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Synthesis of Highly Functionalized Chiral Nitriles by Radical Fragmentation of β-Hydroxy Azides. Convenient Transformation of Aldononitriles into 1,4- and 1,5-Iminoalditols

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The synthesis of highly functionalized nitriles by an alkoxyl radical fragmentation of cyclic β-hydroxy azides is described. The alkoxyl radicals were generated by reaction of the alcohols with (diacetoxyiodo)benzene and iodine under mild conditions compatible with the presence of sensitive substituents and the protective groups most frequently used in carbohydrate chemistry. To explore the scope and limitations of this methodology, experiments were carried out using a variety of β-hydroxy azides of the carbohydrate (**1**−**6**, **33**, and **41**), monoterpenoid (**21** and **22**), and steroid (**23**−**25**) families of natural products. Of special interest are the aldopentonitriles (**15**−**18**, **34**, and **42**) and aldotetrononitriles (**19** and **20**) synthesized from the corresponding 2-azido-2-deoxycarbohydrates. To demonstrate the versatility of these aldononitriles as chiral synthons, 1,4-imino-1-deoxysugar (**37**) and 1,5-imino-1-deoxysugar (**43**) analogues of the polyhydroxypyrrolidine and -piperidine types were prepared.

Introduction

The synthesis of ϵ-ketonitriles from cyclic α-hydroxy oximes through a Beckmann fragmentation has frequently been utilized in synthetic organic chemistry.[1] Related methodologies for the synthesis of ϵ-ketonitriles by cleavage of trisubstituted cyclic olefins with DIB/$(TMS)N_3$ or LTA/$(TMS)N_3$,[2] CAN/NaN_3,[3] or photooxygenation in the presence of NaN_3/$Cu(OTf)_2$[4] have also been described.

On the other hand, several methods for preparing aldononitriles from carbohydrates are described in the literature, involving direct addition of HCN to aldoses (Fischer−Kiliani cyanohydrin synthesis),[5] dehydration of aldose oximes,[5b,6] and the reaction of *N*-bromoglycosylimines with Zn/Ag-graphite.[7] The first method provides aldononitriles with one more carbon atoms than the starting carbohydrate, while the aldononitriles synthesized by the other two methods retain the same number of carbon atoms. Also, special types of sugar nitriles, the 2,6-anhydro- and 2,5-anhydroaldononitriles (pyranosyl and furanosyl cyanides), have attracted considerable attention since they are valuable intermediates in the synthesis of *C*-glycosides.[8]

We have recently published the latest results of several of our ongoing studies of the alkoxyl radical fragmentation (ARF) of reducing sugars.[9] In this paper, we report on an extension of the ARF methodology to cyclic β-hydroxy azides that may be suitable for the synthesis of δ- or ϵ-ketonitriles. The reaction is triggered by the alkoxyl

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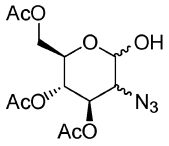
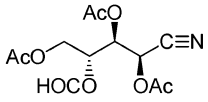
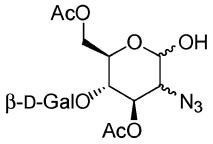
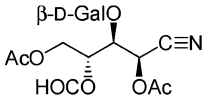
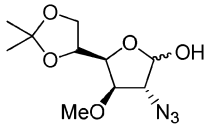
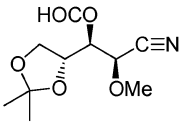
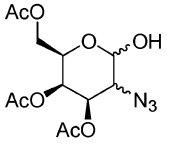
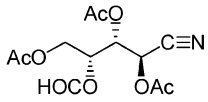
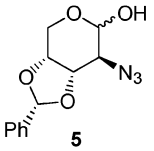
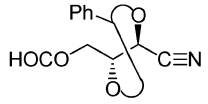
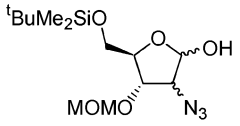
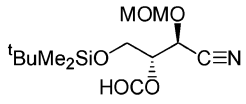
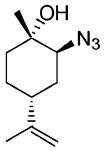
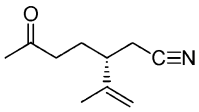
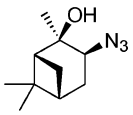
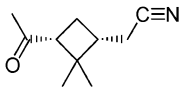
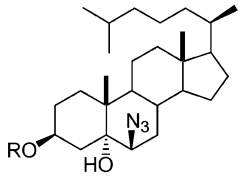
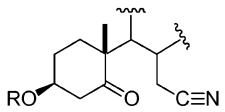
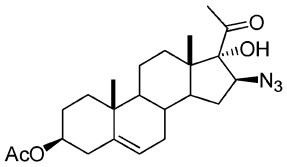
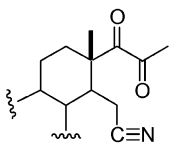
TABLE 1. Aldononitriles by β-Fragmentation of β-Hydroxy Azides in Carbohydrate Systems[a]

entry	substrate	time (h)	products	yield (%)
1	 **1**	2	 **15**	88
2	 **2**	1	 **16**	97
3	 **3**	0.5	 **17**	71
4	 **4**	2	 **18**	65
5	 **5**	1.3	 **19**	64
6	 **6**	2	 **20**	90

[a] All reactions were performed at 20 °C under nitrogen containing (diacetoxyiodo)benzene (1.2 mmol) and iodine (1 mmol), per millimole of substrate, in dry CH_2Cl_2 under normal laboratory lighting conditions.

TABLE 2. Ketonitriles by β-Fragmentation of β-Hydroxy Azides in Terpene and Steroid Systems[a]

entry	substrate	temp. (°C)	time (h)	products	yield (%)
1	 **21**	25-30	1.5	 **26**	79
2	 **22**	25-30	1.5	 **27**	82
3	 **23** R = H	0-2	2.3	 **28** R = H	64[b]
4	**24** R = Ac	20	1.5	**29** R = Ac	88[b]
5	 **25**	0-2	17	 **30**	51[b]

[a] All reactions were performed under nitrogen containing (diacetoxyiodo)benzene (1.2 mmol) and iodine (1 mmol) per millimole of substrate, in dry CH_2Cl_2 and under irradiation with two 80 W tungsten-filament lamps. [b] DIB (2.5 mmol) was used.

radical generated in situ by reaction of the alcohol with the hypervalent iodine reagent (diacetoxyiodo)benzene (DIB) in the presence of iodine under mild conditions. Of special interest is the ARF of glycopyranosyloxy and glycofuranosyloxy radicals in 2-azido-2-deoxycarbohydrates, which leads to aldononitriles with one carbon less than the starting saccharide. In a previous paper we described the preliminary results obtained,[10] and we now disclose herein the full details of these experiments. To examine the scope of this reaction, we attempted the fragmentation of a variety of substrates of the pentose and hexose series of carbohydrates in both pyranose and furanose forms as depicted in Table 1. The reaction can also be extended to β-hydroxy azides belonging to the terpenic and steroid families of natural products (Table 2). The structures of the new compounds were routinely confirmed by ^1H and ^{13}C NMR spectroscopy including COSY, HSQC, HMBC, and DEPT experiments. To our knowledge the radical fragmentation of β-hydroxy azides has not previously been attempted. The methodology developed here has been used by Wipf and Mareska in a study of the reversal of regioselectivity in the fragmentation of hydroindoles.[11]

The present study also shows the utility of these aldononitriles as chiral synthons for the preparation of polyhydroxypiperidines (1,5-iminoalditols) and polyhydroxypyrrolidines (1,4-iminoalditols) related to glycosidase inhibitors.

