De Novo Synthesis of a Methylene-Bridged Neu5Ac-α-(2,3)-Gal *C*-Disaccharide

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A general strategy toward the synthesis of *C*-ketosides of *N*-acetylneuraminic acid (Neu5Ac) has been developed and successfully applied to the synthesis of methylene-bridged Neu5Ac-α-(2,3)-Gal *C*-disaccharide **2**. The key strategic element of this novel approach is a stereoselective, 6-*exo-trig* selective, electrophilic cyclization of the appropriate open chain precursor **4** by means of phenylselenyl triflate. The open chain precursor was formed by the addition of lithiated iodide **18** accessible from D-galactose to open chain aldehyde **5a** obtained from D-glucono-*δ*-lactone by chain elongation. Subsequent C_1-incorporation using Tebbe-reagent, formation of a cyclic carbonate, and deprotection of the two isopropylidene ketals afforded tetrol **4** which, upon treatment with phenylselenyl triflate, was stereoselectively cyclized in a 6-*exo-trig* selective manner. A *selena*-Pummerer rearrangement, oxidation, and esterification readily led to methyl ester **37** which, after deacetylation, could be regioselectively tetrabenzoylated with benzoyl cyanide. Triflate activation of the axial hydroxyl group in **40** and nucleophilic displacement by azide ion with inversion of configuration afforded azide **41**, which was reduced with hydrogen and Pearlman's catalyst. Concomitant removal of the benzyl ethers and subsequent saponification of all ester moieties successfully completed the de novo synthesis of the desired methylene bridged Neu5Ac-α-(2,3)-Gal *C*-disaccharide **2**.

Introduction

As terminating constituents of many glycoconjugates,[1] e.g., gangliosides such as GM2 (**1**, Figure 1), sialic acids are often found at the nonreducing end of the oligosaccharide moiety, and due to this peripheral position they are involved in a significant number of biological events. In particular, they mediate numerous cellular recognition events[2] in cell migration and adhesion,[3] immune response,[4] tumor metastasis,[5] and the development of neural cells.[6] Furthermore, they influence aggregation and agglutination, cell membrane permeability for amino acids, ions, and proteins, mask antigenic oligosaccharides and protect glycoproteins against proteolysis.[7] Additionally, terminal sialic acids serve as attachment sites for many infectious pathogens including viruses,[8] bacteria, and parasites,[9] and upon recognition of this characteristic ligand on the cellular surface by surface proteins of the pathogen, the infection is initiated.[10]

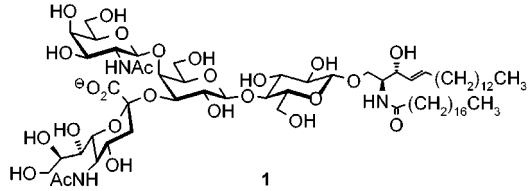

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Figure 1. Ganglioside GM2—a Neu5Ac containing glycosphingolipid.

The most ubiquitous member of this class of structurally unique, natural carbohydrates is *N*-acetylneuraminic

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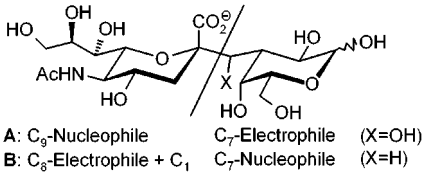

Figure 2. Potential complementary disconnective approaches **A** and **B** leading to the synthesis of Neu5Ac-α-(2,3)-Gal *C*-disaccharides and the corresponding nucleophilic and electrophilic building blocks.

acid (Neu5Ac)—a component essential to many glycoconjugates.[1] Typically, Neu5Ac is attached via an α-*O*-glycosidic linkage to the carbohydrate chain of these glycoconjugates and an important structural motif frequently found in glycoconjugates is the Neu5Ac-α-(2,3)-Gal disaccharide (see also Figure 1).[11]

In vivo, terminal Neu5Ac is removed from the glycoconjugate by neuraminidase, a specific hydrolytic enzyme. Following cleavage, antigenic oligosaccharides are unmasked thereby permitting the catabolism of the entire glycoconjugate. The replacement of the interglycosidic oxygen of such a Neu5Ac-α-(2,3)-Gal disaccharide by a methylene group provides an interesting approach to rationally control many of these important processes in glycobiology since this structural transformation renders the natural disaccharide a nonhydrolyzable *C*-glycoside analogue which is inert to catabolism.

Despite numerous methodologies available for the synthesis of *C*-glycosides of aldoses[12] only a few syntheses of *C*-glycosides of sialic acids have been reported.[13] Only recently, the elegant work of Linhardt and co-workers[14] using samarium iodide provided an approach to the synthesis of more complex *C*-glycosides of various sialic acids including a hydroxymethylene-bridged Neu5Ac-α-(2,3)-Gal *C*-disaccharide (Figure 2, **A**).

Herein, we disclose a different strategy (Figure 2, **B**) leading to methylene bridged *C*-glycosides of *N*-acetylneuraminic acid by applying a versatile approach that is based on the electrophilic cyclization of an open chain precursor using phenylselenyl triflate as cyclization reagent, followed by the generation of the carboxylate moiety and introduction of the nitrogen. For that purpose, readily available and inexpensive precursors were selected as starting materials.

Results and Discussion

In our endeavor toward the synthesis of *C*-glycosides of *N*-acetylneuraminic acid in general and target molecule **2** in particular (Scheme 1) we envisioned an electrophilic cyclization of an open chain precursor to be the key step of the strategy thereby following approach **B** (Figure 2). We assumed that open chain precursor **4** would be ideally suited to reduce the synthesis of target molecule **2** to practice. As delineated in Scheme 1, retrosynthetic processing of **2** by two functional group interchanges readily gives rise to phenyl selenide **3** which reveals the retron for a selenium-induced electrophilic cyclization of open chain precursor **4**. We reasoned that of the four hydroxyl groups present in **4** only the one leading to a six-membered cyclization product would participate in the cyclization step in an *exo-trig* selective manner,[15] therefore rendering a selective protection unnecessary. In addition, we decided to defer the introduction of the nitrogen to a late stage of the synthesis, i.e., after the cyclization step in order to avoid a competitive participation of the nitrogen during the cyclization step; we furthermore anticipated that embedding of the *erythro*-diol unit of **4** into a cyclic carbonate framework would decrease the conformational flexibility of the acyclic scaffold and facilitate the electrophilic cyclization.[16] Open chain precursor **4** was then dissected into two building blocks of equal molecular complexity which generates C_8-electrophile **5a** as the latent sialic acid moiety and lithiated C_7-nucleophile **6** which can be obtained starting from D-galactose. Inspection of C_8-electrophile **5a** reveals a *β*-hydroxy carbonyl unit together with a stereochemical *erythro*-relationship between the contiguous hydroxyl groups at C-3 and C-4. These structural features could be established by an indirect aldol reaction invoking the inherent stereochemical information present in D-glucono-*δ*-lactone as commercially available starting material.

Synthesis of the C_8-Electrophile. The synthesis of the C_8-electrophile (Scheme 2) commences with a chain elongation of known D-glucono-*δ*-lactone derived triacetonide **7**[17] by single addition of freshly prepared allylmagnesium bromide[18] at very low temperatures. After acidic workup, α-hydroxy ketone **8** could be isolated in 89% yield together with unreacted starting material. In this context, neither isomerization of **8** to the thermodynamically more stable α,*β*-unsaturated enone system nor double addition of the *C*-nucleophile to the ketone carbonyl group of **8** was observed. Next, the resulting α-hydroxy ketone **8** was stereoselectively reduced with zinc borohydride[19] in diethyl ether at −10 °C in 91% yield to afford a 9.4:1-mixture of diastereomers **9a**/**b** in favor

(11) Other important motifs yet less frequently occuring are the Neu5Ac-α-(2,6)-Gal disaccharide as expressed, e.g., in *N*-glycans, and the Neu5Ac-α-(2, 8)-Neu5Ac disaccharide as, e.g., in polysialic acid or ganglioside GD2.

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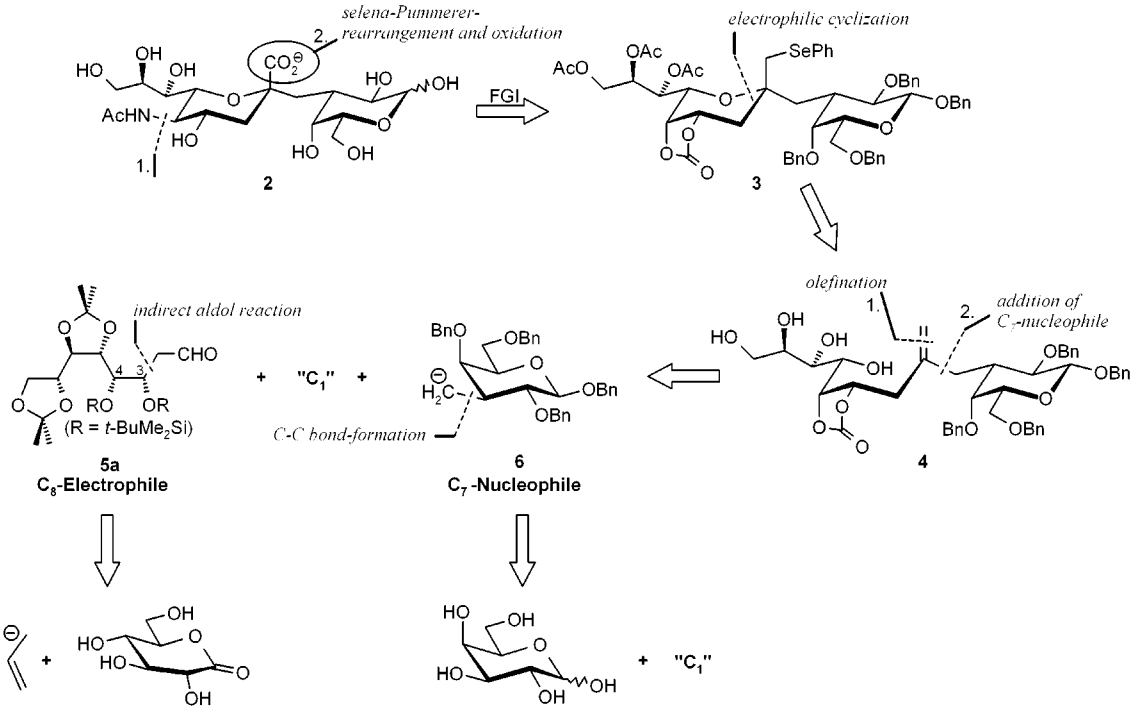
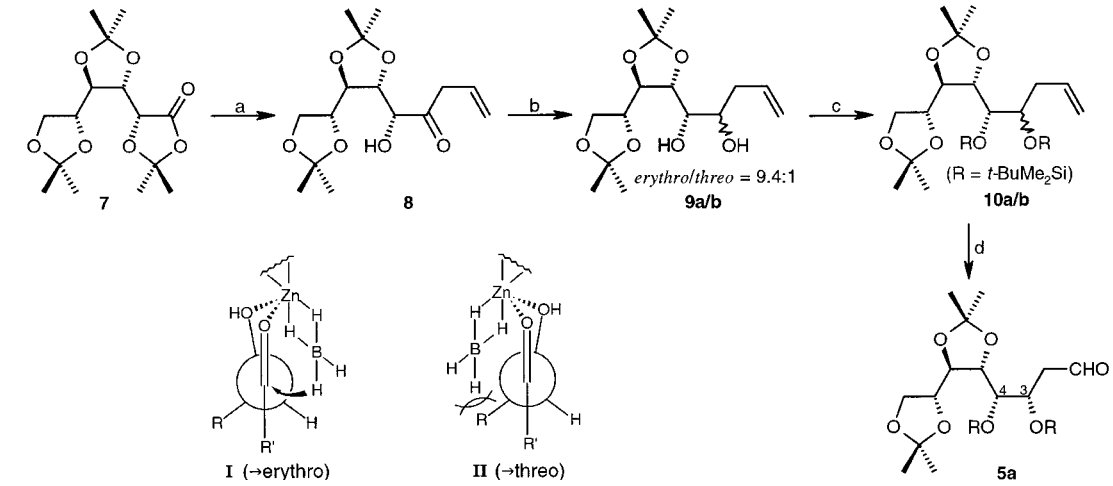
Scheme 1. Retrosynthetic Analysis of Target Molecule 2



