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A Diastereoselective and General Route to 5-Amino-5-deoxysugars: Influence of C-3 Substitution on the Addition of Amines to C-5 of Vinyl Sulfone-Modified Hex-5-enofuranosyl Carbohydrates

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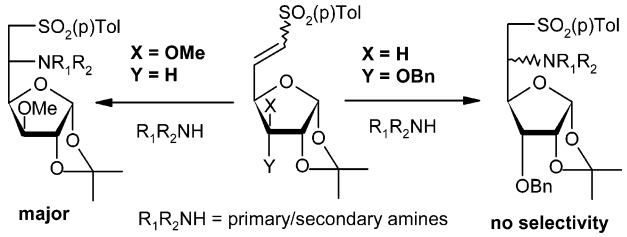

In the synthesis of vinyl sulfone-modified hex-5-enofuranosides, the *E*/*Z* ratios of the products are influenced by the stereoelectronic property of a group present at the C-3 position. This observation has been utilized to influence the diastereoselectivity of addition of amines to C-5 of vinyl sulfone-modified hex-5-enofuranosides, which are efficient Michael acceptors. The stereoelectronic effect of OMe attached to the β-face of C-3 (gluco derivative) is sufficient to impose diastereoselectivity overwhelmingly in favor of L-ido-aminosugars when the Michael acceptor is reacted with both primary and secondary amines. 3-*O*-Benzylated gluco derivative is also effective in producing L-ido-aminosugars but only in reactions with primary amines. The selectivity is lost when an allo derivative with OBn at the α-face of C-3 is used. Selected products were desulfonated to establish this new approach as a general and versatile strategy for accessing 5-amino-5-deoxysugars.

Introduction

Aminosugars in general are one of the most important classes of modified carbohydrates.[1] Several 5-amino-5-deoxysugars such as 5-deoxy-6-*O*-dodecyl-1,2-*O*-isopropylidene-5-pyrrolidinyl-α-D-glucofuranose have been identified for their antiproliferative and immunomodulatory activities,[2] and 5-aminohexoses are the key building blocks for the synthesis of a wide variety of polyhydroxylated piperidines which are glycosidase inhibitors.[3−5] The most common methods for the synthesis of aminosugars involve the reactions of amines with sugar-derived epoxides, tosylates, and ketones.[1] Our interest in the area of aminosugars[6] including aminonucleosides[7] in general and 5-aminosugars in particular prompted us to look for

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(2) (a) Arora, S. K.; Thomson, D. S. Akhtar, M. N. U.S. 1994, 10 pp. Cont.-in-part of U.S. Ser. No. 810,906; *Chem. Abstr*. **1995**, *122*, 64320. (b) Arora, S. K.; Thomson, D. S.; Akhtar, M. N. PCT Int. Appl. 1993, 31 pp; *Chem. Abstr*. 1993, *119*, 271626.

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(4) For the synthesis of deoxynojirimycin from carbohydrates, see: (a) Dhavale, D. D.; Desai, V. N.; Sindkhedkar, M. D.; Mali, R. S.; Castellari, C.; Trombini, C. *Tetrahedron: Asymmetry* **1997**, *8*, 1475. (b) Schaller, C.; Vogel, P.; Jager, V. *Carbohydr. Res*. **1998**, *314*, 25. (c) Pistia-Brueggeman, G.; Hollingsworth, R. I. *Tetrahedron* **2001**, *57*, 8773. (d) Spreitz, J.; Stutz, A. E.; Wrodnigg, T. M. *Carbohydr. Res*. **2002**, 337, 183. (e) Lemaire, M.; Veny, N.; Gefflaut, T.; Gallienne, E.; Chenevert, R.; Bolte, J. *Synlett* **2002**, 1359. (f) Rani, S.; Agarwal, A.; Vankar, Y. D. *Tetrahedron Lett*. **2003**, *44*, 5001. (g) Zechel, D. L.; Boraston, A. B.; Gloster, T.; Boraston, C. M.; MacDonald, J. M.; Tilbrook, D. M. G.; Stick, R. V.; Davies, G. J. *J. Am. Chem. Soc*. **2003**, *125*, 14313. (h) Szczepina, M. G.; Johnston, B. D.; Yuan, Y.; Svensson, B.; Pinto, B. M. *J. Am. Chem. Soc*. **2004**, *126*, 12458. (i) Goujon, J.-Y.; Gueyrard, D.; Compain, P.; Martin, O. R.; Ikeda, K.; Kato, A.; Asano, N. *Bioorg. Med. Chem*. **2005**, *13*, 2313.

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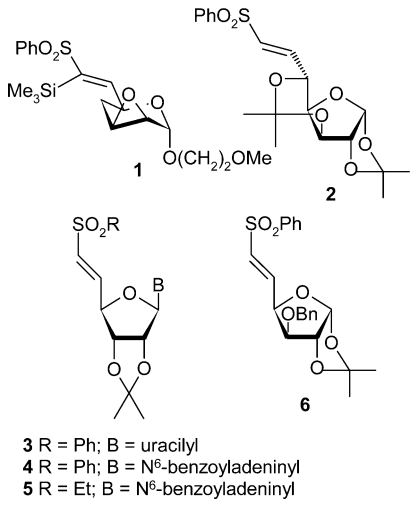
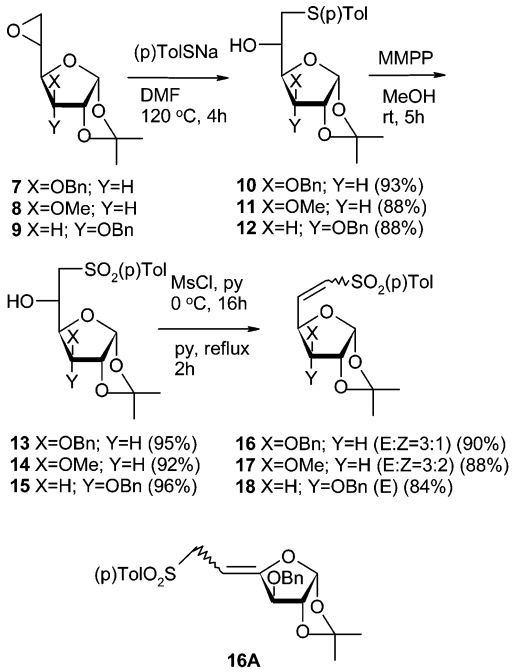


FIGURE 1. Vinyl sulfone-modified carbohydrates with exocylic vinyl sulfone groups.

an alternative strategy for the functionalization of the C-5 position of hexoses. A perusal of literature on the synthesis of 5-amino-5-deoxysugars reveals that methods for the functionalization of the C-5 position of hexose sugars in general are limited in number. This is mainly because of the fact that the 5-*O*-sulfonylated hexoses are reluctant partners in nucleophilic displacement reactions; moreover, because of the secondary nature of the 5-OH group, low-boiling amines cannot be used for such transformations because the reaction has to be carried out at 80 °C and beyond.[2,8] On the other hand, amines react with epoxides (e.g., **7**−**9**, Scheme 1) in a regioselective fashion to attack the C-6 position.[9] Except for a single report on the azidomercuration of the 5,6-unsaturated carbohydrates,[10] olefinic carbohydrates have never been employed in the synthesis of 5-amino-5-deoxysugars; however, this reaction is limited only to the use of azide as the source of masked amino function. Nucleophilic addition (Michael) to double bonds activated by electron-withdrawing groups as part of carbohydrates should serve as a useful methodology for the functionalization of monosaccharides. In fact, the addition of ammonia to 3-*O*-acetyl-5,6-dideoxy-1,2-*O*-isopropylidene-6-nitro-α-D-hex-5-enofuranose produced 5-amino-5-deoxy-L-idofuranose and 5-amino-5-deoxy-D-glucofuranose in a ratio of 1.5:1.[5b]