Results and Discussion

Synthesis of Substrates. Several excellent methods exist in the literature for the synthesis of β-hydroxy azides in general by electrophilic or radical additions to olefins.[12] The known 2-azido-2-deoxysaccharides **1**[13] and **2**[14] (Table 1) were prepared by a sequence of azidonitra-

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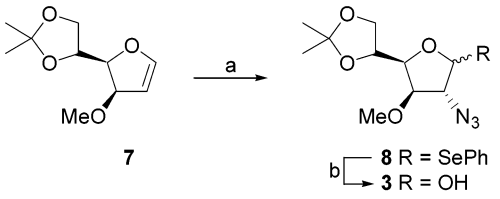
SCHEME 1. Synthesis of 3[a]



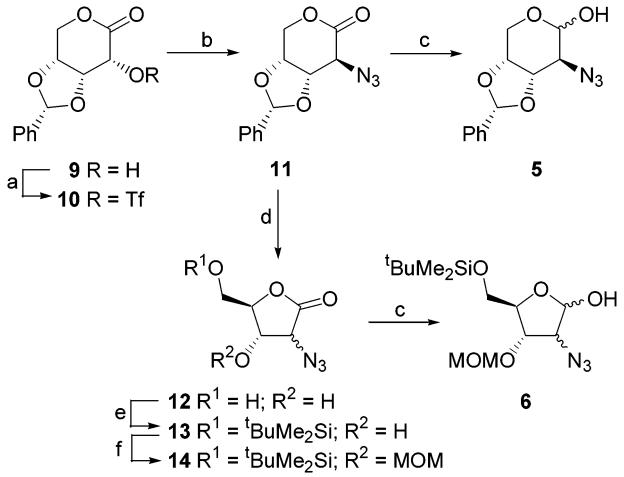
[a] Reagents and conditions: (a) TBAF, $(TMS)N_3$, *N*-(phenylseleno)phthalimide, CH_2Cl_2, 83%; (b) *N*-iodosuccinimide, $THF-H_2O$, 81%.

tion of the respective glycals with the CAN/NaN_3 reagent according to the procedure of Lemieux and Ratcliffe,[15] followed by anomeric denitration with hydrazine acetate.[16] The mixtures of D-*gluco* and D-*manno* (**1**) and β-D-Gal*p*-(1→4)-D-Glc*p* and β-D-Gal*p*-(1→4)-D-Man*p* (**2**) diastereoisomers were subjected to the radical fragmentation without previous separation.

The 2-azido-2-deoxy-D-glucofuranose derivative **3** and 2-azido-2-deoxy-D-galactopyranose derivative **4** were obtained starting from 1,4-anhydro-2-deoxy-3-*O*-methyl-5,6-*O*-isopropylidene-D-*arabino*-hex-1-enitol (**7**)[17] and 2,6-anhydro-5-deoxy-D-*arabino*-hex-5-enitol, respectively, by azidophenylselenation with *N*-(phenylseleno)phthalimide and $(TMS)N_3$ followed by anomeric dephenylselenation with *N*-iodosuccinimide, as illustrated for **3** (Scheme 1).[18]

Compounds **5** and **6** were prepared as described in Scheme 2 starting from 3,4-*O*-benzylidene-D-ribono-1,5-lactone (**9**). Nucleophilic displacement of the triflate group in **10** with lithium azide afforded deoxy derivative **11**, which was subsequently reduced with L-Selectride to give the desired β-hydroxy azide **5**. The hydrolysis of the 3,4-*O*-benzylidene protective group in compound **11** afforded the rearranged[19] 1,4-lactone **12**, which was consecutively protected with (TBDMS)Cl and (MOM)Cl, leading to compound **14**. Under the benzylidene hydrolysis reaction conditions, concomitant partial isomerization

SCHEME 2. Synthesis of 5 and 6[a]



[a] Reagents and conditions: (a) triflyl anhydride, Py, 94%; (b) LiN_3, DMF, 77%; (c) L-Selectride, THF, 61%; (d) TFA, 72%; (e) $^tBuMe_2SiCl$, imidazole, DMF, 68%; (f) dimethoxymethane, P_2O_5, $CHCl_3$, 69%.

of the 2-azide group also occurred. In this case, as a precursor of a nonstereogenic center, the C2 stereochemistry is irrelevant, and no diastereoisomeric separation of compound **14** was attempted at this stage. Finally, the reduction of the carboxyl group with L-Selectride afforded the required β-hydroxy azide **6**.

Monoterpenoid azides **21** and **22** were prepared by photooxygenation in the presence of sodium azide of the corresponding olefins (+)-limonene and (−)-α-pinene and subsequent reduction, with sodium sulfite, of the hydroperoxy azide intermediates (Table 2).[20]

The reaction of cholesterol α-epoxide with sodium azide gave β-hydroxy azide **23** following a previously reported procedure.[21] The diol was later transformed into the monoacetate **24** with acetic anhydride and pyridine. The pregnene derivative **25** was also synthesized by acid-catalyzed opening of the corresponding α-epoxide. It is worthy of note that, under exactly the same reaction conditions, Ponsold described the formation of a derivative with ring D rearranged to a six-membered hydroxy azide (3β-acetoxy-16β-azido-17α-hydroxy-17β-methyl-D-homoandrost-5-en-17a-one) as the sole product[22] but, in our hands, the hitherto unknown five-membered hydroxy azide **25** (77%) is the principal product, the six-membered azide being formed in only 9% yield.

Our fragmentation procedure was applied to differently protected 2-azido-2-deoxyglucopyranose and -glucofuranose derivatives **1**−**3** to give arabinononitriles **15**−**17** in good yields. The reactions proceeded smoothly under the conditions shown in Table 1 (entries 1−3), using approximately equimolecular amounts of DIB and iodine

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(22) (a) Ponsold, K.; Schönecker, B.; Rosenberger, H.; Prousa, R.; Müller, B. *J. Prakt. Chem.* **1969**, *311*, 912−918. For other related examples see: (b) Protiva, J.; Nguyen, T. T. H.; Urban, J.; Klinotová, E. *Collect. Czech. Chem. Commun*. **1997**, *62*, 1095−1104. (c) Nathansohn, G.; Winters, G.; Vigevani, A. *Gazz. Chim. Ital.* **1965**, *95*, 1338−1370.

at room temperature. The diastereoisomeric mixture of D-*galacto* and D-*talo* azides **4** gave the lyxononitrile derivative **18** (entry 4). For the sake of completeness this methodology was also extended to several additional examples of the pentose series of carbohydrates, the results of which are also included in Table 1. We have involved in this study two different D-*ribo*-protected compounds, **5** and **6**, which gave the erythrononitriles **19** and **20** (entries 5 and 6).

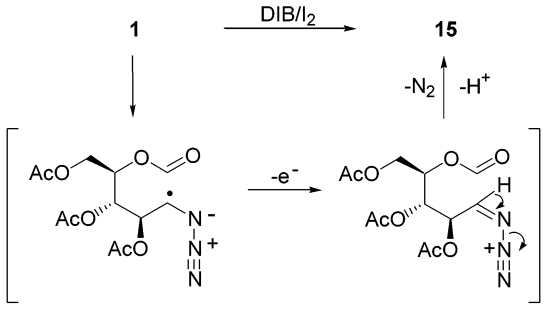
The ARF reaction also occurred in β-hydroxy azides on carbocyclic systems as depicted in Table 2. The reaction of β-hydroxy azides **21** and **22** belonging, respectively, to the (+)-limonene and (−)-α-pinene monoterpene families, afforded ϵ-ketonitriles **26**[23b] and **27**[23] (entries 1 and 2). The reaction is compatible with other hydroxyl groups present in the molecule, but in this case it might be necessary to tune the reaction conditions to increase the chemoselectivity. For example, the temperature of the fragmentation of the steroidal diol **23** had to be lowered with an ice−water bath for optimum yield (entry 3), while a higher temperature led to clearly inferior results (a 51% yield of nitrile **28**[24] was obtained at 20 °C, and a complex mixture of unidentified products was produced at higher temperatures). In any case, a significantly higher yield of ketonitrile **29**[25] (88%) was obtained when the 3β-alcohol was protected with an acetyl group such as compound **24** (entry 4).

An interesting α-diketone, **30**, was obtained when the β-hydroxy azide of the pregnane type **25** was submitted to the DIB/I_2 system; the reaction proceeded in moderate yield at 0 °C (entry 5). Control of the reaction temperature was found to be critical since the yield was significantly reduced at room temperature. Taking into account the possibility of further oxidation of the sensitive α-diketone by the excess of reagent, we examined whether the yield could be improved by decreasing the oxidant ratio. However, this did not result in a significant increase in yield. The α-diketone **30** obtained as light yellow crystals was characterized by spectroscopic means, and by analogy with the related progestomimetic steroid oxopromegestone.[26]

Although in all cases shown in Table 2 the reaction proceeded under natural lighting conditions, assisted irradiation with 2 × 80 W tungsten filament lamps reduced the reaction times, this shortening being especially significant in low-temperature reactions (entries 3 and 5).