Scheme 2. Synthesis of the C_8-Electrophile[a]



[a] Reagents and conditions: (a) allylMgBr, Et_2O, −95 °C, 89%; (b) $Zn(BH_4)_2$, Et_2O, −10 °C, 91%; (c) *t*-$BuMe_2SiOTf$ (2.4 equiv), NEt_3 (3.6 equiv), CH_2Cl_2, 0 °C → rt, 82%; (d) O_3, CH_2Cl_2, −40 °C, then PPh_3, Me_2S, rt, 98%.

of isomer **9a** with the desired C-4/C-5 *erythro*-configuration. The stereocontrolled reduction can be rationalized by transition state **I**[20] (Scheme 2, as opposed to transition state **II**) where, upon formation of an effective five-membered chelate between the metal ion, the carbonyl, and the adjacent hydroxyl group, the hydride delivery preferentially occurs from the sterically less-hindered side. Since the two diastereomeric diols **9a/b** could not be separated by column chromatography at this stage, the mixture of isomers was further subjected to protection of the two hydroxyl groups as *tert*-butyldimethylsilyl (TBDMS) ethers. Initial attempts to achieve double protection using TBDMS chloride as silylating agent failed and resulted in selective monoprotection. However, switching to TBDMS triflate and triethylamine as base afforded the corresponding disilylated compounds **10a**/**b** in 82% yield; oxidative cleavage of the double bond in **10a**/**b** with ozone followed by PPh_3/Me_2S workup provided C_8-electrophile **5a** in almost quantitative yield thereby completing the formally *anti*-selective aldol addition of acetaldehyde to D-glucose.[21,22] Most gratifyingly, the minor C-3/C-4 *threo*-diastereomer **5b** could now be removed very easily by means of column chromatography, thus affording pure C-3/C-4 *erythro*-diastereomer **5a** in multigram quantities and 65% overall yield from **7**.

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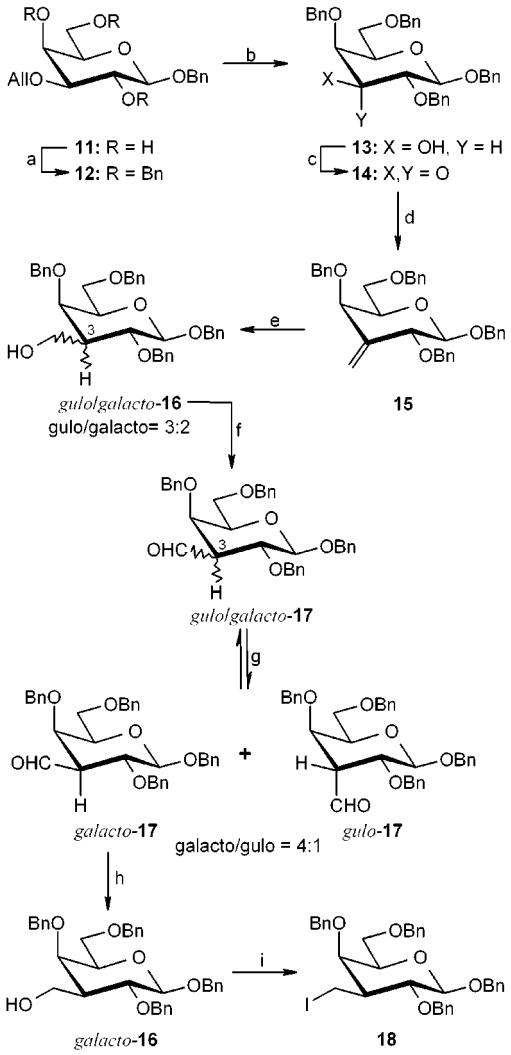
Synthesis of the C_7-Nucleophile. As outlined in the retrosynthetic analysis (Scheme 1), we planned the coupling of C_8-electrophile **5a** with carbanionic C_7-nucleophile **6**, which was conceived to be available from a corresponding carbohydrate-based alkyl iodide via halogen−metal exchange with organolithium compounds. Both the addition of such anionic C_7-nucleophiles to electrophiles and routes to the corresponding C_1-branched monosaccharide precursors have been developed in our laboratories and described earlier.[23] Accordingly, iodide **18** (Scheme 3) was prepared as follows: Readily available benzyl 3-*O*-allyl-*β*-D-galactoside **11**[24] was perbenzylated under standard conditions to give **12** in 95% yield; subsequent deallylation by treatment with $Pd(PPh_3)_4$, acetic acid, and sodium *p*-toluenesulfinate following a protocol described by Nagakura[25] afforded alcohol **13**[24] in 89% yield which was oxidized with Dess−Martin periodinane[26] to ketone **14** (98%) and then methylenated with Tebbe reagent[27] in THF to install the C_1-branching required at the 3-position in 82% yield. Next, a regioselective borane addition to olefin **15** using 9-borabicyclo-[3.3.1]nonane (9-BBN) and oxidative cleavage of the carbon−boron bond with alkaline hydrogen peroxide afforded an inseparable 3:2-mixture of *gulo*- and *galacto*-isomers **16** (determined by NMR spectroscopy) in favor of *gulo*-**16** in 75% combined yield. Using Dess−Martin periodinane, the mixture of isomers *gulo*/*galacto*-**16** was then oxidized almost quantitatively to the corresponding aldehydes *gulo*/*galacto*-**17** which were isomerized by treatment with a 10% solution of triethylamine in dichloromethane at room temperature for 16 h to afford a 4:1 equilibrium in favor of *galacto*-**17**. After separation of the two aldehydes by column chromatography, *galacto*-**17** was quantitatively reduced with excess of sodium borohydride in methanol and the resulting alcohol *galacto*-**16** was converted to iodide **18** (99%) by treatment with iodine, PPh_3, and imidazole[28] thereby generating the precursor for the C_7-nucleophile in 50% overall yield (nine steps) from known **11**.

The configuration at C-3 was deduced from the vicinal coupling constants of the separable aldehydes *gulo*-**17** ($J_{2,3}$ = 6.6 Hz) and *galacto*-**17** ($J_{2,3}$ = 11.3 Hz). In addition,

Scheme 3. Synthesis of Iodide 18—the Precursor of the C_7-Nucleophile[a]



[a] Reagents and conditions: (a) BnBr, NaH, DMF, 0 °C → rt, 95%; (b) $Pd(PPh_3)_4$ (10 mol %), sodium *p*-toluenesulfinate (1.2 equiv), HOAc (2.4 equiv), CH_2Cl_2, rt, 89%; (c) Dess−Martin periodinane, CH_2Cl_2, 98%; (d) Tebbe reagent (1.1 equiv, 1.5 M in toluene), THF, 0 °C, 82%; (e) 9-BBN, THF, Δ; then NaOH, H_2O_2, THF, rt, 75%; (f) Dess−Martin periodinane, CH_2Cl_2, 98%; (g) CH_2Cl_2/NEt_3 = 9:1, 16 h, rt; (h) $NaBH_4$, MeOH, rt, quant.; (i) I_2 (2.5 equiv), PPh_3 (3.0 equiv), imidazole (4.0 equiv), toluene, Δ, 99%.

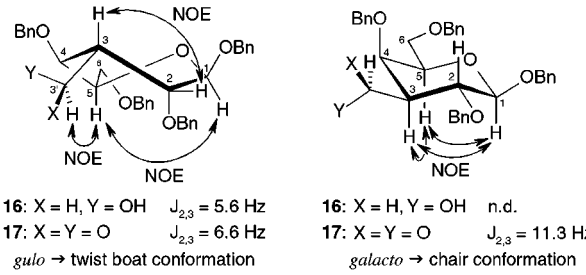


Figure 3. Characteristic NMR data of compounds *gulo*/*galacto*-**16** and **17**.

the corresponding nuclear Overhauser effect (NOE) cross-peaks observed for these compounds are in accordance with this assignment (Figure 3). It should be pointed out that the values for the vicinal $J_{2,3}$ coupling constants of the compounds with *gulo*-configuration suggest a twist boat conformation of the pyranose ring rather than a

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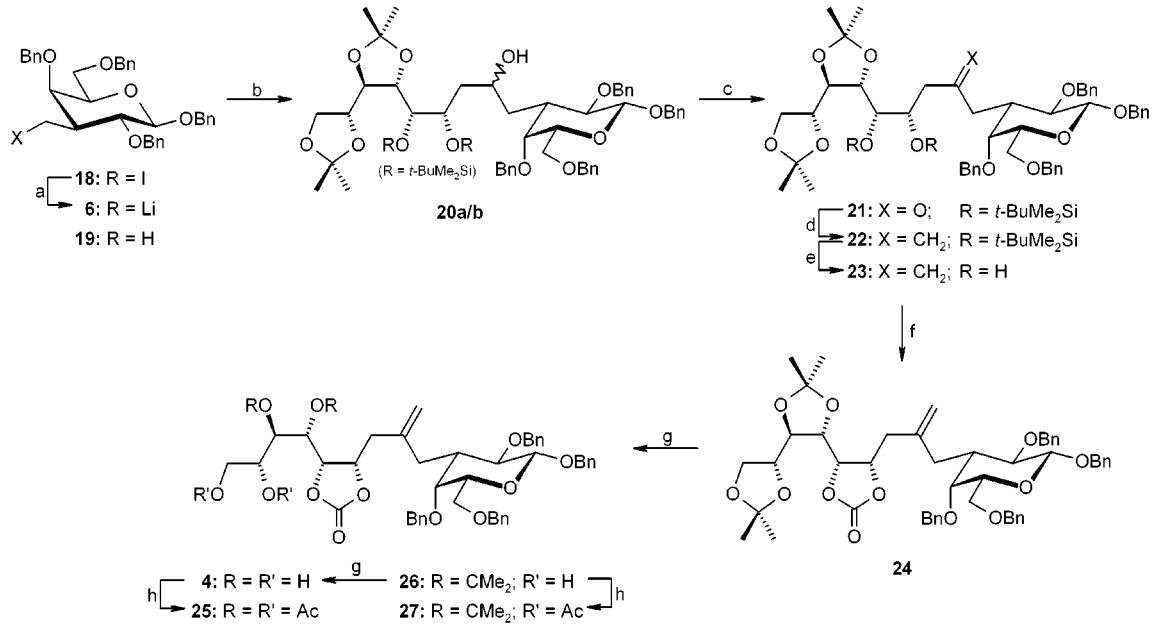
Scheme 4. Coupling, C_1-Incorporation, and Deprotection[a]



[a] Reagents and conditions: (a) *t*-BuLi (1.5 equiv), THF, −100 °C, 2 min; (b) **5**, THF, −100 °C, 5 min, then NH_4Cl, 79%; (c) Dess−Martin periodinane, CH_2Cl_2, 95%; (d) Tebbe reagent (20 equiv, 1.5 M in toluene), toluene/THF (4:1), −40 °C → rt, 62%; (e) TBAF, THF, 40 °C, 94%; (f) diphosgene, CH_2Cl_2/py, 0 °C → rt, 95%; (g) THF/H_2O/TFA = 5:2:2, Δ, 50 min, 69% of **4**, 22% of **26**. (h) Ac_2O/py, quant.

chair conformation, whereas the pyranose ring of the compounds possessing the desired *galacto*-configuration preferentially adopts the expected chair conformation.