SCHEME 1. Synthesis of Vinyl Sulfone-Modified Hex-5-enofuranosides



Interestingly, more than two decades ago, a vinyl sulfone-modified pyranose derivative **1** (Figure 1) was reacted with MeLi in a stereoselective fashion to generate intermediates leading to the synthesis of maytansinol.[11a] Although α,β-unsaturated or vinyl sulfones are now commonly used intermediates in organic synthesis,[6b−f,12] the strategy for the functionalization of a carbon center away from the pyranose or furanose ring using a vinyl sulfone-modified carbohydrate has never been explored in spite of the efficient application of Michael addition reaction to **1**. In addition to the above example, there are only a few reports on the synthesis and properties of vinyl sulfone-modified carbohydrates where the vinyl sulfone group is NOT attached to the ring carbons. Vinyl sulfone-modified carbohydrate **2** and corresponding nucleosides **3** and **4** have been synthesized using radical chemistry for the chain elongation at C-5 of pentose sugars.[13a] A related nucleoside **5** was also obtained[13b] through a much shorter route by using a sulfone-stabilized Horner−Emmons reagent. Except for the only report on the use of a vinyl sulfone-modified hex-5-enofuranoside **6** as a substrate for cycloaddition reaction,[13c] none of the systems represented by compounds **2**−**6** was studied at all to establish their potentials as synthetic intermediates.

(5) For the synthesis of idonojirimycin from carbohydrates, see: (a) Fowler, P. A.; Haines, A. H.; Taylor, R. J. K.; Chrystal, E. J. T.; Gravestock, M. B. *Carbohydr. Res*. **1993**, *246*, 377. (b) Sasinkova, V.; Koos, M. *Chem. Paper*. **1997**, *51*, 147. (c) Szolcsanyi, P.; Gracza, T.; Koman, M.; Pronayova, N.; Liptaj, T. *Chem. Commun*. **2000**, 471. (d) Szolcsanyi, P.; Gracza, T.; Koman, M.; Pronayova, N.; Liptaj, T. *Tetrahedron: Asymmetry* **2000**, *11*, 2579.

(6) (a) Ravindran, B.; Pathak, T. *J. Org. Chem*. **1999**, *64*, 9715. (b) Ravindran, B.; Sakthivel, K.; Suresh, C. G.; Pathak, T. *J. Org. Chem.* **2000**, *65*, 2637. (c) Ravindran, B.; Pathak, T. *Ind. J. Chem.* **2001**, *B* **40**, 1114. (d) Ravindran, B.; Deshpande, S. G.; Pathak, T. *Tetrahedron* **2001**, *57*, 1093. (e) Suresh, C. G.; Ravindran, B.; Pathak, T.; Narasimha Rao, K.; Sasidhar Prasad, J. S.; Lokanath, N. K. *Carbohydr. Res.* **2002**, *337*, 1507. (f) Sanki, A. K.; Pathak, T. *Synlett*, **2002**, 1241.

(7) (a) Sakthivel, K.; Kumar, R. Krishna; Pathak, T. *Tetrahedron* **1993**, *49*, 4365. (b) Sakthivel, K.; Bera, S.; Pathak, T. *Tetrahedron* **1993**, *49*, 10387. (c) Sakthivel, K.; Pathak, T.; Suresh, C. G. *Tetrahedron* **1994**, *50*, 13251. (d) Bera, S.; Pathak, T.; Langley, G. J. *Tetrahedron* **1995**, *51*, 1459. (e) Sakthivel, K.; Pathak, T. *Tetrahedron* **1996**, *52*, 4877. (f) Bera, S.; Pathak, T. *Tetrahedron* **1999**, *55*, 13051. (g) Pathak, T. *Chem. Rev*. **2002**, *102*, 1623.

(8) (a) Robert E. G.; Robert M. B.; Susumu H.; Roy L. W. *J. Org. Chem*. **1963**, *28*, 1401. (b) Roy L. W.; Robert E. G. *J. Org. Chem.* **1964**, *29*, 2609.

(9) Williams, N. R. *Adv. Carbohydr. Chem*. **1970**, *25*, 109.

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On the other hand, since we have already established the efficient and general applications of vinyl sulfone-modified carbohydrates in the synthesis of amino-sugars,[6b−e] we envisaged that it would be pertinent to study the diastereoselectivity of addition of amines to vinyl sulfone-modified hex-5-enofuranosides. Moreover, efficient amination followed by desulfonation of the addition product using a variety of reaction conditions[14] would lead to a range of C-6 functionalized C-5 amino sugars.

Results and Discussion

Synthesis of Vinyl Sulfone-Modified Hex-5-enofuranosides. To access relatively large amounts of vinyl sulfone-modified hex-5-enofuranosides, it was necessary to devise a simple and general methodology suitable for the large-scale preparation of **16** and its analogues. We intended to generate a wide variety of exocyclic vinyl sulfones (analogues of **16**−**18**) having various alkyl and aryl groups attached to sulfur through simple routes. We, therefore, avoided the use of Emmons−Wadsworth−Horner-type reagent, which was used[13c] for the synthesis of **6**. At the same time, the radical chemistry reported for the synthesis of **2**−**4** was also not suitable for the large-scale preparation of **16**−**18**. Since nucleophiles are known to attack regioselectively[9] the C-6 position of epoxides (e.g., **7**−**9**, Scheme 1), we reacted the easily accessible epoxide **7**[15a] with sodium tolylthiolate to get **10** in high yield. Oxidation of **10** produced **13**. Compound **13** was subjected to mesylation followed by olefination to get the desired vinyl sulfone **16** (*E*/*Z* = 3:1) (Scheme 1). The formation of the unexpected *Z* isomer in relatively high amount prompted us to study the influence of steric bulk at the C-3 position on the *E*/*Z* ratio. Therefore, epoxides **8**[15b] and **9**[15c] were transformed to vinyl sulfones **17** and **18** respectively via intermediates **11**/**14** and **12**/**15** following the same route (Scheme 1).

Interestingly, the variation of the group at C-3 affected the *E*/*Z* ratios to some extent. Thus, by changing from OBn in **16** to OMe in **17**, the *E*/*Z* ratio changed from 3:1 to 3:2; in the case of **18**, however, only *E* isomer could be detected. Since the presence of β-OBn (**16**) or β-OMe (**17**) at C-3 caused the formation of *Z* isomer (alongside *E* isomer) as opposed to the exclusive formation of *E* isomer in the case of **18**, it may be argued that the stereoselectivity of abstraction of protons from C-6 during the elimination reactions of the mesylated products of **13**−**15** was dictated by the stereoelectronic properties of the group present at C-3 on the β-face of furanosides. However, the exact cause for the loss of selectivity of abstraction of protons in the formation of **16** and **17** cannot be established at this point.