The reaction mechanism deserves special comment. According to the above results, it seems reasonable that the first step is an alkoxyl radical generation through a hypoiodite intermediate, supported by the fact that in the absence of iodine the starting material was recovered quantitatively. As shown in Scheme 3, the C2 radical consequently formed must be oxidized by the reagent to a carbocation which generates the nitrile group after loss of a molecule of nitrogen.

SCHEME 3. Mechanism of the ARF Reaction



From the products obtained in Table 1, it can be inferred that the aldononitriles possess an easily hydrolyzable formate group at C3 or C4 and that this position only depends on the furanose or pyranose form of the starting carbohydrate. We believe that this is a characteristic of these compounds that could be most valuable in synthetic organic chemistry. 1-Deoxyiminosugar analogues of the polyhydroxypyrrolidine and -piperidine types were prepared to demonstrate the versatility of these aldononitriles as chiral synthons. The methodology developed by Buchanan et al.[27] for the synthesis of 1,4-imino sugar was used.

1,4-Anhydro-5-*O*-benzyl-(4-*tert*-butoxycarbonyl)amino-1,4-dideoxy-2,3-isopropylidene-L-ribitol (**37**) was synthesized in six steps from the D-galactal derivative **31**[28] as described in Scheme 4. Azidophenylselenation of the double bond followed by anomeric deselenation afforded alcohol **33**,[18f] which was submitted to the ARF reaction to give the D-lyxononitrile **34**.

Hydrolysis of the formate group under mild conditions afforded the alcohol **35**, which afterward was mesylated, leading to compound **36**. After some experimentation with several well-known nitrile reductants (Raney Ni,[29] BH_3·THF,[30] and activated $NaBH_4$[31]) we were pleased to find that the simple addition of $LiAlH_4$ in Et_2O is quite effective at reducing the nitrile group and promoting the desired cyclization.[32] The crude pyrrolidine was protected as its Boc-carbamate to give the L-iminoribitol derivative **37** since the aminocyclization occurred with inversion of configuration at C4.[33]

Alternatively, this protocol can be used for the synthesis of 1,5-iminoalditols. As described in Scheme 5, the

(23) For the synthesis of compound **27** using different methodologies, see: (a) Stutz, A.; Zbiral, E. *Justus Liebigs Ann. Chem.* **1972**, *765*, 34−46. (b) Tkachev, A. V.; Rukavishnikov, A. V.; Chibirjaev, A. M.; Volodarsky, L. B. *Synth. Commun*. **1990**, *20*, 2123-2132. (c) Morzherin, Y. Y.; Glukhareva, T. V.; Mokrushin, V. S.; Tkachev, A. V.; Bakulev, V. A. *Heterocycl. Commun*. **2001**, *7*, 173−176.

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(29) Shih, T. L.; Ruiz-Sánchez, J.; Mroizk, H. *Tetrahedron Lett*. **1987**, *28*, 6015−6018.

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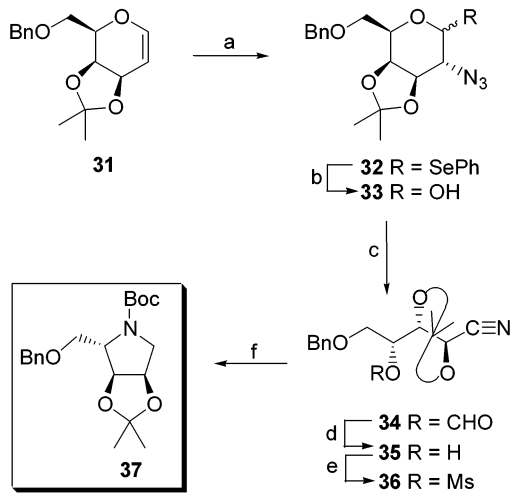
(31) Caddick, S.; Haynes, A. K. K.; Judd, D. B.; Williams, M. R. V. *Tetrahedron Lett*. **2000**, *41*, 3513−3516.

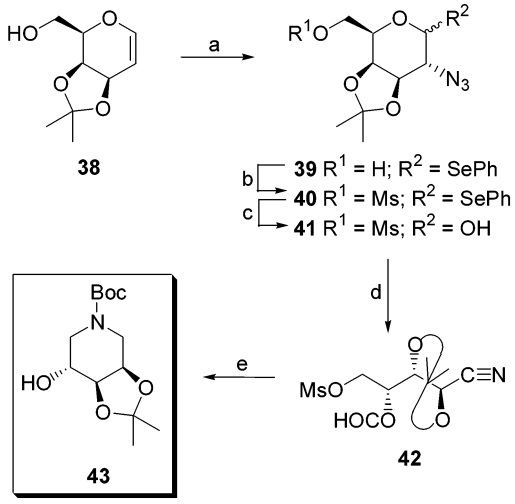
(32) (a) Rahman, S. M. A.; Ohno, H.; Yoshino, H.; Satoh, N.; Tsukaguchi, M.; Murakami, K.; Iwata, C.; Maekazi, N.; Tanaka, T. *Tetrahedron* **2001**, *57*, 127−134. (b) Cimino, G.; Gavagnin, M.; Sodano, G.; Spinella, A.; Strazzullo, G.; Schmitz, F. J.; Yalamanchili, G. *J. Org. Chem*. **1987**, *52*, 2301−2303.

SCHEME 4. Synthesis of 37[a]



[a] Reagents and conditions: (a) TBAF, $(TMS)N_3$, *N*-(phenylseleno)phthalimide, CH_2Cl_2, 67%; (b) *N*-iodosuccinimide, THF−H_2O, 79%; (c) DIB, I_2, CH_2Cl_2, 86%; (d) CSA, MeOH, 70%; (e) MsCl, Et_3N, CH_2Cl_2, 71%; (f) $LiAlH_4$, Et_2O, then di-*tert*-butyl dicarbonate, 69%.

SCHEME 5. Synthesis of 43[a]



[a] Reagents and conditions: (a) TBAF, $(TMS)N_3$, *N*-(phenylseleno)phthalimide, CH_2Cl_2, 51%; (b) MsCl, Et_3N, CH_2Cl_2, 85%; (c) NIS, THF−H_2O, 87%; (d) DIB, I_2, CH_2Cl_2, 71%; (e) $LiAlH_4$, Et_2O, then di-*tert*-butyl dicarbonate, 62%.

galactal derivative **38** was transformed into the 1,5-imino-D-arabinitol **43**. In a very similar sequence of reactions, the synthesis commenced with azidoselenation of the double bond,[18f] followed by mesylation of the primary alcohol, and anomeric deselenation. The ARF reaction of β-hydroxy azide **41** afforded the D-arabinononitrile **42**, which was subsequently reduced with $LiAlH_4$ to give the required 1,5-iminoarabinitol **43**.[34] From the above examples, it is clear that this methodology may be useful for the preparation of 1,4- and 1,5-iminopentitols from a common precursor, in this case 3,4-isopropylidene-D-galactal.

In summary, the application of the ARF reaction to five- and six-membered carbocyclic β-hydroxy azides led to acyclic δ- and ϵ-ketonitriles, respectively. One especially important use of this methodology was the fragmentation of 2-azido-2-deoxyaldoses, which afforded aldononitriles in good yield. The pyranose and furanose models, prepared to study the scope of this method, were constructed to incorporate a variety of commonly employed carbohydrate protecting groups, each of which proved tolerant to the mild reaction conditions. The utility of these aldononitriles as chiral building blocks has been demonstrated by a short synthesis of 1,4- and 1,5-imino-1-deoxypentitols, which are considered to be potential glycosidase inhibitors.[33,34]

Experimental Section

General Procedure for the Preparation of Compounds 15−20. A solution of the β-hydroxy azide (1 mmol) in CH_2Cl_2 (20 mL) containing DIB (1.2 mmol) and iodine (1 mmol) was stirred at 20 °C for the time specified in Table 1, under exposure to ambient light but without irradiation from an external source. The reaction mixture was then poured into a 10% aqueous $Na_2S_2O_3$ solution, extracted with CH_2Cl_2, dried (Na_2SO_4), and concentrated in vacuo. Chromatotron chromatography of the residue (hexanes−EtOAc) as specified gave the nitriles.