Coupling and Cyclization. With both C_8-electrophile **5a** and C_7-nucleophile precursor **18** at hand, the stage was set for the important coupling of these two building blocks to form an open chain "disaccharide". Therefore, after careful preparation of the starting materials,[29] iodide **18** was treated with *t*-BuLi (1.5 equiv) in THF at −100 °C followed by addition of a THF solution of aldehyde **5a** (1.7 equiv) to organolithium intermediate **6** (Scheme 4) affording a 3:2-mixture of diastereomeric alcohols **20a**/**b** in 79% combined yield. Additionally, only very small amounts (<4%) of reduced 3-*C*-methyl branched galactose derivative **19** were isolated. The stereochemistry at the newly created stereogenic center in **20a**/**b** was not assigned since loss of this stereochemical information occurred upon subsequent oxidation of that mixture with Dess−Martin periodinane, which provided ketone **21** in 95% yield. Next, ketone **21** was treated with excess Tebbe reagent in a 4:1 mixture of toluene/THF thereby incorporating the remaining carbon atom required for the completion of the carbon scaffold of the *C*-disaccharide. Thus, olefin **22** could be isolated in 62% yield together with unreacted starting material **21**(29%). After the TBAF induced cleavage (94%) of the silyl ethers in **22**, the reaction of diol **23** with diphosgene resulted in a smooth and almost quantitative formation of cyclic carbonate **24**. To establish reaction conditions for a clean and complete cleavage of both of the isopropylidene ketals in **24**, we explored several acidic cleavage conditions and found that a 5:2:2 mixture of THF, water, and TFA was suited best. Treatment of a THF/H_2O solution of **24** with TFA at room-temperature resulted in almost instantaneous and quantitative cleavage of the primary ketal moiety. Moreover, upon heating to reflux, the secondary, more stable *threo*-ketal could be cleaved in a very clean reaction as well. This protocol led to a mixture of tetrol **4** (69%) together with monodeprotected diol **26** (22%) which was subjected another time to these cleavage conditions in a separate reaction. For full characterization, both tetrol **4** and diol **26** were peracetylated in a mixture of pyridine and acetic anhydride to the corresponding acetates **25** and **27**, respectively (Scheme 4).

Open chain precursor **4** was a pivotal intermediate in our synthesis, and the stereochemical course of its electrophilic cyclization was crucial for the endeavor toward Neu5Ac-*C*-disaccharide **2**. On the basis of the potential and versatility of selenium based reagents[30] as well as our own results,[31] we decided to exploit the capability of cationic selenium species to induce an electrophilic heterocyclization between an olefin and an appropriately located hydroxyl functionality. Addition of tetrol **4** to phenylselenyl triflate at −80 °C in propionitrile resulted in quantitative formation of a 7:1 ratio of products **3** and **28** (Scheme 5). Both **3** and **28** are very sensitive to oxidation and, to avoid elevated temperatures during workup as well as chromatographic purification, the crude mixture was directly subjected to acetylation which provided the more stable products **29** and **30**, respectively, in excellent overall yield.

NMR-studies of **29** and **30** revealed that the cyclization occurred exclusively in a 6-*exo*-*trig* manner due to the presence of a cross-peak between C-2′ and H-6′ in the HMBC spectrum[32] of advanced intermediate **39** (see Scheme 6 for structure), and most importantly, the major

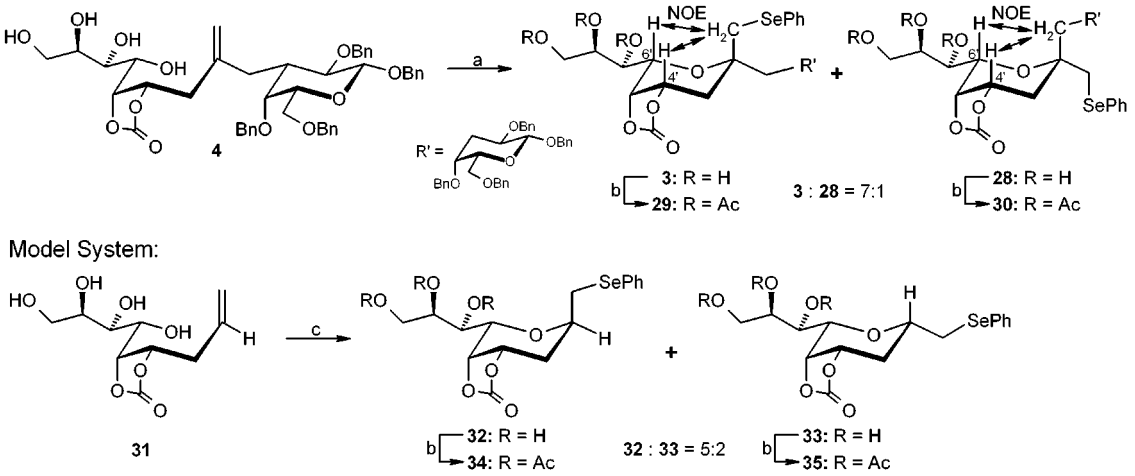
(29) For details, see: Experiemental Section.

(30) (c) Nicolaou, K. C.; Petasis, N. A. *Selenium in Natural Products Synthesis*; CIS: Philadelphia, 1984. (b) Sharpless, K. B.; Gordon, K. M.; Lauer, R. F.; Patrick, D. W.; Singer, S. P.; Young, M. W. *Chemica Scripta* **1975**, *8A*, 9−13. (c) Wirth, T. *Angew. Chem.* **2000**, *112*, 3890−3900; *Angew. Chem., Int. Ed. Engl.* **2000**, *39*, 3740−3749.

(31) Schmidt, R. R.; Vlahov, I. V. *Tetrahedron Asymmetry* **1993**, *4*, 293−296.

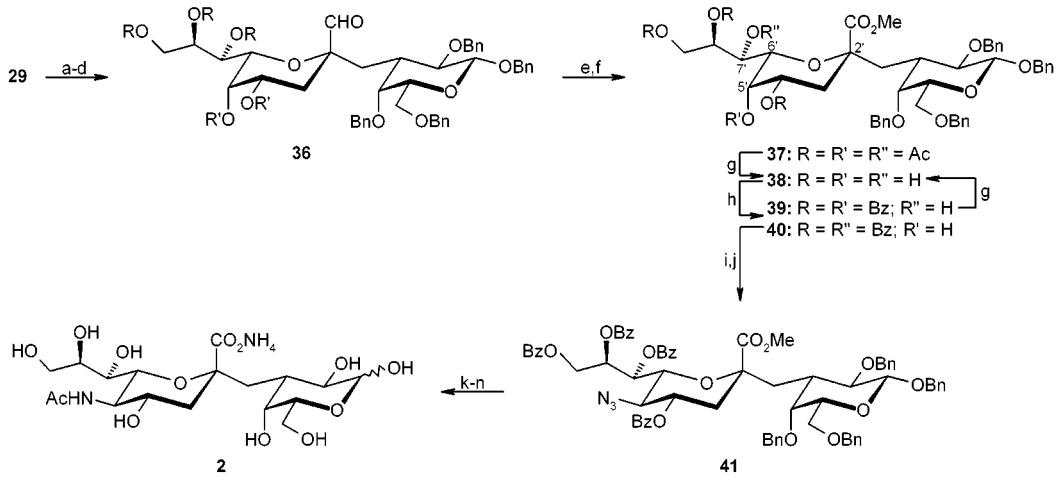
(32) See Supporting Information.

Scheme 5. Electrophilic Cyclization[a]



[a] Reagents and conditions: (a) PhSeCl, AgOTf, EtCN, −80 °C, 98%; (b) Ac_2O/py, quant.; (c) PhSeCl, AgOTf, MeCN, 0 °C, 83%.

Scheme 6. Completion of Neu5Ac-*C*-disaccharide 2[a]



[a] Reagents and conditions: (a) mCPBA (1.0 equiv), THF, −80 °C, 15 min; (b) Ac_2O/NaOAc, THF, −80 °C → rt → Δ, 90 min; (c) NaOMe, THF/MeOH; (d) Ac_2O/py, 90% overall yield; (e) $NaClO_2$, KH_2PO_4, H_2O, $Me_2C{=}CHMe$/MeCN/*t*-BuOH (1:4:4), rt; (f) CH_2N_2, Et_2O, rt, 89% for two steps; (g) NaOMe, MeOH, quant.; (h) BzCN, THF/NEt_3 = 1:1, 0 °C → 5 °C, 64 h, 49% of **40**, 24% of **39**; (i) Tf_2O, CH_2Cl_2/py; (j) *n*-$Bu_4N{-}N_3$, toluene, rt, 94% for two steps; (k) $Pd(OH)_2/H_2$, MeOH/EtOAc, rt, 24 h; (l) Ac_2O/py, NEt_3 (→**42**); (m) THF/H_2O, 0.1 M NaOH; (n) RP-18 silica, Sephadex P-4, 0.3% NH_4HCO_3 buffer.

isomer formed was **3**[33] which bears the phenylselenylmethyl moiety in the axial position at the newly formed quaternary carbon center of the tetrahydropyran ring and consequently possesses the desired α-linkage. The assignment of the stereochemistry of the quaternary carbon center formed was based on the presence of NOE cross-peaks between the protons of the corresponding axial methylene group and H-4′ and H-6′, respectively (see **29** and **30**, Scheme 5).

We assume that the high degree of stereoselectivity during the course of the cyclization is mediated by the cyclic carbonate unit present in **4** which provides (a) decreased conformational flexibility of the acyclic scaffold thereby facilitating the cyclization step and (b) a preferential conformation of the open chain precursor. Thus, the participating hydroxyl group and the quaternary olefinic carbon center are already in spatial proximity prior to the cyclization. This was concluded from our parallel findings in the cyclization of the structurally analogous model system **31**[34] (Scheme 5) which gave a similar stereochemical preference toward an axial phenylselenylmethyl substituent when being cyclized with phenylselenyl triflate in acetonitrile at room temperature. In this case, determination of the coupling constants and NOE data of starting material **31** in CD_3CN under the reaction conditions revealed that **31** adopts a preferential conformation which is similar to the twist boat conformation of its acetylated cyclization product **34** (Figure 4). In particular, the distinct conformation around the C-2/C-3 bond in **31** favors a preferred facial attack of the double bond by the electrophilic selenium reagent as depicted in Figure 4, thus leading to product **32** with the axial phenylselenylmethyl group.

Completion of the Synthesis. Following our strategy, the next task was the installation of the carboxylate functionality. This functional group transformation could be achieved in a straightforward manner by subjecting phenylselenide **29** to a *selena*-Pummerer rearrangement to afford aldehyde **36** in four steps in 90% overall yield. Oxidation of the aldehyde and subsequent esterification

(33) Isolated and characterized as acetylated **29**.

(34) For preparation, see: Supporting Information.

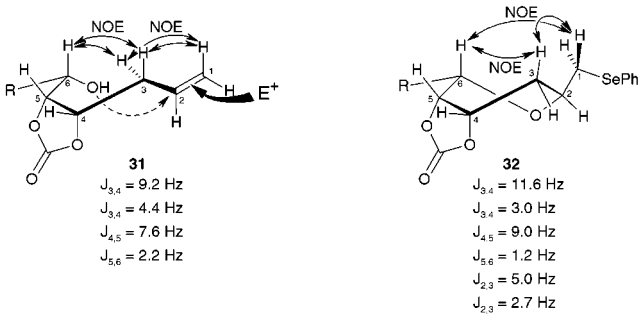


Figure 4. Preferential conformation of open chain model system **31** and comparison of the characteristic NMR data with cyclized **32**.

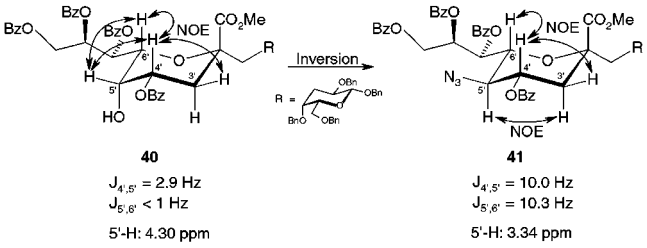


Figure 5. Proof of (a) the inversion of configuration at C-5′ during azide introduction and (b) of the *erythro*-selective Zn-$(BH_4)_2$-reduction of **8** via α-chelation control.

of the carboxylic acid with diazomethane then provided methyl ester **37** in 89% yield (Scheme 6).