The nature of the organic base used for the conversion of **13** to **16** profoundly affected the product formation. Thus, DBU at room temperature in 10 min produced the unwanted β, γ-unsaturated sulfone **16A** exclusively in 95% isolated yield as a crystalline solid. We presumed that DBU was too strong a base to isomerize **16** (formed in situ) to **16A** by deprotonating H-4. In fact, **16A** was obtained exclusively in 3 h when **16** was treated with DBU. Therefore, we reacted the mesylated product of **13** with several organic bases much weaker than DBU. Thus, Et_3N in dichloromethane at room temperature in 3 h and neat *N*,*N*-dimethylaniline at 110−120 °C in 6 h produced *E* and *Z* isomers of **16** in almost equal proportions (^{1}H NMR). Pyridine at 110−120 °C in 2 h generated a mixture of *E*/*Z* of **16** in a ratio 3:1, and 2,4,6-collidine in toluene at 110−120 °C in 8 h changed the ratio to 4:1 (^{1}H NMR). Compound **16A** could not be identified in any of the above reactions. However, we opted for pyridine because of its low basicity and easy accessibility. The above method constitutes a more efficient and general route to compounds such as **16**−**18** than the radical[13a] and Emmons−Wadsworth−Horner-type reagent-based methods.[13b,c] If necessary, sodium tolylthiolate may be replaced by other thiolate salts to access analogues of **16**−**18** or other hexoses.

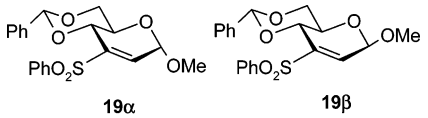


FIGURE 2. Vinyl sulfone-modified hex-2-enopyranosides.

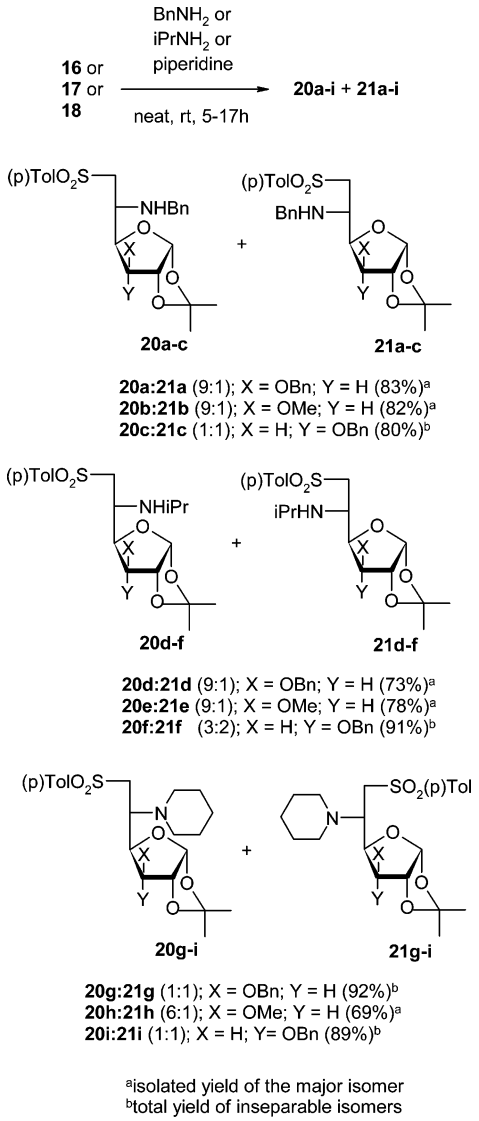
The ratios of *E*/*Z* in **16** and **17** were determined from the peaks arising out of either H-1 protons or the methyl protons of the tolylsulfonyl group in the ^{1}H NMR spectra of the purified mixtures of isomers. Since the *E*-isomer of **16** is a higher homologue of **6**, the isomers of the former could be easily identified even in mixtures by comparing peaks at δ 6.69 (dd, J = 1.8, 15 Hz, 1H) and δ 6.96 (dd, J = 3.8, 15 Hz, 1H) arising out of H-5 and H-6 protons, respectively, of the *E* isomer of **16** and 6.39 ppm (m, 2H) for the same protons of the *Z* isomer.[13c] In fact, in the case of **18**, peaks at δ 6.62 (dd, J = 1.9, 15.1 Hz, 1H) and δ 6.99 (dd, J = 3.9, 15.2 Hz, 1H) indicated the presence of only *E* isomer. Similarly, δ 6.62 (dd, J = 1.8, 15 Hz, 1H)/δ 6.96 (dd, J = 3.8, 15 Hz, 1H) and δ 6.35 (m, 2H) for **17** were indicative of the presence of the *E* or *Z* isomers, respectively.

Reactions of Vinyl Sulfone-Modified Hex-5-enofuranosides. It should be noted that in the case of vinyl sulfone-modified hex-2-enopyranosides amines added in diastereoselective fashion to **19**α and **19**β (Figure 2).[6b−f] The addition of primary amines to **19**α and **19**β exclusively produced C-2 equatorial (gluco) products. Secondary amines, on reactions with **19**β, produced only gluco derivative but with **19**α produced a mixture in which gluco was still the predominant isomer.[6b] On the other hand, sterically bulky *tert*-butylamine reacted only with **19**β (and not **19**α) at elevated temperature to produce the gluco derivative in high yield.[6e] It may be concluded from these reactions that the directive effect of the anomeric configuration to a great extent determined the stereochemical outcome of the reactions but the nature of nucleophiles also played an important role. Although no such directive group was available at C-4, adjacent to the electrophilic reactive site C-5 of **16**−**18**, our observation related to the influence of C-3 substitution on the *E*/*Z* ratios for **16**−**18** led us to envisage that the same structural features would also affect the diastereoselectivity of addition of amines to C-5 of **16**−**18**.

(14) For a review on desulfonation, see: Najera, C.; Yus, M. *Tetrahedron* **1999**, *40*, 10547.

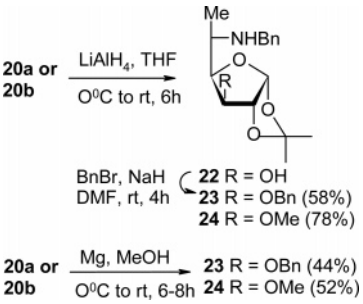
(15) (a) Morillo, M.; Lequart, V.; Grand, E.; Goethals, G.; Usubillaga, A.; Villa, P.; Martin, P. *Carbohydr.* Res. **2001**, *334*, 281. (b) Yoshimura, J.; Tamaru, M. *Carbohydr. Res*. **1979**, *72*, C9. (c) Hanaya, T.; Sugiyama, K.-I.; Kawamoto, H.; Yamamoto, H. *Carbohydr. Res*. **2003**, *338*, 1641.

SCHEME 2. Diastereoselective Addition of Amines to Vinyl Sulfone-Modified Hex-5-enofuranosides



Thus, the 3-*O*-benzylated gluco derivative **16** on reactions with neat benzyl and isopropylamines produced **20a/21a** and **20d/21d**, respectively, in a ratio 9:1 (^{1}H NMR). In both cases, the ido derivatives **20a** and **20d** were the major products, which were isolated and identified unambiguously (see later). The 3-*O*-methylated gluco derivative **17** also reacted in a similar fashion with benzyl and isopropylamines to produce the **20b/21b** and **20e/21e**, respectively, in a ratio of 9:1 (^{1}H NMR). In this case also, the ido isomer was the major product (Scheme 2). It is significant to note that the stereoelectronic effect of OMe at C-3 (compound **17**) is sufficient to impose diastereoselectivity in favor of the L-ido derivative. However, the allo derivative **18**, where the steric bulk at C-3 was significantly reduced because of the presence of a hydrogen atom instead of β-OBn/OMe at C-3, showed a complete or significant lack of the diastereoselectivity of addition when reacted with benzyl and isopropylamines. In these cases, **20c/21c** and **20f/21f** were formed in ratios 1:1 and 3:2 (^{1}H NMR), respectively, as inseparable mixtures. A secondary amine piperidine reacted with **16**−**18** to produce **20g/21g**, **20h/21h**, and **20i/21i** in 1:1, 6:1, and 1:1 ratios, respectively (Scheme 2). In these cases, except for **17**, an increase in the interaction of bulky piperidine with OBn at C-3 (for **16**) or absence of interaction with H at C-3 (for **18**) resulted into the loss of diastereoselectivity of addition. Here also, the stereoelectronic properties of OMe group (for **17**) render optimum interactions with piperidine for better selectivity. The major product **20h** obtained from the reaction of **17** was isolated in 69% yield. It should be noted that the use of a solvent like THF affected the reactions adversely in almost all cases; on an average the reaction time increased from 5−17 h to 2.5−4 days.