2,3,5-Tri-*O*-acetyl-4-*O*-formyl-D-arabinononitrile (15). The product was isolated by chromatography (hexanes−EtOAc, 70:30) as a crystalline solid (88%): mp 82−83 °C (from *n*-hexane−EtOAc); $[\alpha]_D$ −10 (*c* 0.4); IR 2100, 1764, 1740 cm^{-1}; ^1H NMR δ_H 2.07 (3H, s), 2.17 (3H, s), 2.20 (3H, s), 4.21 (1H, dd, J = 5.0, 12.6 Hz), 4.32 (1H, dd, J = 3.0, 12.6 Hz), 5.39 (1H, m), 5.59 (1H, d, J = 3.4 Hz), 5.61 (1H, dd, J = 3.4, 5.4 Hz), 8.01 (1H, s); ^{13}C NMR δ_C 20.1 (CH_3), 20.4 (CH_3), 20.5 (CH_3), 59.5 (CH), 61.0 (CH_2), 67.2 (CH), 67.7 (CH), 113.8 (C), 159.0 (CH), 168.5 (C), 168.8 (C), 170.3 (C); FABMS *m/z* (glycerol, NaCl) (rel intens) 302 (M^+ + H, 21). Anal. Calcd for $C_{12}H_{15}NO_8$: C, 47.84; H, 5.02; N, 4.65. Found: C, 47.92; H, 5.11; N, 4.56.

2,5-Di-*O*-acetyl-4-*O*-formyl-3-*O*-(2,3,4,6-tetra-*O*-acetyl-β-D-galactopyranosyl)-D-arabinononitrile (16). The product was isolated by chromatography (hexanes−EtOAc, 1:1) as a crystalline solid (97%): mp 36−38 °C (from *n*-hexane−EtOAc); $[\alpha]_D$ +4 (*c* 0.74); IR 2125, 1756 cm^{-1}; ^1H NMR δ_H 1.97 (3H, s), 2.03 (3H, s), 2.06 (3H, s), 2.07 (3H, s), 2.15 (3H, s), 2.16 (3H, s), 3.96 (1H, dd, J = 6.5, 6.4 Hz), 4.20−4.11 (4H, m), 4.51 (1H, dd, J = 3.1, 12.4 Hz), 4.67 (1H, d, J = 7.9 Hz), 5.00 (1H, dd, J = 3.4, 10.5 Hz), 5.21 (1H, dd, J = 7.9, 10.5 Hz), 5.37 (1H, d, J = 3.3 Hz), 5.39 (1H, ddd, J = 3.1, 5.8, 6.0 Hz), 5.75 (1H, d, J = 4.3 Hz), 8.02 (1H, s); ^{13}C NMR (100.4 MHz) δ_C 20.1 (CH_3), 20.4 (CH_3), 20.5 (2 × CH_3), 20.56 (CH_3), 20.60 (CH_3), 60.6 (CH), 61.2 (2 × CH_2), 66.7 (CH), 68.5 (CH), 69.0 (CH), 70.6 (CH), 71.2 (CH), 76.4 (CH), 101.8 (CH), 114.3 (C), 159.1 (CH), 168.3 (C), 169.2 (C), 170.0 (C), 170.1 (C), 170.13 (C), 170.4 (C); MS *m/z* (rel intens) 529 (M^+ − AcOH, 1), 516 (<1), 331 (56), 169 (100); HRMS *m/z* calcd for $C_{22}H_{27}NO_{14}$ 529.1432, found 530.1437. Anal. Calcd for $C_{24}H_{31}NO_{16}$: C, 48.88; H, 5.30; N, 2.38. Found: C, 48.69; H, 5.23; N, 2.31.

(33) For other syntheses of 1,4-iminoalditols using different methodologies, see: (a) Huang, Y.; Dalton, D. R.; Carroll, P. *J. Org. Chem.* **1997**, *62*, 372−376. (b) Takano, S.; Moriya, M.; Ogasawara, K. *Tetrahedron: Asymmetry* **1992**, *3*, 681−684. (c) Fleet, G. W. J.; Son, J. C.; Green, D. St. C.; Bello, I. C.; Winchester, B. *Tetrahedron* **1988**, *44*, 2649−2655. (d) Setoi, H.; Kayakiri, H.; Takeno, H.; Hashimoto, M. *Chem. Pharm. Bull.* **1987**, *35*, 3995−3999. (e) Sawada, D.; Takahashi, H.; Ikegami, S. *Tetrahedron Lett.* **2003**, *44*, 3085−3088. For the synthesis of *ent*-**37** see: (f) Kumareswaran, R.; Hassner, A. *Tetrahedron: Asymmetry* **2001**, *12*, 3409−3415.

(34) Compound **43** has been previously prepared as an intermediate in the synthesis of 1-iminosugars but was not characterized; see: (a) Ichikawa, Y.; Igarashi, Y.; Ichikawa, M.; Suhara, Y. *J. Am. Chem. Soc.* **1998**, *120*, 3007−3018. (b) Igarashi, Y.; Ichikawa, M.; Ichikawa, Y. *Tetrahedron Lett.* **1996**, *37*, 2707−2708.

3-*O*-Formyl-4,5-*O*-isopropylidene-2-*O*-methyl-D-arabinononitrile (17). The product was isolated by chromatography (hexanes−EtOAc, 80:20) as a syrup (71%): $[\alpha]_D$ −11.0 (*c* 0.3); IR 2112, 1737 cm^{-1}; ^1H NMR δ_H 1.35 (3H, s), 1.43 (3H, s), 3.57 (3H, s), 3.90 (1H, dd, *J* = 5.0, 9.0 Hz), 4.06 (1H, dd, *J* = 6.3, 9.0 Hz), 4.34 (1H, m), 4.42 (1H, d, *J* = 3.0 Hz), 5.31 (1H, ddd, *J* = 0.7, 3.0, 7.4 Hz), 8.17 (1H, s); ^{13}C NMR δ_C 25.1 (CH_3), 28.6 (CH_3), 58.8 (CH_3), 65.9 (CH_2), 69.5 (CH), 71.3 (CH), 72.5 (CH), 110.1 (C), 115.3 (C), 159.1 (CH); MS *m/z* (rel intens) 214 (M^+ − Me, 100), 101 (27); HRMS *m/z* calcd for $C_9H_{12}NO_5$ 214.0715, found 214.0721. Anal. Calcd for $C_{10}H_{15}NO_5$: C, 52.39; H, 6.59; N, 6.11. Found: C, 52.48; H, 6.62; N, 6.01.

2,3,5-Tri-*O*-acetyl-4-*O*-formyl-D-lyxononitrile (18). The product was isolated by chromatography (hexanes−EtOAc, 70:30) as a syrup (65%): $[\alpha]_D$ −11 (*c* 0.12); IR 2115, 1757 cm^{-1}; ^1H NMR δ_H 2.08 (3H, s), 2.17 (3H, s), 2.22 (3H, s), 4.09 (1H, dd, *J* = 6.5, 12.0 Hz), 4.33 (1H, dd, *J* = 5.1, 12.0 Hz), 5.51 (1H, m), 5.53 (1H, d, *J* = 6.7 Hz), 5.58 (1H, dd, *J* = 3.3, 6.9 Hz), 8.09 (1H, s); ^{13}C NMR δ_C 20.1 (CH_3), 20.3 (CH_3), 20.5 (CH_3), 59.3 (CH), 61.1 (CH_2), 67.1 (CH), 68.2 (CH), 114.0 (C), 159.4 (CH), 168.3 (C), 169.1 (C), 170.1 (C); MS *m/z* (rel intens) 302 (M^+ + 1, <1), 203 (66), 141 (95), 115 (100); HRMS *m/z* calcd for $C_{12}H_{16}NO_8$ 302.0876, found 302.0878. Anal. Calcd for $C_{12}H_{15}NO_8$: C, 47.84; H, 5.02; N, 4.65. Found: C, 48.13; H, 5.29; N, 4.50.