To complete the assembly of the *N*-acetylneuraminic acid moiety by the introduction of nitrogen, a different protective group pattern of methyl ester **37** was required to enable a selective nucleophilic displacement of the hydroxyl group at C-5′. We anticipated that the use of benzoyl cyanide could provide a regioselective tetrabenzoylation[35] of the five hydroxyl groups present in deacetylated **38** thereby affording **40** which would be well suited for the introduction of the nitrogen. In fact, treatment of **38** with benzoyl cyanide in THF/NEt_3 via syringe pump addition over 64 h gave a 2:1 mixture of regioisomers **39** and **40** in favor of the desired isomer **40** (Scheme 6) which could be isolated in 49% yield after medium-pressure liquid chromatography. It should be noted that the undesired regioisomer **39** can be easily recycled by deprotection to afford **38** which in turn can be subjected another time to the benzoylation protocol. The regiochemistry of the benzoylation was proven by the presence of cross-peaks between the proton of the unprotected hydroxyl group and the proton at the adjacent carbon center in the DQF−COSY spectrum of **39** and **40**. These results are also in accordance with the chemical shifts observed for H-5′ (**39**: 5.84 ppm and **40**: 4.30 ppm) and H-7′ (**39**: 4.24 ppm and **40**: 5.97 ppm). Next, the axial hydroxyl group of tetrabenzoate **40** was converted into a leaving group by triflate activation and smoothly displaced by treatment with tetra-*n*-butylammonium azide to afford azido compound **41** in 94% yield.[36] The inversion of the configuration at C-5′ in **40** could be unambiguously confirmed by the comparison of the corresponding coupling constants and NOEs observed for **40** and azide **41** (Figure 5). Moreover, the presence of an NOE between H-4′ and H-6′ together with $J_{4',5'} =$ 10.0 Hz for the value of the vicinal coupling constant between H-4′ and H-5′ in **41** also proved the *erythro*-selectivity of the Zn$(BH_4)_2$ reduction of **8** via the α-chelation-controlled transition state **I** (Scheme 2).

To accomplish the synthesis of the Neu5Ac-*C*-disaccharide, the azide functionality in **41** was reduced with hydrogen using Pearlman's catalyst with concomitant reductive cleavage of the benzyl ethers, and the crude reaction product was directly peracetylated in a mixture of acetic anhydride and pyridine. After removal of the catalyst by filtration through silica, saponification of all the ester moieties in **42** under mild conditions, and purification by RP-18 silica and Sephadex P-4 column using 0.3% aqueous ammonium bicarbonate buffer as eluent, the de novo synthesis of the methylene bridged Neu5Ac-α-(2,3)-Gal *C*-disaccharide **2** was complete.

Summary and Conclusion

In summary, we have developed a novel approach toward the synthesis of *C*-glycosides of *N*-acetylneuraminic acid, and its potential was demonstrated by the successful application to the synthesis of the important Neu5Ac-α-(2,3)-Gal *C*-disaccharide **2**. Important features of this strategy are the following: (a) The approach is general and allows for variability within the *C*-glycosidic part as well as the sialic acid moiety (e.g., *C*-glycosides of KDN); (b) The key step of this strategy consists of a 6-*exo*-*trig* selective electrophilic cyclization of open chain precursor **4** by means of phenylselenyl triflate with a high degree of stereoselectivity which can be attributed to a preferential conformation adopted by the acyclic scaffold and mediated by the cyclic carbonate unit present in **4**; (c) The strategy presented is not based on expensive Neu5Ac precursors but uses inexpensive and readily available precursors as starting materials; (d) Due to the masked amino functionality, azide **41** constitutes a valuable building block. This circumstance permits possible further transformations within the molecule with an ideally protected nitrogen and furthermore provides the option to attach, upon reduction, a large variety of substituents other than *N*-acetyl to the nitrogen atom (e.g., fluorescent or photosensitive groups).[37]

The open chain precursor **4** was constructed by the coupling of C_8-electrophile **5a**, obtained from D-gluconoδ-lactone via chain elongation and *erythro*-selective ketone reduction, with C_7-nucleophile **6** having the desired *galacto*-configuration and subsequent C_1-incorporation. In general, this *C*-disaccharide is suitable for incorporation into larger oligosaccharide structures which in turn provides novel terminal *C*-sialylated glycoconjugates.

(35) Such regioselective benzoylations are not without precedent. For an example with unprotected lactose derivatives, see: Lay, L.; Windmüller, R.; Reinhardt, S.; Schmidt, R. R. *Carbohydr. Res.* **1997**, *303*, 39−49.

(36) Successful transformation of 3-deoxy-2-glyculosonates into the corresponding 5-azido-3,5-dideoxy derivatives has been already described: (a) Danishefsky, S. J.; DeNinno, M. P.; Chen, S. *J. Am. Chem. Soc.* **1988**, *110*, 3929−3940. (b) Haag-Zeino, B.; Schmidt, R. R. *Liebigs Ann. Chem.* **1990**, 1197−1203. (c) Yamamoto, T.; Teshima, T.; Inami, K.; Shiba, T. *Tetrahedron Lett.* **1992**, *33*, 325−328.

(37) (a) Gross, H. J.; Rose, U.; Krause, J. M.; Paulson, J. C.; Schmid, K.; Feeney, R. E.; Brossmer, R. *Biochemistry* **1989**, *28*, 7386-7392. (b) Gross, H. J.; Brossmer, R. *Eur. J. Biochem.* **1988**, *177*, 583−589. (c) Gross, H. J.; Sticher, U.; Brossmer, R. *Anal. Biochem.* **1990**, *186*, 127−134. (d) Horst, G. T. J. v. d.; Mancini, G. M. S.; Brossmer, R.; Rose, U.; Verheijen, F. W. *J. Biol. Chem.* **1990**, *265*, 10801−10804. (e) Mirelis, P.; Brossmer, R. *Bioorg. Med. Chem. Lett.* **1995**, *5*, 2809−2814. (f) Dufner, G.; Schwörer, R.; Müller, B.; Schmidt, R. R. *Eur. J. Org. Chem.* **2000**, 1467−1482.

Experimental Section

General Methods and Instrumentation. See Supporting Information.

3,4-Di-*O*-(*tert*-butyldimethylsilyl)-2-deoxy-5,6:7,8-di-*O*-isopropylidene-D-*glycero*-D-*gulo*-*aldehydo*-octose (5a) and 3,4-di-*O*-(*tert*-butyldimethylsilyl)-2-deoxy-5,6:7,8-di-*O*-isopropylidene-D-*glycero*-D-*ido*-*aldehydo*-octose (5b). A solution of **10a**/**b** (5.75 g, 10.83 mmol) in dry dichloromethane (50 mL) was cooled to −40 °C and saturated with ozone until the color of the mixture turned blue. Then argon was passed through the mixture (15 min) followed by addition of dimethyl sulfide (25 mL), and stirring was continued while warming up to room temperature. Then PPh_3 (2.84 g, 10.83 mmol, 1 equiv) was added, and the mixture was stirred until the reaction was complete (monitored by TLC). Removal of the solvent in vacuo and purification of the residue by flash chromatography (SiO_2, petroleum ether/ethyl acetate = 15:1) afforded both **5a** (5.14 g. 9.65 mmol, 89%) and **5b** (519 mg, 0.975 mmol, 9%) as a colorless syrup. **5a** was formed from **10a**. Data for **5a**: $[\alpha]_D = +8.8$ ($c = 0.4$; $CHCl_3$). TLC (SiO_2): $R_f = 0.27$ (SiO_2, petroleum ether/ethyl acetate = 15:1). ^{1}H NMR (250 MHz, $CDCl_3$): $\delta = 0.09, 0.10, 0.11, 0.12$ (4 s, 12 H, 2 × $SiMe_2$); 0.89, 0.92 (2 s, 18 H, 2 × Si^{t}Bu); 1.31, 1.33, 1.38, 1.39 (4 s, 2 × CMe_2); 2.62 (ddd, $J = 2.9$ Hz, $J = 6.7$ Hz, $J_{gem} = 16.8$ Hz, 1 H, 2-H^a); 2.81 (ddd, $J = 1.7$ Hz, $J = 4.0$ Hz, $J_{gem} = 16.8$ Hz, 1 H, 2-H^b); 3.75−3.84 (m, 2 H, 6-H, 8-H^a); 3.91−4.03 (m, 3 H, 4-H, 5-H, 7-H); 4.18 (dd, $J_{7,8Hb} = 5.9$ Hz, $J_{gem} = 8.3$ Hz, 1 H, 8-H^b); 4.41 (ddd, $J = 1.4$ Hz, $J = 4.0$ Hz, $J = 6.6$ Hz, 1 H, 3-H); 9.82 (dd, $J_{1,2Ha} = 1.7$ Hz, $J_{1,2Hb} = 2.9$ Hz, 1 H, 1-H). Anal. Calcd for $C_{26}H_{52}O_6Si_2$ (532.9): C: 58.60, H: 9.84. Found: C: 58.58 H: 9.67. Data for **5b**: $[\alpha]_D = +42.9$ ($c = 2$; $CHCl_3$); TLC: $R_f = 0.39$ (SiO_2, petroleum ether/ethyl acetate = 15:1). ^{1}H NMR (600 MHz, $CDCl_3$): $\delta = 0.06, 0.09, 0.11$ (3 s, 12 H, 2 × $SiMe_2$); 0.87, 0.90 (2 s, 18 H, 2 × Si^{t}Bu); 1.32, 1.36, 1.39 (3 s, 12 H, 2 × CMe_2); 2.78−2.84 (m, 2 H, 2-H^a, 2-H^b); 3.76−3.86 (m, 3 H, 4-H, 6-H, 8-H^a); 3.99 (m, 1 H, 7-H); 4.16−4.29 (m, 3 H, 3-H, 5-H, 8-H^b); 9.82 (m, 1 H, 1-H). Anal. Calcd for $C_{26}H_{52}O_6Si_2$ (532.9): C: 58.60, H: 9.84. Found: C: 58.55, H: 9.56.

Benzyl 2,4,6-Tri-*O*-benzyl-3-deoxy-3-*C*-(hydroxymethyl)-β-D-*galacto*-hexopyranoside (*galacto*-16). (a) From **15**: A solution of **15** (1.59 g, 2.963 mmol) in dry THF (75 mL) was treated with a 9-BBN solution in THF (0.5 M, 37 mL) and heated to reflux for 4 h. After cooling to 0 °C, a 10% aqueous sodium hydroxide solution (30 mL) and a 30% hydrogen peroxide solution (30 mL) were added simultaneously within 5 min and stirring was continued for 30 min. Then diethyl ether was added followed by careful addition of a 20% aqueous sodium hydrogen sulfite solution (2 mL). This mixture was stirred for further 60 min and extracted with diethyl ether, and the combined organic layers were dried ($MgSO_4$), filtered, and concentrated in vacuo. Flash chromatography (SiO_2, petroleum ether/ethyl acetate = 2:1) of the residue afforded a mixture of *gulo*-**16** and *galacto*-**16** (1.23 g, 2.217 mmol, 75%) which cannot be separated. The ratio of *gulo*/*galacto*-**16** was determined by NMR-spectroscopy to be 3:2 in favor of the *gulo*-isomer.

(b) From reduction of *galacto*-**17**: *Galacto*-**17** was dissolved in methanol, and excess sodium borohydride was added. After 5 min, the mixture was concentrated in vacuo, the residue dissolved in diethyl ether and washed with brine. The organic phase was dried ($MgSO_4$), filtered, concentrated in vacuo, and purified by flash chromatography (SiO_2, petroleum ether/ethyl acetate = 2:1) to afford pure *galacto*-**16** quantitatively. $[\alpha]_D = -1.7$ ($c = 2.7$; $CHCl_3$). TLC (SiO_2): $R_f = 0.28$ (petroleum ether/ethyl acetate = 2:1). ^{1}H NMR (600 MHz, $CDCl_3$): $\delta = 1.80$ (m, 1 H, 3-H); 2.03 (m, 1 H, OH); 3.59 (m, 1 H, 3′-H^b); 3.64−3.73 (m, 4 H, 2-H, 4-H, 6-H^a, 6-H^b); 3.79 (dd, $J = 10.9$ Hz, $J = 4,7$ Hz, 1 H, 3′-H^b); 3.89 (d, $J = 2.9$ Hz, 1 H, 4-H); 4.51−4.58 (m, 5 H, 1-H, $PhCH_2$); 4.63−4.66 (2d, $J = 11.5$ Hz, $J = 12.0$ Hz, 2 H, $PhCH_2$); 4.93 (d, $J = 10.9$ Hz, 1 H, $PhCH_2$); 4.97 (d, $J = 12.0$ Hz, 1 H, $PhCH_2$); 7.25−7.36 (m, 20 H, 4 × Ph). Anal. Calcd for $C_{35}H_{38}O_6$ (554.7): C: 75.78, H: 6.91. Found: C: 75.50, H: 7.10.

