7.22–7.20 (m, 2H, Ar), 6.91–6.88 (m, 2H, Ar), 4.97 (d, 1H, J 10.7 Hz, C*H*HPh), 4.81 (d, 1H, J 11.3 Hz, C*H*HPh), 4.56–4.51 (m, 1H, H-7), 4.52 (d, 1H, J 11.2 Hz, CH*H*Ph), 4.49 (d, 1H, J 10.7 Hz, CH*H*Ph), 4.19 (dd, 1H, $J_{8a,8b}$ 8.8, $J_{8a,7}$ 6.3 Hz, H-8a), 4.17–4.14 (m, 2H, H-3, H-5), 4.04 (dd, 1H, $J_{8b,7}$ 5.4 Hz, H-8b), 3.82–3.80 (m, 1H, H-4), 3.81 (s, 3H, PhOCH_3), 3.68 (s, 3H, CO_2CH_3), 3.68 (d, 1H, $J_{OH,5}$ 10.1 Hz, O*H*), 3.46 (dd, 1H, $J_{6,7}$ 7.7, $J_{6,5}$ 1.3 Hz, H-6), 3.19 (s, 3 H, OCH_3), 1.43 [s, 3H, C(CH_3)], 1.37 [s, 3H, C(CH_3)]; ^{13}C NMR ($CDCl_3$): δ 167.47 (s, C=O), 159.27, 137.22, 130.03 (s, 3C, Ar), 129.20, 128.36, 128.19, 127.95, 113.86 (d, 9C, Ar), 109.07 [s, $C(CH_3)_2$], 100.79 (s, C-2), 78.20 (d, C-3), 75.99 (t, CH_2Ph), 74.04 (d, C-6), 73.62, 73.60 (d, 2C, C-4, C-7), 69.36 (t, CH_2Ph), 66.87 (t, C-8), 65.84 (d, C-5), 55.26 (q, PhOCH_3), 52.44 (q, CO_2CH_3), 51.07 (q, OCH_3), 26.68, 25.40 [q, 2C, 2 × C(CH_3)]; ESI-TOF HRMS: m/z = 550.2641; calcd for $C_{28}H_{36}O_{10}NH_4^+$: 550.2647.

3.30. 2,3-Di-*O*-benzyl-4,6-*O*-benzylidene-α-D-*gluco*pyranosyl-(1→5)-methyl [methyl 3-*O*-benzyl-7,8-*O*-isopropylidene-4-*O*-(4-methoxybenzyl)-D-*glycero*-α-D-*talo*-oct-2-ulopyranosid]onate (38)