SCHEME 3. Reductive Removal of *p*-Tolylsulfonyl Group



To establish the usefulness of this methodology, we desulfonated compounds **20a** and **20b** using two different reagents. Compound **20a** on treatment with LAH underwent desulfonation with partial debenzylation to produce a mixture of **22** and **23**. The mixture was rebenzylated to produce **23** in 58% overall yield in two steps. The 3-OMe derivative **20b** was desulfonated smoothly to produce **24** in 78% yields. Alternatively, **20a** and **20b** could be desulfonated less efficiently to **23** and **24**, respectively, using Mg in MeOH (Scheme 3).

The second purpose of the desulfonation was to establish the structures of the synthetic aminosugars unambiguously because compound **23** was apparently reported in the literature in connection with the synthesis of a deoxynojirimycin analogue.[4a] However, the data reported[4a] for the β-L-idofuranose and the α-D-glucofuranose derivatives appear to be confusing. We therefore decided to establish the identity of our compounds unambiguously by synthesizing them through alternative routes. Thus, the known glucotosyl derivative **25**[16a] was reacted with benzylamine to produce aminosugars, which matched with compound **23** in every respect (Scheme 4). On the other hand, the aminosugar obtained by reacting the idotosyl derivative **27**[16b,c] with benzylamine did not match with compound **23** and was **28** instead (Scheme 4). For the "β-L-idofuranose" derivative, the authors reported[4a] $[\alpha]^{29}_D$ −52.8 (c = 1.3, $CHCl_3$)/δ_H 1.31 (d, J = 6.3 Hz, 3H, H-6)/δ_C 17.83 (C-6). For the "α-D-glucofuranose" derivative, the authors reported[4a] $[\alpha]^{29}_D$ −10.3 (c = 1.3, $CHCl_3$)/δ_H 1.01 (d, J = 6.3 Hz, 3H, H-6)/δ_C 15.4 (C-6). We, on the other hand recorded the following combinations. Compound **23**: $[\alpha]^{29}_D$ −10.5 (c 0.65, $CHCl_3$)/δ_H 0.98 (d, J = 6.5 Hz, 3H)/δ_C 15.6. Compound **28**: $[\alpha]^{29}_D$ −56.2 (c 0.45, $CHCl_3$)/δ_H 1.25 (d, J = 6.4 Hz, 3H)/δ_C 17.7. It is clear

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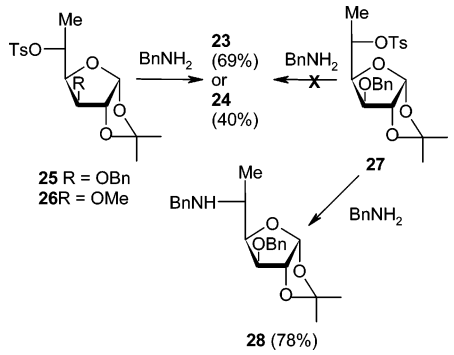
SCHEME 4. Alternative Synthesis of 5-Amino-5,6-dideoxyhexofuranosides



from the above comparisons that the data reported[4a] for "α-D-glucofuranose derivative"[4a] compares favorably with compound **23**, which in fact is a β-L-idofuranose derivative. Further analysis of the data revealed that the 6-Me peak for the 6-deoxy-gluco derivative in a pair of gluco/ido compounds such as **25** (δ 1.34, d) and **27** (δ 1.26, d) appears at a higher δ value. The chemical shifts for the 6-Me groups of 3-*O*-benzyl-6-deoxy-1,2-*O*-isopropylidene-α-D-gluco-1,4-furanose and 3-*O*-benzyl-6-deoxy-1,2-*O*-isopropylidene-β-L-ido-1,4-furanose[16c] are 1.25 (d) and 1.14 (d), respectively. The same trend is followed in the case of **28** (δ 1.25, d) and **23** (δ 0.98, d) pair. The identity of 3-*O*-methyl analogue **24** was also established unambiguously through alternative synthesis from **26**[16b] (Scheme 4). The identity of the major isomer **20h** was established by X-ray diffraction of the single crystal; the configuration of the three groups around the asymmetric carbon C5 as viewed from the side of H atom can be clearly seen in Figure 3. Since all of **20a**, **20b**, and **20h** were identified

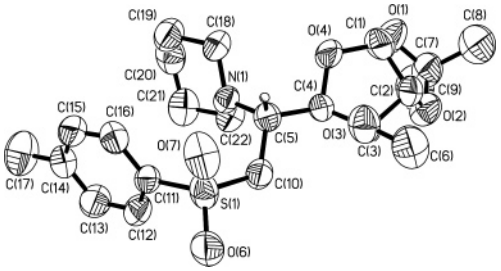


FIGURE 3. ORTEP diagram of compound **20h**. Only one molecule of the crystallographic asymmetric unit is shown with the H-atom attached to C-5.

as L-ido isomers, compounds **20d** and **20e** were also assigned the L-ido configuration.

To explain the diastereoselectivity of addition of amines to **16**−**18**, one could postulate the formation of an H-bonded precursor having the geometry of a six-membered ring (Figure 4). This system fixes the transition state in the L-ido configuration. It may be argued that the stereoelectronic interactions between the R group (OBn/OMe/H) would allow the amine nucleophile to take up the position as shown in Figure 4. Minimum interactions of primary amines with OBn (compound **16**) or OMe (compound **17**) allow the amines to attack C-5 in a diastereoselective fashion via the H-bonded intermediate. A more severe interaction of OBn (compound **16**) with a bulky secondary amine piperidine does not

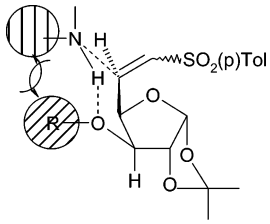


FIGURE 4. Proposed mode of addition of amines to vinyl sulfone-modified hex-5-enofuranosides.

allow the formation of the hydrogen-bonded intermediate but highly reactive piperidine reacts with **16** anyway without any selectivity. A moderate interaction between OMe (compound **16**) and piperidine allows most of the reaction to proceed through a 6-membered intermediate. In the absence of any such intermediates in case of **18**, both primary and secondary amines attack C-5 from both sides without any diastereoselectivity.