Benzyl 2,4,6-Tri-*O*-benzyl-3-deoxy-3-*C*-formyl-β-D-*galacto*-hexopyranoside (*galacto*-17). (a) From *galacto*-**16**: To a solution of a mixture of *gulo*/*galacto*-**16** (525 mg, 0.946 mmol) in dry dichloromethane (15 mL), Dess-Martin periodinane[26] (480 mg, 1.132 mmol, 1.2 equiv) was added, and the mixture was stirred for 20 min at room temperature. Then a saturated solution of sodium hydrogen carbonate (15 mL) containing sodium thiosulfate (1.80 g) was added to the mixture with vigorous stirring for 15 min. The mixture was washed with dichloromethane, and the combined organic layers were dried ($MgSO_4$), filtered, and concentrated in vacuo. Flash chromatography (SiO_2, petroleum ether/ethyl acetate = 6:1) afforded pure *gulo*-**17** (331 mg, 0.599 mmol, 63%) and pure *galacto*-**17** (184 mg, 0.333 mmol, 35%). (b) From isomerization of *gulo*-**17**: Pure *gulo*-**17** (1.00 g) was dissolved in dry CH_2Cl_2/NEt_3 (50 mL, 9:1), and the mixture was stirred at room temperature for 16 h. After removal of the solvents in vacuo at room temperature, the residue was thoroughly dried in vacuo, and the two isomers were separated by flash chromatography (SiO_2, petroleum ether/ethyl acetate = 6:1) to give an approximate 4:1 ratio in favor of *galacto*-**17**. $[\alpha]_D = -0.8$ ($c = 2$; $CHCl_3$). TLC (SiO_2): $R_f = 0.40$ (petroleum ether/ethyl acetate = 4:1). ^{1}H NMR (600 MHz, $CDCl_3$): $\delta = 2.46$ (ddd, 2 × J ≈ 2.4 Hz, $J_{2,3} = 11.3$ Hz, 1 H, 3-H); 3.64−3.69 (m, 3 H, 5-H, 6-H^a, 6-H^b); 4.13 (dd, $J_{1,2} = 7.7$ Hz, $J_{2,3} = 11.3$ Hz, 1 H, 2-H); 4.17 (d, $J = 3.1$ Hz, 1 H, 4-H); 4.43−4.55 (m, 5 H, 1-H, $PhCH_2$); 4.67 (d, $J = 11.9$ Hz, 1 H, $PhCH_2$); 4.71 (d, $J = 10.9$ Hz, 1 H, $PhCH_2$); 4.96 (d, $J = 10.9$ Hz, 1 H, $PhCH_2$); 4.99 (d, $J = 11.9$ Hz, 1 H, $PhCH_2$); 7.18−7.38 (m, 20 H 4 × Ph); 9.50 (d, $J = 1.7$ Hz, 1 H, CHO). Anal. Calcd for $C_{35}H_{36}O_6$ (552.7): C: 76.06, H: 6.57. Found: C: 75.76, H: 6.80.

Benzyl 2,4,6-Tri-*O*-benzyl-3-deoxy-3-*C*-(iodomethyl)-β-D-*galacto*-hexopyranoside (18). *Galacto*-**16** (2.72 g, 4.90 mmol) was dissolved in dry toluene (150 mL) and PPh_3 (3.86 g, 14.72 mmol, 3.0 equiv), imidazole (1.33 g, 19.54 mmol, 4.0 equiv), and iodine (3.11 g, 12.25 mmol, 2.5 equiv) were successively added at room temperature, and the resulting mixture was heated to reflux (15 min). After cooling to room temperature and addition of saturated aqueous sodium hydrogen carbonate solution (75 mL), the mixture was vigorouly stirred, and then iodine was added until the organic layer remained iodine-colored. Excess iodine was removed by addition of sodium thiosulfate until the mixture was completely decolorized. The layers were separated, the aqueous layer was extracted with toluene (3×), and the combined organic layers were dried ($MgSO_4$). Filtration, concentration in vacuo, and purification of the residue by flash chromatography (SiO_2, petroleum ether/ethyl acetate = 12:1) afforded iodide **18** (3.22 g, 4.85 mmol, 99%) as a colorless syrup. $[\alpha]_D = +11.2$ ($c = 2$; $CHCl_3$). TLC (SiO_2): $R_f = 0.38$ (petroleum ether/ethyl acetate = 9:1); ^{1}H NMR (600 MHz, $CDCl_3$): $\delta = 1.92$ (dddd, 2 × $J \approx$ 2.9 Hz, 2 × $J \approx 11.2$ Hz, 1 H, 3-H); 3.13 (dd, $J = 9.7$ Hz, $J_{gem} = 11.4$ Hz, 1 H, 3′-H^a); 3.37 (d, $J_{2,3} = 11.2$ Hz, $J_{1,2} = 7.6$ Hz, 1 H, 2-H); 3.61−3.69 (m, 4 H, 3′-H^b, 5-H, 6-H^a, 6-H^b); 4.02 (d, $J = 2.6$ Hz, 1 H, 4-H); 4.44 (d, $J_{1,2} = 7.6$ Hz, 1 H 1-H); 4.50−4.57 (m, 3 H, $PhCH_2$); 4.65 (d, $J = 12.0$ Hz, 1 H, $PhCH_2$); 4.68 (d, $J = 11.4$ Hz, 1 H, $PhCH_2$); 4.75 (d, $J = 11.4$ Hz, 1 H, $PhCH_2$); 4.93 (d, $J = 11.0$ Hz, 1 H, $PhCH_2$); 4.96 (d, $J = 12.0$ Hz, 1 H, $PhCH_2$); 7.24−7.36 (m, 20 H, 4 × Ph). Anal. Calcd for $C_{35}H_{37}IO_5$ (664.6): C: 63.26, H: 5.61. Found: C: 63.26, H: 5.56.

Benzyl 2,4,6-Tri-*O*-benzyl-3-deoxy-3-*C*-[4,5-di-*O*-(*tert*-butyldimethylsilyl)-1,3-dideoxy-6,7:8,9-di-*O*-isopropylidene-D-*erythro*-L-*talo*/L-*galacto*-nonit-1-yl]-β-D-*galacto*-hexopyranoside (20a/b). All starting materials were successively coevaporated several times with dry toluene and then dry dichloromethane and subsequently thoroughly dried in vacuo ($P \leq 0.5$ mbar) for several days. All operations were carried out under an inert atmosphere of nitrogen. At −100 °C a 1.5 M solution of ^{t}BuLi in pentane (8.2 mL, 12.3 mmol, 1.5 equiv) was quickly added to a solution of iodide **18** (5.48 g, 8.25 mmol) in dry THF (210 mL) via syringe. After stirring for 2 min, a solution of aldehyde **5a** (7.47 g, 14.02 mmol, 1.7 equiv) in dry THF (30 mL) was quickly added via syringe and after stirring for further 5 min, the reaction was quenched by

pouring the cold mixture into a saturated aqueous ammonium chloride solution. The layers were separated, and the aqueous layer was extracted several times with diethyl ether. The combined organic layers were dried ($MgSO_4$), filtered, concentrated in vacuo, and purified by flash chromatography (SiO_2, petroleum ether/ethyl acetate = 7:1 → 3:1) to afford both **20a** (2.82 g, 2.67 mmol, 32%) and **20b** (4.14 g, 3.86 mmol, 47%) as a colorless syrup. Additionally, small amounts of **19** (437 mg, 0.81 mmol, 10%) could be isolated together with recovered aldehyde **5a** (3.84 g, 7.21 mmol). Data for **20a**: $[\alpha]_D = -4.6$ ($c = 1$; $CHCl_3$). TLC (SiO_2): $R_f = 0.58$ (petroleum ether/ethyl acetate = 4:1) ^{1}H NMR (600 MHz, $CDCl_3$): $\delta = 0.06, 0.08, 0.11, 0.18$ (4s, 12 H, 2 × $SiMe_2$); 0.90, 0.92 (2s, 18 H, 2 × Si^{t}Bu); 1.28, 1.30, 1.36, 1.38 (4s, 12 H, 2 × CMe_2); 1.74 (m, 4 H, 3-H, 1′-H^a, 1′-H^b, 3′-H^a); 1.82 (ddd, $J_{gem} = 15.2$ Hz, $J = 4.7$ Hz, $J = 1.7$ Hz, 1 H 3′-H^b); 3.39 (dd, $J_{2,3} = 10.0$ Hz, $J_{1,2} = 7.3$ Hz, 1 H, 2-H); 3.60−3.70 (m, 4 H, 5-H, 6-H^a, 6-H^b, OH); 3.75−3.80 (m, 2 H, 7′-H, 9′-H^a); 3.87 (m, 1 H, 5′-H); 3.93−3.99 (m, 4 H, 4-H, 2′-H, 6′-H, 8′-H); 4.01 (ddd, 2 × $J \approx 5.6$ Hz, $J < 1$ Hz, 1 H, 4′-H); 4.15 (dd, $J_{gem} = 8.5$ Hz, $J_{8',9'Ha} = 6.2$ Hz, 1 H, 9′-H^b); 4.47 (m, 4 H, 1-H, $PhCH_2$); 4.60 (d, $J = 11.4$ Hz, 1 H, $PhCH_2$); 4.64 (d, $J = 12.0$ Hz, 1 H, $PhCH_2$); 4.75 (d, $J = 11.4$ Hz, 1 H, $PhCH_2$); 4.96 (d, $J = 10.9$ Hz, 1 H, $PhCH_2$); 4.97 (d, $J = 12.0$ Hz, 1 H, $PhCH_2$); 7.23−7.35 (m, 20 H, 4 × Ph). Anal. Calcd for $C_{61}H_{90}O_{12}Si_2$ (1071.6): C: 68.37, H: 8.47. Found: C: 68.71, H: 8.17. Data for **20b**: $[\alpha]_D = +1.2$ ($c = 2$; $CHCl_3$). TLC (SiO_2): $R_f = 0.24$ (petroleum ether/ethyl acetate = 4:1). ^{1}H NMR (600 MHz, $CDCl_3$): $\delta = 0.08, 0.10$ (m, 12 H, 2 × $SiMe_2$); 0.87, 0.90 (2s, 18 H, 2 × Si^{t}Bu); 1.30, 1.32, 1.38, 1.39 (4s, 12 H, 2 × CMe_2); 1.52−1.60 (m, 2 H, 1′-H^a, 3′-H^a); 1.64−1.73 (m, 2 H, 1′-H^b, 3′-H^b); 2.00 (dddd, 2 × $J \approx 10.5$ Hz, 2 × $J \approx 3.0$ Hz, 1 H, 3-H); 2.07 (bs, 1 H, OH); 3.40 (dd, $J_{2,3} = 11.1$ Hz, $J_{1,2} = 7.6$ Hz, 1 H, 2-H); 3.66 (m, 1 H, 6-H^a); 3.75 (m, 2 H, 5-H, 6-H^b); 3.79 (m, 2 H, 4-H, 9′-H^a); 3.84−3.88 (m, 3 H, 2′-H, 5′-H, 7′-H); 3.92 (dd, $J = 3.1$ Hz, $J = 6.9$ Hz, 1 H, 6′-H); 4.00 (dd, $J = 8.1$ Hz, $J = 5.8$ Hz, 1 H, 8′-H); 4.10 (d, $J = 6.1$ Hz, 1 H, 10 H); 4.14 (dd, $J = 6.1$ Hz, $J = 8.5$ Hz, 1 H, 9′-H^b); 4.49−4.52 (m, 3 H, 1-H, $PhCH_2$); 4.55−4.58 (m, 3 H, $PhCH_2$); 4.65 (d, $J = 12.1$ Hz, 1 H, $PhCH_2$); 4.95 (d, $J = 11.2$ Hz, 1 H, $PhCH_2$); 4.96 (d, $J = 12.1$ Hz, 1 H, $PhCH_2$); 7.23−7.35 (m, 20 H, 4 × Ph). Anal. Calcd for $C_{61}H_{90}O_{12}Si_2$ (1071.6): C: 68.37, H: 8.47. Found: C: 68.16, H: 8.42.