A suspension of predried compounds **37** (34.6 mg, 0.065 mmol) and **10** (52.3 mg, 0.084 mmol) in dry CH_2Cl_2 (1.0 mL) containing 4 Å molecular sieves was stirred at ambient temperature for 1 h. At −30 °C TMSOTf (0.6 μL, 0.004 mmol) in dry CH_2Cl_2 (0.2 mL) was added in two portions within an interval of 1 h. The mixture was kept at −30 °C for 10 min after complete addition. The promoter was destroyed by addition of Et_3N (19 μL, 0.130 mmol) in dry CH_2Cl_2 (0.3 mL). The suspension was allowed to warm up to ambient temperature, filtered over a pad of Celite®, rinsed with CH_2Cl_2, and the filtrate was concentrated. Product **38** (26.0 mg, 42%) was isolated by chromatography (*n*-hexane/EtOAc 3:1) as a colorless oil; $[\alpha]_D^{20}$ +27.8 (c 0.68, $CHCl_3$); R_f 0.45 (*n*-hexane/EtOAc 3:2, HPTLC); ^{1}H NMR ($CDCl_3$): δ 7.41–7.32 (m, 9H, Ar), 7.31–7.20 (m, 10H, Ar), 7.08–7.03 (m, 3H, Ar), 6.91–6.88 (m, 2H, Ar), 5.43 (s, 1H, C*H*Ph), 5.20 (d, 1H, $J_{1',2'}$ 3.8 Hz, H-1′), 5.18 (d, 1H, J 11.9 Hz, C*H*HPh), 4.91 (d, 1H, J 11.6 Hz, C*H*HPh), 4.78 (ddd, 1H, $J_{7,6}$ 9.6, $J_{7,8b}$ 6.1, $J_{7,8a}$ 3.5 Hz, H-7), 4.73 (d, 1H, J 12.0 Hz, C*H*HPh), 4.69 (d, 1H, J 11.8 Hz, CH*H*Ph), 4.62 (d, 1H, J 11.6 Hz, CH*H*Ph), 4.54 (d, 1H, J 11.3 Hz, CH*H*Ph), 4.49 (app. dt, 1H, $J_{5',6'b} = J_{5',4'}$ 9.9, $J_{5',6'a}$ 5.1 Hz, H-5′), 4.48 (d, 1H, J 11.7 Hz, C*H*HPh), 4.20 (d, 1H, J 11.2 Hz, CH*H*Ph), 4.13–4.12 (m, 2H, H-3, H-5), 3.93 (dd, 1H, $J_{8a,8b}$ 8.9 Hz, H-8a), 3.91 (dd, 1H, $J_{6'a,6'b}$ 10.0 Hz, H-6′a), 3.88 (app. t, 1H, $J_{3',2'} = J_{3',4'}$ 9.4 Hz, H-3′), 3.84 (dd, 1H, H-8b), 3.78 (s, 3H, PhOCH_3), 3.78–3.77 (m, 1H, H-4), 3.70 (s, 3H, CO_2CH_3), 3.57 (dd, 1H, H-2′), 3.51 (app. t, 1H, H-6′b), 3.48 (app. t, 1H, H-4′), 3.38 (dd, 1H, $J_{6,5}$ 1.1 Hz, H-6), 3.18 (s, 3H, OCH_3), 1.36 [s, 3H, C(CH_3)], 1.23 [s, 3H, C(CH_3)]; ^{13}C NMR ($CDCl_3$): δ 167.72 (s, C=O), 159.33, 139.12, 138.75, 138.62, 137.97, 129.74 (s, 6C, Ar), 129.11, 128.56, 128.13, 128.11, 128.08, 127.94, 127.83, 127.75, 127.31, 127.29, 127.22, 127.02, 126.16, 114.05 (d, 24C, Ar), 109.19 [s, $C(CH_3)_2$], 101.59 (s, C-2), 101.02 (d, C*H*Ph), 99.98 (d, C-1′), 83.01 (d, C-4′), 78.87 (d, C-2′), 77.55 (d, C-3′), 76.96 (d, C-3), 75.38 (t, CH_2Ph), 75.22 (d, C-4), 74.64 (t, CH_2Ph), 73.83 (d, C-6), 72.79 (d, C-5), 71.96 (d, C-7), 71.75 (t, CH_2Ph), 70.93 (t, CH_2Ph), 69.16 (t, C-6′), 67.16 (t, C-8), 62.61 (d, C-5′), 55.23 (q, PhOCH_3), 52.36 (q, CO_2CH_3), 51.11 (q, OCH_3), 27.37, 25.34 [q, 2C, 2 × C(CH_3)]; ESI-TOF HRMS: m/z = 985.3979; calcd for $C_{55}H_{62}O_{15}Na^+$: 985.3981.

3.31. 2,3-Di-*O*-benzyl-α-D-*gluco*pyranosyl-(1→5)-methyl [methyl 3-*O*-benzyl-4-*O*-(4-methoxybenzyl)-D-*glycero*-α-D-*talo*-oct-2-ulopyranosid]onate (39)