2,3-*O*-Benzylidene-4-*O*-formyl-D-erythrononitrile (19). The product was isolated by chromatography (hexanes−EtOAc, 70:30) as a crystalline solid (64%): mp 78−80 °C (from *n*-hexane−EtOAc); $[\alpha]_D$ −5.1 (*c* 0.82); IR 2109, 1734 cm^{-1}; ^1H NMR (C_6D_6) δ_H 3.67 (1H, ddd, *J* = 5.3, 6.3, 6.3 Hz), 3.96 (1H, d, *J* = 6.3, Hz), 4.24 (1H, dd, *J* = 5.3, 11.9 Hz), 4.33 (1H, dd, *J* = 6.3, 11.9 Hz), 5.40 (1H, s), 7.16−7.13 (3H, m), 7.42 (1H, s), 7.49−7.47 (2H, m); ^{13}C NMR δ_C 61.3 (CH_2), 66.1 (CH), 76.2 (CH), 106.5 (CH), 115.1 (C), 127.0 (2 × CH), 128.6 (2 × CH), 130.4 (CH), 134.5 (C), 159.9 (CH); MS *m/z* (rel intens) 233 (M^+, 25), 232 (30), 105 (100); HRMS *m/z* calcd for $C_{12}H_{11}NO_4$ 233.0688, found 233.0683. Anal. Calcd for $C_{12}H_{11}NO_4$: C, 61.80; H, 4.75; N, 6.01. Found: C, 61.95; H, 4.88; N, 6.08.

4-*O*-(*tert*-Butyldimethylsilyl)-3-*O*-formyl-2-*O*-(methoxymethyl)-D-erythrononitrile (20). The product was isolated by chromatography (hexanes−EtOAc, 90:10) as a syrup (90%) which solidified at low temperature: mp 24−26 °C (from *n*-hexane); $[\alpha]_D$ + 42.3 (*c* 0.26); IR 2109, 1733 cm^{-1}; ^1H NMR δ_H 0.08 (6H, s), 0.85 (9H, s), 3.40 (3H, s), 3.79 (1H, dd, *J* = 5.5, 11.2 Hz), 3.84 (1H, dd, *J* = 4.5, 11.2 Hz), 4.68 (1H, d, *J* = 7.0 Hz), 4.74 (1H, d, *J* = 5.5 Hz), 4.81 (1H, d, *J* = 7.0 Hz), 5.23 (1H, ddd, *J* = 4.5, 5.5, 5.5 Hz), 8.10 (1H, s); ^{13}C NMR δ_C −5.5 (2 × CH_3), 18.2 (C), 25.8 (3 × CH_3), 56.5 (CH_3), 60.2 (CH_2), 63.7 (CH), 72.1 (CH), 96.0 (CH_2), 115.9 (C), 159.5 (CH); MS *m/z* (rel intens) 304 (M^+ + H, <1), 288 (2), 73 (100); HRMS *m/z* calcd for $C_{13}H_{26}NO_5Si$ 304.1580, found 304.1490. Anal. Calcd for $C_{13}H_{25}NO_5Si$: C, 51.46; H, 8.30; N, 4.62. Found: C, 51.24; H, 8.35; N, 4.73.

General Procedure for the Preparation of Compounds 26−30. A solution of β-hydroxy azide (1 mmol) in CH_2Cl_2 (40 mL) containing DIB (1.2 mmol) and iodine (1 mmol) was irradiated with two 80 W tungsten-filament lamps at the temperature and for the time specified in Table 2. The reaction mixture was then poured into a 10% aqueous $Na_2S_2O_3$ solution, extracted with CH_2Cl_2, dried (Na_2SO_4), and concentrated in vacuo. Chromatotron chromatography of the residue (hexanes−EtOAc) as specified gave the nitriles.

(3*R*)-3-(1-Methylethenyl)-6-oxoheptanenitrile (26). The product was isolated by chromatography (hexanes−EtOAc, 75:25) as an oil (79%): $[\alpha]_D$ −13 (*c* 0.12); IR 3079, 2243, 1715, 1648, 908 cm^{-1}; ^1H NMR (C_6D_6) δ_H 1.26 (3H, s), 1.28 (1H, dddd, *J* = 6.0, 8.3, 9.0, 14.1 Hz), 1.39 (1H, dddd, *J* = 5.0, 6.7, 8.5, 13.9 Hz), 1.53 (1H, dd, *J* = 6.0, 16.8 Hz), 1.54 (1H, dd, *J* = 7.6, 16.7 Hz), 1.58 (3H, s), 1.70 (1H, ddd, *J* = 6.9, 6.9, 8.0 Hz), 1.71 (1H, ddd, *J* = 6.0, 6.0, 8.5 Hz), 1.87 (1H, dddd, *J* = 5.1, 7.2, 7.2, 10.0 Hz), 4.56 (1H, br s), 4.68 (1H, dd, *J* = 1.5, 1.5 Hz); ^{13}C NMR (C_6D_6, 125.7 MHz) δ_C 18.1 (CH_3), 21.7 (CH_2), 25.9 (CH_2), 29.4 (CH_3), 40.3 (CH_2), 43.0 (CH), 114.0 (CH_2), 118.1 (C), 144.0 (C), 205.3 (C); MS *m/z* (rel intens) 165 (M^+, 6), 150 (7), 147 (12), 132 (6), 125 (15), 122 (57), 108 (59), 58 (100); HRMS *m/z* calcd for $C_{10}H_{15}NO$ 165.1154, found 165.1124. Anal. Calcd for $C_{10}H_{15}NO$: C, 72.69; H, 9.15; N, 8.48. Found: C, 72.47; H, 9.31; N, 8.36.

(1*S*,3*S*)-(3-Acetyl-2,2-dimethylcyclobutyl)acetonitrile (27). The product isolated by chromatography (hexanes−EtOAc, 85:15) has already been partially described.[2b] In our hands, it was obtained as an oil (82%): $[\alpha]_D$ −97 (*c* 0.196) (lit.[2b] $[\alpha]_D$ −215.0); IR 2250, 1703, 1185 cm^{-1}; ^1H NMR δ_H 0.94 (3H, s), 1.39 (3H, s), 1.99 (2H, m), 2.06 (3H, s), 2.29 (3H, m), 2.91 (1H, dd, *J* = 7.7, 9.8 Hz); ^{13}C NMR δ_C 16.9 (CH_3), 17.5 (CH_2), 22.8 (CH_2), 30.0 (CH_3), 30.2 (CH_3), 38.1 (CH), 42.9 (C), 53.7 (CH), 118.5 (C), 206.6 (C); MS *m/z* (rel intens) 165 (M^+, 15), 150 (16), 125 (40), 122 (26), 108 (12), 98 (42), 95 (37), 83 (100), 71 (77), 68 (36); HRMS *m/z* calcd for $C_{10}H_{15}NO$ 165.1154, found 165.1150. Anal. Calcd for $C_{10}H_{15}NO$: C, 72.69; H, 9.15; N, 8.48. Found: C, 72.57; H, 9.35; N, 8.30.

