Design and Use of an Oxazolidine Silyl Enol Ether as a New Homoalanine Carbanion Equivalent for the Synthesis of Carbon-Linked Isosteres of *O*-Glycosyl Serine and *N*-Glycosyl Asparagine†

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A trimethylsilyl enol ether carrying the *N*-Boc 2,2-dimethyloxazolidine ring was designed to serve as a synthetic equivalent of the homoalanine carbanion for the introduction of the α-amino acid side chain at the anomeric carbon of sugars. This new functionalized silyl enol ether was prepared in multigram scale and high enantiomeric purity starting from methyl *N*-Boc-L-threoninate (six steps, 49% yield). This reagent was employed in two synthetic approaches to *C*-glycosyl amino acids. In one approach, the BF_3·Et_2O-promoted coupling with tetra-*O*-benzyl-D-galactopyranosyl trichloroacetimidate afforded the α-linked *C*-glycoside as main product (30% isolated yield), which upon treatment with *tert*-butyllithium was converted into the *β*-linked isomer. Deoxygenation of these compounds by the Barton−McCombie method and unmasking of the glycyl moiety from the oxazolidine ring by oxidative cleavage with the Jones reagent gave the *C*-glycosyl serine isosteres α- and *β*-Gal-CH_2-Ser. In a similar way were prepared α- and *β*-Glc-CH_2-Ser starting from tetra-*O*-benzyl-D-glucopyranosyl trichloroacetimidate. In a second approach, the same oxazolidine silyl enol ether was condensed with formyl tetra-*O*-benzyl-*β*-D-*C*-galactopyranoside in the presence of BF_3·Et_2O to give the *β*-linked *C*-glycoside in 78% yield without any anomerization. The deoxygenation of this product and the cleavage of the oxazolidine ring as described above afforded the glycosyl asparagine isostere *β*-Gal-$(CH_2)_2$-Asn. The same reaction sequence was applied to convert formyl tetra-*O*-benzyl-*β*-D-*C*-glucopyranoside and mannopyranoside into the *C*-glycosyl amino acids *β*-Glc-$(CH_2)_2$-Asn and *β*-Man-$(CH_2)_2$-Asn, respectively.

Introduction

There are two main types of glycosidic linkages in natural glycoproteins that merit particular attention. One involves either oxygen in the side chain of serine and threonine; the other involves the nitrogen of the side chain of asparagine. The recognition that oligosaccharide side chains of these *O*- and *N*-glycoconjugates play key roles as carriers of biological information at the cellular level, such as the adhesion of bacteria and viruses to cells and cell-to-cell communication,[1] has stimulated in recent years a remarkable progress in the synthesis of homogeneous and structurally defined compounds[2] that served as models for biological studies. Also the roles of glycosylation in the modulation of protein function[3] and in affecting their physical properties such as folding and conformation[4] are of current interest. A related topic of intense research is the synthesis of carbon-linked analogues (*C*-glycopeptides) in which the native *O*- and *N*-glycosidic linkages have been replaced by the chemically more resistant and in vivo stable carbon−carbon bond. The development of such a structural diversity is important for an understanding of the mutual interactions between the carbohydrate and peptide domains and the discovery of new lead compounds in drug design. In fact biologically stable *C*-glycopeptides may have applications in many areas of modern medicine such as the control of bacterial and viral diseases, cancer therapy, and treatment of inflammatory processes. Therefore various carbon-linked isosteres of natural glycosyl amino

† Respectfully dedicated to the memory of Professor Sir Derek H. R. Barton (1918-1998).

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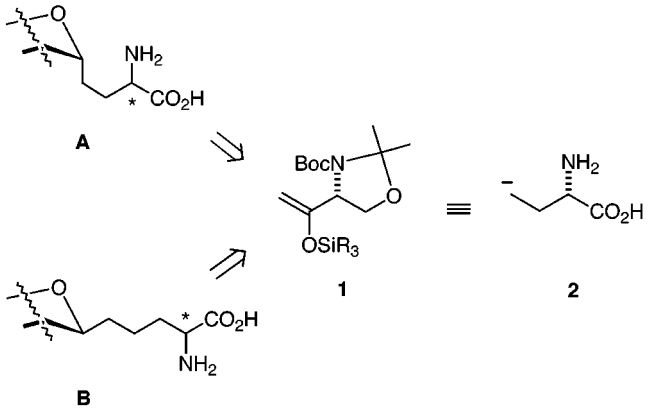
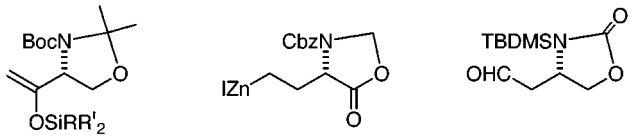


Figure 1.



1a R = R' = Me **3** (ref. 5d) **4** (ref. 5i)
1b R = *t*-Bu, R' = Me

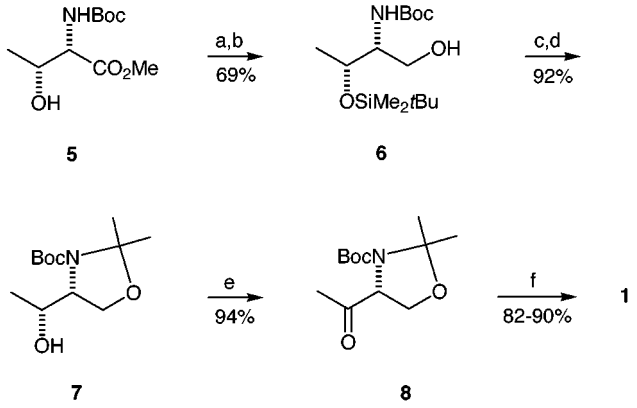
Figure 2. Homoalanine equivalent reagents.

acids as potential building blocks for *C*-glycopeptide synthesis have been reported in recent years.[5] In one case the product β-D-galactose-CH_2-serine (β-Gal-CH_2-Ser) was incorporated into a peptide chain for biological evaluation.[5c] Most of the methods were employed for the synthesis of only one target *C*-glycosyl amino acid. Only a few syntheses relied on the coupling of a sugar derivative with a chiral amino acid-derived reagent.[5b−f,i] This type of approach eliminates the problem of the construction of a stereocenter bearing the amino group since this is already in place with the desired configuration. We now wish to describe here the coupling of the threonine-derived silyl enol ether **1a**, an equivalent of the homoalanine γ-carbanion synthon **2** (Figure 1) with two types of electrophilic carbohydrate derivatives, i.e., glycosyl trichloroacetimidates and formyl *C*-glycosides. We demonstrate these approaches for the stereoselective synthesis of α-linked *C*-glycosyl amino acids of type **A** bearing two methylene groups, i.e., methylene isosteres of *O*-glycosyl serines, and β-linked compounds of type **B** with a three-methylene tether between the sugar and amino acid moiety, i.e., ethylene isosteres of *N*-glycosyl asparagines. Moreover also β-linked anomers of compounds **A** were obtained by anomerization of their precursors. Partial results of this chemistry have been recently reported in preliminary communications from this laboratory.[6,7]

Results and Discussion

Synthesis of Oxazolidine Silyl Enol Ethers 1a and 1b. At the outset of this program in 1997, the only documented synthetic equivalent of the carbanion **2** was the iodohomoalanine-derived zinc reagent **3** developed by Dorgan and Jackson[5d] (Figure 2). This organometal was employed for the synthesis of only one glycosyl amino acid

Scheme 1[a]



[a] Reagents and conditions: (a) TBDMSOTf, Et_3N, DMAP; (b) $LiAlH_4$; (c) 2-methoxypropene, CSA; (d) *n*-Bu_4NF; (e) PCC; (f) TMSOTf or TBDMSOTf, Et_3N.

isostere, i.e., α-D-mannopyranose-CH_2-serine (α-Man-CH_2-Ser). Quite recently, while our work was in progress,[6] the oxazolidinone acetaldehyde **4**, a homoalanine cation equivalent, was employed by Urban, Skrydstrup, and Beau[5i] in a SmI_2-based coupling with a sugar sulfone directed to the synthesis of 2-acetylamino-α-D-galacto-pyranose-CH_2-serine (α-GalNAc-CH_2-Ser).

The Lewis acid-mediated coupling of suitably activated *O*-glycosides with silyl enol ethers is a well-established method for the synthesis of *C*-glycosides, predominantly with α-D-linkage.[8] We therefore envisaged a silyl enol ether **1** as a new synthetic equivalent of **2** for the synthesis of *C*-glycosyl serine isosteres of type **A** (see Figure 1). The *N*-Boc 2,2-dimethyl oxazolidine ring constituted a convenient masked glycyl moiety[9,10] that was expected to be unaffected under the conditions of the glycosylation reaction and tolerate the synthetic elaborations of the resulting *C*-glycoside. The bulky *tert*-butoxycarbonyl (Boc) group would provide the configurational stability of the C-4 carbon atom, as amply documented in other *N*-Boc oxazolidine-based reagents[9] and at the same time would protect the nitrogen atom from the attack of electrophilic species. Thus, the chiral 4-acetyl oxazolidine **8**, the ultimate common precursor of both silyl enol ethers **1a** and **1b**, was prepared starting from the known[9b] *tert*-butoxycarbonyl-protected methyl L-threoninate **5** (Scheme 1). This ester was first transformed into the alcohol **6** by silylation (92%) of the secondary hydroxy group with *tert*-butyldimethylsilyl triflate (TBDMSOTf) and reduction of the carbomethoxy group ($LiAlH_4$).[11] Acetonation with 2-methoxypropene and desilylation (*n*-Bu_4NF) converted **6** into the (*R*,*R*)-hydroxyethyl oxazolidine **7**. The differentiation of the two hydroxy groups in **6** by a selective protection was a necessary operation. In fact separate experiments showed that the acetonation

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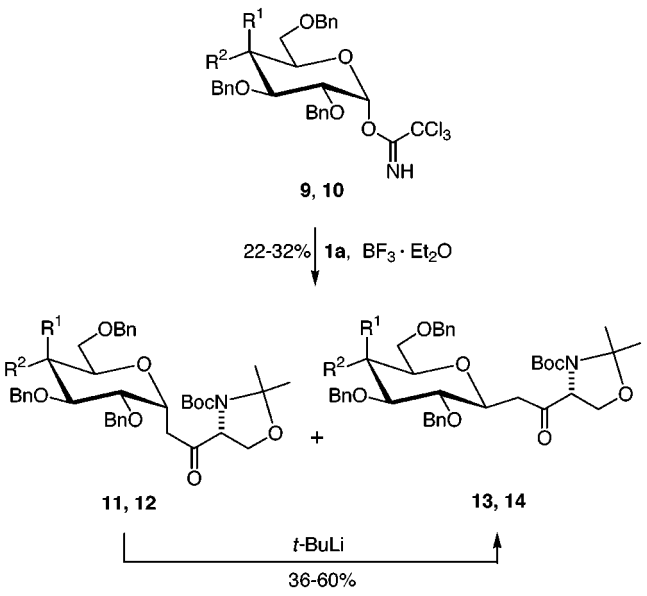
(11) In an alternative protective approach, the selective *O*-benzylation of **5** under suitable conditions (BnBr, Ag_2O, DMF, 0 °C to room temperature, 20 h) gave the corresponding 3-*O*-benzyl ether in only 20% yield. The main product was the α,β-unsaturated *N*-Boc amino ester (45%).

Scheme 2[a]



[a] Key: **9**, **11**, **13**: R^1 = OBn, R^2 = H. **10**, **12**, **14**: R^1 = H, R^2 = OBn.

of *N*-Boc L-threoninol (2-methoxypropene, CSA, DMF, 0 °C, 30 min) leads to a mixture of *N*,*O*- and *O*,*O*-isopropylidene derivatives in which the desired oxazolidine **7** is the minor product. Compound **7** was readily converted into **8** by oxidation of the hydroxy group to carbonyl with pyridinium chlorochromate (PCC). The preparation of the ketone **8** was conveniently carried out in multigram scale (10 g) with an average overall yield of 60% from **5** after purification by column chromatography. The enantiomeric purity of **8** was established by reduction to the alcohol **7** with $NaBH_4$ (ds 75%), conversion of the latter into the Mosher ester, and ^{1}H NMR analysis. Finally, silylation of the ketone **8** was readily effected using trimethylsilyl triflate (TMSOTf) or *tert*-butyldimethylsilyl triflate (TBDMSOTf) in the presence of triethylamine.[12] Under these conditions the kinetic trimethylsilyl enol ether **1a** and *tert*-butyldimethylsilyl analogue **1b** formed exclusively in 82 and 90% isolated yields, respectively.

Coupling of Silyl Enol Ether 1a with Glycosyl Trichloroacetimidates. Initially we attempted a *C*-glycosylation reaction using the D-galactopyranosyl trichloroacetimidate[13] **9** and the *tert*-butyldimethylsilyl enol ether **1b** in CH_2Cl_2 in the presence of TMSOTf or $ZnBr_2$ as Lewis acid catalyst. We thought that the stability of this silyl enol ether under these acidic conditions would concur to a successful reaction. Instead, no *C*-glycoside formation was observed from this first attempt. In contrast, the addition via syringe pumping of an Et_2O solution of **9** (2 equiv) to the trimethylsilyl enol ether **1a** and $BF_3{\cdot}Et_2O$ (1 equiv) in Et_2O at −15 °C afforded the desired α-*C*-glycoside **11** and the *β*-anomer **13** in a 19:1 ratio and 32% overall yield[14] (Scheme 2). Unreacted silyl enol ether **1a** (40%) and ketone **8** (15%)[15] were recovered unaltered and proved to be identical with authentic samples. This demonstrates that the silyl enol ether **1a** is configurationally stable under the glycosylation conditions. Hence the overall yield of *C*-glycosides **11** and **13** calculated on consumed **1a** was 71%. Also isolated were the anomeric galactosyl trichloroacetamides **15** (70%) arising from the acid-catalyzed rearrangement of the trichloroacetimidate **9** and the side-product *O*-glycoside **17** (4%) produced by electrophilic attack of activated **9** on the *N*-Boc protective group of **1a**. Under more forcing conditions (0 °C, 1 h), the amount of the *O*-glycoside **17** increased substantially. Hence effective *C*-glycosylation of **1a** to give the desired products **11** and **13** appeared to be hampered by this side reaction. The use of $ZnBr_2$ as the Lewis acid in CH_2Cl_2 at −15 °C gave a lower degree of α-selectivity (α/*β* = 4:1) and a similar overall yield of isolated *C*-glycosides **11** and **13**. Modest yields of these products were obtained by changing the sugar precursor, the Lewis acid promoter, and the solvent.[16]

Guided by earlier work regarding the base-catalyzed equilibration of α-*C*-glycosides bearing a carbonyl group in the side chain,[17] the anomerization of the ketone **11** was carried out by treatment with *tert*-butyllithium in Et_2O (−78 °C to room temperature, 4 h). The conversion was satisfactory but not complete since the reaction mixture was constituted of the α- and *β*-anomer **11** and **13** in 3:7 ratio (90% overall yield). Compound **13**, isolated by column chromatography, proved to contain (ca. 5% by ^{1}H NMR analysis) the corresponding epimer at the carbon bearing the nitrogen atom (C-2). The amount of this epimer became more substantial when the anomerization of **11** to **13** was carried out at room temperature using MeONa in MeOH or *t*-BuOK in toluene. In all instances this byproduct was removed by chromatography in a subsequent step (see Experimental Section).

The glycosylation of **1a** with tetra-*O*-benzyl-D-glucopyranosyl trichloroacetimidate[18] **10** in CH_3CN at −20 °C in the presence of $BF_3{\cdot}Et_2O$ produced results similar to those described above (Scheme 2). The reaction afforded a mixture of α- and *β*-*C*-glycosides **12** and **14** in 10:1 ratio and 22% overall yield.[14] Since also from this reaction the silyl enol ether **1a** (35%) and the ketone **8** (15%) were recovered unaltered, the calculated yield on consumed **1a** was 44%. In addition to the trichloroacetamides **16** and the *O*-glycoside **18**, the mixed[14] *O*- and *C*-glycoside **19** was obtained in 5% yield. The latter compound is very likely produced by *O*-glycosylation of the initially formed *C*-glycoside **12**. Nevertheless, the anomerization of **12** to **14** was carried out in Et_2O by the use of *tert*-butyllithium as the promoting base to give a mixture of these compounds in almost equal amounts (82% overall yield). The *β*-linked isomer **14** proved to contain about 20% of the

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(13) Schmidt, R. R.; Michel, J.; Roos, M. *Liebigs Ann.* **1984**, 1343−1357.