Benzyl 2,4,6-Tri-*O*-benzyl-3-deoxy-3-*C*-[4,5-di-*O*-(*tert*-butyldimethylsilyl)-1,2,3-trideoxy-6,7:8,9-di-*O*-isopropylidene-2-methylene-D-*glycero*-D-*gulo*-non-2-ulos-1-yl]-*β*-D-*galacto*-hexopyranoside (22). Ketone **21** (8.63 g, 8.069 mmol) was dissolved in dry toluene/THF (750 mL, 4:1) and cooled to −40 °C. Then Tebbe reagent[27] (160 mL, 1 M in toluene) was added, and the mixture was stirred while warming up to room temperature. After 48 h, the reaction was cooled to 0 °C, diethyl ether was added followed by careful addition of a 10% aqueous sodium hydroxide solution (30 mL). The mixture was vigorously stirred (60 min) and filtered through Celite. Concentration in vacuo and purification of the residue by flash chromatography (SiO_2, petroleum ether/ethyl acetate = 7:1) afforded **22** (5.34 g, 5.00 mmol, 62%) as colorless syrup together with recovered, unreacted ketone **21** (2.50 g, 2.34 mmol, 29%). $[\alpha]_D = +1.2$ ($c = 5$; $CHCl_3$). TLC (SiO_2): $R_f = 0.39$ (petroleum ether/ethyl acetate = 7:1). ^{1}H NMR (600 MHz, $CDCl_3$): $\delta = -0.08, -0.01, 0.07, 0.13$ (m, 12 H, 2 × $SiMe_2$); 0.84, 0.90 (2s, 18 H, 2 × Si^{t}Bu); 1.24, 1.29, 1.33, 1.38 (4s, 12 H, 2 × CMe_2); 1.95 (dddd, 2 × $J \approx 10.6$ Hz, 2 × $J \approx 3.2$ Hz, 1 H, 3-H); 2.11−2.16 (m, 2 H, 1′-H^a, 3′-H^a); 2.45 (dd, $J_{gem} = 14.4$ Hz, $J_{3'Hb,4'} = 1.45$ Hz, 1 H, 3′-H^b); 2.60 (dd, $J_{gem} = 15.8$ Hz, $J_{3,1'Hb} = 2.5$ Hz, 1 H, 1′-H^b); 3.42 (dd, $J_{2,3} = 10.2$ H, $J_{1,2} = 7.6$ Hz, 1 H, 2-H); 3.61 (m, 2 H, 6-H^a, 6-H^b); 3.67 (m, 1 H, 5-H); 3.74−3.77 (m, 2 H, 4-H, 9′-H^a); 3.84−3.89 (m, 3 H, 4′-H, 5′-H, 7′-H); 3.95 (dd, $J = 8.2$ Hz, $J = 6.2$ Hz, 1 H, 6′-H); 3.99 (m, 1 H, 8′-H); 4.14 (dd, $J_{gem} = 8.2$ Hz, $J_{8',9'Hb} = 6.2$ Hz, 1 H, 9′-H^b); 4.48−4.59 (m, 6 H, 1-H, $PhCH_2$); 4.64 (d, $J = 12.0$ Hz, 1 H, $PhCH_2$); 4.77 (s, 1 H, =CH_2); 4.92 (s, 1 H, =CH_2); 4.95−4.97 (m, 2 H, $PhCH_2$); 7.24−7.34 (m, 20 H, 4 × Ph). Anal. Calcd for $C_{62}H_{90}O_{11}Si_2$ (1067.6): C: 69.76, H: 8.50. Found: C: 69.97, H: 8.28.

Benzyl 2,4,6-Tri-*O*-benzyl-3-deoxy-3-*C*-[4,5-*O*-carbonylidene-1,2,3-trideoxy-2-methylene-D-*glycero*-D-*gulo*-non-2-ulos-1-yl]-*β*-D-*galacto*-hexopyranoside (4). (a) From **24**: Cyclic carbonate **24** (1.08 g, 1.25 mmol) was dissolved in THF/H_2O (28 mL, 5:2), and trifluoroacetic acid (8 mL) was added. The mixture was placed in a hot oil bath (100 °C), stirred at this temperature for 50 min, and then poured into ethyl acetate containing ice with stirring. After 15 min, the layers were separated and the aqueous layer was extracted with ethyl acetate (3×). The combined organic layers were dried ($MgSO_4$), filtered, concentrated in vacuo, and coevaporated with toluene until complete removal of trifluoroacetic acid. Flash chromatography (SiO_2, toluene/acetone = 3:1) of the residue afforded both **4** (675 mg, 0.860 mmol, 69%) and **26** (227 mg, 0.275 mmol, 22%) as a colorless syrup.

(b) From **26**: A solution of monoprotected **26** (227 mg, 0.275 mmol) in THF/H_2O was treated with TFA as described under (a) to afford **4** (153 mg, 0.195 mmol, 71%). $[\alpha]_D = +4.8$ ($c = 1$; $CHCl_3$). TLC (SiO_2): $R_f = 0.28$ (toluene/acetone = 1:1). ^{1}H NMR (600 MHz, CD_3CN): $\delta = 1.91$ (dddd, 2 × $J \approx 10.5$ Hz, 2 × $J \approx 3.2$ Hz, 1 H, 3-H); 2.19 (dd, $J_{3,1'Ha} = 10.6$ Hz, $J_{gem} = 15.6$ Hz, 1 H, 1′-H^a); 2.44 (dd, $J_{gem} = 15.6$ Hz, $J_{3,1'Hb} < 1$ Hz, 1 H, 1′-H^b); 2.50 (dd, $J_{3'Ha,4'} = 5.0$ Hz, $J_{gem} = 16.1$ Hz, 1 H, 3′-H^a); 2.63 (dd, $J_{3'Hb,4'} = 9.1$ Hz, $J_{gem} = 16.1$ Hz, 1 H, 3′-H^b); 3.22 (dd $J_{2,3} = 10.9$ Hz, $J_{1,2} = 7.6$ Hz, 1 H, 2-H); 3.54−3.55 (m, 3 H, 7′-H, 8′-H, 9′-H^a); 3.60 (dd, $J_{5,6Ha} = 6.5$ Hz, $J_{gem} = 9.7$ Hz, 1 H, 6-H^a); 3.63−3.67 (m, 3 H, 4-H, 6-H^b, 9′-H^a); 3.75 (dd, 2 × $J = 6.5$ Hz, 1 H, 5-H); 3.90 (d, $J = 3.2$ Hz, 1 H, 6′-H); 4.49−4.56 (m, 6 H, $PhCH_2$); 4.64 (d, $J = 11.9$ Hz, 1 H, $PhCH_2$); 4.82−4.90 (m, 6 H, =CH_2, 4′-H, 5′-H, $PhCH_2$); 7.25−7.37 (m, 20 H, 4 × Ph). FAB-MS (positive mode, NBA): $m/z = 807$ $[M + Na]^+$; Calcd: 784.3 for $C_{45}H_{52}O_{12}$.

Benzyl 2,4,6-Tri-*O*-benzyl-3-deoxy-3-*C*-[8,9-di-*O*-acetyl-4,5-*O*-carbonylidene-1,2,3-trideoxy-6,7-*O*-isopropylidene-2-methylene-D-*glycero*-D-*gulo*-non-2-ulos-1-yl]-*β*-D-*galacto*-hexopyranoside (27). For characterization, **26** was peracetylated by treatment with a mixture of pyridine and acetic anhydride to give **27** after coevaporation with toluene and purification by flash chromatography (petroleum ether/ethyl acetate = 2:1). $[\alpha]_D = +18.7$ ($c = 2$; $CHCl_3$); TLC (SiO_2): $R_f = 0.31$ (petroleum ether/ethyl acetate = 2:1). ^{1}H NMR (600 MHz, $CDCl_3$): $\delta = 1.36, 1.53$ (2s, 6 H, CMe_2); 1.8 (dddd, 2 × $J \approx 2.9$ Hz, 2 × $J \approx 10.6$ Hz, 1 H 3-H); 2.00, 2.05 (2s, 6 H, 2 × OAc); 2.18 (dd, $J_{3,1'Ha} = 10.2$ Hz, $J_{gem} = 15.0$ Hz, 1 H, 1′-H^a); 2.34 (dd, $J_{3,1'Hb} < 1$ Hz, $J_{gem} = 15.0$ Hz, 1 H, 1′-H^b); 2.47 (dd, $J_{gem} = 16.1$ Hz, $J_{3'Ha,4'} = 7.7$ Hz, 1 H, 3′-H^a); 2.65 (dd, $J_{gem} = 16.1$ Hz, $J_{3'Hb,4'} = 6.9$ Hz, 1 H, 3′-H^b); 3.41 (dd, $J_{2,3} = 11.0$ Hz, $J_{1,2} = 7.5$ Hz, 1 H, 2-H); 3.64−3.71 (m, 4 H, 4-H, 5-H, 6-H^a, 6-H^b); 3.94 (d, $J = 8.1$ Hz, 1 H, 6′-H); 4.10 (dd, $J_{8',9'Ha} = 5.5$ Hz, $J_{gem} = 12.4$ Hz, 1 H, 9′-H^a); 4.21 (dd, 2 × $J \approx 7.7$ Hz, 1 H, 7′-H); 4.36 (d, $J = 7.5$ Hz, 1 H, 5′-H); 4.46−4.55 (m, 6 H, 1-H, 9′-H^b, $PhCH_2$); 4.64 (d, $J = 11.4$ Hz, 1 H, $PhCH_2$); 4.66 (d, $J = 12.0$ Hz, 1 H, $PhCH_2$); 4.75 (s, 2 H, =CH_2); 4.97 (d, $J = 12.0$ Hz, 1 H, $PhCH_2$); 4.98 (d, $J = 11.4$ Hz, 1 H, $PhCH_2$); 5.02 (m, 1 H, 8′-H); 7.23−7.36 (m, 20 H, 4 × Ph). Anal. Calcd for $C_{52}H_{60}O_{14}$ (909.0): C: 68.71, H: 6.65. Found: C: 68.46, H: 6.56.