3β-Hydroxy-5,6-seco-5-oxocholestane-6-nitrile (28). The product isolated by chromatography (hexanes−EtOAc, 70:30) has already been partially described.[24a] It was obtained as a crystalline solid (64%): mp 68−69 °C (from *n*-hexane); $[\alpha]_D$ +90.4 (*c* 0.77, $CHCl_3$) [lit.[24a] mp 67−69; $[\alpha]_D$ +84.6 (MeOH)]; IR 3621, 3489, 2250, 1703 cm^{-1}; ^1H NMR δ_H 0.66 (3H, s), 0.84 (3H, d, *J* = 6.7 Hz), 0.85 (3H, d, *J* = 6.4 Hz), 0.89 (3H, d, *J* = 6.4 Hz), 0.96 (3H, s), 2.10 (1H, dd, *J* = 3.9, 17.6 Hz), 2.46 (1H, dd, *J* = 3.5, 17.5 Hz), 2.49 (1H, ddd, *J* = 2.8, 2.8, 13.6 Hz), 3.42 (1H, dd, *J* = 3.9, 14.3 Hz), 4.49 (1H, br s); ^{13}C NMR (125.7 MHz) δ_C 11.8 (CH_3), 17.5 (CH_3), 18.5 (CH_3), 19.1 (CH_2), 22.5 (CH_3), 22.69 (CH_2), 22.74 (CH_3), 23.6 (CH_2), 24.3 (CH_2), 27.6 (CH_2), 27.7 (CH_2), 27.9 (CH), 33.6 (CH_2), 35.6 (2 × CH), 35.9 (CH_2), 39.3 (CH_2), 39.4 (CH_2), 41.5 (CH), 42.4 (C), 47.2 (CH_2), 52.4 (C), 53.2 (CH), 56.0 (CH), 70.8 (CH), 118.7 (C), 217.9 (C); MS *m/z* (rel intens) 415 (M^+, 4), 397 (10), 371 (18), 343 (68), 317 (94), 128 (100); HRMS *m/z* calcd for $C_{27}H_{45}NO_2$ 415.3450, found 415.3485. Anal. Calcd for $C_{27}H_{45}NO_2$: C, 78.02; H, 10.91; N, 3.37. Found: C, 78.09; H, 10.80; N, 3.25.

3β-Acetoxy-5,6-seco-5-oxocholestane-6-nitrile (29). The product isolated by chromatography (hexanes−EtOAc, 93:7) has already been partially described.[25] It was obtained as a crystalline solid (88%): mp 95−97 °C (from *n*-hexane); $[\alpha]_D$ +63 (c 0.27) (lit.[25] mp 96−97 °C; $[\alpha]_D$ +73.7); IR 2250, 1733, 1703 cm^{-1}; ^1H NMR δ_H 0.67 (3H, s), 0.84 (3H, d, *J* = 6.7 Hz), 0.85 (3H, d, *J* = 6.4 Hz), 0.90 (3H, d, *J* = 6.4 Hz), 0.99 (3H, s), 2.00 (3H, s), 2.11 (1H, dd, *J* = 3.8, 17.8 Hz), 2.49 (1H, dd, *J* = 3.5, 17.8 Hz), 2.57 (1H, ddd, *J* = 2.4, 2.4, 15.0 Hz), 3.40 (1H, dd, *J* = 4.3, 15.0 Hz), 5.40 (1H, br s); ^{13}C NMR (125.7 MHz) δ_C 11.8 (CH_3), 17.5 (CH_3), 18.5 (CH_3), 19.1 (CH_2), 21.2 (CH_3), 22.5 (CH_3), 22.7 (CH_2), 22.8 (CH_3), 23.7 (CH_2), 24.4 (CH_2), 25.0 (CH_2), 27.7 (CH_2), 28.0 (CH), 34.0 (CH_2), 35.6 (CH), 35.7 (CH), 35.9 (CH_2), 39.3 (CH_2), 39.4 (CH_2), 41.5 (CH), 42.4 (C), 43.6 (CH_2), 52.0 (C), 53.2 (CH), 56.0 (CH), 73.2 (CH), 118.6 (C), 179.1 (C), 216.5 (C); MS *m/z* (rel intens) 457 (M^+, 18), 397 (47), 369 (71), 110 (100); HRMS *m/z* calcd for $C_{29}H_{47}NO_3$ 457.3470, found 457.3545. Anal. Calcd for $C_{29}H_{47}NO_3$: C, 76.10; H, 10.35; N, 3.06. Found: C, 76.15; H, 10.40; N, 3.02.

3β-Acetoxy-16,17-seco-17,20-dioxopregn-5-ene-16-nitrile (30). The product was isolated by chromatography (benzene−EtOAc, 93:7) as light yellow crystals (51%): mp 121−122 °C (from *n*-hexane−acetone); $[\alpha]_D$ −58.7 (*c* 1.46); IR 2248, 1722 cm^{-1}; ^1H NMR (400 MHz) δ 1.03 (3H, s), 1.33 (3H, s), 2.02 (3H, s), 2.34 (3H, s), 2.59 (1H, m), 2.37 (1H, m); ^{13}C NMR (100.4 MHz) δ 14.3 (CH_3), 18.0 (CH_2), 19.1 (CH_3), 19.2 (CH_2), 21.3 (CH_3), 26.8 (CH_3), 27.5 (CH_2), 31.3 (CH_2), 31.8 (CH), 35.5 (CH_2), 36.6 (CH_2), 36.7 (C), 37.7 (CH_2), 41.9 (CH), 48.4 (CH), 50.1 (C), 73.4 (CH), 118.7 (C), 121.0 (CH), 139.3 (C), 170.4 (C), 200.6 (C), 206.2 (C); MS *m/z* (rel intens) 342 (M^+ − $COCH_3$, 1), 325 (11), 254 (100), 213 (10); HRMS *m/z* calcd for $C_{21}H_{28}NO_3$ 342.2069, found 342.2071. Anal. Calcd for $C_{23}H_{31}NO_4$: C, 71.66; H, 8.11; N, 3.63. Found: C, 71.84; H, 8.10; N, 3.63.

5-*O*-Benzyl-4-*O*-formyl-2,3-*O*-isopropylidene-D-lyxononitrile (34). A solution of β-hydroxy azide **33**[18f] (100.1 mg, 0.30 mmol) in CH_2Cl_2 (6 mL) was treated with DIB (115.5 mg, 0.36 mmol) and iodine (75.9 mg, 0.30 mmol). The reaction mixture was stirred at 20 °C for 1 h, then poured into a 10% aqueous $Na_2S_2O_3$ solution, and extracted with CH_2Cl_2. The organic layer was dried over anhydrous Na_2SO_4 and concentrated under reduced pressure. The residue was purified by column chromatography (hexanes−EtOAc, 80:20) to give the nitrile **34** (78.3 mg, 0.26 mmol, 86%) as an oil: $[\alpha]_D$ +10.1 (*c* 1.10); IR 2103, 1732 cm^{-1}; ^1H NMR δ_H 1.39 (3H, s), 1.59 (3H, s), 3.66 (1H, dd, *J* = 5.5, 10.8 Hz), 3.77 (1H, dd, *J* = 4.3, 10.8 Hz), 4.45 (1H, dd, *J* = 5.2, 8.1 Hz), 4.56 (2H, m), 4.75 (1H, d, *J* = 5.2 Hz), 5.46 (1H, ddd, *J* = 4.3, 5.5, 8.1 Hz), 7.32−7.37 (3H, m), 7.37−7.40 (2H, m), 8.12 (1H, s); ^{13}C NMR (125.7 MHz) δ_C 25.7 (CH_3), 26.8 (CH_3), 65.4 (CH), 67.8 (CH_2), 70.8 (CH), 73.7 (CH_2), 76.5 (CH), 112.4 (C), 116.3 (C), 128.1 (3 × CH), 128.4 (2 × CH), 136.8 (C), 159.6 (CH); MS *m/z* (rel intens) 305 (M^+, <1), 198 (1), 91 (100); HRMS *m/z* calcd for $C_{16}H_{19}NO_5$, 305.1263, found 305.1256. Anal. Calcd for $C_{16}H_{19}NO_5$: C, 62.94; H, 6.27; N, 4.59. Found: C, 62.86; H, 6.11; N, 4.73.