(14) The anomeric configuration of α-D-*C*-glycosides **11**, **12**, **19** and *β*-D-*C*-glycosides **13**, **14** was assigned by ^{1}H NMR analysis of the corresponding peracetylated derivatives ($J_{5,6}$ = 4.7, 5.2, 5.0 Hz for **11**, **12**, **19** and 9.8, 9.0 Hz for **13**, **14**, respectively, in DMSO-d_6 at 120−140 °C; see Experimental Section).

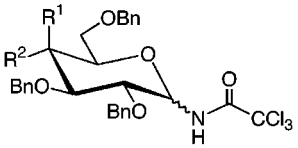
(15) Only traces of **8** were present in the crude reaction mixture. A partial desilylation of **1a** to give **8** occurred during the chromatographic separation. Both compounds **8** and **1a** were reused in appropriate reactions of Schemes 1 and 2, respectively.

(16) Other glycosylation conditions employed were: **9**, TMSOTf, CH_2Cl_2, −20 °C; **9**, $Yb(OTf)_3$, CH_3CN, 0 °C to r.t.; **9**, 1 M $LiClO_4$ in CH_2Cl_2, r.t.; thiopyridyl tetra-*O*-benzyl-D-galactopyranoside, AgOTf, CH_2Cl_2, r.t.; 1-*O*-acetyl-tetra-*O*-benzyl-D-galactopyranose, TMSOTf, CH_2Cl_2, −20 °C; tetra-*O*-benzyl-D-galactopyranosyl diethyl phosphate, $BF_3{\cdot}Et_2O$, CH_2Cl_2, −20 °C.

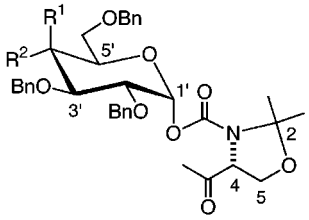
(17) (a) Ohrui, H.; Jones, G. H.; Moffatt, J. G.; Maddox, M. L.; Christensen, A. T.; Byram, S. K. *J. Am. Chem. Soc.* **1975**, *97*, 4602−4613. (b) Allevi, P.; Anastasia, M.; Ciuffreda, P.; Fiecchi, A.; Scala, A. *J. Chem. Soc., Perkin Trans. 1* **1989**, 1275−1280. (c) Dondoni, A.; Marra, A. *Tetrahedron Lett.* **1993**, *34*, 7327−7330.

(18) Schmidt, R. R.; Stumpp, M. *Liebigs Ann.* **1983**, 1249−1256.

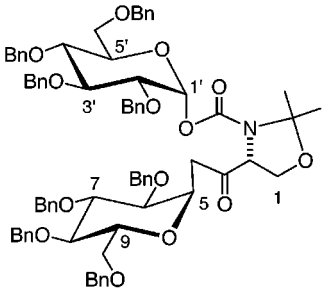
epimer at C-2, as judged by ^{1}H NMR spectroscopy. Fortunately, also this byproduct was easily removed in the subsequent steps (see Experimental Section).



15 R^1 = OBn, R^2 = H
16 R^1 = H, R^2 = OBn



17 R^1 = OBn, R^2 = H
18 R^1 = H, R^2 = OBn

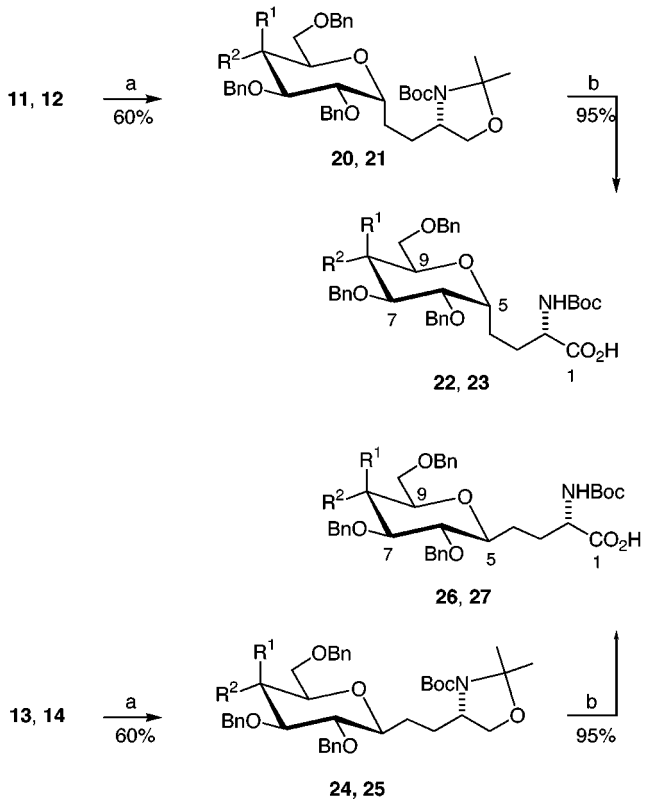


19

Synthesis of Galactose and Glucose-CH_2-Serine. Having in hand the α- and *β*-linked *C*-galactosides **11** and **13** and *C*-glucosides **12** and **14**, the conversion of each individual compound into the corresponding *C*-glycosyl amino acid was straightforward (Scheme 3). The first operation consisted of the deoxygenation of the alkyl side chain by reduction of the carbonyl with $NaBH_4$ and removal of the hydroxy group through the classical Barton−McCombie procedure,[19] i.e., activation of the crude alcohols as thiocarbonylimidazolides and reduction with Bu_3SnH and AIBN, to give the corresponding *C*-glycosides **20**, **21**, **24**, and **25** in ca. 60% yield. The second operation consisted of the unmasking of the latent glycyl moiety from the oxazolidine ring by the use of the Jones reagent, as described in recent work from this laboratory.[10] This reagent induced both the cleavage of the oxazolidine ring and the oxidation of the primary amino alcohol to give in a single step the α-linked *C*-glycosyl amino acids α-Gal-*CH*$_2$-Ser **22** and α-Glc-*CH*$_2$-Ser **23** and the corresponding *β*-isomers *β*-Gal-*CH*$_2$-Ser **26** and *β*-Glc-*CH*$_2$-Ser **27** in very good yields (ca. 95%).[20] All these compounds were conveniently characterized through their methyl esters.[21]

A few comments are worth adding here before closing this section. A method has been described that allows the synthesis of α- and *β*-linked pairs of glycosyl serine methylene isosteres starting from a single activated sugar. Evidently, the key intermediate of this divergent synthetic route is the α-linked coupling product, a glycosyl ketone, that can be anomerized to the *β*-linked isomer. Thus the use of a silyl enol ether as a synthetic equivalent of the carbanion **2** offers this new synthetic opportunity. Unfortunately the sluggish glycosylation of the silyl enol ether **1a** at the nucleophilic carbon atom and the occurrence of competitive reactions produced the target *C*-glycoside in low yield.

Scheme 3[a]



[a] Key: **20**, **22**, **24**, **26**: R^1 = OBn, R^2 = H. **21**, **23**, **25**, **27**: R^1 = H, R^2 = OBn. Reagents and conditions: (a) (i) $NaBH_4$, (ii) 1,1′-thiocarbonyldiimidazole, DMAP, (iii) Bu_3SnH, AIBN; (b) Jones reagent.

Coupling of the Silyl Enol Ether 1a with Formyl *C*-Glycosides. Synthesis of Glycosyl Asparagine Ethylene Isosteres. The Mukaiyama-type aldol condensation is a useful carbon−carbon bond forming reaction that involves the Lewis acid-promoted carbonyl addition of silyl enol ethers of ketones.[22] Thus we foresee the opportunity to capitalize on the new reagent **1a** and some formyl *C*-glycosides, readily available by a thiazole-based method developed in our laboratory,[23] in the Mukaiyama condensation directed to the synthesis of one-carbon-higher homologues of the *C*-glycosyl amino acids described above (see structure **B** in Figure 1). This coupling would offer the remarkable advantage of exploiting the existing configuration at the anomeric center of the sugar aldehyde and therefore would lead to a single *C*-glycoside. This concept led us to use *β*-linked formyl *C*-glycopyranosides as starting materials since these compounds are known to be configurationally more stable than the α-linked isomers.[23]

We first carried out the condensation of **1a** with the tetra-*O*-benzylated formyl *C*-galactopyranoside **28** and

(19) Barton, D. H. R.; McCombie, S. W. *J. Chem. Soc., Perkin Trans. 1* **1975**, 1574−1585.

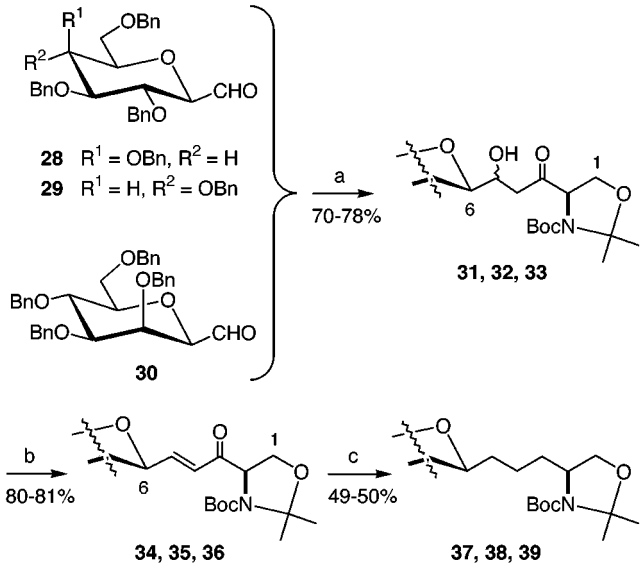
(20) Crude products were slightly contaminated by unreacted oxazolidines and the corresponding *N*-Boc alcohol derivatives (ca. 5% overall yield by ^{1}H NMR analysis). For a two-step method (methanolysis of the oxazolidine ring and RuO_2−$NaIO_4$ oxidation of the alcohol), see ref 9c.

(21) Only compound **26** had been originally reported by Bednarsky and co-workers (ref 5b). However, we have recently carried out an alternative synthesis of **26** and an adequate characterization (ref 10).

(22) Mukaiyama, T. *Angew. Chem., Int. Ed. Engl.* **1977**, *16*, 6; 818−826. Mukaiyama, T. *Org. React.* **1982**, *28*, 203−331.

(23) Dondoni, A.; Scherrmann, M.-C. *J. Org. Chem.* **1994**, *59*, 6404−6412.

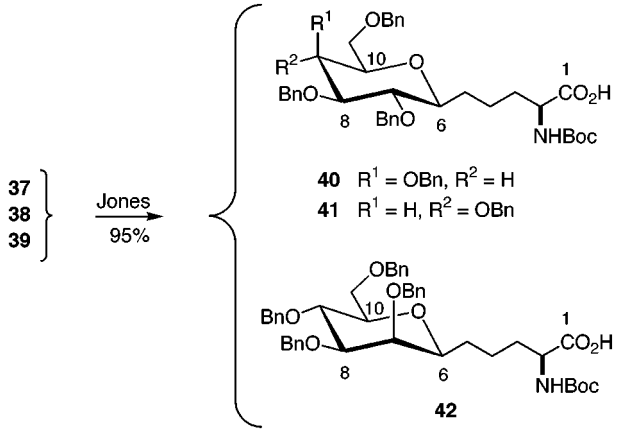
Scheme 4[a]



[a] Key: *Galacto* series: **31**, **34**, **37**. *Gluco* series: **32**, **35**, **38**. *Manno* series: **33**, **36**, **39**. Reagents and conditions. (a) **1a**, $BF_3{\cdot}Et_2O$; (b) DCC, $Cu(OTf)_2$; (c) (i) $NaBH_4$, (ii) $TsNHNH_2$, NaOAc, (iii) 1,1′-thiocarbonyldiimidazole, DMAP; (iv) Bu_3SnH, AIBN.

explored suitable conditions for the elaboration of the product into the target sugar amino acid (Scheme 4). We observed that the Mukaiyama coupling between these compounds occurred smoothly in CH_2Cl_2 at −30 °C in the presence of $BF_3{\cdot}Et_2O$ as a promoter to give the aldol **31** as a mixture of stereoisomers (3.5:1 ratio) in good overall yield (78%). Suitable conditions were searched for the removal of the hydroxy and carbonyl groups from this compound since we were not aware of literature procedures dealing with the deoxygenation of *β*-hydroxy ketones. In a first attempt the carbonyl was reduced to the hydroxy group and the 1,3-diol was treated with 1,1′-thiocarbonyldiimidazole with the hope of removing simultaneously the two hydroxy groups by the Barton−McCombie method.[19] Instead this reaction led to the formation of a cyclic thiocarbonate that precluded a further elaboration toward the desired product.[24] The complete deoxygenation of **31** was carried out by a sequence involving a DCC−$Cu(OTf)_2$-promoted α,*β*-elimination[25] to the α,*β*-enone **34** as the initial step. The mild conditions under which this reaction takes place did not affect the configurational integrity of the stereocenter of the oxazolidine moiety, as proved by ^1H NMR analysis. Then the carbonyl and the carbon−carbon double bond of **34** were reduced sequentially by the use of $NaBH_4$ and in situ generated diimide,[10,26] respectively, and the resulting alcohol was deoxygenated by the venerable Barton−McCombie method[19] to give the alkyl oxazolidine **37** (*galacto* series). To probe the validity of method, the above reaction sequence was repeated under the same conditions starting from the formyl *C*-glucopyranoside[23] **29** and *C*-mannopyranoside[23] **30**. Also in these cases the coupling with **1a** afforded in high yields[27] the corresponding aldols **32** and **33** as single stereoisomers (70 and 71%, respectively), which were elaborated by the same procedure to the alkyl oxazolidines **38** (*gluco* series) and **39** (*manno* series). The ^1H NMR analysis of a selected compound in each series confirmed the conservation of the *β*-D-configuration of the starting sugar aldehyde. The *galacto*-aldol **31** and the *gluco*-enone **35** showed $J_{6,7}$ coupling constant values of ca. 9 Hz, as expected for a trans-diaxial relationship of protons in pyranose rings adopting a $^4C_1$ conformation. For the compounds of the *manno* series the small $J_{6,7}$ coupling constant values did not allow distinguishing between the α- and *β*-D-configuration. Instead NOE experiments proved to be more conclusive. Irradiation of the anomeric proton (H-6) of the *manno*-aldol **33** induced a significant enhancement of the axial pyranosyl protons, i.e., H-8 and H-10.

Scheme 5



The oxidative cleavage of the oxazolidine ring of compounds **37**, **38**, and **39** with the Jones reagent as described above revealed the target *C*-glycosyl amino acids *β*-D-galactose-$(CH_2)_2$-asparagine (*β*-Gal-$(CH_2)_2$-Asn, **40**), the *gluco* isomer (*β*-Glu-$(CH_2)_2$-Asn, **41**), and the *manno* isomer (*β*-Man-$(CH_2)_2$-Asn, **42**) (Scheme 5). In fact each of these compounds can be considered as the ethylene isostere of the natural glycosyl *N*-asparagine where the amidic bond holding the sugar and the amino acid has been replaced by an all-carbon chain. None of these compounds appeared to have been previously reported to the best of our knowledge. Instead Kessler and co-workers described recently the aminated analogue of **41**, i.e., *β*-GlcNAc-$(CH_2)_2$-Asn. The synthesis of this compound relied on the stereocontrolled coupling of dilithio *N*-acetylglucosamine with a five-carbon-atom aldehyde derived from glutamic acid.[5f] However, the method of Kessler may fail for the synthesis of compounds **40**−**42** carrying a benzyloxy group at C-2 of the sugar moiety because the metalation at C-1 is very likely accompanied by extensive 1,2-elimination.[28] On the other hand, the use of glycosyl dianions generated from 2-hydroxy sugars to prevent *β*-elimination would produce two

(24) This undesired reaction has been recently reported to occur also for 1,2-diol derivatives; see: Jung, P. M. J.; Burger, A.; Biellmann, J.-F. *J. Org. Chem.* **1997**, *62*, 8309−8314.

(25) Corey, E. J.; Andersen, N. H.; Carlson, R. M.; Paust, J.; Vedejs, E.; Vlattas, I.; Winter, R. E. K. *J. Am. Chem. Soc.* **1968**, *90*, 3245−3247. Miyazawa, T.; Otomatsu, T.; Yamada, T.; Kuwata, S. *Tetrahedron Lett.* **1984**, *25*, 771−772. We found that the use of the CH_3CN-soluble salt $Cu(OTf)_2$ as Lewis acid gives higher and more reproducible yields than anhydrous $CuCl_2$ either commercially available or prepared in situ.

(26) Dewey, R. S.; van Tamelen, E. E. *J. Am. Chem. Soc.* **1961**, *83*, 3729. Hart, D. J.; Hong, W.-P.; Hsu, L.-Y. *J. Org. Chem.* **1987**, *52*, 4665−4673.