To conclude, we have developed an efficient and general strategy for the synthesis of vinyl sulfone-modified hex-5-enofuranosides. The usefulness of these compounds as Michael acceptors leading to the synthesis of 5-amino-5-deoxysugars has been established for the first time. The stereoelectronic properties of the substituents at C-3 position and their interactions with the incoming nitrogen nucleophiles have been used to control the diastereoselectivity of addition. Primary amines, on reaction with vinyl sulfone-modified gluco derivatives (compounds **16** and **17**) imparted better selectivity patterns in favor of L-ido isomers. The selectivity is absent in most cases with a bulky secondary amine or in all cases with vinyl sulfone-modified allo derivative (compound **18**) as the Michael acceptor. It may be suggested that the influence of the OMe group present at C-3 is optimum because even piperidine, a secondary amine, reacted with **17** to produce the L-ido-aminosugar as a major component. The application of these amination reactions for the generation of a wide variety of intermediates for polyhydroxylated piperidines and other related molecules as well as the diastereoselectivity of addition of carbon nucleophiles to these systems are currently being explored.

Experimental Section

General Methods. Melting points were determined in open-end capillary tubes and are uncorrected. Carbohydrates and other fine chemicals were obtained from commercial suppliers and are used without purification. Solvents were dried and distilled following the standard procedures. TLC was carried out on precoated plates (Merck silica gel 60, f_{254}), and the spots were visualized with UV light or by charring the plate dipped in 5% H_2SO_4−MeOH solution. Column chromatography was performed on silica gel (60−120 or 230−400 mesh). ^1H and ^{13}C NMR spectra for most of the compounds were recorded at 200 and 50.3 MHz, respectively, in $CDCl_3$ unless stated otherwise. Optical rotations were recorded at 589 nm. Compound **7** was synthesized from 3-*O*-benzyl-1,2-*O*-isopropylidene-6-*O*-tosyl-α-D-glucofuranose following a reported procedure.[15a] Compounds **8**[15b] and **9**[15c] were synthesized from the corresponding tosyl derivatives following the same route.

General Procedure for the Synthesis of Sulfides 10−**12.** To a well-stirred solution of **7**, **8**, or **9** in DMF (4 mL/mmol) were added *p*-thiocresol (5 equiv/mmol) and NaOMe (2.5 equiv/

mmol). The mixture was heated at 100−120 °C with stirring for 4−5 h under N_2. After completion of the reaction (TLC), the reaction mixture was poured into a saturated solution of $NaHCO_3$, and the product was extracted with EtOAc (3 × 10 mL). The combined organic layers were dried over anhyd Na_2SO_4 and filtered, and the filtrate was concentrated under reduced pressure to get a gummy residue. The residue was purified over silica gel column to afford sulfides **10**−**12**.

General Procedure for the Synthesis of Sulfones 13−**15.** To a well-stirred solution of sulfides **10**, **11**, or **12** in dry MeOH (10 mL/mmol) was added magnesium monoperoxyphthalate hexahydrate (2.5 equiv/mmol), and the mixture was stirred for 6 h under N_2. After completion of the reaction (TLC), MeOH was evaporated to dryness under reduced pressure, and the residue was dissolved in satd $NaHCO_3$. The aqueous part was washed with EtOAc (3 × 10 mL). The combined organic layers were dried over anhyd Na_2SO_4 and filtered, and the filtrate was concentrated under reduced pressure to get a residue. The residue was purified over silica gel column to obtain sulfones **13**−**15**.

General Procedure for the Synthesis of Vinyl Sulfone-Modified Carbohydrates 16−**18.** To a well-stirred solution of sulfones **13**, **14**, or **15** in pyridine (5 mL/mmol) was added methanesulfonyl chloride (4 equiv/mmol) in pyridine (1 mL/mmol of MsCl) dropwise at 0 °C under N_2. After completion of the addition, the reaction mixture was kept at 4 °C. After 16 h (TLC), the reaction mixture was poured into ice-cold water, and the aqueous layer was washed with EtOAc (3 × 10 mL). The combined organic layers were dried over anhyd Na_2SO_4 and filtered, and the filtrate was concentrated under reduced pressure to get a residue. The residue was heated under reflux with pyridine (4 mL/mmol). After 2 h (TLC), the reaction mixture was poured into ice-cold water, and the aqueous layer was extracted with EtOAc (3 × 10 mL). The combined organic layers were dried over anhyd Na_2SO_4 and filtered, and the filtrate was concentrated under reduced pressure to get a residue. The residue was purified over silica gel column to afford **16**−**18**.

General Procedure for the Synthesis of 20a−**i and 21a**−**i.** A mixture of **16**, **17**, or **18** and the appropriate amine (neat; 5 equiv/mmol) was stirred at ambient temperature. After completion of the reaction (TLC), satd NH_4Cl solution was added, and the mixture was extracted with EtOAc (3 × 10 mL). The combined organic layers were dried over anhyd Na_2SO_4 and filtered, and the filtrate was concentrated under reduced pressure to get a residue. The residue was purified over silica gel column to afford **20a**−**i** and **21a**−**i**.

3-*O*-Benzyl-1,2-*O*-isopropylidene-(6-*C*-*p*-tolyl sulfide)-α-D-gluco-1,4-furanose 10. Compound **7** (2.2 g, 7.53 mmol) was converted to **10** following the general procedure (2.9 g, 93%). Eluent: EtOAc/petroleum ether (1:5). Yellow gum. ^{1}H NMR ($CDCl_3$): δ 1.30 (s, 3H), 1.44 (s, 3H), 2.30 (s, 3H), 2.96 (dd, *J* = 7.8, 13.9 Hz, 1H), 3.33 (dd, *J* = 3.4, 13.9 Hz, 1H), 4.06 (m, 3H), 4.50−4.71 (m, 3H), 5.90 (d, *J* = 3.8 Hz, 1H), 7.08 (d, *J* = 8.1 Hz, 2H), 7.26−7.37 (m, 7H). ^{13}C NMR ($CDCl_3$): δ 20.7, 26.0, 26.5, 39.6, 66.8, 71.9, 81.5, 82.0, 104.8, 111.4, 127.5, 127.7, 128.2, 129.5, 130.0, 131.4, 136.0, 137.0. Anal. Calcd for $C_{23}H_{28}O_5S\cdot{}^1/_4H_2O$: C, 65.61; H, 6.82. Found: C, 65.49; H, 6.79.

1,2-*O*-Isopropylidene-3-*O*-methyl-(6-*C*-*p*-tolyl sulfide)-α-D-gluco-1,4-furanose 11. Compound **8** (1.9 g, 8.8 mmol) was converted to **11** following the general procedure (2.6 g, 88%). Eluent: EtOAc/petroleum ether (1:6). Yellow gum. ^{1}H NMR ($CDCl_3$): δ 1.31 (s, 3H), 1.46 (s, 3H), 2.30 (s, 3H), 3.00 (dd, *J* = 8.2, 13.9 Hz, 1H), 3.38 (m, 1H), 3.42 (s, 3H), 3.85 (d, *J* = 3.0 Hz, 1H), 3.93−4.11 (m, 2H), 4.56 (d, *J* = 3.8 Hz, 1H), 5.88 (d, *J* = 3.8 Hz, 1H), 7.08 (d, *J* = 7.9 Hz, 2H), 7.30 (d, 2H). ^{13}C NMR ($CDCl_3$): δ 20.9, 26.2, 26.7, 39.8, 57.9, 67.2, 81.5, 84.2, 105.0, 111.6, 129.7, 130.0, 131.6, 136.4. Anal. Calcd for $C_{17}H_{24}O_5S\cdot1H_2O$: C, 56.96; H, 7.30. Found: C, 56.56; H, 7.28.