5-*O*-Benzyl-2,3-*O*-isopropylidene-D-lyxononitrile (35). A solution of **34** (188.6 mg, 0.62 mmol) in MeOH was treated at 0 °C with camphorsulfonic acid (28.3 mg, 15%) and stirred at this temperature for 5 min. The stirring was continued for 2 h at rt, and then the reaction mixture was poured into a saturated aqueous solution of $NaHCO_3$ and extracted with EtOAc. The organic layer was washed with brine, dried over anhydrous Na_2SO_4, and concentrated under reduced pressure. The residue was purified by column chromatography (*n*-hexanes−EtOAc, 85:15) to give **35** (120.6 mg, 0.44 mmol, 70%) as an oil: $[\alpha]_D$ +12.0 (*c* 0.74); IR 3692, 3599 cm^{-1}; ^1H NMR δ_H 1.50 (3H, s), 1.68 (3H, s), 3.61 (1H, dd, *J* = 5.5, 9.7 Hz), 3.71 (1H, dd, *J* = 4.0, 9.7 Hz), 4.24 (1H, d, *J* = 4.6 Hz), 4.26 (1H, dd, *J* = 4.0, 5.5 Hz), 4.60 (2H, m), 4.74 (1H, d, *J* = 4.6 Hz), 7.23−7.33 (5H, m); ^{13}C NMR (125.7 MHz) δ_C 25.8 (CH_3), 27.0 (CH_3), 65.6 (CH), 69.8 (CH), 70.2 (CH_2), 73.7 (CH_2), 79.1 (CH), 111.9 (C), 116.6 (C), 127.8 (2 × CH), 128.0 (CH), 128.5 (2 × CH), 137.2 (C); MS *m/z* (rel intens) 277 (M^+, <1), 262 (1), 91 (100); HRMS *m/z* calcd for $C_{15}H_{19}NO_4$, 277.1314, found 277.1287. Anal. Calcd for $C_{15}H_{19}NO_4$: C, 64.97; H, 6.91; N, 5.05. Found: C, 65.22; H, 6.55; N, 4.95.

5-*O*-Benzyl-2,3-*O*-isopropylidene-4-*O*-(methylsulfonyl)-D-lyxononitrile (36). A solution of **35** (120.6 mg, 0.44 mmol) and Et_3N (90 μL, 66.0 mg, 0.65 mmol) in dry CH_2Cl_2 (3 mL) was treated with MsCl (67 μL, 0.87 mmol) under N_2 at 0 °C. The reaction mixture was then stirred at rt for 1 h and concentrated under reduced pressure. The residue was purified by column chromatography (benzene−EtOAc, 93:7) to give **36** (109.9 mg, 0.31 mmol, 71%) as an oil: $[\alpha]_D$ +8.0 (*c* 0.29); IR 1365 cm^{-1}; ^1H NMR δ_H 1.39 (3H, s), 1.59 (3H, s), 3.11 (3H, s), 3.76 (1H, dd, *J* = 6.1, 11.2 Hz), 3.86 (1H, dd, *J* = 4.6, 11.2 Hz), 4.40 (1H, dd, *J* = 5.1, 8.7 Hz), 4.57 (2H, s), 4.74 (1H, d, *J* = 5.0 Hz), 4.98 (1H, ddd, *J* = 4.8, 5.7, 8.6 Hz), 7.32−7.40 (5H, m); ^{13}C NMR (125.7 MHz) δ_C 25.9 (CH_3), 26.9 (CH_3), 38.3 (CH_3), 65.4 (CH), 68.7 (CH_2), 73.9 (CH_2), 76.9 (CH), 78.9 (CH), 112.4 (C), 116.2 (C), 127.9 (2 × CH), 128.2 (CH), 129.6 (2 × CH), 136.5 (C); MS *m/z* (rel intens) 355 (M^+, 8), 340 (2), 91 (100); HRMS *m/z* calcd for $C_{16}H_{21}NO_6S$, 355.1090, found 355.1054. Anal. Calcd for $C_{16}H_{21}NO_6S$: C, 54.07; H, 5.96; N, 3.94; S, 9.00. Found: C, 54.19; H, 6.05; N, 3.99; S, 8.91.

1,4-Anhydro-5-*O*-benzyl-4-[(*tert*-butoxycarbonyl)amino]-1,4-dideoxy-2,3-*O*-isopropylidene-L-ribitol (37). To a stirred solution of **36** (55.7 mg, 0.16 mmol) in THF (6 mL) at 0 °C under N_2 was added $LiAlH_4$ in Et_2O (1 M) (2.8 mL, 2.82 mmol) dropwise. The mixture was stirred for 1 h, and the excess reagent was carefully destroyed by dropwise addition of a saturated aqueous solution of Na_2SO_4 at 0 °C. After 30 min Boc_2O (0.18 mL, 171.2 mg, 0.78 mmol) was added and stirring continued at rt for 30 min. The reaction mixture was poured into water and extracted with EtOAc. The organic layer was washed with brine, dried over anhydrous Na_2SO_4, and concentrated under reduced pressure. The residue was purified by column chromatography (hexanes−EtOAc, 85:15) to give the iminosugar **37** (40.2 mg, 0.11 mmol, 69%) as an oil: $[\alpha]_D$ +63.0 (*c* 0.35); IR 1687 cm^{-1}; ^1H NMR (65 °C) δ_H 1.34 (3H, s), 1.48 (12H, s), 3.53 (1H, dd, *J* = 12.3, 5.3 Hz), 3.61 (1H, m), 3.66−3.83 (2H, m), 4.17 (1H, m), 4.52 (2H, s), 4.71 (1H, d, *J* = 6.0 Hz), 4.75 (1H, dd, *J* = 5.7, 5.5 Hz), 7.26−7.32 (3H, m), 7.36−7.38 (2H, m); ^{13}C NMR (125.7 MHz, 65 °C) δ_C 25.2 (CH_3), 27.1 (CH_3), 28.5 (3 × CH_3), 53.4 (CH_2), 63.5 (CH), 70.4 (CH_2), 73.5 (CH_2), 79.3 (C), 79.7 (CH), 83.2 (CH), 111.5 (C), 127.4 (2 × CH), 127.7 (CH), 128.5 (2 × CH), 138.1 (C), 154.3 (C); MS *m/z* (rel intens) 363 (M^+, <1), 348 (2), 262 (6), 142 (100); HRMS *m/z* calcd for $C_{20}H_{29}NO_5$, 363.2046, found 363.2088. Anal. Calcd for $C_{20}H_{29}NO_5$: C, 66.09; H, 8.04, N; 3.85. Found: C, 66.20; H, 8.10, N; 3.91.

Phenyl 2-Azido-2-deoxy-3,4-*O*-isopropylidene-6-*O*-(methylsulfonyl)-1-seleno-α-D-galactopyranoside (40). To a solution of β-phenylseleno azide **39** (656.8 mg, 1.71 mmol) and Et_3N (0.35 mL, 258.5 mg, 2.6 mmol) in dry CH_2Cl_2 (17 mL) at 0 °C under N_2 was added MsCl (0.26 mL, 391.0 mg, 3.41 mmol). The reaction mixture was stirred at rt for 1 h and concentrated under reduced pressure. The residue was purified by column chromatography (hexanes−EtOAc, 60:40) to give **40** (669.7 mg, 1.45 mmol, 85%) as an oil: $[\alpha]_D$ +198.5 (*c* 0.95); IR 2114 cm^{-1}; ^1H NMR δ_H 1.36 (3H, s), 1.52 (3H, s), 2.80 (3H, s), 4.01 (1H, dd, *J* = 5.2, 7.3 Hz), 4.25 (1H, d, *J* = 2.5, 5.8 Hz), 4.31 (1H, dd, *J* = 6.1, 7.0 Hz), 4.41 (1H, dd, *J* = 4.8, 11.5 Hz), 4.44 (1H, dd, *J* = 7.6, 11.5 Hz), 4.72 (1H, ddd, *J* = 2.6, 4.7, 7.3 Hz), 5.83 (1H, d, *J* = 5.2 Hz), 7.31 (3H, m), 7.61 (2H, m); ^{13}C NMR (125.7 MHz) δ_C 26.0 (CH_3), 27.8 (CH_3), 37.5 (CH_3), 62.0 (CH), 68.4 (CH_2), 68.6 (CH), 72.2 (CH), 75.0 (CH), 82.8 (CH), 110.7 (C), 127.8 (C), 128.2 (CH), 129.3 (2 × CH), 134.7 (2 × CH); MS *m/z* (rel intens) 463/461 (M^+, 12/7), 436/434 (5/3), 306 (40), 251 (100); HRMS *m/z* calcd for $C_{16}H_{21}N_3O_6S^{80}Se$ 463.0316, found 463.0341. Anal. Calcd for $C_{16}H_{21}N_3O_6SSe$: C, 41.56; H, 4.58; N, 9.09; S, 6.93. Found: C, 41.73; H, 4.49; N, 9.26; S, 6.73.