(27) The Mukaiyama-type aldol condensation in the presence of $ZnBr_2$ instead of $BF_3{\cdot}Et_2O$ was sluggish and gave variable amounts of byproducts such as α,*β*-unsaturated formyl *C*-glycosides (up to 40% in the *manno* series).

(28) Wittman, V.; Kessler, H. *Angew. Chem., Int. Ed. Engl.* **1993**, *32*, 1091−1193.

free hydroxy groups in the resulting coupling product, making the selective removal of the one in the side chain quite problematic. Hence the method of Kessler and our method nicely complement each other for the preparation of new members of this important class of isosteric *C*-glycosyl amino acids.

Conclusions

In summary we described in this article synthetic studies culminating with the chemical synthesis of various *C*-glycosyl amino acid isosteres of *O*-glycosyl serine and *N*-glycosyl asparagine. Two approaches have been employed, both relying on the use of an oxazolidine silyl enol ether serving as a synthetic equivalent of the homoalanine carbanion. All compounds that have been prepared feature the *O*-benzyl protection of the hydroxy groups of the sugar moiety[29] and the *N*-Boc protection of the amino group in the side chain. By contrast the carboxylate function is free. This constitutes a suitable structure for the incorporation of these glycosyl amino acids into peptide chains and their subsequent elaboration.

Experimental Section

All moisture-sensitive reactions were performed under a nitrogen atmosphere using oven-dried glassware. Anhydrous solvents were dried over standard drying agents[30] and freshly distilled prior to use. Commercially available powdered 4-Å molecular sieves (50 μm average particle size) were used without further activation. Reactions were monitored by TLC on silica gel 60 F_{254} with detection by charring with sulfuric acid. Flash column chromatography[31] was performed on silica gel 60 (230−400 mesh). Medium-pressure (8 bar) chromatography was performed on silica gel 60 (230 mesh) using a Chromatospac Prep 100. Preparative TLC was performed on silica gel 60 F_{254} (0.5 mm layer). Optical rotations were measured at 20 ± 2 °C in $CHCl_3$. ^{1}H (300 MHz) and ^{13}C (75 MHz) NMR were recorded at room temperature for $CDCl_3$ solutions, unless otherwise specified. Assignments were aided by homo- and heteronuclear two-dimensional experiments. MALDI-TOF mass spectra were acquired using 2,6-dihydroxybenzoic acid or α-cyano-4-hydroxycinnamic acid as the matrix. Known[9b] methyl *N*-Boc-L-threoninate **5** was prepared from L-threonine in 0.1 mol scale as reported for the synthesis of methyl *N*-Boc-phenylglycinate.[32] Known[13,18] trichloroacetimidates **9** and **10** were prepared as pure α-D-anomers (ca. 80% yield after column chromatography) by reacting 2,3,4,6-tetra-*O*-benzyl-D-galacto- and glucopyranose with freshly distilled Cl_3CCN (6 equiv) and DBU (1 equiv) at 0 °C for 1 h.

(2*R*,3*R*)-2-(*tert*-Butoxycarbonylamino)-3-*O*-(*tert*-butyldimethylsilyl)-1,3-butandiol (6). To a cooled (0 °C), stirred mixture of **5** (15.00 g, 64.4 mmol), triethylamine (13.4 mL, 96.6 mmol), 4-*N*,*N*-(dimethylamino)pyridine (787 mg, 6.44 mmol), and anhydrous DMF (40 mL) was added *tert*-butyldimethylsilyl triflate (17.7 mL, 77.3 mmol). The mixture was stirred at room temperature for 1.5 h, then treated with CH_3OH (3 mL), stirred for an additional 30 min, diluted with Et_2O (300 mL), and washed with saturated aqueous NH_4Cl (3 × 25 mL). The organic phase was dried ($MgSO_4$) and concentrated to give the correspondig silyl derivative (20.6 g, ∼92%), at least 95% pure by NMR analysis, suitable for the next step.

To a cooled (−50 °C), stirred mixture of $LiAlH_4$ (4.37 g, 115.2 mmol) and anhydrous THF (150 mL) was added a solution of the above crude silyl derivative (10.0 g, ∼28.8 mmol) in anhydrous THF (10 mL) during 20 min. The mixture was stirred at −50 °C for an additional 30 min, diluted with 1 M phosphate buffer at pH = 7 (14 mL) and AcOEt (∼300 mL), warmed to room temperature, and filtered through a pad of Celite. The solution was concentrated, and the residue was eluted from a column of silica gel with 4:1 cyclohexane−AcOEt to give **6** (6.90 g, 75%) as a syrup: $[\alpha]_D = -7.5$ (*c* 0.8). ^{1}H NMR: δ 4.94 (bd, 1 H, J = 7.0 Hz), 4.08 (dq, 1 H, J = 2.2, 6.2 Hz), 3.71−3.48 (m, 3 H), 2.22 (bs, 1 H), 1.46 (s, 9 H), 1.18 (d, 3 H, J = 6.2 Hz), 0.90 (s, 9 H), 0.09 (s, 6 H). Anal. Calcd for $C_{15}H_{33}NO_4Si$: C, 56.39; H, 10.41; N, 4.38. Found: C, 56.54; H, 10.44; N, 4.39.

(4*R*)-4-[(*R*)-1-Hydroxyethyl]-2,2-dimethyl-*N*-(*tert*-butoxycarbonyl)-1,3-oxazolidine (7). To a cooled (0 °C), stirred solution of **6** (8.00 g, 25.0 mmol) and 2-methoxypropene (6.0 mL, 62.5 mmol) in anhydrous CH_2Cl_2 (100 mL) was added 10-camphorsulfonic acid (581 mg, 2.50 mmol). The mixture was stirred for 1 h at 0 °C and for 30 min at room temperature, then diluted with CH_2Cl_2 (150 mL) and washed with saturated aqueous $NaHCO_3$ (30 mL). The organic phase was dried ($MgSO_4$) and concentrated to give (4*R*)-4-[(*R*)-1-*tert*-butyldimethylsilyloxyethyl]-2,2-dimethyl-*N*-(*tert*-butoxycarbonyl)-1,3-oxazolidine (8.63 g, ∼96%), at least 95% pure by NMR analysis, suitable for the next step.

A solution of the crude silyl ether derivative (8.00 g, ∼22.2 mmol) in anhydrous THF (100 mL) was treated with *n*-$Bu_4NF{\cdot}3H_2O$ (8.39 g, 26.6 mmol) at room temperature for 6 h, then concentrated. The residue was dissolved in CH_2Cl_2 (200 mL), washed with H_2O (2 × 20 mL), dried ($MgSO_4$), and concentrated to give crude **7**. The residue was eluted from a column of silica gel with 4:1 cyclohexane−AcOEt (containing 0.3% of Et_3N) to afford **7** (5.23 g, 96%) as a white solid: mp 87−88 °C (from cyclohexane); $[\alpha]_D = +24.2$ (*c* 0.7). ^{1}H NMR: δ 4.18−4.11 and 4.00−3.77 (2 m, 4 H), 1.58 (s, 3 H), 1.50 (s, 12 H), 1.18 (d, 3 H, J = 6.5 Hz). Anal. Calcd for $C_{12}H_{23}NO_4$: C, 58.75; H, 9.45; N, 5.71. Found: C, 58.90; H, 9.46; N, 5.70.

(4*R*)-4-Acetyl-2,2-dimethyl-*N*-(*tert*-butoxycarbonyl)-1,3-oxazolidine (8). A mixture of alcohol **7** (6.00 g, 24.5 mmol), activated 4-Å powdered molecular sieves (24.5 g), and anhydrous CH_2Cl_2 (180 mL) was stirred at room temperature for 15 min, and then pyridinium chlorochromate (26.4 g, 122.5 mmol) was added. The suspension was stirred for 20 min, and then cyclohexane (180 mL) and Et_2O (360 mL) were added. The mixture was stirred for an additional 10 min, filtered through a pad of silica gel (11 × 4 cm, d × h), and concentrated. The residue was eluted from a column of silica gel with 4:1 cyclohexane−AcOEt to afford **8** (5.60 g, 94%) as an oil: $[\alpha]_D = +56.9$ (*c* 2.1). ^{1}H NMR ($C_2D_2Cl_4$, 120 °C): δ 4.36 (dd, 1 H, J = 3.1, 7.2 Hz), 4.15 (dd, 1 H, J = 7.2, 9.0 Hz), 3.95 (dd, 1 H, J = 3.1, 9.0 Hz), 2.20 (s, 3H), 1.70 and 1.57 (2 s, 6 H), 1.51 (s, 9 H). Anal. Calcd for $C_{12}H_{21}NO_4$: C, 59.24; H, 8.70; N, 5.76. Found: C, 59.11; H, 8.71; N, 5.77.

Conversion of the Ketone 8 into the 7 Mosher Ester. To a cooled (−20 °C), stirred solution of **8** (25 mg, 0.10 mmol) in CH_3OH (0.2 mL) and Et_2O (0.2 mL) was added $NaBH_4$ (8 mg, 0.22 mmol). The mixture was stirred at −20 °C for an additional 1 h, then diluted with acetone (0.2 mL), warmed to room temperature, and concentrated. The residue was suspended in CH_2Cl_2 (10 mL), washed with 1 M phosphate buffer at pH = 7 (2 × 1 mL), dried ($MgSO_4$), and concentrated to afford the syn alcohol **7** together with its anti epimer ***anti*-7** (25 mg, ∼100%) in a 3:1 ratio (^{1}H NMR analysis).

To a stirred solution of this mixture (25 mg, ∼0.10 mmol) in anhydrous CH_2Cl_2 (1.0 mL) were added (*R*)-(+)-α-methoxy-α-(trifluoromethyl)phenylacetic acid (29 mg, 0.12 mmol), 1,3-dicyclohexylcarbodiimide (25 mg, 0.12 mmol), and a catalytic amount of 4-*N*,*N*-(dimethylamino)pyridine. The mixture was stirred for an additional 12 h at room temperature, then concentrated. The residue was purified by preparative TLC (8:1 cyclohexane−AcOEt) to give **7 Mosher ester** (35 mg, 74%) and ***anti*-7 Mosher ester** (11 mg, 23%). ^{1}H NMR (DMSO-d_6, 120 °C) for **7 Mosher ester**: δ 7.46 (s, 5 H, Ph), 5.49 (dq, 1 H,

(29) The syntheses of one *C*-glycopeptide (ref 5c) and several *O*-glycopeptides (Fields, G. B.; Noble, R. L. *Int. J. Peptide Protein Res.* **1990**, *35*, 161−214) by the use of *O*-benzylated glycosyl amino acids have been reported.

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(31) Still, W. C.; Kahn, M.; Mitra, A. *J. Org. Chem.* **1978**, *43*, 2923−2925.

(32) Dondoni, A.; Perrone, D.; Semola, T. *Synthesis* **1995**, 181−186.

J = 4.5, 6.2 Hz), 4.10 (ddd, 1 H, J = 2.3, 4.5, 6.5 Hz), 3.96 (dd, 1 H, J = 6.5, 9.8 Hz), 3.87 (dd, 1 H, J = 2.3, 9.8 Hz), 3.49 (q, 1 H, J = 0.7 Hz), 1.52 and 1.44 (2 s, 6 H), 1.46 (s, 9 H), 1.22 (d, 1 H, J = 6.2 Hz). ^{1}H NMR (DMSO-d_6, 120 °C) for ***anti*-7 Mosher ester**: δ 7.54−7.40 (m, 5 H, Ph), 5.42 (dq, 1 H, J = 3.8, 6.2 Hz), 3.99−3.91 (m, 2 H), 3.83−3.75 (m, 1 H), 3.53 (q, 1 H, J = 1.8 Hz), 1.42 (s, 9 H), 1.40 and 1.22 (2 s, 6 H), 1.29 (d, 1 H, J = 6.2 Hz).

(4*R*)-2,2-Dimethyl-*N*-(*tert*-butoxycarbonyl)-4-(1-trimethylsilyloxyvinyl)-1,3-oxazolidine (1a). A mixture of ketone **8** (500 mg, 2.06 mmol), activated 4-Å powdered molecular sieves (700 mg), and anhydrous CH_2Cl_2 (6 mL) was stirred at room temperature for 15 min, then cooled to −15 °C. Freshly distilled triethylamine (460 μL, 3.29 mmol) and TMSOTf (520 μL, 2.88 mmol) were added in three portions every 15 min. After an additional 30 min at −15 °C, the mixture was diluted with Et_2O (80 mL), filtered through a pad of Celite, and washed with cold saturated aqueous NH_4Cl (2 × 10 mL). The organic phase was dried ($MgSO_4$), concentrated (bath temperature not exceeding 40 °C), and eluted from a short column of silica gel (4 × 2 cm, d × h) with 4:1 cyclohexane−AcOEt (100 mL) to give the trimethylsilyl enol ether **1a** (531 mg, 82%) as a low-melting solid: mp 45−48 °C; $[\alpha]_D$ = +23.4 (*c* 0.6). ^{1}H NMR ($C_2D_2Cl_4$, 120 °C): δ 4.26 (d, 1 H, J = 1.5 Hz), 4.24 (dd, 1 H, J = 3.5, 7.0 Hz), 4.21 (d, 1 H, J = 1.5 Hz), 4.04 (dd, 1 H, J = 7.0, 8.5 Hz), 3.95 (dd, 1 H, J = 3.5, 8.5 Hz), 1.63 and 1.58 (2 s, 6 H), 1.46 (s, 9 H), 0.30 (s, 9 H). Anal. Calcd for $C_{15}H_{29}NO_4Si$: C, 57.11; H, 9.26; N, 4.44. Found: C, 56.99; H, 9.28; N, 4.44.

(4*R*)-2,2-Dimethyl-*N*-(*tert*-butoxycarbonyl)-4-(1-*tert*-butyldimethylsilyloxyvinyl)-1,3-oxazolidine (1b). A mixture of ketone **8** (100 mg, 0.41 mmol), activated 4-Å powdered molecular sieves (200 mg), and anhydrous CH_2Cl_2 (2 mL) was stirred at room temperature for 15 min, then cooled to 0 °C. Freshly distilled triethylamine (91 μL, 0.66 mmol) and *tert*-butyldimethylsilyl triflate (132 μL, 0.58 mmol) were added in three portions every 15 min. After an additional 30 min at 0 °C, the mixture was diluted with Et_2O (20 mL), filtered through a pad of Celite, and washed with cold saturated aqueous NH_4Cl (2 × 4 mL). The organic phase was dried ($MgSO_4$), concentrated, and eluted from a column of silica gel with 20:1 cyclohexane−AcOEt to give the *tert*-butyldimethylsilyl enol ether **1b** (132 mg, 90%) as an oil: $[\alpha]_D$ = +22.5 (*c* 0.8). ^{1}H NMR ($C_2D_2Cl_4$, 120 °C): δ 4.26 (d, 1 H, J = 1.4 Hz), 4.23 (dd, 1 H, J = 3.6, 6.6 Hz), 4.22 (d, 1 H, J = 1.4 Hz), 4.03 (dd, 1 H, J = 6.6, 8.7 Hz), 3.97 (dd, 1 H, J = 3.6, 8.7 Hz), 1.65 and 1.58 (2 s, 6 H), 1.48 (s, 9 H), 1.00 (s, 9H), 0.22 (s, 6 H). Anal. Calcd for $C_{18}H_{35}NO_4Si$: C, 60.46; H, 9.87; N, 3.92. Found: C, 60.48; H, 9.68; N, 3.81.