3-*O*-Benzyl-1,2-*O*-isopropylidene-(6-*C*-*p*-tolylsulfide)-α-D-allo-1,4-furanose 12. Compound **9** (1.2 g, 4.1 mmol) was converted to **12** following the general procedure (1.5 g, 88%). Eluent: EtOAc/petroleum ether (1:5). Yellow gum. ^{1}H NMR ($CDCl_3$): δ 1.34 (s, 3H), 1.57 (s, 3H), 2.30 (s, 3H), 2.93 (dd, *J* = 9.3, 13.8 Hz, 1H), 3.13 (dd, *J* = 3.5, 14.0 Hz, 1H), 3.88−4.00 (m, 2H), 4.09 (dd, *J* = 3.2, 8.6 Hz, 1H), 4.56 (m, 2H), 4.75 (d, *J* = 12.0 Hz, 1H), 5.72 (d, *J* = 3.6 Hz, 1H), 7.08 (d, *J* = 8.1 Hz, 2H), 7.24−7.37 (m, 7H). ^{13}C NMR ($CDCl_3$): δ 20.9, 26.5, 26.7, 37.7, 68.8, 72.0, 77.0, 77.6, 79.8, 104.0, 113.0, 127.9, 128.0, 128.4, 129.7, 130.7, 131.3, 136.6, 137.2. Anal. Calcd for $C_{23}H_{28}O_5S$: C, 66.32; H, 6.78. Found: C, 66.02; H, 6.50.

3-*O*-Benzyl-1,2-*O*-isopropylidene-(6-*C*-*p*-tolylsulfonyl)-α-D-gluco-1,4-furanose 13. Compound **10** (2.8 g, 6.72 mmol) was converted to **13** following the general procedure (2.8 g, 95%). Eluent: EtOAc/petroleum ether (1:2). White needles. ^{1}H NMR ($CDCl_3$): δ 1.27 (s, 3H), 1.44 (s, 3H), 2.43 (s, 3H), 3.26 (dd, *J* = 10.1, 14.4 Hz, 1H), 3.58 (dd, *J* = 3.1, 14.4 Hz, 1H), 4.06 (m, 2H), 4.41−4.69 (m, 4H), 5.80 (d, *J* = 3.7 Hz, 1H), 7.27−7.37 (m, 7H), 7.77 (d, *J* = 8.3 Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 21.5, 26.1, 26.7, 59.8, 64.0, 72.4, 81.0, 81.4, 82.3, 104.9, 111.9, 127.7, 127.8, 128.0, 128.5, 129.9, 136.2, 137.2, 144.9. Anal. Calcd for $C_{23}H_{28}O_7S$: C, 61.59; H, 6.29. Found: C, 61.22; H, 6.21.

1,2-*O*-Isopropylidene-3-*O*-methyl-(6-*C*-*p*-tolylsulfonyl)-α-D-gluco-1,4-furanose 14. Compound **11** (1.6 g, 4.7 mmol) was converted to **14** following the general procedure (1.6 g, 92%). Eluent: EtOAc/petroleum ether (1:3). Yellow gum. ^{1}H NMR ($CDCl_3$): δ 1.29 (s, 3H), 1.44 (s, 3H), 2.45 (s, 3H), 3.28 (dd, *J* = 10.0, 14.5 Hz, 1H), 3.41 (s, 3H), 3.58 (dd, *J* = 1.6, 14.3 Hz, 1H), 3.84 (d, *J* = 3.1 Hz, 1H), 4.02 (dd, *J* = 3.1, 8.0 Hz, 1H), 4.39−4.43 (m, 1H), 4.53 (d, *J* = 3.7 Hz, 1H), 5.79 (d, *J* = 3.7 Hz, 1H), 7.36 (d, *J* = 8.2 Hz, 2H), 7.81 (d, *J* = 8.3 Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 21.5, 26.1, 26.7, 58.1, 60.0, 63.9, 81.3, 81.5, 83.2, 104.9, 111.8, 127.8, 129.9, 136.5, 144.9. Anal. Calcd for $C_{17}H_{24}O_7S$: C, 54.82; H, 6.50. Found: C, 55.22; H, 6.53.

3-*O*-Benzyl-1,2-*O*-isopropylidene-(6-*C*-*p*-tolylsulfonyl)-α-D-allo-1,4-furanose 15. Compound **12** (0.98 g, 2.34 mmol) was converted to **15** following the general procedure (1.0 g, 96%). Eluent: EtOAc/petroleum ether (1:2). Yellow gum. ^{1}H NMR ($CDCl_3$): δ 1.32 (s, 3H), 1.53 (s, 3H), 2.44 (s, 3H), 3.25 (m, 2H), 3.91 (m, 2H), 4.35 (m, 1H), 4.54 (m, 2H), 4.73 (d, *J* = 11.6 Hz, 1H), 5.69 (d, *J* = 3.6 Hz, 1H), 7.25−7.36 (m, 7H), 7.76 (d, *J* = 8.2 Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 21.5, 26.4, 26.7, 58.5, 65.3, 72.0, 76.6, 77.3, 79.7, 104.0, 113.0, 127.9, 128.0, 128.4, 129.4, 129.8, 136.1, 136.9, 144.9. Anal. Calcd for $C_{23}H_{28}O_7S$: C, 61.59; H, 6.29. Found: C, 61.26; H, 6.20.

3-*O*-Benzyl-5,6-didehydro-5,6-dideoxy-(*E*)- and 3-*O*-Benzyl-5,6-didehydro-5,6-dideoxy-(*Z*)-1,2-*O*-isopropylidene-(6-*C*-*p*-tolylsulfonyl)-α-D-gluco-1,4-furanose 16. Compound **13** (2.8 g, 5.3 mmol) was converted to **16** (mixture) following the general procedure (2.0 g, 90%). Eluent: EtOAc/petroleum ether (1:3). Yellow solid. ^{1}H NMR ($CDCl_3$): *E*-isomer δ 1.27 (s, 3H), 1.45 (s, 3H), 2.40 (s, 3H), 4.02 (d, *J* = 3.3 Hz, 1H), 4.46 (d, *J* = 11.9 Hz, 1H), 4.56 (s, 1H), 4.63 (d, *J* = 8.1 Hz, 1H), 4.87−4.82 (m, 1H), 5.94 (d, *J* = 3.7 Hz, 1H), 6.69 (dd, *J* = 1.8, 15.0 Hz, 1H), 6.96 (dd, *J* = 3.8, 15.0 Hz, 1H), 7.22−7.36 (m, 7H), 7.72 (d, *J* = 8.3 Hz, 2H); *Z*-isomer δ 1.33 (s, 3H), 1.55 (s, 3H), 2.43 (s, 3H), 4.34 (d, *J* = 3.3 Hz, 1H), 4.56−4.65 (m, 3H), 5.74 (m, 1H), 5.98 (d, *J* = 3.7 Hz, 1H), 6.39 (m, 2H), 7.25−7.34 (m, 7H), 7.77 (d, *J* = 8.3 Hz, 2H).