Benzyl 2,4,6-Tri-*O*-benzyl-3-deoxy-3-*C*-[(7,8,9-tri-*O*-acetyl-2,6-anhydro-4,5-*O*-carbonylidene-1,3-dideoxy-1-phenylselenyl-D-*erythro*-L-*talo*-nonit-2-yl)-methyl]-*β*-D-*galacto*-hexopyranoside (29) and Benzyl 2,4,6-Tri-*O*-benzyl-3-deoxy-3-*C*-[(7,8,9-tri-*O*-acetyl-2,6-anhydro-4,5-*O*-carbonylidene-1,3-dideoxy-1-phenylselenyl-D-*erythro*-L-*galacto*-nonit-2-yl)-methyl]-*β*-D-*galacto*-hexopyranoside (30). Compound **4** was coevaporated several times with dry toluene prior to use and dried in vacuo. All operations were carried out under an inert atmosphere of nitrogen. To a solution of phenylselenyl chloride (99 mg, 0.517 mmol, 1.5 eq) in dry propionitrile (12 mL) was added silver trifluoromethanesulfonate (141 mg, 0.549 mmol, 1.6 equiv) at room temperature. A white solid precipitated, and the yellow mixture was quickly cooled to −80 °C and stirred for 60 min. Then a solution of **4** (270 mg, 0.344 mmol) in dry propionitrile (4 mL) was added within 2 min via syringe, and the mixture was stirred for another 60 min. The reaction was worked up by pouring the cold reaction mixture on a cold (0 °C) mixture of

dichloromethane and brine with vigorous stirring (5 min). The layers were separated, the aqueous layer was extracted with dichloromethane (3×), and the combined organic layers were dried ($MgSO_4$) and filtered. To this solution containing **3** and **28** were added pyridine and acetic anhydride, and the resulting mixture was stirred at room temperature until acetylation was complete (monitored by TLC). Removal of the solvents in vacuo at 25 °C by coevaporation with toluene and rapid flash chromatographic purification of the residue afforded **29** (317 mg. 0.297 mmol, 86%) as a colorless syrup and **30** (45 mg, 0.042 mmol, 12%) containing a very small amount of **25** as impurity. Data for **29**: $[\alpha]_D = +4.1$ ($c = 2$; $CHCl_3$). TLC (SiO_2): $R_f = 0.37$ (toluene/ethyl acetate = 2:1). ^{1}H NMR (600 MHz, $CDCl_3$): 1.63 (d, $J_{gem} = 14.7$ Hz, 1 H, 3″-H^a); 1.85 (dd, $J_{3'Ha,4'} = 6.0$ Hz, $J_{gem} = 15.7$ Hz, 1 H, 3′-H^a); 1.94 (ddd, $J_{2,3} = 11.2$ Hz, $J_{3,4} = 2.7$ Hz, $J_{3,3''Hb} = 8.5$ Hz, 1 H, 3-H); 2.00, 2.01, 2.02 (3s, 9 H, 3 × OAc); 2.18 (dd, $J_{3'Hb,4'} = 6.2$ Hz, $J_{gem} = 15.7$ Hz, 1 H, 3′-H^b); 2.27 (dd, $J_{3,3''Hb} = 8.5$ Hz, $J_{gem} = 14.7$ Hz, 1 H, 3″-H^b); 2.81 (d, $J_{gem} = 12.1$ Hz, 1 H, $PhSeCH_2$); 3.09 (d, $J_{gem} = 12.1$ Hz, 1 H, $PhSeCH_2$); 3.28 (dd, $J_{2,3} = 11.2$, $J_{1,2} = 7.5$ Hz, 1 H, 2-H); 3.69 (dd, $J_{gem} = 9.5$ Hz, $J_{5,6Ha} = 6.3$ Hz, 1 H, 6-H^a); 3.76 (dd, $J_{gem} = 9.5$ Hz, $J_{5,6Hb} = 6.5$ Hz, 1 H, 6-H^b); 3.80−3.82 (m, 2 H, 4-H, 5-H); 3.92 (dd, $J_{5',6'} = 2.5$ Hz, $J_{6',7'} = 3.6$ Hz, 1 H, 6′-H); 4.02 (dd, $J_{8',9'Ha} = 5.7$ Hz, $J_{gem} = 12.6$ Hz, 1 H, 9′-H^a); 4.39 (dd, $J_{8',9'Hb} = 2.6$ Hz, $J_{gem} = 12.6$ Hz, 1 H, 9′-H^b); 4.43 (d, $J = 11.4$ Hz, 1 H, $PhCH_2$); 4.53−4.66 (m, 6 H, 1-H, 5′-H, $PhCH_2$); 4.78 (d, $J = 11.6$ Hz, 1 H, $PhCH_2$); 4.83 (dd, $J_{4',5'} = 5.3$ Hz, $J_{3'Hb,4'} = 6.3$ Hz, 1H, 4′-H); 4.95 (d, $J = 10.7$ Hz, 1 H, $PhCH_2$); 4.97 (d, $J = 11.3$ Hz, 1 H, $PhCH_2$); 5.28 (ddd, $J_{8',9'Hb} = 2.5$ Hz, $J_{8',9'Ha} = 5.7$ Hz, $J_{7',8'} = 6.2$ Hz, 1 H, 8′-H); 5.52 (dd, $J_{6',7'} = 3.7$ Hz, $J_{7',8'} = 6.7$ Hz, 1 H, 7′-H); 7.21−7.36 (m, 25 H, 5 × Ph). Anal. Calcd for $C_{57}H_{62}O_{15}Se$ (1066.1): C: 64.22, H: 5.86. Found: C: 64.05, H: 6.23. Data for **30**: TLC (SiO_2): $R_f = 0.55$ (toluene/ethyl acetate = 2:1). ^{1}H NMR (600 MHz, $CDCl_3$): 1.25 (m, 1 H, 3-H); 1.62 (d, $J_{gem} = 14.2$ Hz, 1 H, 3″-H^a); 1.82 (dd, $J_{3'Ha,4'} = 4.0$ Hz, $J_{gem} = 16.2$ Hz, 1 H, 3′-H^a); 1.97, 2.00, 2.01 (3s, 9 H, 3 × OAc); 2.09 (dd, $J_{3'Hb,4'} = 3.7$ Hz, $J_{gem} = 16.2$ Hz, 1 H, 3′-H^b); 2.14 (dd, $J_{gem} = 14.2$ Hz, $J_{3,3''Hb} = 4.0$ Hz, 1 H, 3″-H^b); 2.90 (d, $J_{gem} = 12.8$ Hz, 1 H, $PhSeCH_2$); 3.16 (m, 1 H, 6′-H); 3.34 (d, $J_{gem} = 12.8$ Hz, 1 H, $PhSeCH_2$); 3.45 (dd, $J_{2,3} = 11.0$ Hz, $J_{1,2} = 7.4$ Hz, 1 H, 2-H); 3.60−3.66 (m, 3 H, 5-H, 6-H^a, 6-H^b); 3.70 (d, $J = 2.8$ Hz, 1 H, 4-H); 3.97 (dd, $J = 1.6$ Hz, $J = 8.4$ Hz, 1 H, 5′-H); 4.05 (dd, $J_{gem} = 12.7$ Hz, $J_{8',9'Ha} = 6.0$ Hz, 1 H, 9′-H^a); 4.37−4.43 (m, 4 H, 1-H, 4′-H, 9′-H^b, $PhCH_2$); 4.52 (m, 2 H, $PhCH_2$); 4.61, 4.66 (2s, 2 H, $PhCH_2$); 5.06 (ddd, 2 × $J \approx 6.3$ Hz, $J_{7',8'} = 2.3$ Hz, 1 H, 8′-H); 5.09 (d, $J = 10.9$ Hz, 1 H, $PhCH_2$); 5.28 (dd, $J = 3.4$ Hz, $J = 6.4$ Hz, 1 H, 7′-H); 7.16−7.49 (m, 25 H, 5 × Ph). Anal. Calcd for $C_{57}H_{62}O_{15}Se$ (1066.1): C: 64.22, H: 5.86. Found: C: 64.05, H: 6.23.

Benzyl 2,4,6-Tri-*O*-benzyl-3-deoxy-3-*C*-[{methyl-(2,6-anhydro-4,7,8,9-tetra-*O*-benzoyl-3-deoxy-D-*erythro*-L-*talo*-non-2-yl)onate}-methyl]-β-D-*galacto*-hexopyranoside (40). The reaction progress of the benzoylation of **38** was carefully monitored by TLC. Deprotected methyl ester **38** (121 mg, 0.151 mmol) was dissolved in dry THF/NEt_3 (8 mL, 1:1) and cooled to 0 °C. Then, 0.5 mL of a freshly prepared solution of benzoyl cyanide (80 mg, 0.610 mmol, 4.0 equiv) in THF (2 mL) was added every 120 min while stirring at 0 °C. After complete addition, the reaction mixture was stirred at 0 °C for further 18 h and then warmed to 5 °C. Further benzoyl cyanide was added (21 mg), and stirring was continued for 24 h at 5 °C. At this point of the reaction monitoring by TLC revealed the formation of three products, two of which corresponded to **40** ($R_f = 0.38$, toluene/ethyl acetate = 9:1) and **39** ($R_f = 0.33$, toluene/ethyl acetate = 9:1), together with a less mobile product ($R_f = 0.53$, toluene/ethyl acetate = 3:1). Then, additional benzoyl cyanide (25 mg) was added, the mixture was stirred for 7 h, benzoyl cyanide (40 mg) was added once again, and stirring was continued for another 12 h. Monitoring by TLC now indicated both complete disappearance of the less mobile spot and **39** and **40** to be the products exclusively formed. For workup, methanol was added, the mixture was allowed to warm to room temperature and stirred for 2 h. Removal of the solvents in vacuo and purification by flash chromatography (SiO_2, toluene/ethyl acetate = 9:1) gave a mixture of **39** and **40** (176 mg, 0.144 mmol, 95%). The two isomers were separated by means of medium-pressure liquid chromatography (SiO_2, toluene/ethyl acetate = 9:1, 4.5 bar, flow: 6 mL/min) to afford pure **39** (41 mg, 34 μmol) and pure **40** (86 mg, 71 μmol). $[\alpha]_D = -2.4$ ($c = 1$; $CHCl_3$). TLC (SiO_2): $R_f = 0.38$ (toluene/ethyl acetate = 9:1). ^{1}H NMR (600 MHz, $CDCl_3$): $\delta = 1.58$ (m, 1 H, 3″-H^a); 1.95−2.00 (m, 2 H, 3-H, 3″-H^b); 2.08 (dd, $J_{gem} = 12.9$ Hz, $J_{3'Heq,4'} = 5.0$ Hz, 1 H, 3′-H^{eq}); 2.12 (d, $J = 4.1$ Hz, 1 H, OH); 2.28 (dd, 2 × J ≈ 12.7 Hz, 1 H, 3′-H^{ax}); 3.20 (dd, $J_{2,3} = 10.6$ Hz, $J_{1,2} = 7.3$ Hz, 1 H, 2-H); 3.35 (s, 3 H, CO_2Me); 3.64 (m, 1 H, 6-H^a); 3.72−3.76 (m, 3 H, 4-H, 5-H, 6-H^b); 4.03 (d, $J = 5.6$ Hz, 1 H, 6′-H); 4.27−4.35 (m, 3 H, 1-H, 9′-H^a, $PhCH_2$); 4.48 (d, $J = 11.9$ Hz, 1 H, $PhCH_2$); 4.54−4.56 (m, 2 H, $PhCH_2$); 4.86−4.90 (m, 3 H, 9′-H^b, $PhCH_2$); 4.96 (ddd, $J_{4',5'} = 2.9$ Hz, $J_{3'Heq,4'} = 5.0$ Hz, $J_{3'Hax,4'} = 12.3$ Hz, 1 H, 4′-H); 5.84 (m, 1 H, 8′-H); 5.97 (m, 1 H, 7′-H); 6.97−7.36 (m, 28 H, 4 × Ph, *m*-PhCO); 7.44−7.50 (m, 4 H, p-PhCO); 7.90−8.00 (m, 8 H, o-PhCO). Anal. Calcd for $C_{73}H_{70}O_{17}$ (1219.4): C: 71.91, H: 5.79. Found: C: 71.70, H: 5.82. FAB-MS (positive mode, NBA): $m/z = 1241$ $[M + Na]^+$; 1257 $[M + Na]^+$; Calcd: 1218.5 for $C_{73}H_{70}O_{17}$.