5,9-Anhydro-6,7,8,10-tetra-*O*-benzyl-2,4-dideoxy-1,2-*N*,*O*-isopropylidene-2-(*tert*-butoxycarbonylamino)-D-*threo*-L-*gulo*-3-deculose (11) and 5,9-Anhydro-6,7,8,10-tetra-*O*-benzyl-2,4-dideoxy-1,2-*N*,*O*-isopropylidene-2-(*tert*-butoxycarbonylamino)-D-*threo*-L-*galacto*-3-deculose (13). A mixture of silyl enol ether **1a** (631 mg, 2.00 mmol), trichloroacetimidate **9** (1.37 g, 2.00 mmol), activated 4-Å powdered molecular sieves (600 mg), and anhydrous Et_2O (10 mL) was stirred at room temperature for 15 min, then cooled to −15 °C. To the mixture were added freshly distilled BF_3·Et_2O (250 μL, 2.00 mmol) and then, after 10 min at −15 °C, a solution of trichloroacetimidate **9** (1.37 g, 2.00 mmol) in anhydrous Et_2O (2 mL) by a syringe-pump apparatus during 1.5 h. The mixture was stirred at −15 °C for an additional 20 min, diluted with 1 M phosphate buffer at pH = 7 (0.5 mL) and Et_2O (200 mL), filtered through a pad of Celite, and washed with 1 M phosphate buffer at pH = 7 (2 × 20 mL). The organic phase was dried ($MgSO_4$) and concentrated. The residue was purified by MPLC (8:1 cyclohexane−AcOEt) to afford first silyl enol ether **1a** (252 mg, 40%). Eluted second was a ∼1:1 mixture of anomeric galactosyl trichloroacetamides **15** (1.96 g, 72%). Eluted third was the ketone **8** (72 mg, 15%). Eluted forth was the β-linked *C*-glycoside **13** (25 mg, 2%) as a syrup: $[\alpha]_D$ = +22.4 (*c* 0.4). ^{1}H NMR (DMSO-d_6, 120 °C): δ 7.42−7.21 (m, 20 H, 4 Ph), 4.85 and 4.67 (2 d, 2 H, J = 11.7 Hz, PhCH_2), 4.83 and 4.63 (2 d, 2 H, J = 11.9 Hz, PhCH_2), 4.80 and 4.56 (2 d, 2 H, J = 12.0 Hz, PhCH_2), 4.49 and 4.44 (2 d, 2 H, J = 12.1 Hz, PhCH_2), 4.47 (dd, 1 H, $J_{1a,2}$ = 7.8, $J_{1b,2}$ = 3.8 Hz, H-2), 4.07 (dd, 1 H, $J_{7,8}$ = 2.8, $J_{8,9}$ = ∼0.5 Hz, H-8), 4.05 (dd, 1 H, $J_{1a,1b}$ = 9.0 Hz, H-1a), 3.81 (dd, 1 H, H-1b), 3.76 (dd, 1 H, $J_{6,7}$ = 9.1 Hz, H-7), 3.74 (ddd, 1 H, $J_{4a,5}$ = 2.5, $J_{4b,5}$ = 8.8, $J_{5,6}$ = 9.2 Hz, H-5), 3.69 (ddd, 1 H, $J_{9,10a}$ = 6.0, $J_{9,10b}$ = 6.5 Hz, H-9), 3.60 (t, 1 H, H-6), 3.57 (dd, 1 H, $J_{10a,10b}$ = 10.0 Hz, H-10a), 3.51 (dd, 1 H, H-10b), 2.82 (dd, 1 H, $J_{4a,4b}$ = 16.1 Hz, H-4a), 2.63 (dd, 1 H, H-4b), 1.52 and 1.44 (2 s, 6 H, 2 Me), 1.32 (s, 9 H, *t*-Bu). MALDI-TOF MS: 788.5 (M^+ + Na), 804.4 (M^+ + K). Anal. Calcd for $C_{46}H_{55}NO_9$: C, 72.13; H, 7.24; N, 1.83. Found: C, 72.21; H, 7.25; N, 1.83. Eluted fifth was the α-linked *C*-glycoside **11** (465 mg, 30%) as a syrup: $[\alpha]_D$ = +53.3 (*c* 0.9). ^{1}H NMR (DMSO-d_6, 120 °C): δ 7.35−7.20 (m, 20 H, 4 Ph), 4.74−4.41 (m, 10 H, 4 PhCH_2, H-2, H-5), 4.09 (dd, 1 H, $J_{1a,1b}$ = 9.0, $J_{1a,2}$ = 7.2 Hz, H-1a), 4.04−3.97 (m, 2 H), 3.86 (dd, 1 H, $J_{1b,2}$ = 3.2 Hz, H-1b), 3.85−3.62 (m, 4 H), 2.91 (dd, 1 H, $J_{4a,4b}$ = 17.0, $J_{4a,5}$ = 8.2 Hz, H-4a), 2.68 (dd, 1 H, $J_{4b,5}$ = 4.5 Hz, H-4b), 1.55 and 1.46 (2 s, 6 H, 2 Me), 1.38 (s, 9 H, *t*-Bu). MALDI-TOF MS: 788.6 (M^+ + Na), 804.7 (M^+ + K). Anal. Calcd for $C_{46}H_{55}NO_9$: C, 72.13; H, 7.24; N, 1.83. Found: C, 72.15; H, 7.30; N, 1.63. Eluted sixth was (4*R*)-4-acetyl-2,2-dimethyl-*N*-[(2,3,4,6-tetra-*O*-benzyl-α-D-galactopyranosyl)oxycarbonyl]-1,3-oxazolidine (**17**, 57 mg, 4%) as a syrup: $[\alpha]_D$ = +72.2 (*c* 0.9). ^{1}H NMR ($C_2D_2Cl_4$, 120 °C): δ 7.44−7.22 (m, 20 H, 4 Ph), 6.37 (d, 1 H, $J_{1',2'}$ = 3.4 Hz, H-1′), 4.98 and 4.63 (2 d, 2 H, J = 11.6 Hz, PhCH_2), 4.84 and 4.78 (2 d, 2 H, J = 11.7 Hz, PhCH_2), 4.77 and 4.72 (2 d, 2 H, J = 11.8 Hz, PhCH_2), 4.55 and 4.49 (2 d, 2 H, J = 12.0 Hz, PhCH_2), 4.35 (dd, 1 H, $J_{4,5b}$ = 3.1, $J_{4,5a}$ = 7.2 Hz, H-4), 4.20 (dd, 1 H, $J_{2',3'}$ = 9.2 Hz, H-2′), 4.15 (dd, 1 H, $J_{5a,5b}$ = 9.0 Hz, H-5a), 4.04 (dd, 1 H, $J_{3',4'}$ = 2.5, $J_{4',5'}$ = ∼0.5 Hz, H-4′), 3.98 (dd, 1 H, H-5b), 3.86 (ddd, 1 H, $J_{5',6'a}$ = $J_{5',6'b}$ = 6.0 Hz, H-5′), 3.80 (dd, 1 H, H-3′), 3.68 (dd, 1 H, $J_{6'a,6'b}$ = 9.1 Hz, H-6′a), 3.61 (dd, 1 H, H-6′b), 2.16 (s, 3 H, COMe), 1.72 and 1.50 (2 s, 6 H, 2 Me). MALDI-TOF MS: 733.0 (M^+ + Na), 749.0 (M^+ + K). Anal. Calcd for $C_{42}H_{47}NO_9$: C, 71.07; H, 6.67; N, 1.97. Found: C, 71.00; H, 6.74; N, 1.80.

The reaction of **1a** (631 mg, 2.00 mmol) with trichloroacetimidate **9** (2.73 g, 4.00 mmol) in anhydrous CH_2Cl_2 (−15 °C, addition in 4.5 h, total reaction time 5 h) using freshly sublimed $ZnBr_2$ (1.35 g, 6.00 mmol) instead of BF_3·Et_2O, afforded the β-linked *C*-glycoside **13** (92 mg, 6%) and the α-linked *C*-glycoside **11** (367 mg, 24%).

Conversion of the Tetra-*O*-benzyl-α-*C*-glycoside 11 into the Tetra-*O*-acetyl Derivative. To prove the α-D-configuration the *C*-glycoside **11** was debenzylated (H_2, 20% $Pd(OH)_2$/C, 1:1 MeOH−AcOEt, 1 bar, room temperature) and peracetylated (Ac_2O, Py, room temperature, 2 h). ^{1}H NMR (DMSO-d_6, 120 °C): δ 5.31 (dd, 1 H, $J_{7,8}$ = 3.2, $J_{8,9}$ = 2.8 Hz, H-8), 5.21 (dd, 1 H, $J_{6,7}$ = 8.7 Hz, H-7), 5.14 (dd, 1 H, $J_{5,6}$ = 4.7 Hz, H-6), 4.66 (ddd, 1 H, $J_{4a,5}$ = 8.0, $J_{4b,5}$ = 4.6 Hz, H-5), 4.50 (dd, 1 H, $J_{1a,2}$ = 7.6, $J_{1b,2}$ = 3.2 Hz, H-2), 4.23 (ddd, 1 H, $J_{9,10a}$ = 9.8, $J_{9,10b}$ = 4.6 Hz, H-9), 4.16 (dd, 1 H, $J_{10a,10b}$ = 11.2 Hz, H-10a), 4.16 (dd, 1 H, $J_{1a,1b}$ = 9.4 Hz, H-1a), 4.06 (dd, 1 H, H-10b), 3.90 (dd, 1 H, H-1b), 3.07 (dd, 1 H, $J_{4a,4b}$ = 17.6 Hz, H-4a), 2.70 (dd, 1 H, H-4b), 2.08, 2.01, 1.99, and 1.98 (4 s, 12 H, 4 Ac), 1.58 and 1.48 (2 s, 6 H, 2 Me), 1.42 (s, 9 H, *t*-Bu).

Conversion of the Tetra-*O*-benzyl-β-*C*-glycoside 13 into the Tetra-*O*-acetyl Derivative. To prove the β-D-configuration the *C*-glycoside **13** was debenzylated (H_2, 20% $Pd(OH)_2$/C, 1:1 MeOH−AcOEt, 1 bar, room temperature) and peracetylated (Ac_2O, Py, room temperature, 2 h). ^{1}H NMR (DMSO-d_6, 120 °C): δ 5.34 (dd, 1 H, $J_{7,8}$ = 3.5, $J_{8,9}$ = ∼0.8 Hz, H-8), 5.18 (dd, 1 H, $J_{6,7}$ = 10.0 Hz, H-7), 4.94 (dd, 1 H, $J_{5,6}$ = 9.8 Hz, H-6), 4.48 (dd, 1 H, $J_{1a,2}$ = 7.6, $J_{1b,2}$ = 3.6 Hz, H-2), 4.16−4.05 (m, 3 H, H-1a, H-5, H-9), 4.00 (d, 2 H, $J_{9,10}$ = 6.0 Hz, 2 H-10), 3.88 (dd, 1 H, $J_{1a,1b}$ = 9.3 Hz, H-1b), 2.73 (dd, 1 H, $J_{4a,5}$ = 8.6, $J_{4a,4b}$ = 17.0 Hz, H-4a), 2.61 (dd, 1 H, $J_{4b,5}$ = 3.2 Hz, H-4b), 2.10, 2.00, 1.99, and 1.96 (4 s, 12 H, 4 Ac), 1.58, 1.46 (2 s, 6 H, 2 Me), 1.40 (s, 9 H, *t*-Bu).

5,9-Anhydro-6,7,8,10-tetra-*O*-benzyl-2,4-dideoxy-1,2-*N*,*O*-isopropylidene-2-(*tert*-butoxycarbonylamino)-D-*erythro*-L-*gulo*-3-deculose (12) and 5,9-Anhydro-6,7,8,10-tetra-*O*-benzyl-2,4-dideoxy-1,2-*N*,*O*-isopropylidene-2-(*tert*-butoxycarbonylamino)-D-*erythro*-L-*galacto*-3-deculose

(14). A mixture of silyl enol ether **1a** (631 mg, 2.00 mmol), trichloroacetimidate **10** (1.37 g, 2.00 mmol), activated 4-Å powdered molecular sieves (600 mg), and anhydrous CH_3CN (10 mL) was stirred at room temperature for 15 min, then cooled to −20 °C. To the mixture were added freshly distilled $BF_3{\cdot}Et_2O$ (127 μL, 1.00 mmol) and, after 10 min at −20 °C, a solution of trichloroacetimidate **10** (1.37 g, 2.00 mmol) in anhydrous CH_3CN (2 mL) by a syringe-pump apparatus during 30 min. At the end of the addition, to the mixture was added an additional amount of freshly distilled $BF_3{\cdot}Et_2O$ (64 μL, 0.50 mmol). The mixture was stirred at −20 °C for an additional 30 min, diluted with 1 M phosphate buffer at pH = 7 (0.5 mL), filtered through a pad of Celite, and concentrated. The residue was diluted with CH_2Cl_2 (200 mL) and washed with 1 M phosphate buffer at pH = 7 (2 × 20 mL). The organic phase was dried ($MgSO_4$) and concentrated. The residue was purified by MPLC (5:1 cyclohexane−AcOEt) to afford first silyl enol ether **1a** (221 mg, 35%). Eluted second was a ∼1:1 mixture of anomeric glucosyl trichloroacetamides **16** (1.91 g, 70%). Eluted third was a 10:1 mixture of α- and β-linked *C*-glycosides **12** and **14** (337 mg, 22%). Eluted forth was the ketone **8** (72 mg, 15%). Eluted fifth was 5,9-anhydro-6,7,8,10-tetra-*O*-benzyl-2,4-dideoxy-1,2-*N*,*O*-isopropylidene-2-[(2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranosyl)oxycarbonyl]-D-*erythro*-L-*gulo*-3-deculose (**19**, 123 mg, 5%) as a syrup: $[\alpha]_D = +64.7$ (*c* 0.9). ^{1}H NMR (DMSO-d_6, 120 °C) selected data: δ 7.36−7.18 (m, 40 H, 8 Ph), 6.19 (d, 1 H, $J_{1',2'} = 3.5$ Hz, H-1′), 4.12 (dd, 1 H, $J_{1a,2} = 7.3$, $J_{1a,1b} = 9.5$ Hz, H-1a), 4.01 (dd, 1 H, $J_{1b,2} = 2.8$ Hz, H-1b), 3.08 (dd, 1 H, $J_{4a,5} = 8.8$, $J_{4a,4b} = 16.6$ Hz, H-4a), 2.78 (dd, 1 H, $J_{4b,5} = 3.6$ Hz, H-4b), 1.62 and 1.45 (2 s, 6 H, 2 Me). MALDI-TOF MS: 1256.0 (M^+ + Na), 1272.1 (M^+ + K). Anal. Calcd for $C_{76}H_{81}NO_{14}$: C, 74.07; H, 6.62; N, 1.14; Found: C, 74.18; H, 6.74; N, 1.25. Eluted sixth was (4*R*)-4-acetyl-2,2-dimethyl-*N*-[(2,3,4,6-tetra-*O*-benzyl-α-D-glucopyranosyl)oxycarbonyl]-1,3-oxazolidine (**18**, 85 mg, 6%) as a syrup: $[\alpha]_D = +78.2$ (*c* 1.1). ^{1}H NMR (DMSO-d_6, 120 °C): δ 7.36−7.20 (m, 20 H, 4 Ph), 6.19 (d, 1 H, $J_{1',2'} = 3.2$ Hz, H-1′), 4.85 and 4.76 (2 d, 2 H, $J = 11.5$ Hz, PhCH_2), 4.77 and 4.59 (2 d, 2 H, $J = 11.3$ Hz, PhCH_2), 4.68 and 4.64 (2 d, 2 H, $J = 12.0$ Hz, PhCH_2), 4.54 (dd, 1 H, $J_{4,5a} = 7.5$, $J_{4,5b} = 3.0$ Hz, H-4), 4.52 and 4.47 (2 d, 2 H, $J = 12.0$ Hz, PhCH_2), 4.20 (dd, 1 H, $J_{5a,5b} = 9.6$ Hz, H-5a), 4.00 (dd, 1 H, H-5b), 3.76 (dd, 1 H, $J_{2',3'} = 9.2$, $J_{3',4'} = 8.2$ Hz, H-3′), 3.70 (dd, 1 H, H-2′), 3.67−3.53 (m, 4 H, H-4′, H-5′, 2 H-6′), 2.12 (s, 3 H, COMe), 1.61 and 1.47 (2 s, 6 H, 2 Me). Anal. Calcd for $C_{42}H_{47}NO_9$: C, 71.07; H, 6.67; N, 1.97. Found: C, 71.20; H, 6.72, N, 1.89.