A suspension of **38** (26.4 mg, 0.027 mmol) and *p*-toluenesulfonic acid monohydrate (0.9 mg, 0.005 mmol) in dry MeOH (1.5 mL) was kept at 0 °C for 1 h followed by stirring at ambient temperature for 24 h. Et_3N (10 μL) was added to the mixture, stirring was continued for 10 min, and the solution was concentrated. Chromatography of the residue afforded **39** (16.0 mg, 70%) as a colorless oil; $[\alpha]_D^{20}$ +53.8 (c 0.71, $CHCl_3$); R_f 0.16 (*n*-hexane/EtOAc 1:4); ^{1}H NMR ($CDCl_3$): δ 7.39–7.27 (m, 16H, Ar), 7.25–7.21 (m, 1H, Ar), 6.91–6.89 (m, 2H, Ar), 5.01 (d, 1H, J 12.0 Hz, C*H*HPh), 4.92 (d, 1H, J 11.5 Hz, C*H*HPh), 4.81 (d, 1H, J 11.5 Hz, C*H*HPh), 4.80 (d, 1H, $J_{1',2'}$ 3.4 Hz, H-1′), 4.79 (d, 1H, J 11.0 Hz, CH*H*Ph), 4.61 (d, 1H, J 12.4 Hz, C*H*HPh), 4.59 (d, 1H, J 11.9 Hz, CH*H*Ph), 4.54 (d, 1H, J 11.8 Hz, CH*H*Ph), 4.52 (d, 1H, J 11.9 Hz, CH*H*Ph), 4.20–4.15 (m, 1H, H-7), 4.12 (d, 1H, $J_{OH,7}$ 6.0 Hz, O*H*), 4.02–3.99 (m, 2H, H-3, H-5), 3.83–3.79 (m, 4H, PhOCH_3, H-5′), 3.78–3.72 (m, 3H, H-3′, H-4, H-8a), 3.68 (s, 3H, CO_2CH_3), 3.66–3.62 (m, 1H, H-8b), 3.61 (dd, 1H, $J_{6,7}$ 9.2, $J_{6,5}$ 1.7 Hz, H-6), 3.44 (dd, 1H, $J_{2',3'}$ 9.6 Hz, H-2′), 3.33–3.28 (m, 1H, H-4′), 3.26–3.19 (m, 2H, H-6′a, H-6′b), 3.16 (s, 3H, OCH_3), 1.85 (bt, 1H, $J_{OH,8a} = J_{OH,8b}$ 6.5 Hz, O*H*), 1.80 (bt, 1H, $J_{OH,6'a} = J_{OH,6'b}$ 6.0 Hz, O*H*), 0.88 (d, 1H, $J_{OH,4'}$ 7.5 Hz, O*H*); ^{13}C NMR ($CDCl_3$): δ 167.81 (s, C=O), 159.47, 139.09, 138.59, 137.05, 129.53 (s, 5C, Ar), 129.27, 128.72, 128.71, 128.51, 128.48, 128.32, 127.99, 127.74, 127.35, 126.29, 113.99 (d, 19C, Ar), 101.25 (d, C-1′), 101.10 (s, C-2), 82.07 (d, C-3′), 80.31 (d, C-2′), 76.56, 75.82 (d, 2C, C-3, C-5), 75.26 (t, CH_2Ph), 75.07 (d, C-4), 75.00 (t, CH_2Ph), 74.39 (t, CH_2Ph), 72.55 (d, C-4′), 71.79 (d, C-6), 71.61 (d, C-5′), 70.85 (t, CH_2Ph), 68.05 (d, C-7), 64.12 (t, C-8), 62.45 (t, C-6′), 55.27 (q, PhOCH_3), 52.46 (q, CO_2CH_3), 51.04 (q, OCH_3); ESI-TOF HRMS: m/z = 857.3351; calcd for $C_{45}H_{54}O_{15}Na^+$: 857.3355.

3.32. α-D-*Gluco*pyranosyl-(1→5)-sodium (methyl D-*glycero*-α-D-*talo*-oct-2-ulopyranosid)onate (40)

A suspension of **39** (5.9 mg, 0.007 mmol) in dry MeOH (1 mL) was hydrogenated for 4 h with 10% Pd–C (1 mg) as described for **13.** Fresh catalyst (1 mg) was added and stirring was continued under H_2 for 14 h. The suspension was diluted with MeOH and passed through a 0.45 μm syringe filter. The filtrate was concentrated and the residue was treated with 0.01 M aq. NaOH (2 mL) at ambient temperature for 3 h. The solution was neutralized by addition of DOWEX 50 H^+ resin. The ion-exchange resin was filtered off and the filtrate was lyophilized. Purification of the residue on a PD10 column (H_2O) and freeze-drying of pooled fractions gave **40** (2.9 mg, 92%) as a colorless amorphous solid; $[\alpha]_D^{20}$ +128.1 (c 0.25, H_2O); ^{1}H NMR (D_2O): δ 5.13 (d, 1H, $J_{1',2'}$ 3.9 Hz, H-1′), 4.21–4.19 (m, 1H, H-5), 4.15–4.10 (m, 2H, H-5′, H-7), 4.01 (app. t, 1H, $J_{4,3} = J_{4,5}$ 3.3 Hz, H-4), 3.95 (dd, 1H, $J_{8a,8b}$ 11.8, $J_{8a,7}$ 2.8 Hz, H-8a), 3.85 (dd, 1H, $J_{3,5}$ 0.9 Hz, H-3), 3.81 (dd, 1H, $J_{6'a,6'b}$ 12.5, $J_{6'a,5'}$ 3.6 Hz, H-6′a), 3.75 (dd, 1H, $J_{6'b,5'}$ 2.4 Hz, H-6′b), 3.69 (dd, 1H, $J_{8b,7}$

5.9 Hz, H-8b), 3.64 (dd, 1H, $J_{6,7}$ 9.9, $J_{6,5}$ 1.0 Hz, H-6), 3.59 (dd, 1H, $J_{3',2'}$ 10.1, $J_{3',4'}$ 9.2 Hz, H-3′), 3.52 (dd, 1H, H-2′), 3.44 (dd, 1H, $J_{4',5'}$ 10.2 Hz, H-4′), 3.15 (s, 3H, OCH_3); ^{13}C NMR data: see Table 1; ESI-TOF HRMS: m/z = 453.1210; calcd for $C_{15}H_{26}O_{14}Na^+$: 453.1215.

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