3-*O*-Benzyl-4,5-didehydro-5,6-dideoxy-1,2-*O*-isopropylidene-(6-*C*-*p*-tolylsulfonyl)-α-D-gluco-1,4-furanose 16A: Method A. Compound **13** (0.2 g, 0.45 mmol) was mesylated following the general procedure. A solution of the crude mesylated product in dichloromethane (10 mL) was treated with DBU (0.13 mL, 0.9 mmol) for 10 min at ambient temperature. Solvent was evaporated under reduced pressure, and the resulting residue was purified over silica gel to afford **16A** (0.18 g, 95%). **Method B.** A solution of **16** (0.11 g, 0.25 mmol) in dichloromethane (10 mL) was treated with DBU (0.07 mL, 0.3 mmol) for 3 h at ambient temperature. Usual workup and purification afforded **16A** (0.1 g, 91%). Eluent: EtOAc/petroleum ether (1:3). White crystals. Mp: 110 °C. $[\alpha]^{29}_D$ −94.2 (*c* 0.32, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 1.22 (s, 3H), 1.32 (s, 3H),

2.40 (s, 3H), 3.84−4.10 (m, 2H), 4.22 (m, 1H), 4.38−4.73 (m, 4H), 5.92 (d, J = 3.1 Hz, 1H), 7.24−7.40 (m, 7H), 7.78 (d, J = 8.2 Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 21.5, 27.0, 27.6, 53.8, 70.4, 80.1, 82.8, 90.6, 107.0, 114.2, 127.8, 128.0, 128.4, 128.5, 129.6, 136.0, 136.8, 144.4, 157.7. Anal. Calcd for $C_{23}H_{26}O_6S\cdot 2H_2O$: C, 59.21; H, 6.48. Found: C, 59.06; H, 6.09.

5,6-Didehydro-5,6-dideoxy-(*E*)- and 5,6-didehydro-5,6-dideoxy-(*Z*)-1,2-*O*-isopropylidene-3-*O*-methyl-(6-*C*-*p*-tolylsulfonyl)-α-D-gluco-1,4-furanose 17. Compound **14** (1.6 g, 4.30 mmol) was converted to **17** (mixture) following the general procedure (1.3 g, 88%). Eluent: EtOAc/petroleum ether (1:3). Yellow gum.^{1}H NMR ($CDCl_3$): *E*-isomer δ 1.30 (s, 3H), 1.46 (s, 3H), 2.42 (s, 3H), 3.35 (s, 3H), 3.81 (d, J = 3.1 Hz, 1H), 4.59 (d, J = 3.7 Hz, 1H), 4.83 (m, 1H), 5.90 (d, J = 3.7 Hz, 1H), 6.62 (dd, J = 1.8, 15.0 Hz, 1H), 6.96 (dd, J = 3.8, 15.0 Hz, 1H), 7.32 (d, J = 8.1 Hz, 2H), 7.74 (d, J = 8.1 Hz, 2H); *Z*-isomer δ 1.34 (s, 3H), 1.56 (s, 3H), 2.44 (s, 3H), 3.39 (s, 3H), 4.10 (d, J = 3.2 Hz, 1H), 4.62 (d, J = 3.8 Hz, 1H), 5.72 (m, 1H), 5.95 (d, J = 3.8 Hz, 1H), 6.35 (m, 2H), 7.37 (d, J = 8.2 Hz, 2H), 7.76 (d, J = 8.2 Hz, 2H).

3-*O*-Benzyl-5,6-didehydro-5,6-dideoxy-(*E*)-1,2-*O*-isopropylidene-(6-*C*-*p*-tolylsulfonyl)-α-D-allo-1,4-furanose 18. Compound **15** (0.5 g, 1.11 mmol) was converted to **18** following the general procedure (0.4 g, 84%). Eluent: EtOAc/petroleum ether (1:4). Yellow gum. $[\alpha]^{29}_D$ +18.3 (*c* 0.18, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 1.34 (s, 3H), 1.56 (s, 3H), 2.42 (s, 3H), 3.52 (dd, J = 3.9, 9.2 Hz, 1H), 4.55−4.75 (m, 4H), 5.72 (d, J = 3.6 Hz, 1H), 6.62 (dd, J = 1.9, 15.1 Hz, 1H), 6.99 (dd, J = 3.9, 15.2 Hz, 1H,), 7.25−7.38 (m, 7H), 7.72 (d, J = 8.3 Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 21.5, 26.3, 26.6, 72.4, 76.1, 77.2, 81.4, 103.9, 113.4, 127.7, 128.0, 128.2, 128.5, 129.8, 131.4, 136.7, 137.0, 140.8, 144.4. Anal. Calcd for $C_{23}H_{26}O_6S\cdot{}^1/_2H_2O$: C, 62.85; H, 6.19. Found: C, 62.49; H, 5.96.

3-*O*-Benzyl-5-benzylamino-5,6-dideoxy-1,2-*O*-isopropylidene-(6-*C*-*p*-tolylsulfonyl)-β-L-ido-1,4-furanose 20a. Compound **16** (0.35 g, 0.813 mmol) was converted to **20a** following the general procedure (0.37 g, 83%). Eluent: EtOAc/petroleum ether (1:3). Yellow gum. $[\alpha]^{29}_D$ −28.5 (*c* 0.5, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 1.29 (s, 3H), 1.44 (s, 3H), 2.40 (s, 3H), 3.34 (m, 1H), 3.43 (dd, J = 3.4, 14.8 Hz, 1H), 3.54 (m, 1H), 3.74 (s, 2H), 3.98 (d, J = 3.25 Hz, 1H), 4.30 (m, 1H), 4.47 (d, J = 11.6 Hz, 1H), 4.55 (d, J = 3.9 Hz, 1H), 4.64 (d, J = 11.6 Hz, 1H), 5.87 (d, J = 3.9 Hz, 1H), 7.16−7.33 (m, 12H), 7.65 (d, J = 8.2 Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 22.0, 26.7, 27.2, 52.3, 53.0, 57.6, 72.2, 80.6, 82.1, 82.7, 105.2, 112.1, 127.3, 128.4, 128.5, 128.7, 129.0, 130.2, 137.3, 140.4, 144.8. Anal. Calcd for $C_{30}H_{35}O_6NS$: C, 67.02; H, 6.56; N, 2.61. Found: C, 67.40; H, 6.54; N, 2.45.

5-Benzylamino-5,6-dideoxy-1,2-*O*-isopropylidene-3-*O*-methyl-(6-*C*-*p*-tolylsulfonyl)-β-L-ido-1,4-furanose 20b. Compound **17** (0.29 g, 0.824 mmol) was converted to **20b** following the general procedure (0.31 g, 82%). Eluent: EtOAc/petroleum ether (1:3). Yellow gum. $[\alpha]^{29}_D$ −30.8 (*c* 0.7, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 1.29 (s, 3H), 1.45 (s, 3H), 2.42 (s, 3H), 3.30 (s, 3H), 3.32−3.48 (m, 3H), 3.73 (d, J = 3.3 Hz, 1H), 3.79 (s, 2H), 4.28 (m, 1H), 4.50 (d, J = 3.9 Hz, 1H), 5.85 (d, J = 3.9 Hz, 1H), 7.22−7.31 (m, 7H), 7.70 (d, J = 8.3 Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 22.0, 26.6, 27.1, 52.3, 52.8, 57.7, 57.8, 80.9, 81.4, 85.0, 105.2, 112.0, 127.4, 128.5, 128.7, 128.8, 130.0, 130.2, 137.1, 140.5, 144.9. Anal. Calcd for $C_{24}H_{31}O_6NS\cdot{}^1/_2H_2O$: C, 61.25; H, 6.85; N, 2.98. Found: C, 61.49; H, 6.73; N, 3.0.