The 10:1 mixture of **12** and **14** was purified by MPLC (30:1 $CHCl_3$−CH_3CN) to afford first the α-linked *C*-glycoside **12** (305 mg, 20%) as a white foam: $[\alpha]_D = +66.9$ (*c* 1.8). ^{1}H NMR (DMSO-d_6, 120 °C): δ 7.40−7.18 (m, 20 H, 4 Ph), 4.80 and 4.72 (2 d, 2 H, $J = 11.5$ Hz, PhCH_2), 4.72 and 4.55 (2 d, 2 H, $J = 11.5$ Hz, PhCH_2), 4.64−4.58 (m, 1 H, H-5), 4.63 and 4.59 (2 d, 2 H, $J = 11.8$ Hz, PhCH_2), 4.50 and 4.46 (2 d, 2 H, $J = 12.0$ Hz, PhCH_2), 4.48 (dd, 1 H, $J_{1a,2} = 7.6$, $J_{1b,2} = 3.4$ Hz, H-2), 4.09 (dd, 1 H, $J_{1a,1b} = 9.2$ Hz, H-1a), 3.88 (dd, 1 H, H-1b), 3.78−3.60 (m, 5 H, H-6, H-7, H-8, H-9, H-10a), 3.48 (dd, 1 H, $J_{9,10b} = 7.5$, $J_{10a,10b} = 9.0$ Hz, H-10b), 3.02 (dd, 1 H, $J_{4a,4b} = 17.0$, $J_{4a,5} = 8.5$ Hz, H-4a), 2.76 (dd, 1 H, $J_{4b,5} = 4.0$ Hz, H-4b), 1.56 and 1.44 (2 s, 6 H, 2 Me), 1.38 (s, 9 H, *t*-Bu). Anal. Calcd for $C_{46}H_{55}NO_9$: C, 72.13; H, 7.24; N, 1.83. Found: C, 72.07; H, 7.15; N, 1.68. Eluted second was the β-linked *C*-glycoside **14** (30 mg, ∼2%) slightly contamined by the α-anomer. ^{1}H NMR (DMSO-d_6, 120 °C) selected data: δ 4.84 and 4.81 (2 d, 2 H, $J = 11.0$ Hz, PhCH_2), 4.75 and 4.61 (2 d, 2 H, $J = 11.5$ Hz, PhCH_2), 4.65 and 4.47 (2 d, 2 H, $J = 11.4$ Hz, PhCH_2), 4.52 and 4.46 (2 d, 2 H, $J = 12.0$ Hz, PhCH_2), 4.09 (dd, 1 H, $J = 7.5$, $J = 9.2$ Hz), 3.85 (dd, 1 H, $J = 4.0$, $J = 9.2$ Hz), 3.37 (t, 1 H, $J = 9.0$ Hz), 2.81 (dd, 1 H, $J = 2.9$, $J = 16.2$ Hz), 2.67 (dd, 1 H, $J = 8.8$, $J = 16.2$ Hz), 1.56 and 1.44 (2 s, 6 H), 1.38 (s, 9 H, *t*-Bu).

For preparative purposes the 10:1 mixture of **12** and **14** was used without further purification, since the β-anomer was easily removed by column chromatography as deoxygenated derivative **25**.

Conversion of the Tetra-*O*-benzyl-α-*C*-glycoside 12 into the Tetra-*O*-acetyl Derivative. To prove the α-D-configuration the *C*-glycoside **12** was debenzylated (H_2, 10% Pd/C, 1:1 MeOH−AcOEt, 1 bar, room temperature) and peracetylated (Ac_2O, Py, room temperature, 2 h). ^{1}H NMR (DMSO-d_6, 120 °C): δ 5.19 (dd, 1 H, $J_{6,7} = J_{7,8} = 8.3$ Hz, H-7), 4.98 (dd, 1 H, $J_{5,6} = 5.2$ Hz, H-6), 4.87 (dd, 1 H, $J_{8,9} = 8.0$ Hz, H-8), 4.63 (ddd, 1 H, $J_{4a,5} = 8.0$, $J_{4b,5} = 4.5$ Hz, H-5), 4.52 (dd, 1 H, $J_{1a,2} = 7.5$, $J_{1b,2} = 3.2$ Hz, H-2), 4.17 (dd, 1 H, $J_{9,10a} = 6.0$, $J_{10a,10b} = 12.0$ Hz, H-10a), 4.16 (dd, 1 H, $J_{1a,1b} = 9.5$ Hz, H-1a), 4.08 (dd, 1 H, H-10b), 3.98 (ddd, 1 H, H-9), 3.92 (dd, 1 H, H-1b), 3.10 (dd, 1 H, $J_{4a,4b} = 17.5$ Hz, H-4a), 2.73 (dd, 1 H, H-4b), 2.00 (s, 12 H, 4 Ac), 1.59 and 1.48 (2 s, 6 H, 2 Me), 1.41 (s, 9 H, *t*-Bu).

Conversion of the Tetra-*O*-benzyl-β-*C*-glycoside 14 into the Tetra-*O*-acetyl Derivative. To prove the β-D-configuration the *C*-glycoside **14** was debenzylated (H_2, 10% Pd/C, 1:1 MeOH−AcOEt, 1 bar, room temperature) and peracetylated (Ac_2O, Py, room temperature, 2 h). ^{1}H NMR (DMSO-d_6, 120 °C): δ 5.22 (dd, 1 H, $J_{6,7} = J_{7,8} = 9.3$ Hz, H-7), 4.89 (dd, 1 H, $J_{5,6} = 9.0$ Hz, H-6), 4.80 (dd, 1 H, H-8), 4.47 (dd, 1 H, $J_{1a,2} = 7.6$, $J_{1b,2} = 3.7$ Hz, H-2), 4.29 (ddd, 1 H, $J_{4a,5} = 8.2$, $J_{4b,5} = 3.3$ Hz, H-5), 4.15−4.04 (m, 4 H, H-1a, H-9, 2 H-10), 3.87 (dd, 1 H, $J_{1a,1b} = 9.4$ Hz, H-1b), 2.71 (dd, 1 H, $J_{4a,4b} = 17.0$ Hz, H-4a), 2.60 (dd, 1 H, H-4b), 1.99 and 1.94 (2 s, 12 H, 4 Ac), 1.57 and 1.46 (2 s, 6 H, 2 Me), 1.40 (s, 9 H, *t*-Bu).

Conversion of the Octa-*O*-benzylglycoside 19 into the Octa-*O*-acetyl Derivative. To prove the α-D-configuration the *C*-glycoside **19** was debenzylated (H_2, 20% $Pd(OH)_2$/C, 1:1 MeOH−AcOEt, 1 bar, room temperature) and peracetylated (Ac_2O, Py, room temperature, 2 h). ^{1}H NMR (DMSO-d_6, 140 °C) selected data: δ 6.15 (d, 1 H, $J_{1',2'} = 3.8$ Hz, H-1′), 5.03 (dd, 1 H, $J_{2',3'} = 10.3$ Hz, H-2′), 5.00 (dd, 1 H, $J_{5,6} = 5.0$, $J_{6,7} = 8.0$ Hz, H-6), 4.72 (dd, 1 H, $J_{1a,2} = 7.5$, $J_{1b,2} = 3.0$ Hz, H-2), 4.65 (ddd, 1 H, $J_{4a,5} = 8.6$, $J_{4b,5} = 4.1$ Hz, H-5), 4.30 (dd, 1 H, $J_{1a,1b} = 9.6$ Hz, H-1a), 3.16 (dd, 1 H, $J_{4a,4b} = 17.5$ Hz, H-4a), 2.73 (dd, 1 H, H-4b), 1.66 and 1.56 (2 s, 6 H, 2 Me).

5,9-Anhydro-6,7,8,10-tetra-*O*-benzyl-2,3,4-trideoxy-1,2-*N*,*O*-isopropylidene-2-(*tert*-butoxycarbonylamino)-D-*threo*-L-*gulo*-decitol (20). To a cooled (−20 °C), stirred solution of **11** (500 mg, 0.65 mmol) in CH_3OH (2 mL) and Et_2O (2 mL) was added $NaBH_4$ (52 mg, 1.37 mmol). The mixture was stirred at −20 °C for an additional 1 h, then diluted with acetone (0.5 mL), warmed to room temperature, and concentrated. The residue was suspended in CH_2Cl_2 (60 mL), washed with 1 M phosphate buffer at pH = 7 (2 × 10 mL), dried ($MgSO_4$), and concentrated.

To a warmed (70 °C), stirred solution of the mixture of diastereomeric alcohols (500 mg, ∼0.65 mmol) in anhydrous THF (4 mL) were added 1,1′-thiocarbonyldiimidazole (1.16 g, 6.53 mmol) and 4-*N*,*N*-(dimethylamino)pyridine (1.19 g, 9.75 mmol). The mixture was stirred for an additional 6 h at 70 °C, then concentrated. The residue was eluted from a short column of silica gel (2 × 8 cm, d × h) with 2.5:1 cyclohexane−AcOEt to give the corresponding thiocarbonylimidazolides (474 mg, ∼83%) slightly contamined by uncharacterized byproducts.

To a warmed (85 °C), stirred solution of the thiocarbonylimidazolides (474 mg, ∼0.54 mmol) in anhydrous toluene (2.5 mL) were added Bu_3SnH (1.46 mL, 5.42 mmol) and AIBN (8.9 mg, 0.054 mmol). The solution was stirred at 85 °C for an additional 2 h, then concentrated. The residue was eluted from a column of silica gel (4 × 15 cm, d × h) with 9:1 cyclohexane−AcOEt to give **20** (293 mg, 60% from **11**) as a syrup: $[\alpha]_D = +37.1$ (*c* 0.8). ^{1}H NMR (DMSO-d_6, 160 °C): δ 7.38−7.20 (m, 20 H, 4 Ph), 4.71 and 4.55 (2 d, 2 H, $J = 11.7$ Hz, PhCH_2), 4.71 and 4.65 (2 d, 2 H, $J = 12.2$ Hz, PhCH_2), 4.63 and 4.56 (2 d, 2 H, $J = 12.0$ Hz, PhCH_2), 4.50 (s, 2 H, PhCH_2), 4.02−3.73 (m, 8 H), 3.69 (dd, 1 H, $J = 4.2$, 11.3 Hz), 3.65 (dd, 1 H, $J = 2.2$, 8.1 Hz), 1.76−1.50 (m, 4 H), 1.49, 1.44 (2 s, 6 H, 2 Me), 1.42 (s, 9 H, *t*-Bu). MALDI-TOF MS: 775.1 (M^+ + Na), 791.4 (M^+ + K) Anal. Calcd for $C_{46}H_{57}NO_8$: C, 73.48; H, 7.64; N, 1.86. Found: C, 73.50; H, 7.75; N, 1.74.

5,9-Anhydro-6,7,8,10-tetra-*O*-benzyl-2,3,4-trideoxy-1,2-*N*,*O*-isopropylidene-2-(*tert*-butoxycarbonylamino)-D-*erythro*-L-*gulo*-decitol (21). The α-linked *C*-glycoside **12** (500 mg,

0.65 mmol) was deoxygenated as described for the preparation of **20**. Column chromatography (from 10:1 to 5:1 cyclohexane−AcOEt) of the residue gave **21** (293 mg, 60% from **12**) as a white foam: $[\alpha]_D = +42.0$ (*c* 1.1). ^{1}H NMR (DMSO-d_6, 120 °C): δ 7.38−7.15 (m, 20 H, 4 Ph), 4.82 and 4.72 (2 d, 2 H, J = 11.5 Hz, PhCH_2), 4.73 and 4.55 (2 d, 2 H, J = 11.8 Hz, PhCH_2), 4.65 and 4.59 (2 d, 2 H, J = 12.0 Hz, PhCH_2), 4.53 and 4.48 (2 d, 2 H, J = 11.9 Hz, PhCH_2), 3.99−3.93 (m, 1 H), 3.92 (dd, 1 H, J = 6.0, 8.8 Hz), 3.85−3.78 (m, 1 H), 3.77 (t, 1 H, J = 8.5 Hz), 3.70−3.59 (m, 5 H), 3.46 (dd, 1 H, J = 8.1, 8.2 Hz), 1.78−1.58 (m, 4 H), 1.48, 1.39 (2 s, 6 H, 2 Me), 1.42 (s, 9 H, *t*-Bu). Anal. Calcd for $C_{46}H_{57}NO_8$: C, 73.48; H, 7.64; N, 1.86. Found: C, 73.32; H, 7.70; N, 1.71.

5,9-Anhydro-6,7,8,10-tetra-*O*-benzyl-2,3,4-trideoxy-2-(*tert*-butoxycarbonylamino)-D-*threo*-L-*gulo*-deconic Acid (22). To a cooled (0 °C), stirred solution of **20** (150 mg, 0.20 mmol) in acetone (4 mL) was added freshly prepared 1 M Jones reagent (0.60 mL, 0.6 mmol). The mixture was allowed to warm to room temperture in 30 min, stirred at room temperature for an additional 3 h, and then diluted with 2-propanol (∼0.3 mL). The suspension was neutralized with saturated aqueous $NaHCO_3$, diluted with Et_2O (60 mL), and washed with brine (2 × 10 mL). The organic phase was dried ($MgSO_4$) and concentrated to afford **22** (138 mg, ∼95%) as an oil ∼95% pure by ^{1}H NMR analysis. ^{1}H NMR selected data: δ 5.29 (bd, 1 H, $J_{2,NH}$ = 6.5 Hz, NH), 4.30−4.24 (m, 1 H, H-2), 1.99−1.84 and 1.80−1.51 (2 m, 4 H, 2 H-3, 2 H-4), 1.42 (s, 9 H, *t*-Bu). ^{13}C NMR selected data: δ 176.3 (CO_2H), 155.8 (CO_2*t*-Bu), 53.5 (C-2), 28.3 (CH_3).

Prolonged reaction time or larger excess of the Jones reagent gave **22** in lower yields due to acidic cleavage of the benzyl groups.

5,9-Anhydro-6,7,8,10-tetra-*O*-benzyl-2,3,4-trideoxy-2-(*tert*-butoxycarbonylamino)-D-*erythro*-L-*gulo*-deconic Acid (23). Treatment of **21** (150 mg, 0.20 mmol) as described for the preparation of **22** gave **23** (138 mg, ∼95%) as an oil ∼95% pure by ^{1}H NMR analysis. ^{1}H NMR selected data: δ 5.27 (bd, 1 H, $J_{2,NH}$ = 6.5 Hz, NH), 4.38−4.26 (m, 1 H, H-2), 2.19−1.88 and 1.86−1.60 (2 m, 4 H, 2 H-3, 2 H-4), 1.42 (s, 9 H, *t*-Bu). ^{13}C NMR selected data: δ 176.3 (CO_2H), 155.9 (CO_2*t*-Bu), 53.8 (C-2), 28.4 (CH_3).

Prolonged reaction time or larger excess of the Jones reagent gave **23** in lower yields due to acidic cleavage of the benzyl groups.

Methyl 5,9-Anhydro-6,7,8,10-tetra-*O*-benzyl-2,3,4-trideoxy-2-(*tert*-butoxycarbonylamino)-D-*threo*-L-*gulo*-deconate (22 Me ester). Treatment of a solution of crude acid **22** in 1:1 Et_2O−MeOH with ethereal diazomethane at 0 °C for 5 min gave, after column chromatography on silica gel (5:1 cyclohexane−AcOEt), **22 Me ester** as a syrup: $[\alpha]_D = +29.0$ (*c* 1.0).^{1}H NMR (DMSO-d_6, 120 °C): δ 7.38−7.20 (m, 20 H, 4 Ph), 6.53 (bd, 1 H, $J_{2,NH}$ = 7.5 Hz, NH), 4.70 and 4.66 (2 d, 2 H, J = 12.0 Hz, PhCH_2), 4.70 and 4.53 (2 d, 2 H, J = 11.7 Hz, PhCH_2), 4.61 and 4.56 (2 d, 2 H, J = 12.0 Hz, PhCH_2), 4.51 and 4.47 (2 d, 2 H, J = 11.8 Hz, PhCH_2), 4.06−3.84 (m, 5 H), 3.79−3.72 (m, 2 H), 3.65 (dd, 1 H, $J_{9,10b}$ = 4.4, $J_{10a,10b}$ = 10.8 Hz, H-10b), 3.61 (s, 3 H, OMe), 1.92−1.57 (m, 4 H), 1.38 (s, 9 H, *t*-Bu). MALDI-TOF MS: 762.3 (M^+ + Na), 778.8 (M^+ + K). Anal. Calcd for $C_{44}H_{53}NO_9$: C, 71.43; H, 7.22; N, 1.89. Found: C, 71.50; H, 7.31; N, 1.95.

Methyl 5,9-Anhydro-6,7,8,10-tetra-*O*-benzyl-2,3,4-trideoxy-2-(*tert*-butoxycarbonylamino)-D-*erythro*-L-*gulo*-deconate (23 Me ester). Treatment of a solution of crude acid **23** in 1:1 Et_2O−MeOH with ethereal diazomethane at 0 °C for 5 min gave, after column chromatography on silica gel (5:1 cyclohexane−AcOEt), **23 Me ester** as a white foam: $[\alpha]_D = +33.1$ (*c* 0.5).^{1}H NMR (acetone-d_6): δ 7.48−7.22 (m, 20 H, 4 Ph), 6.40 (bd, 1 H, $J_{2,NH}$ = 8.0 Hz, NH), 4.98 and 4.83 (2 d, 2 H, J = 11.5 Hz, PhCH_2), 4.88 and 4.64 (2 d, 2 H, J = 11.8 Hz, PhCH_2), 4.74 (s, 2 H, PhCH_2), 4.63 and 4.56 (2 d, 2 H, J = 12.0 Hz, PhCH_2), 4.34−4.25 (m, 1 H, H-2), 4.12 (ddd, 1 H, $J_{4a,5}$ = 3.0, $J_{4b,5}$ = 11.0, $J_{5,6}$ = 6.0 Hz, H-5), 3.83 (dd, 1 H, J = 9.0, 9.1 Hz), 3.78−3.65 (m, 4 H, H-6, H-9, 2 H-10), 3.69 (s, 3 H, OMe), 3.55 (dd, 1 H, J = 8.9, 9.1 Hz), 2.20−1.70 (m, 4 H, 2 H-3, 2 H-4), 1.42 (s, 9 H, *t*-Bu). Anal. Calcd for $C_{44}H_{53}NO_9$: C, 71.43; H, 7.22; N, 1.89. Found: C, 71.38; H, 7.15; N, 1.64.