Benzyl 2,4,6-Tri-*O*-benzyl-3-deoxy-3-*C*-[{methyl-(2,6-anhydro-5-azido-4,7,8,9-tetra-*O*-benzoyl-3,5-dideoxy-D-*erythro*-D-*manno*-non-2-yl)onate}-methyl]-β-D-*galacto*-hexopyranoside (41). A solution of **40** (18 mg, 15 μmol) in dry dichloromethane (1 mL) was cooled to 0 °C, pyridine (50 μL) was added followed by trifluoromethanesulfonic anhydride (20 μL), and the mixture was stirred for 12 h while warming up to room temperature. Then the mixture was diluted with dichloromethane (2 mL), saturated aqueous sodium hydrogen carbonate solution (3 mL) was added, the layers were separated, and the organic layer was extracted with dichloromethane (4×). The combined organic layers were concentrated in vacuo at room temperature and purified by rapid flash chromatography (SiO_2, toluene/ethyl acetate = 9:1) to afford the corresponding triflate ($R_f = 0.45$, toluene/ethyl acetate = 9:1) as a colorless syrup which was immediately subjected to further conversion. The triflate was dissolved in dry toluene (1 mL) and treated with tetra-*n*-butylammonium azide (52 mg). After stirring for 15 min, the mixture was concentrated in vacuo and purified by flash chromatography (SiO_2, toluene/ethyl acetate = 25:1) to afford azide **41** (18 mg, 14 μmol, 94%) as a colorless syrup. $[\alpha]_D = -5.3$ (c = 1; $CHCl_3$). TLC (SiO_2): $R_f = 0.55$ (toluene/ethyl acetate = 9:1). ^{1}H NMR (600 MHz, $CDCl_3$): $\delta = 1.66$ ($J_{3'Hax,4'} = J_{gem} \approx 12.3$ Hz, 1 H, 3′-H^{ax}); 1.68 (d, $J_{gem} = 14.4$ Hz, 1 H, 3″-H^a); 1.93 (ddd, $J_{2,3} = 11.2$ Hz, $J_{3,3''Hb} = 7.3$ Hz, $J_{3,4} = 3.2$ Hz, 1 H, 3-H); 2.13 (dd, $J_{gem} = 14.4$ Hz, $J_{3,3''Hb} = 7.3$ Hz, 1 H, 3″-H^b); 2.55 (dd, $J_{gem} = 13.2$ Hz, $J_{3'Heq,4'} = 5.0$ Hz, 1 H, 3′-H^{eq}); 3.26 (s, 3 H, CO_2Me); 3.30 (dd, $J_{2,3} = 11.2$ Hz, $J_{1,2} = 7.3$ Hz, 1 H, 2-H); 3.34 (dd, 2 × J ≈ 10.3 Hz, 1 H, 5′-H); 3.76 (dd, $J_{gem} = 7.0$ Hz, $J_{5,6Ha} = 3.8$ Hz, 1 H, 6-H^a); 3.84−3.88 (m, 3 H, 5-H, 6-H^b, 6′-H); 3.92 (d, $J_{3,4} = 3.2$ Hz, 1 H, 4-H); 4.28 (dd, $J_{gem} = 12.6$ Hz, $J_{8',9'Ha} = 5.0$ Hz, 1 H, 9′-H^a); 4.47−4.49 (m, 2 H, 1-H, $PhCH_2$); 4.55−4.62 (m, 3 H, $PhCH_2$); 4.79 (m, 2 H, $PhCH_2$); 4.90 (d, $J = 11.3$ Hz, 1 H, $PhCH_2$); 4.95−4.97 (m, 2 H, 9′-H^b, $PhCH_2$); 5.01 (ddd, $J_{3'Hax,4'} = 11.7$ Hz, $J_{4',5'} = 10.0$ Hz, $J_{3'Heq,4'} = 4.7$ Hz, 1 H, 4′-H); 5.98 (ddd, $J_{7',8'} = 8.8$ Hz, $J_{8',9'Ha} = 5.0$ Hz, $J_{8',9'Hb} = 2.6$ Hz, 1 H, 8′-H); 6.08 (dd, J < 1 Hz, $J_{7',8'} = 8.8$ Hz, 1 H, 7′-H); 7.03−7.64 (m, 32 H, 4 × Ph, *m*,*p*-PhCO); 7.95−8.15 (4m, 8 H, o-PhCO). FAB-MS (positive mode, NBA): $m/z = 1266$ $[M + Na]^+$; 1282 $[M + K]^+$; Calcd: 1243.5 for $C_{73}H_{69}N_3O_{16}$.

3-Deoxy-3-*C*-[{ammonium-(5-acetamido-2,6-anhydro-3,5-dideoxy-D-*erythro*-L-*manno*-non-2-yl)onate}-methyl]-D-*galacto*-hexopyranose (2). A mixture of azide **41** (10 mg, 32 μmol) and $Pd(OH)_2$/C (18 mg) in MeOH/EtOAc = 4:1 (6 mL) was kept under an atmosphere of hydrogen for 24 h. Then, the mixture was filtered through Celite and concentrated, and the residue was taken up in a 1:1 mixture of pyridine and acetic anhydride. After stirring for 24 h at room temperature, the mixture was concentrated in vacuo and coevaporated several times with toluene. Purification of the residue by flash chromatography (toluene/acetone = 6:1) afforded **42** (3.8 mg, 3.65 μmol, 45%). This was dissolved in THF/H_2O (1:1, 10 mL)

and aqueous NaOH solution (0.1 M, 2 mL) was added. After stirring for 14 h at room temperature, the reacion mixture was lyophilized and passed through a RP-18 silica gel column (H_2O/EtOH = 9:1) and further purified by gel filtration on a Sephadex P-4 column eluting with a 0.3% ammonium hydrogen carbonate buffer solution (flow rate: 0.7 mL/min, t_R = 28 min). After removal of the buffer solution, the residue was lyophilized from water to give the ammonium salt **2** (0.9 mg) as a white amorphous solid. ^{1}H NMR (600 MHz, D_2O): δ = 1.42−1.84 (m, 4 H, 3-H, 3″-H^a, 3″-H^b, 3′-H^{ax}); 1.94 (s, 3H, NAc); 2.52 (dd, J = 4.4 Hz, J = 12.9 Hz, 1 H, 3′-H^{eq}); 3.44−3.94 (m, 12 H, 2-H, 4-H, 5-H, 6-H^a, 6-H^b, 4′-H, 5′-H, 6′-H, 7′-H, 8′-H, 9′-H^a, 9′-H^b); 4.65 (bs, 1H, 1-H). MALDI-MS (positive mode, DHB): m/z = 487.2 [$C_{18}H_{30}NO_{13}$ + NH_4 + H]$^+$; Calcd: 487.2 for $C_{18}H_{34}N_2O_{13}$.

7,8,9-Tri-*O*-acetyl-2,6-anhydro-4,5-*O*-carbonylidene-1,2,3-trideoxy-1-phenylseleno-D-*erythro*-D-*talo*-nonitol (34) and 7,8,9-Tri-*O*-acetyl-2,6-anhydro-4,5-*O*-carbonylidene-1,2,3-trideoxy-1-phenylseleno-D-*erythro*-L-*galacto*-nonitol (35). Compound **31** was coevaporated with dry toluene several times prior to use and dried in vacuo. To a solution of phenylselenyl chloride (106 mg, 0.553 mmol, 1.3 equiv) in dry acetonitrile (5 mL) was added silver trifluoromethanesulfonate (142 mg, 0.553 mmol, 1.3 equiv) at room temperature. A white solid precipitated, and the yellow mixture was stirred for 5 min at room temperature. Then, a solution of **31** (106 mg, 0.427 mmol) in dry acetonitrile (10 mL) was added via syringe, and the mixture was stirred for further 15 min. The reaction was worked up by adding saturated sodium hydrogen carbonate solution with vigorous stirring (5 min) and extracting the mixture with ethyl acetate. The combined organic layers were dried ($MgSO_4$), filtered, concentrated in vacuo, and purified by flash chromatography (SiO_2, ethyl acetate) to afford an inseparable mixture of **32** and **33** (144 mg, 0.357 mmol, 83%) as a colorless syrup. The ratio of the two isomers was determined by NMR spectroscopy to be approximately 2−3:1 in favor of **32**. For further characterization, both isomers were peracetylated in a mixture of pyridine and acetic anhydride. Coevaporation with toluene and flash chromatography (SiO_2, petroleum ether/ethyl acetate = 1:2) afforded **34** and **35** as a colorless syrup. Data for **34**: $[\alpha]_D$ = +42.3 (c = 2; $CHCl_3$). TLC: R_f = 0.33 (SiO_2, petroleum ether/ethyl acetate = 1:2). ^{1}H NMR (250 MHz, $CDCl_3$): δ = 1.81 (ddd, J_{gem} = 15.8 Hz, $J_{2,3Ha}$ = 2.7 Hz, $J_{3Ha,4}$ = 11.6 Hz, 1 H, 3-H^a); 2.05, 2.11, 2.15 (3 s, 9 H, 3 × OAc); 2.38 (ddd, J_{gem} = 15.8 Hz, $J_{2,3Hb}$ = 5.0 Hz, $J_{3Hb,4}$ = 3.0 Hz, 1 H, 3-H^b); 2.98 (dd, $J_{1Ha,1Hb}$ = 12.7 Hz, $J_{1Ha,2}$ = 7.5 Hz, 1 H, 1-H^a); 3.10 (dd, J_{gem} = 12.7 Hz, $J_{1Hb,2}$ = 4.7 Hz, 1 H, 1-H^b); 3.95 (dd, $J_{5,6}$ = 1.2 Hz, $J_{6,7}$ = 3.3 Hz, 1 H, 6-H); 4.16 (dd, J_{gem} = 12.5 Hz, $J_{8,9Ha}$ = 5.7 Hz, 1 H, 9-H^a); 4.31 (m, 1 H, 2-H); 4.49 (dd, J_{gem} = 12.5 Hz, $J_{8,9Hb}$ = 2.4 Hz, 1 H, 9-H^b); 4.79 (dd, $J_{4,5}$ = 9.0 Hz, $J_{5,6}$ = 1.2 Hz, 1 H, 5-H); 5.03 (ddd, $J_{3Hax,4}$ = 11.6 Hz, $J_{3Heq,4}$ = 3.0 Hz, $J_{4,5}$ = 9.0 Hz, 1 H, 4-H); 5.31 (ddd, $J_{7,8}$ = 6.5 Hz, $J_{8,9Ha}$ = 5.7 Hz, $J_{8,9Hb}$ = 2.4 Hz, 1 H, 8-H); 5.47 (dd, $J_{7,8}$ = 6.5 Hz, $J_{6,7}$ = 3.3 Hz, 1 H, 7-H); 7.24−7.26 (m, 3 H, Ph); 7.46−7.48 (m, 2 H, Ph). Anal. Calcd for $C_{22}H_{26}O_{10}Se$ (529.4): C: 49.91, H: 4.95. Found: C: 49.52, H: 5.15. Data for **35**: $[\alpha]_D$ = +36.6 (c = 1; $CHCl_3$); TLC: R_f = 0.38 (SiO_2, petroleum ether/ethyl acetate = 1:2). ^{1}H NMR (250 MHz, $CDCl_3$): δ = 1.67 (m, 1 H, 3-H^a); 2.04, 2.06, 2.15 (3 s, 9 H, 3 × OAc); 2.39 (ddd, J = 3.1 Hz, J = 6.6 Hz, J_{gem} = 14.1 Hz, 1 H, 3-H^b); 2.91 (dd, J_{gem} = 12.9 Hz, $J_{1Ha,2}$ = 6.5 Hz, 1 H, 1-H^a); 3.20 (dd, J_{gem} = 12.9 Hz, $J_{1Hb,2}$ = 6.7 Hz, 1 H, 1-H^b); 3.49 (m, 1 H, 2-H); 3.70 (dd, $J_{5,6}$ = 1.8 Hz, $J_{6,7}$ = 3.8 Hz, 1 H, 6-H); 4.15 (dd, J_{gem} = 12.5 Hz, $J_{8,9Ha}$ = 5.7 Hz, 1 H, 9-H^a); 4.45 (dd, J_{gem} = 12.5 Hz, $J_{8,9Hb}$ = 2.4 Hz, 1 H, 9-H^b); 4.57 (dd, $J_{4,5}$ = 6.5 Hz, $J_{5,6}$ = 1.8 Hz, 1 H, 5-H); 4.84 (m, 1 H, 4-H); 5.32 (m, 1 H, 8-H); 5.52 (dd, $J_{6,7}$ = 3.8 Hz, $J_{7,8}$ = 6.5 Hz, 1 H, 7-H); 7.24−7.30 (m, 3 H, Ph); 7.45−7.55 (m, 2 H, Ph). Anal. Calcd for $C_{22}H_{26}O_{10}Se$ (529.4): C: 49.91, H: 4.95. Found: C: 49.52, H: 5.15.

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Supporting Information Available: NMR spectra of all new compounds. Experimental procedures and analytical data for all compounds not described herein. This material is available free of charge via the Internet at http://pubs.acs.org.

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