2-Azido-2-deoxy-3,4-*O*-isopropylidene-6-*O*-(methylsulfonyl)-D-galactopyranose (41). A solution of **40** (412.2 mg, 0.89 mmol) in THF−H_2O (1:1, 9 mL) at 0 °C was treated with *N*-iodosuccinimide (1.0 g, 4.45 mmol). The reaction mixture was stirred for 30 min, poured into an aqueous solution of K_2CO_3, and extracted with EtOAc. The organic layer was washed with brine, dried over Na_2SO_4, and concentrated under reduced pressure. The residue was purified by column chromatography (hexanes−EtOAc, 1:1) to give **41** (251.1 mg, 0.78 mmol, 87%) as an anomeric mixture (α:β = 2:1), crystalline solid: $[\alpha]_D$ +83.5 (*c* 0.71, MeOH); IR 3593, 3473, 2117 cm^{-1}; ^1H NMR (major isomer) δ_H 1.35 (3H, s), 1.51 (3H, s), 3.07 (3H, s), 3.46 (1H, dd, *J* = 3.3, 7.9 Hz), 4.22 (1H, dd, *J* = 2.6, 5.6 Hz), 4.44−4.47 (3H, m), 4.57 (1H, ddd, *J* = 2.6, 4.2, 7.4 Hz), 5.31 (1H, d, *J* = 3.3 Hz); ^{13}C NMR (100.6 MHz) (major isomer) δ_C 26.1 (CH_3), 28.0 (CH_3), 37. 5 (CH_3), 61.3 (CH), 66.2 (CH), 69.0 (CH_2), 72.2 (CH), 73.6 (CH), 91.7 (CH), 110.4 (C); ^1H NMR (500 MHz) (minor isomer) δ_H 1.34 (3H, s), 1.55 (3H, s), 3.08 (3H, s), 3.40 (1H, dd, *J* = 7.9, 7.9 Hz), 4.05 (1H, dd, *J* = 7.7, 5.4 Hz), 4.11 (1H, dd, *J* = 5.6, 2.3 Hz), 4.14 (1H, ddd, *J* = 7.1, 4.8, 2.3 Hz), 4.41 (1H, dd, *J* = 11.0, 7.7 Hz), 4.44−4.47 (1H, m), 4.63 (1H, d, *J* = 8.1 Hz); ^{13}C NMR (100.6 MHz) (minor isomer) δ_C 26.1 (CH_3), 28.0 (CH_3), 37.5 (CH_3), 65.7 (CH), 68.7 (CH_2), 71.0 (CH), 72.2 (CH), 77.0 (CH), 95.5 (CH), 111.1 (C); MS *m/z* (rel intens) 308 (M^+ − CH_3, 10), 280 (9), 68 (100); HRMS *m/z* calcd for $C_9H_{14}N_3O_7S$, 308.0552, found 308.0562. Anal. Calcd for $C_{10}H_{17}N_3O_7S$: C, 37.15; H, 5.30; N, 13.00; S, 9.90. Found: C, 37.17; H, 5.15; N, 13.02; S, 9.92.

4-*O*-Formyl-2,3-*O*-isopropylidene-5-*O*-(methylsulfonyl)-D-lyxononitrile (42). A solution of β-hydroxy azide **41** (140.5 mg, 0.43 mmol) in CH_2Cl_2 (9 mL) was treated with DIB (172.3 mg, 0.53 mmol) and I_2 (113.3 mg, 0.45 mmol). The reaction mixture was stirred at 0−5 °C for 2.5 h under irradiation with two 80 W tungsten-filament lamps, then poured into a 10% aqueous $Na_2S_2O_3$ solution, and extracted with CH_2Cl_2. The

organic layer was dried over anhydrous Na_2SO_4 and concentrated under reduced pressure. The residue was purified by column chromatography (hexanes−EtOAc, 70:30) to give nitrile **42** (90.0 mg, 0.31 mmol, 71%): mp 57−59 °C (from *n*-hexane−EtOAc); $[\alpha]_D$ +0.7 (*c* 2.27); IR 2100, 1737 cm^{-1}; ^1H NMR (C_6D_6) δ_H 0.93 (3H, s), 1.32 (3H, s), 2.10 (3H, s), 3.82 (1H, dd, J = 5.9, 6.0 Hz), 3.91 (1H, dd, J = 4.9, 11.6 Hz), 3.98 (1H, dd, J = 5.0, 11.6 Hz), 4.10 (1H, d, J = 5.8 Hz), 5.41 (1H, ddd, J = 4.9, 5.0, 6.0 Hz), 7.47 (1H, s); ^{13}C NMR (100.6 MHz) δ_C 25.6 (CH_3), 26.6 (CH_3), 37.7 (CH_3), 64.8 (CH), 66.3 (CH_2), 68.8 (CH), 75.1 (CH), 113.1 (C), 116.0 (C), 159.5 (CH); MS *m/z* (rel intens) 278 ($M^+ - CH_3$, 100), 126 (43); HRMS *m/z* calcd for $C_9H_{12}NO_7S$, 278.0334, found 278.0329. Anal. Calcd for $C_{10}H_{15}NO_7S$: C, 40.95; H, 5.15; N, 4.78; S, 10.93. Found: C, 41.12; H, 5.35; N, 4.90; S, 10.92.

1,5-Anhydro-5-[(*tert*-butoxycarbonyl)amino]-1,5-dideoxy-2,3-*O*-isopropylidene-D-lyxitol (43). To a stirred solution of **42** (70.5 mg, 0.24 mmol) in THF (9 mL) at 0 °C under N_2 was added $LiAlH_4$ in Et_2O (1 M) (2.8 mL, 2.82 mmol) dropwise. The mixture was stirred for 1 h, and the excess reagent was carefully destroyed by dropwise addition of a saturated aqueous solution of Na_2SO_4 at 0 °C. After 30 min at 0−10 °C, Boc_2O (0.28 mL, 262.6 mg, 1.2 mmol) was added and stirring continued for 30 min. The reaction mixture was poured into water and extracted with EtOAc. The organic layer was washed with brine, dried over anhydrous Na_2SO_4, and concentrated under reduced pressure. The residue was purified by column chromatography (hexanes−EtOAc, 1:1) to give the iminosugar **43** (40.6 mg, 0.15 mmol, 62%) as an oil: $[\alpha]_D$ +3.9 (*c* 0.76); IR 3608, 3448, 1682 cm^{-1}; ^1H NMR (65 °C) δ_H 1.35 (3H, s), 1.46 (9H), 1.47 (3H, s), 1.95 (1H, s), 3.30 (1H, dd, J = 13.6, 5.8 Hz), 3.50 (1H, dd, J = 14.3, 3.9 Hz), 3.61 (1H, dd, J = 13.6, 3.4 Hz), 3.78 (1H, dd, J = 4.2, 14.3 Hz), 3.95 (1H, ddd, J = 3.4, 4.6, 5.8 Hz), 4.07 (1H, dd, J = 4.2, 6.4 Hz), 4.31 (1H, ddd, J = 4.0, 4.1, 6.5 Hz); ^{13}C NMR (125.7 MHz, 65 °C) δ_C 25.3 (CH_3), 27.5 (CH_3), 28.5 (3 × CH_3), 43.3 (CH_2), 45.1 (CH_2), 68.2 (CH), 72.1 (CH), 76.5 (CH), 80.0 (C), 109.3 (C), 155.8 (C); MS *m/z* (rel intens) 273 (M^+, 2), 258 (4), 57 (100); HRMS *m/z* calcd for $C_{13}H_{23}NO_5$, 273.1576, found 273.1592. Anal. Calcd $C_{13}H_{23}NO_5$: C, 57.13; H, 8.48; N, 5.12. Found: C, 57.19; H, 8.22, N; 5.04.

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Supporting Information Available: Detailed experimental procedures and spectral and analytical data for compounds **3**, **5**, **6**, **8**, **10**−**14**, and **25**. This material is available free of charge via the Internet at http://pubs.acs.org.

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