Anomerization of 11 into 13. To a cooled (−78 °C), stirred mixture of *t*-BuLi (94 μL, 0.16 mmol, of a 1.7 M solution in pentane), activated 4-Å powdered molecular sieves (100 mg), and anhydrous Et_2O (1.5 mL) was added dropwise a solution of **11** (100 mg, 0.13 mmol) in anhydrous Et_2O (0.5 mL). The mixture was stirred at − 78 °C for 5 min, then allowed to warm to −20 °C in 2 h. After an additional 2 h at room temperature, the mixture was diluted with Et_2O (50 mL), filtered through a pad of Celite, and washed with 1 M phosphate buffer at pH = 7 (2 × 5 mL). The organic phase was dried ($MgSO_4$) and concentrated to give a 3:7 mixture of crude α- and β-linked *C*-glycosides **11** and **13** (90 mg, ∼90%). Elution of this mixture from a column of silica gel with 9:1 toluene−Et_2O afforded the β-anomer **13** (60 mg, ∼60%) contamined by ca. 5% (^{1}H NMR analysis) of the corresponding epimer at the carbon bearing the nitrogen atom.

A similar equilibration mixture was obtained starting from the 19:1 mixture of α- and β-anomers resulting from the glycosylation reaction.

Anomerization of 12 into 14. Treatment of **12** (100 mg, 0.13 mmol) as described for the anomerization of **11** gave a ∼1:1 mixture of crude α- and β-linked *C*-glycoside **12** and **14** (82 mg, 82%). Purification of this mixture by MPLC (30:1 $CHCl_3$−CH_3CN) afforded first the α-anomer **12** (37 mg, 37%). Eluted second was the β-anomer **14** (43 mg, ∼43%) contamined by 20% (^{1}H NMR analysis) of the corresponding epimer at the carbon bearing the nitrogen atom. ^{1}H NMR (DMSO-d_6, 120 °C) selected data of **2-epi-14**: δ 4.11 (dd, 1 H, J = 7.5, 9.2 Hz), 3.89 (dd, 1 H, J = 4.0, 9.2 Hz), 3.38 (t, 1 H, J = 9.0 Hz), 1.39 (s, 9 H, *t*-Bu).

A similar equilibration mixture was obtained starting from the 10:1 mixture of α- and β-anomers resulting from the glycosylation reaction.

5,9-Anhydro-6,7,8,10-tetra-*O*-benzyl-2,3,4-trideoxy-1,2-*N*,*O*-isopropylidene-2-(*tert*-butoxycarbonylamino)-D-*threo*-L-*galacto*-decitol (24). The β-linked *C*-glycoside **13** (250 mg, ∼0.33 mmol) was deoxygenated as described for the preparation of **20** to afford pure **24** (135 mg, 55%) as a syrup. The small amount of the above-mentioned C-2 epimer was easily removed by column chromatography as thiocarbonylimidazolide derivative. Compound **24** was identical in all respects to the product that we prepared by another route.[10]

5,9-Anhydro-6,7,8,10-tetra-*O*-benzyl-2,3,4-trideoxy-2-(*tert*-butoxycarbonylamino)-D-*erythro*-L-*galacto*-deconic Acid (27). Treatment of a 4:1 mixture of **14** and its epimer (250 mg, ∼0.33 mmol) as described for the preparation of **20** gave **25** together with its C-2 epimer (149 mg, ∼60%), which could not be removed by chromatography. This mixture was oxidized as described for the preparation of **22** to afford crude **27** (137 mg, ∼95%) as an oil. ^{1}H NMR selected data: δ 5.30 (bd, 0.2 H, $J_{2,NH}$ = 7.5 Hz, NH), 5.23 (bd, 0.8 H, $J_{2,NH}$ = 7.5 Hz, NH), 4.38−4.26 (m 1 H, H-2), 1.46 (s, 9 H, *t*-Bu). ^{13}C NMR selected data: δ 175.6 (CO_2H), 155.7 (CO_2*t*-Bu), 53.3 (C-2), 28.4 (CH_3).

Prolonged reaction time or larger excess of the Jones reagent gave **27** in lower yields due to acidic cleavage of the benzyl groups.

Methyl 5,9-Anhydro-6,7,8,10-tetra-*O*-benzyl-2,3,4-trideoxy-2-(*tert*-butoxycarbonylamino)-D-*erythro*-L-*galacto*-deconate (27 Me ester). Treatment of a solution of crude acid **27** (contamined by 20% of its C-2 epimer) in 1:1 Et_2O−MeOH with ethereal diazomethane at 0 °C for 5 min gave, after preparative TLC (8:1 toluene−Et_2O), **27 Me ester** as a syrup: $[\alpha]_D = +1.9$ (*c* 0.9).^{1}H NMR: δ 7.38−7.15 (m, 20 H, 4 Ph), 5.05 (bd, 1 H, $J_{2,NH}$ = 8.0 Hz, NH), 4.90 (s, 2 H, PhCH_2), 4.88 and 4.57 (2 d, 2 H, J = 11.0 Hz, PhCH_2), 4.82 and 4.62 (2 d, 2 H, J = 10.8 Hz, PhCH_2), 4.63 and 4.54 (2 d, 2 H, J = 12.0 Hz, PhCH_2), 4.34−4.24 (m, 1 H, H-2), 3.74−3.57 (m, 4 H, H-7, H-8, 2 H-10), 3.69 (s, 3 H, OMe), 3.38 (ddd, 1 H, $J_{8,9}$ = 9.5, $J_{9,10a}$ = 3.0, $J_{9,10b}$ = 9.5 Hz, H-9), 3.30−3.18 (m, 2 H, H-5, H-6), 1.98−1.80 and 1.70−1.40 (2 m, 4 H, 2 H-3, 2 H-4), 1.42 (s, 9 H, *t*-Bu). Anal. Calcd for $C_{44}H_{53}NO_9$: C, 71.43; H, 7.22; N, 1.89. Found: C, 71.45; H, 7.19; N, 1.71. ^{1}H NMR selected data of **2-epi-27 Me**

ester: δ 5.15 (bd, 1 H, $J_{2,NH}$ = 8.0 Hz, NH), 3.70 (s, 3 H, OMe), 1.44 (s, 9 H, *t*-Bu).

2,6-Anhydro-3,4,5,7-tetra-*O*-benzyl-*aldehydo*-D-glycero-L-*manno*-heptopyranose (28). A mixture of 2-(2,3,4,6-tetra-*O*-benzyl-β-D-galactopyranosyl)thiazole[23] (700 mg, 1.15 mmol), activated 4-Å powdered molecular sieves (1.20 g), and anhydrous CH_3CN (12 mL) was stirred at room temperature for 10 min, then methyl triflate (156 μL, 1.38 mmol) was added. The suspension was stirred at room temperature for 15 min and then concentrated to dryness. To a cooled (0 °C), stirred suspension of the crude *N*-methylthiazolium salt in CH_3OH (12 mL) was added $NaBH_4$ (91 mg, 2.42 mmol). The mixture was stirred at room temperature for an additional 5 min, diluted with acetone (1 mL), filtered through a pad of Celite, and concentrated. A solution of the crude mixture of diastereomeric thiazolidines in CH_3CN (10.9 mL) and H_2O (1.1 mL) was treated, under vigorous stirring, with CuO (366 mg, 4.60 mmol) and then $CuCl_2 \cdot 2H_2O$ (196 mg, 1.15 mmol). The mixture was stirred at room temperature for 35 min, then filtered through a pad of Celite, and concentrated to remove acetonitrile and most of the water (bath temperature not exceeding 40 °C). The brown residue was triturated with Et_2O (4 × 12 mL), and the liquid phase was pipetted and filtered through a pad (4 × 1.5 cm, d × h) of Florisil (100−200 mesh) to afford a colorless solution. After a further washing of Florisil with AcOEt (12 mL) the combined organic phases were concentrated. The residue was eluted from a short column (2.5 × 8 cm, d × h) of silica gel with 2.5:1 cyclohexane−AcOEt to afford the aldehyde **28** (495 mg, 78%) as a syrup. For NMR data see ref 23.

We found that trace amounts of mercury salts present in formyl *C*-glycosides **28**, **29**, and **30** were detrimental to the Mukaiyama-type aldol condensation. Therefore we performed the hydrolysis of the thiazolidine derivatives in the presence of $CuCl_2$−CuO instead of $HgCl_2$.[33]

2,6-Anhydro-3,4,5,7-tetra-*O*-benzyl-*aldehydo*-D-*glycero*-D-*gulo*-heptopyranose (29). 2-(2,3,4,6-Tetra-*O*-benzyl-β-D-glucopyranosyl)thiazole[23] (700 mg, 1.15 mmol) was treated as described for the preparation of **28**. The crude aldehyde was eluted from a short column (2.5 × 8 cm, d × h) of silica gel with 2.5:1 cyclohexane−AcOEt to give **29** (476 mg, 75%) as a syrup. For NMR data see ref 23.

2,6-Anhydro-3,4,5,7-tetra-*O*-benzyl-*aldehydo*-D-*glycero*-D-*galacto*-heptopyranose (30). 2-(2,3,4,6-Tetra-*O*-benzyl-β-D-mannopyranosyl)thiazole[23] (700 mg, 1.15 mmol) was treated as described for the preparation of **28**. The crude aldehyde was eluted from a short column (2.5 × 8 cm, d × h) of silica gel with 2.5:1 cyclohexane−AcOEt to give **30** (508 mg, 80%) as a syrup. For NMR data see ref 23.

6,10-Anhydro-7,8,9,11-tetra-*O*-benzyl-2,4-dideoxy-1,2-*N*,*O*-isopropylidene-2-(*tert*-butoxycarbonylamino)-D-*lyxo*-D-*manno*- and -D-*altro*-3-undeculose (31). A mixture of aldeyde **28** (552 mg, 1.00 mmol), silyl enol ether **1a** (473 mg, 1.50 mmol), activated 4-Å powdered molecular sieves (400 mg), and anhydrous CH_2Cl_2 (6 mL) was stirred at room temperature for 15 min, then cooled to −30 °C and treated with freshly distilled $BF_3 \cdot Et_2O$ (127 μL, 1.00 mmol). The mixture was stirred at −30 °C for 50 min, neutralized with Et_3N, filtered through a pad of Celite, and concentrated. The residue was diluted with CH_2Cl_2 (100 mL), washed with 1 M phosphate buffer at pH = 7 (20 mL), dried ($MgSO_4$), and concentrated. The residue was eluted from a column of silica gel with cyclohexane−AcOEt (from 9:1 to 2.5:1) to afford first silyl enol ether **1a** (150 mg, 32%). Eluted second was ketone **8** (36 mg, 10%). Eluted third was a 3.5:1 mixture of hydroxy ketones **31** (620 mg, 78%). Higher R_f **31**; ^{1}H NMR (DMSO-d_6 + D_2O, 140 °C): δ 7.40−7.21 (m, 20 H, 4 Ph), 4.85 and 4.57 (2 d, 2 H, J = 11.8 Hz, PhCH_2), 4.84 and 4.73 (2 d, 2 H, J = 11.0 Hz, PhCH_2), 4.78 and 4.68 (2 d, 2 H, J = 11.5 Hz, PhCH_2), 4.54 and 4.49 (2 d, 2 H, J = 12.0 Hz, PhCH_2), 4.43 (dd, 1 H, $J_{1a,2}$ = 7.8, $J_{1b,2}$ = 3.2 Hz, H-2), 4.31 (ddd, 1 H, $J_{5,6}$ = 1.8, $J_{4a,5}$ = 6.3, $J_{4b,5}$ = 6.7 Hz, H-5), 4.08 (dd, 1 H, $J_{1a,1b}$ = 9.2 Hz, H-1a), 4.04 (dd, 1 H, $J_{6,7}$ = 9.5, $J_{7,8}$ = 9.0 Hz, H-7), 4.03 (dd, 1 H, $J_{8,9}$ = 2.6, $J_{9,10}$ = ∼0.5 Hz, H-9), 3.90 (dd, 1 H, H-1b), 3.72 (dd, 1 H, H-8), 3.68−3.55 (m, 3 H, H-10, 2 H-11), 3.19 (dd, 1 H, H-6), 2.81 (dd, 1 H, $J_{4a,4b}$ = 17.0 Hz, H-4a), 2.72 (dd, 1 H, H-4b), 1.56 and 1.44 (2 s, 6 H, 2 Me), 1.34 (s, 9 H, *t*-Bu). MALDI-TOF MS: 818.8 (M^+ + Na), 834.8 (M^+ + K). Anal. Calcd for $C_{47}H_{57}NO_{10}$: C, 70.92; H, 7.22; N, 1.76. Found: C, 70.85; H, 7.20; N, 1.80. Lower R_f **31**; ^{1}H NMR (DMSO-d_6 + D_2O, 120 °C): δ 7.40−7.21 (m, 20 H, 4 Ph), 4.84 and 4.61 (2 d, 2 H, J = 11.0 Hz, PhCH_2), 4.83 and 4.66 (2 d, 2 H, J = 11.8 Hz, PhCH_2), 4.79 and 4.56 (2 d, 2 H, J = 11.5 Hz, PhCH_2), 4.53 and 4.47 (2 d, 2 H, J = 12.0 Hz, PhCH_2), 4.37 (dd, 1 H, $J_{1a,2}$ = 7.8, $J_{1b,2}$ = 3.5 Hz, H-2), 4.32 (ddd, 1 H, $J_{4a,5}$ = 8.5, $J_{4b,5}$ = 3.2, $J_{5,6}$ = 1.8 Hz, H-5), 4.04 (dd, 1 H, $J_{8,9}$ = 2.5, $J_{9,10}$ = ∼0.5 Hz, H-9), 4.02 (dd, 1 H, $J_{1a,1b}$ = 9.2 Hz, H-1a), 3.85 (dd, 1 H, H-1b), 3.75 (dd, 1 H, $J_{7,8}$ = 8.9 Hz, H-8), 3.67 (dd, 1 H, $J_{6,7}$ = 9.2 Hz, H-7), 3.64 (ddd, 1 H, $J_{10,11a}$ = 5.8, $J_{10,11b}$ = 6.0 Hz, H-10), 3.62 (dd, 1 H, $J_{11a,11b}$ = 9.0 Hz, H-11a), 3.56 (dd, 1 H, H-11b), 3.37 (dd, 1 H, H-6), 2.75 (dd, 1 H, $J_{4a,4b}$ = 17.0 Hz, H-4a), 2.61 (dd, 1 H, H-4b), 1.53 and 1.44 (2 s, 6 H, 2 Me), 1.34 (s, 9 H, *t*-Bu). MALDI-TOF MS: 818.6 (M^+ + Na), 834.6 (M^+ + K). Anal. Calcd for $C_{47}H_{57}NO_{10}$: C, 70.92; H, 7.22; N, 1.76. Found: C, 70.90; H, 7.22; N, 1.54.

6,10-Anhydro-7,8,9,11-tetra-*O*-benzyl-2,4-dideoxy-1,2-*N*,*O*-isopropylidene-2-(*tert*-butoxycarbonylamino)-D-*arabino*-D-*manno*- and -D-*altro*-3-undeculose (32). Aldehyde **29** (552 mg, 1.00 mmol) was treated as described for the preparation of **31**. Column chromatography on silica gel (from 9:1 to 2.5:1 cyclohexane−AcOEt) of the residue afforded first silyl enol ether **1a** (160 mg, 34%). Eluted second was ketone **8** together with small amounts of α,β-unsaturated formyl *C*-glycosides (130 mg). Eluted third was the hydroxy ketone **32** (557 mg, 70%) as a syrup: $[\alpha]_D$ = +26.0 (*c* 1.0). ^{1}H NMR (DMSO-d_6 + D_2O, 120 °C): δ 7.40−7.18 (m, 20 H, 4 Ph), 4.82 (s, 2 H, PhCH_2), 4.78 (s, 2 H, PhCH_2), 4.74 and 4.60 (2 d, 2 H, J = 11.5 Hz, PhCH_2), 4.58 and 4.52 (2 d, 2 H, J = 12.0 Hz, PhCH_2), 4.44 (dd, 1 H, $J_{1a,2}$ = 7.5, $J_{1b,2}$ = 3.2 Hz, H-2), 4.31 (ddd, 1 H, $J_{4a,5}$ = 6.5, $J_{4b,5}$ = 6.0, $J_{5,6}$ = 1.8 Hz, H-5), 4.09 (dd, 1 H, $J_{1a,1b}$ = 9.1 Hz, H-1a), 3.93 (dd, 1 H, H-1b), 3.76−3.62 (m, 4 H), 3.49−3.44 (m, 2 H), 3.27−3.22 (m, 1 H, H-6), 2.85 (dd, 1 H, $J_{4a,4b}$ = 17.0 Hz, H-4a), 2.78 (dd, 1 H, H-4b), 1.58 and 1.42 (2 s, 6 H, 2 Me), 1.38 (s, 9 H, *t*-Bu). Anal. Calcd for $C_{47}H_{57}NO_{10}$: C, 70.92; H, 7.22; N, 1.76. Found: C, 70.82; H, 7.25; N, 1.48.

6,10-Anhydro-7,8,9,11-tetra-*O*-benzyl-2,4-dideoxy-1,2-*N*,*O*-isopropylidene-2-(*tert*-butoxycarbonylamino)-D-*arabino*-L-*galacto*- and -L-*gulo*-3-undeculose (33). Aldehyde **30** (552 mg, 1.00 mmol) was treated as described for the preparation of **31**. Column chromatography on silica gel (from 9:1 to 2.5:1 cyclohexane−AcOEt) of the residue afforded first silyl enol ether **1a** (160 mg, 34%). Eluted second was ketone **8** together with small amounts of α,β-unsaturated formyl *C*-glycosides (125 mg). Eluted third was the hydroxy ketone **33** (564 mg, 71%) as a syrup: $[\alpha]_D$ = −5.5 (*c* 0.5). ^{1}H NMR (DMSO-d_6 + D_2O, 140 °C): δ 7.40−7.18 (m, 20 H, 4 Ph), 4.90 and 4.74 (2 d, 2 H, J = 11.5 Hz, PhCH_2), 4.79 and 4.68 (2 d, 2 H, J = 12.0 Hz, PhCH_2), 4.79 and 4.58 (2 d, 2 H, J = 11.2 Hz, PhCH_2), 4.55 and 4.46 (2 d, 2 H, J = 11.8 Hz, PhCH_2), 4.45 (dd, 1 H, $J_{1a,2}$ = 7.5, $J_{1b,2}$ = 3.8 Hz, H-2), 4.29 (dd, 1 H, $J_{6,7}$ = ∼0.5, $J_{7,8}$ = 3.0 Hz, H-7), 4.21 (ddd, 1 H, $J_{5.6}$ = 8.5, $J_{4a,5}$ = 4.0, $J_{4b,5}$ = 8.2 Hz, H-5), 4.07 (dd, 1 H, $J_{1a,1b}$ = 9.1 Hz, H-1a), 3.92 (dd, 1 H, H-1b), 3.84 (dd, 1 H, $J_{8.9}$ = 8.9, $J_{9,10}$ = 9.3 Hz, H-9), 3.70 (dd, 1 H, $J_{10,11a}$ = 2.1, $J_{11a,11b}$ = 11.5 Hz, H-11a), 3.69 (dd, 1H, H-8), 3.64 (dd, 1 H, $J_{10,11b}$ = 4.5 Hz, H-11b), 3.43 (ddd, 1 H, H-10), 3.27 (dd, 1 H, H-6), 2.90 (dd, 1 H, $J_{4a,4b}$ = 16.2 Hz, H-4a), 2.63 (dd, 1 H, H-4b), 1.58, 1.44 (2 s, 6 H, 2 Me), 1.38 (s, 9 H, *t*-Bu). Anal. Calcd for $C_{47}H_{57}NO_{10}$: C, 70.92; H, 7.22; N, 1.76. Found: C, 70.79; H, 7.18; N, 1.53.

(*E*)-6,10-Anhydro-7,8,9,11-tetra-*O*-benzyl-2,4,5-trideoxy-1,2-*N*,*O*-isopropylidene-2-(*tert*-butoxycarbonylamino)-D-*threo*-L-*galacto*-undec-4-en-3-ulose (34). A mixture of hydroxy ketone **31** (398 mg, 0.50 mmol), 1,3-dicyclohexylcarbodiimide (1.03 g, 5.00 mmol), activated 4-Å powdered molecular sieves (200 mg), and anhydrous CH_3CN (3 mL) was stirred at room temperature for 15 min, then anhydrous Cu-

(33) Dondoni, A.; Marra, A.; Perrone, D. *J. Org. Chem*. **1993**, *58*, 275−277.

$(OTf)_2$ was added (250 μL of a 1.0 M solution of $Cu(OTf)_2$ in anhydrous CH_3CN). The mixture was stirred at room temperature for 50 min, then diluted with 1 M phosphate buffer at pH = 7 (0.5 mL), filtered through a pad of Celite, and concentrated. The residue was diluted with CH_2Cl_2 (100 mL), washed with 1 M phosphate buffer at pH = 7 (2 × 15 mL), dried ($MgSO_4$), and concentrated. The residue was eluted from a column of silica gel with cyclohexane−AcOEt (from 9:1 to 4:1, containing 0.3% of Et_3N) to give the enone **34** (315 mg, 81%) as a syrup: $[\alpha]_D = -9.6$ (*c* 0.8). ^{1}H NMR (DMSO-d_6, 140 °C): δ 7.42−7.20 (m, 20 H, 4 Ph), 6.93 (dd, 1 H, $J_{4,5} = 15.9$, $J_{5,6} = 4.7$ Hz, H-5), 6.54 (dd, 1 H, $J_{4,6} = 1.6$ Hz, H-4), 4.85 and 4.58 (2 d, 2 H, $J = 11.5$ Hz, PhCH_2), 4.80 and 4.57 (2 d, 2 H, $J = 11.8$ Hz, PhCH_2), 4.79 and 4.70 (2 d, 2 H, $J = 11.9$ Hz, PhCH_2), 4.59 (dd, 1 H, $J_{1a,2} = 3.5$, $J_{1b,2} = 7.5$ Hz, H-2), 4.53 and 4.48 (2 d, 2 H, $J = 12.0$ Hz, PhCH_2), 4.15 (dd, 1 H, $J_{1a,1b} = 9.2$ Hz, H-1a), 4.08 (dd, 1 H, $J_{8,9} = 2.5$, $J_{9,10} = \sim 0.5$ Hz, H-9), 4.01 (ddd, 1 H, $J_{6,7} = 9.2$ Hz, H-6), 3.84−3.74 (m, 3 H), 3.70−3.56 (m, 3 H), 1.53 and 1.45 (2 s, 6 H, 2 Me), 1.34 (s, 9 H, *t*-Bu). Anal. Calcd for $C_{47}H_{55}NO_9$: C, 72.56; H, 7.13; N, 1.80. Found: C, 72.38; H, 7.33; N, 1.62.

(*E*)-6,10-Anhydro-7,8,9,11-tetra-*O*-benzyl-2,4,5-trideoxy-1,2-*N*,*O*-isopropylidene-2-(*tert*-butoxycarbonylamino)-D-*erythro*-L-*galacto*-undec-4-en-3-ulose (35). Treatment of the hydroxy ketone **32** (398 mg, 0.50 mmol) as described for the preparation of **34** gave the enone **35** (311 mg, 80%) as a syrup: $[\alpha]_D = -3.2$ (*c* 0.6). ^{1}H NMR (DMSO-d_6, 140 °C): δ 7.40−7.18 (m, 20 H, 4 Ph), 6.93 (dd, 1 H, $J_{4,5} = 16.0$, $J_{5,6} = 5.0$ Hz, H-5), 6.58 (dd, 1 H, $J_{4,6} = 1.2$ Hz, H-4), 4.83 (s, 2 H, PhCH_2), 4.76 and 4.63 (2 d, 2 H, $J = 11.2$ Hz, PhCH_2), 4.73 and 4.59 (2 d, 2 H, $J = 11.5$ Hz, PhCH_2), 4.63 (dd, 1 H, $J_{1a,2} = 7.5$, $J_{1b,2} = 3.0$ Hz, H-2), 4.57 and 4.52 (2 d, 2 H, $J = 11.8$ Hz, PhCH_2), 4.16 (dd, 1 H, $J_{1a,1b} = 9.2$ Hz, H-1a), 4.10 (ddd, 1 H, $J_{6,7} = 9.2$ Hz, H-6), 3.84−3.51 (m, 5 H), 3.78 (dd, 1 H, H-1b), 3.37 (dd, 1 H, $J = 8.8$, 9.2 Hz), 1.58 and 1.44 (2 s, 6 H, 2 Me), 1.38 (s, 9 H, *t*-Bu). Anal. Calcd for $C_{47}H_{55}NO_9$: C, 72.56; H, 7.13; N, 1.80. Found: C, 72.42; H, 7.28; N, 1.54.

(*E*)-6,10-Anhydro-7,8,9,11-tetra-*O*-benzyl-2,4,5-trideoxy-1,2-*N*,*O*-isopropylidene-2-(*tert*-butoxycarbonylamino)-D-*erythro*-L-*gluco*-undec-4-en-3-ulose (36). Treatment of the hydroxy ketone **33** (398 mg, 0.50 mmol) as described for the preparation of **34** gave the enone **36** (311 mg, 80%) as a syrup: $[\alpha]_D = +11.7$ (*c* 1.0). ^{1}H NMR (DMSO-d_6, 140 °C): δ 7.40−7.18 (m, 20 H, 4 Ph), 6.90 (dd, 1 H, $J_{4,5} = 16.0$, $J_{5,6} = 4.5$ Hz, H-5), 6.54 (dd, 1 H, $J_{4,6} = 1.8$ Hz, H-4), 4.81 and 4.60 (2 d, 2 H, $J = 11.5$ Hz, PhCH_2), 4.78 and 4.68 (2 d, 2 H, $J = 12.0$ Hz, PhCH_2), 4.76 and 4.58 (2 d, 2 H, $J = 11.2$ Hz, PhCH_2), 4.68 (dd, 1 H, $J_{1a,2} = 7.5$, $J_{1b,2} = 3.2$ Hz, H-2), 4.60 and 4.52 (2 d, 2 H, $J = 12.1$ Hz, PhCH_2), 4.29 (ddd, 1 H, $J_{6,7} = 1.5$ Hz, H-6), 4.17 (dd, 1 H, $J_{7,8} = 2.8$ Hz, H-7), 4.14 (dd, 1 H, $J_{1a,1b} = 9.2$ Hz, H-1a), 3.89−3.68 (m, 5 H, H-1b, H-8, H-9, 2 H-11), 3.57−3.51 (m, 1 H, H-10), 1.59, 1.49 (2 s, 6 H, 2 Me), 1.38 (s, 9 H, *t*-Bu). Anal. Calcd for $C_{47}H_{55}NO_9$: C, 72.56; H, 7.13; N, 1.80. Found: C, 72.53; H, 7.25; N, 1.62.

6,10-Anhydro-7,8,9,11-tetra-*O*-benzyl-2,4,5-trideoxy-1,2-*N*,*O*-isopropylidene-2-(*tert*-butoxycarbonylamino)-D-*lyxo*-D-*manno*- and -D-*altro*-undecitol (3-hydroxy-37). To a cooled (0 °C), stirred solution of the enone **34** (400 mg, 0.51 mmol) in MeOH (1.5 mL) and Et_2O (1.5 mL) was added $NaBH_4$ (41 mg, 1.07 mmol). The mixture was stirred at 0 °C for 10 min and at room temperature for 10 min, then diluted with acetone (1.0 mL) and partially concentrated. The residue was suspended in CH_2Cl_2 (100 mL), washed with H_2O (2 × 10 mL), dried ($MgSO_4$), and concentrated. To a warmed (85 °C), stirred solution of crude allylic alcohols and freshly recrystallized *p*-toluenesulfonhydrazide (285 mg, 1.53 mmol) in dimethoxyethane (7 mL) was added 1 M aqueous sodium acetate (1.53 mL) in six portions during 3 h. After an additional 2.5 h at 85 °C the mixture was diluted with H_2O (5 mL) and extracted with CH_2Cl_2 (2 × 30 mL). The organic phase was dried ($MgSO_4$) and concentrated. The residue was eluted from a column of silica gel with cyclohexane−AcOEt (from 9:1 to 4:1) to give a ∼6:1 mixture of diastereomeric alcohols **3-hydroxy-37** (3*R*/3*S* = ∼1:1) and their C-5 transposed isomers **5-hydroxy-37** (5*R*/5*S* = ∼1:1) (311 mg, 78%). An analytical sample of **3-hydroxy-37** was obtained by preparative TLC (2.5:1 cyclohexane−AcOEt). ^{1}H NMR (DMSO-d_6, 140 °C) selected data: δ 7.40−7.18 (m, 20 H, 4 Ph), 7.87−7.43 (14 d, 8 H, PhCH_2), 4.03 (dd, 1 H, $J_{8,9} = 2.5$, $J_{9,10} = \sim 0.5$ Hz, H-9), 3.68 (dd, 1 H, $J_{7,8} = 9.0$ Hz, H-8), 3.24 (ddd, 1 H, $J_{5a,6} = 2.7$, $J_{5b,6} = 8.8$, $J_{6,7} = 9.2$ Hz, H-6). Anal. Calcd for $C_{47}H_{59}NO_9$: C, 72.19; H, 7.60; N, 1.79. Found: C, 72.08; H, 7.65; N, 1.61.

6,10-Anhydro-7,8,9,11-tetra-*O*-benzyl-2,4,5-trideoxy-1,2-*N*,*O*-isopropylidene-2-(*tert*-butoxycarbonylamino)-D-*arabino*-D-*manno*- and -D-*altro*-undecitol (3-hydroxy-38). Treatment of the enone **35** (400 mg, 0.51 mmol) as described for the preparation of **3-hydroxy-37** gave a ∼6:1 mixture of diastereomeric alcohols **3-hydroxy-38** (3*R*/3*S* = ∼2.5:1) and their C-5 transposed isomers **5-hydroxy-38** (5*R*/5*S* = ∼1:1) (319 mg, 80%). An analytical sample of **3-hydroxy-38** was obtained by preparative TLC (2.5:1 cyclohexane−AcOEt). ^{1}H NMR (DMSO-d_6, 140 °C) selected data: δ 7.38−7.18 (m, 20 H, 4 Ph), 4.83−4.47 (10 d, 8 H, PhCH_2), 4.02−3.62 (m, 8 H), 3.55−3.41 (m, 2 H), 3.36−3.22 (m, 2 H), 1.50 and 1.43 (2 s, 4.3 H, 2 Me), 1.48 and 1.44 (2 s, 1.7 H, 2 Me), 1.42 (s, 2.6 H, *t*-Bu), 1.41 (s, 6.4 H, *t*-Bu). Anal. Calcd for $C_{47}H_{59}NO_9$: C, 72.19; H, 7.60; N, 1.79. Found: C, 72.22; H, 7.73; N, 1.60.

6,10-Anhydro-7,8,9,11-tetra-*O*-benzyl-2,4,5-trideoxy-1,2-*N*,*O*-isopropylidene-2-(*tert*-butoxycarbonylamino)-D-*arabino*-L-*galacto*- and -L-*gulo*-undecitol (3-hydroxy-39). Treatment of the enone **36** (400 mg, 0.51 mmol) as described for the preparation of **3-hydroxy-37** gave a ∼6:1 mixture of diastereomeric alcohols **3-hydroxy-39** (3*R*/3*S* = ∼1:1) and their C-5 transposed isomers **5-hydroxy-39** (5*R*/5*S* = ∼1:1) (327 mg, 82%). An analytical sample of **3-hydroxy-39** was obtained by preparative TLC (2.5:1 cyclohexane−AcOEt). ^{1}H NMR (DMSO-d_6, 140 °C) selected data: δ 7.40−7.15 (m, 20 H, 4 Ph), 4.87−4.42 (12 d, 8 H, PhCH_2), 4.04−3.34 (m, 11 H), 2.00−1.50 (m, 4 H), 1.52−1.40 (6 s, 15 H). Anal. Calcd for $C_{47}H_{59}NO_9$: C, 72.19; H, 7.60; N, 1.79. Found: C, 72.15; H, 7.54; N, 1.68.

6,10-Anhydro-7,8,9,11-tetra-*O*-benzyl-2,3,4,5-tetradeoxy-1,2-*N*,*O*-isopropylidene-2-(*tert*-butoxycarbonylamino)-D-*threo*-L-*galacto*-undecitol (37). To a warmed (70 °C), stirred solution of a ∼6:1 mixture of **3-hydroxy-37** and **5-hydroxy-37** (300 mg, 0.38 mmol) in anhydrous THF (3 mL) were added 1,1′-thiocarbonyldiimidazole (677 mg, 3.80 mmol) and 4-*N*,*N*-(dimethylamino)pyridine (696 mg, 5.70 mmol). After an additional 6 h at 70 °C the mixture was concentrated. The residue was eluted from a short column of silica gel (1.5 × 8 cm, d × h) with 2.5:1 cyclohexane−AcOEt to give the corresponding thiocarbonylimidazolides (285 mg, ∼83%) slightly contamined by uncharacterized byproducts. To a warmed (85 °C), stirred solution of thiocarbonylimidazolides (285 mg, ∼0.32 mmol) in anhydrous toluene (3.0 mL) were added Bu_3SnH (0.86 mL, 3.20 mmol) and AIBN (5.3 mg, 0.032 mmol). The solution was stirred at 85 °C for an additional 2 h, then concentrated. The residue was eluted from a column of silica gel (3.5 × 15 cm, d × h) with 10:1 cyclohexane−AcOEt to give **37** (185 mg, 63% from **3-hydroxy-37** and **5-hydroxy-37**) as a syrup: $[\alpha]_D = +5.9$ (*c* 0.7). ^{1}H NMR (DMSO-d_6, 140 °C): δ 7.42−7.20 (m, 20 H, 4 Ph), 4.84 and 4.56 (2 d, 2 H, $J = 11.5$ Hz, PhCH_2), 4.84 and 4.62 (2 d, 2 H, $J = 11.6$ Hz, PhCH_2), 4.78 and 4.67 (2 d, 2 H, $J = 11.8$ Hz, PhCH_2), 4.52 and 4.47 (2 d, 2 H, $J = 12.0$ Hz, PhCH_2), 4.04 (dd, 1 H, $J_{8,9} = 2.6$, $J_{9,10} = \sim 0.5$ Hz, H-9), 3.86 (dd, 1 H, $J_{1a,2} = 5.8$, $J_{1a,1b} = 8.8$ Hz, H-1a), 3.78−3.71 (m, 1 H, H-2), 3.69 (dd, 1 H, $J_{7,8} = 9.0$ Hz, H-8), 3.65−3.50 (m, 5 H, H-1b, H-7, H-10, 2 H-11), 3.21 (ddd, 1 H, $J_{5a,6} = J_{6,7} = 9.0$, $J_{5b,6} = 2.8$ Hz, H-6), 1.82−1.58 and 1.55−1.20 (2 m, 6 H, 2 H-3, 2 H-4, 2 H-5), 1.43 and 1.39 (2 s, 6 H, 2 Me), 1.39 (s, 9 H, *t*-Bu). MALDI-TOF MS: 788.6 (M^+ + Na). Anal. Calcd for $C_{47}H_{59}NO_8$: C, 73.70; H, 7.76; N, 1.83. Found: C, 73.55; H, 7.68; N, 1.80.

Similar results were obtained when the same two-step deoxygenation reaction was performed using a ∼3:1 mixture of **3-hydroxy-37** and **5-hydroxy-37** as starting material.

6,10-Anhydro-7,8,9,11-tetra-*O*-benzyl-2,3,4,5-tetradeoxy-1,2-*N*,*O*-isopropylidene-2-(*tert*-butoxycarbonylamino)-D-*erythro*-L-*galacto*-undecitol (38). Treatment of a ∼6:1 mixture of **3-hydroxy-38** and **5-hydroxy-38** (300 mg, 0.38 mmol)

as described for the preparation of **37** gave **38** (184 mg, 63%) as a white foam: $[\alpha]_D = +6.2$ (*c* 1.0). ^{1}H NMR (DMSO-d_6, 120 °C): δ 7.40−7.15 (m, 20 H, 4 Ph), 4.79 (s, 2 H, PhCH_2), 4.77 and 4.60 (2 d, 2 H, $J = 11.2$ Hz, PhCH_2), 4.71 and 4.57 (2 d, 2 H, $J = 11.5$ Hz, PhCH_2), 4.53 and 4.48 (2 d, 2 H, $J = 11.8$ Hz, PhCH_2), 3.85 (dd, 1 H, $J_{1a,1b} = 8.8$, $J_{1a,2} = 5.8$ Hz, H-1a), 3.76−3.68 (m, 1 H, H-2), 3.68−3.56 (m, 4 H), 3.51−3.36 (m, 2 H), 3.28−3.16 (m, 2 H), 1.82−1.45 and 1.44−1.20 (2 m, 2 and 4 H, 2 H-3, 2 H-4, 2 H-5), 1.42 and 1.38 (2 s, 6 H, 2 Me), 1.38 (s, 9 H, *t*-Bu). Anal. Calcd for $C_{47}H_{59}NO_8$: C, 73.70; H, 7.76; N, 1.83. Found: C, 73.58; H, 7.73; N, 1.85.

Similar results were obtained when the same two-step deoxygenation reaction was performed using a ∼3:1 mixture of **3-hydroxy-38** and **5-hydroxy-38** as starting material.

6,10-Anhydro-7,8,9,11-tetra-*O*-benzyl-2,3,4,5-tetradeoxy-1,2-*N*,*O*-isopropylidene-2-(*tert*-butoxycarbonylamino)-D-*erythro*-L-*gluco*-undecitol (39). Treatment of a ∼6:1 mixture of **3-hydroxy-39** and **5-hydroxy-39** (300 mg, 0.38 mmol) as described for the preparation of **37** gave **39** (175 mg, 60%) as an oil: $[\alpha]_D = +7.1$ (*c* 1.0). ^{1}H NMR (DMSO-d_6, 140 °C): δ 7.42−7.18 (m, 20 H, 4 Ph), 4.91 and 4.69 (2 d, 2 H, $J = 11.5$ Hz, PhCH_2), 4.80 and 4.61 (2 d, 2 H, $J = 11.2$ Hz, PhCH_2), 4.80 and 4.58 (2 d, 2 H, $J = 11.3$ Hz, PhCH_2), 4.57 and 4.49 (2 d, 2 H, $J = 12.0$ Hz, PhCH_2), 3.96−3.60 (m, 8 H), 3.44−3.35 (m, 2 H), 1.80−1.18 (m, 6 H), 1.48, 1.41 (2 s, 6 H, 2 Me), 1.41 (s, 9 H, *t*-Bu). Anal. Calcd for $C_{47}H_{59}NO_8$: C, 73.70; H, 7.76; N, 1.83. Found: C, 73.77; H, 7.52; N, 1.63.

Similar results were obtained when the same two-step deoxygenation reaction was performed using a ∼3:1 mixture of **3-hydroxy-39** and **5-hydroxy-39** as starting material.

6,10-Anhydro-7,8,9,11-tetra-*O*-benzyl-2,3,4,5-tetradeoxy-2-(*tert*-butoxycarbonylamino)-D-*threo*-L-*galacto*-undeconic Acid (40). Treatment of **37** (150 mg, 0.20 mmol) as described for the preparation of **22** gave **40** (141 mg, ∼95%) as an oil ∼95% pure by ^{1}H NMR analysis. ^{1}H NMR selected data: δ 5.07 (bd, 1 H, $J_{2,NH} = 7.0$ Hz, NH), 4.35−4.25 (m, 1 H, H-2), 3.20 (ddd, 1 H, $J_{5a,6} = J_{6,7} = 9.0$, $J_{5b,6} = 2.3$ Hz, H-6), 1.42 (s, 9 H, *t*-Bu). ^{13}C NMR selected data: δ 176.1 (CO_2H), 155.6 (CO_2*t*-Bu), 53.5 (C-2), 28.3 (CH_3). Prolonged reaction time or larger excess of the Jones reagent gave **40** in lower yield due to acidic cleavage of the benzyl groups.

6,10-Anhydro-7,8,9,11-tetra-*O*-benzyl-2,3,4,5-tetradeoxy-2-(*tert*-butoxycarbonylamino)-D-*erythro*-L-*galacto*-undeconic Acid (41). Treatment of **38** (150 mg, 0.20 mmol) as described for the preparation of **22** gave **41** (141 mg, ∼95%) as an oil ∼95% pure by ^{1}H NMR analysis. ^{1}H NMR selected data: δ 5.13 (bd, 1 H, $J_{2,NH} = 7.5$ Hz, NH), 4.35−4.25 (m, 1 H, H-2), 4.93−4.77 and 4.67−4.51 (8 H, PhCH_2), 1.42 (s, 9 H, *t*-Bu). ^{13}C NMR selected data: δ 176.1 (CO_2H), 155.7 (CO_2*t*-Bu), 53.5 (C-2), 28.3 (CH_3). Prolonged reaction time or larger excess of the Jones reagent gave **41** in lower yield due to acidic cleavage of the benzyl groups.

6,10-Anhydro-7,8,9,11-tetra-*O*-benzyl-2,3,4,5-tetradeoxy-2-(*tert*-butoxycarbonylamino)-D-*erythro*-L-*gluco*-undeconic Acid (42). Treatment of **39** (150 mg, 0.20 mmol) as described for the preparation of **22** gave **42** (141 mg, ∼95%) as an oil ∼95% pure by ^{1}H NMR analysis. ^{1}H NMR selected data: δ 7.40−7.12 (m, 20 H, 4 Ph), 5.06 (bd, 1 H, $J_{2,NH} = 7.5$ Hz, NH), 4.99 and 4.69 (2 d, 2 H, $J = 11.8$ Hz, PhCH_2), 4.88 and 4.53 (2 d, 2 H, $J = 11.0$ Hz, PhCH_2), 4.79 and 4.72 (2 d, 2 H, $J = 11.5$ Hz, PhCH_2), 4.60 (s, 2 H, PhCH_2), 4.30−4.18 (m, 1 H, H-2), 3.86−3.55 (m, 5 H, H-7, H-8, H-10, 2 H-11), 3.46−3.38 (m, 1 H, H-9), 3.32−3.22 (m, 1 H, H-6), 1.90−1.10 (m, 6 H, 2 H-3, 2 H-4, 2 H-5), 1.42 (s, 9 H, *t*-Bu). ^{13}C NMR selected data: δ 175.7 (CO_2H), 155.5 (CO_2*t*-Bu), 53.0 (C-2), 27.9 (CH_3). Prolonged reaction time or larger excess of the Jones reagent gave **42** in lower yield due to acidic cleavage of the benzyl groups.

Methyl 6,10-Anhydro-7,8,9,11-tetra-*O*-benzyl-2,3,4,5-tetradeoxy-2-(*tert*-butoxycarbonylamino)-D-*threo*-L-*galacto*-undeconate (40 Me ester). Treatment of a solution of crude acid **40** in 1:1 Et_2O−MeOH with ethereal diazomethane at 0 °C for 5 min gave, after column chromatography on silica gel (5:1 cyclohexane−AcOEt), **40 Me ester** as a syrup: $[\alpha]_D = +6.4$ (*c* 0.5).^{1}H NMR: δ 7.42−7.20 (m, 20 H, 4 Ph), 4.98 (bd, 1 H, $J = 8.0$ Hz, NH), 4.94 and 4.62 (2 d, 2 H, $J = 11.0$ Hz, PhCH_2), 4.93 and 4.63 (2 d, 2 H, $J = 11.6$ Hz, PhCH_2), 4.75 and 4.66 (2 d, 2 H, $J = 11.5$ Hz, PhCH_2), 4.48 and 4.42 (2 d, 2 H, $J = 11.8$ Hz, PhCH_2), 4.30−4.21 (m, 1 H, H-2), 3.98 (dd, 1 H, $J_{8,9} = 2.6$, $J_{9,10} = \sim 0.5$ Hz, H-9), 3.68 (s, 3 H, OMe), 3.64 (dd, 1 H, $J_{6,7} = 9.0$, $J_{7,8} = 8.8$ Hz, H-7), 3.57 (dd, 1 H, H-8), 3.56−3.44 (m, 3 H, H-10, 2 H-11), 3.16 (ddd, 1 H, $J_{5a,6} = J_{6,7} = 9.0$, $J_{5b,6} = 2.3$ Hz, H-6), 1.95−1.20 (m, 6 H, 2 H-3, 2 H-4, 2 H-5), 1.41 (s, 9 H, *t*-Bu). Anal. Calcd for $C_{45}H_{55}NO_9$: C, 71.69; H, 7.35; N, 1.86. Found: C, 71.83; H, 7.40; N, 1.65.

Methyl 6,10-Anhydro-7,8,9,11-tetra-*O*-benzyl-2,3,4,5-tetradeoxy-2-(*tert*-butoxycarbonylamino)-D-*erythro*-L-*galacto*-undeconate (41 Me ester). Treatment of a solution of crude acid **41** in 1:1 Et_2O−MeOH with ethereal diazomethane at 0 °C for 5 min gave, after column chromatography on silica gel (5:1 cyclohexane−AcOEt), **41 Me ester** as a syrup: $[\alpha]_D = +6.2$ (*c* 0.7).^{1}H NMR: δ 7.40−7.20 and 7.18−7.10 (2 m, 20 H, 4 Ph), 5.04 (bd, 1 H, $J = 8.0$ Hz, NH), 4.90 (s, 2 H, PhCH_2), 4.88 and 4.62 (2 d, 2 H, $J = 11.0$ Hz, PhCH_2), 4.82 and 4.54 (2 d, 2 H, $J = 10.9$ Hz, PhCH_2), 4.63 and 4.54 (2 d, 2 H, $J = 12.0$ Hz, PhCH_2), 4.33−4.22 (m, 1 H, H-2), 3.74−3.58 (m, 4 H, H-8, H-9, 2 H-11), 3.70 (s, 3 H, OMe), 3.36 (ddd, 1 H, $J_{9,10} = 9.1$, $J_{10,11a} = 2.2$, $J_{10,11b} = 3.5$ Hz, H-10), 3.25 (dd, 1 H, $J_{6,7} = J_{7,8} = 9.0$ Hz, H-7), 3.20 (ddd, 1 H, $J_{5a,6} = J_{6,7} = 9.0$, $J_{5b,6} = 2.4$ Hz, H-6), 1.88−1.72, 1.70−1.51, and 1.50−1.29 (3 m, 6 H, 2 H-3, 2 H-4, 2 H-5), 1.43 (s, 9 H, *t*-Bu). Anal. Calcd for $C_{45}H_{55}NO_9$: C, 71.69; H, 7.35; N, 1.86. Found: C, 71.75; H, 7.44; N, 1.63.

Methyl 6,10-Anhydro-7,8,9,11-tetra-*O*-benzyl-2,3,4,5-tetradeoxy-2-(*tert*-butoxycarbonylamino)-D-*erythro*-L-*gluco*-undeconate (42 Me ester). Treatment of a solution of crude acid **42** in 1:1 Et_2O−MeOH with ethereal diazomethane at 0 °C for 5 min gave, after column chromatography on silica gel (5:1 cyclohexane−AcOEt), **42 Me ester** as a syrup: $[\alpha]_D = +5.5$ (*c* 0.6). ^{1}H NMR: δ 7.42−7.10 (m, 20 H, 4 Ph), 5.01 and 4.68 (2 d, 2 H, $J = 11.8$ Hz, PhCH_2), 4.94 (bd, 1 H, $J = 8.0$ Hz, NH), 4.88 and 4.54 (2 d, 2 H, $J = 11.0$ Hz, PhCH_2), 4.80 and 4.73 (2 d, 2 H, $J = 11.6$ Hz, PhCH_2), 4.62 and 4.56 (2 d, 2 H, $J = 12.0$ Hz, PhCH_2), 4.26−4.15 (m, 1 H, H-2), 3.90 (dd, 1 H, $J_{8,9} = J_{9,10} = 9.2$ Hz, H-9), 3.75 (dd, 1 H, $J_{10,11a} = 1.7$, $J_{11a,11b} = 10.8$ Hz, H-11a), 3.71 (dd, 1 H, $J_{6,7} = \sim 0.5$, $J_{7,8} = 3.0$ Hz, H-7), 3.69 (s, 3 H, OMe), 3.67 (dd, 1 H, $J_{10,11b} = 5.8$ Hz, H-11b), 3.61 (dd, 1 H, H-8), 3.41 (ddd, 1 H, H-10), 3.26−3.19 (m, 1 H, H-6), 1.92−1.10 (m, 6 H, 2 H-3, 2 H-4, 2 H-5), 1.42 (s, 9 H, *t*-Bu). Anal. Calcd for $C_{45}H_{55}NO_9$: C, 71.69; H, 7.35; N, 1.86. Found: C, 71.55; H, 7.32; N, 1.80.

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