3-*O*-Benzyl-5-benzylamino-5,6-dideoxy-1,2-*O*-isopropylidene-(6-*C*-*p*-tolylsulfonyl)-α-D-allo- and -β-L-talo-1,4-furanose 20c and 21c. Compound **18** (0.22 g, 0.51 mmol) was converted to an inseparable mixture of two diastereomers **20c/21c** (1:1) following the general procedure (0.22 g, 83%). Eluent: EtOAc/petroleum ether (1:3). Yellow gum. Selected NMR data of the mixture: ^{1}H NMR ($CDCl_3$): δ 2.41/2.42 (each s, 6H), 3.75 (s, 4H), 5.60/5.64 (each d, 2H).

3-*O*-Benzyl-5,6-dideoxy-5-isopropylamino-1,2-*O*-isopropylidene-(6-*C*-*p*-tolylsulfonyl)-β-L-ido-1,4-furanose 20d. Compound **16** (0.23 g, 0.53 mmol) was converted to **20d** following the general procedure (0.19 g, 73%). Eluent: EtOAc/petroleum ether (1:2). Yellow gum. $[\alpha]^{29}_D$ −14.1 (*c* 0.55, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 0.95 (d, J = 6.1 Hz, 6H), 1.29 (s, 3H), 1.46 (s, 3H), 2.42 (s, 3H), 2.85 (m, 1H), 3.27 (m, 1H), 3.52 (dd, J = 3.7, 14.8 Hz, 1H), 3.60 (m, 1H), 4.03 (d, J = 3.3 Hz, 1H), 4.32 (m, 1H), 4.47 (d, J = 11.7 Hz, 1H), 4.55 (d, J = 3.9 Hz, 1H), 4.66 (d, J = 11.7 Hz, 1H), 5.87 (d, J = 3.9 Hz, 1H), 7.26−7.36 (m, 7H), 7.71 (d, J = 8.2 Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 21.3, 22.9, 23.3, 26.2, 26.7, 46.6, 50.0, 57.9, 71.8, 80.4, 81.6, 82.4, 104.8, 111.6, 127.9, 128.1, 128.6, 129.6, 136.9, 137.3, 144.2. Anal. Calcd for $C_{26}H_{35}O_6NS\cdot 1H_2O$: C, 61.51; H, 6.94; N, 2.76. Found: C, 61.01; H, 7.14; N, 2.69.

5,6-Dideoxy-5-isopropylamino-1,2-*O*-isopropylidene-3-*O*-methyl-(6-*C*-*p*-tolylsulfonyl)-β-L-ido-1,4-furanose 20e. Compound **17** (0.25 g, 0.71 mmol) was converted to **20e** following the general procedure (0.23 g, 78%). Eluent: EtOAc/petroleum ether (1:2). Yellow gum. $[\alpha]^{29}_D$ −23.4 (*c* 0.95, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 0.99 (m, 6H), 1.30 (s, 3H), 1.47 (s, 3H), 2.44 (s, 3H), 2.89 (m, 1H), 3.24 (m, 1H), 3.34 (s, 3H), 3.52 (m, 2H), 3.79 (d, J = 3.3 Hz, 1H), 4.29 (m, 1H), 4.50 (d, J = 3.9 Hz, 1H), 5.84 (d, J = 3.9 Hz, 1H), 7.34 (d, J = 8.0 Hz, 2H), 7.79 (d, J = 8.2 Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 21.2, 22.7, 23.0, 25.9, 26.3, 46.3, 49.8, 56.9, 57.8, 80.3, 80.6, 84.4, 104.4, 111.2, 127.6, 129.4, 136.8, 144.1. Anal. Calcd for $C_{20}H_{31}O_6NS\cdot{}^1/_4H_2O$: C, 57.46; H, 7.59; N, 3.35. Found: C, 57.29; H, 7.39; N, 3.24.

3-*O*-Benzyl-5,6-dideoxy-5-isopropylamino-1,2-*O*-isopropylidene-(6-*C*-*p*-tolylsulfonyl)-α-D-allo- and -β-L-talo-1,4-furanose 20f and 21f. Compound **18** (0.2 g, 0.46 mmol) was converted to an inseparable mixture of two diastereomers **20f/21f** (3:2) following the general procedure (0.21 g, 91%). Eluent: EtOAc/petroleum ether (1:2). Yellow gum. Selected NMR data of the mixture: ^{1}H NMR ($CDCl_3$): δ 0.97−0.92 (m, 12H), 2.43 (each s, 6H), 5.64/5.66 (each d, 2H).

3-*O*-Benzyl-5,6-dideoxy-1,2-*O*-isopropylidene-5-piperidino-(6-*C*-*p*-tolylsulfonyl)-α-D-gluco- and -β-L-ido-1,4-furanose 20g and 21g. Compound **16** (0.27 g, 0.63 mmol) was converted to an inseparable mixture of two diastereomers **20g/21g** (1:1) following the general procedure (0.28 g, 88%). Eluent: EtOAc/petroleum ether (1:3). Yellow gum. Selected NMR of the mixture: ^{1}H NMR ($CDCl_3$) δ 0.88−1.31 (m, 12H), 2.31 (m, 4H), 2.41/2.39 (each s, 6H), 2.58 (m, 4H), 5.88/5.92 (each d, 2H).

5,6-Dideoxy-1,2-*O*-isopropylidene-3-*O*-methyl-5-piperidino-(6-*C*-*p*-tolylsulfonyl)-β-L-ido-1,4-furanose 20h. Compound **17** (0.27 g, 0.759 mmol) was converted to **20h** following the general procedure (0.23 g, 69%). Eluent: EtOAc/petroleum ether (1:3). Yellow crystalline solid. Mp: 135 °C. $[\alpha]^{29}_D$ −80.5 (*c* 0.3, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 1.01 (m, 2H), 1.23 (m, 4H), 1.30 (s, 3H), 1.45 (s, 3H), 2.32 (m, 2H), 2.45 (s, 3H), 2.61 (m, 2H), 2.94 (m, 1H), 3.39 (s, 3H), 3.43 (m, 2H), 3.53 (d, J = 3.1 Hz, 1H), 4.18 (m, 1H), 4.53 (d, J = 3.9 Hz, 1H), 5.86 (d, J = 3.9 Hz, 1H), 7.31 (d, J = 8.0 Hz, 2H), 7.80 (d, J = 8.2 Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 21.9, 24.7, 26.2, 26.6, 27.2, 55.9, 57.8, 59.4, 79.1, 80.9, 85.2, 105.1, 111.9, 128.7, 129.7, 138.3, 144.2. Anal. Calcd for $C_{22}H_{33}O_6NS$: C, 60.11; H, 7.57; N, 3.19. Found: C, 60.34; H, 7.84; N, 3.05.

3-*O*-Benzyl-5,6-dideoxy-1,2-*O*-isopropylidene-5-piperidino-(6-*C*-*p*-tolylsulfonyl)-α-D-allo- and -β-L-talo-1,4-furanose 20i and 21i. Compound **18** (0.17 g, 0.39 mmol) was converted to an inseparable mixture of two diastereomers **20i/21i** (1:1) following the general procedure (0.13 g, 63%). Eluent: EtOAc/petroleum ether (1:3). Yellow gum. Selected NMR data of the mixture: ^{1}H NMR ($CDCl_3$): δ 1.23−1.31 (m, 12H), 2.26 (m, 4H), 2.44 (s, 6H), 2.58 (m, 4H), 5.65/5.83 (each d, 2H).

3-*O*-Benzyl-5-benzylamino-5,6-dideoxy-1,2-*O*-isopropylidene-β-L-ido-1,4-furanose 23: Method A. To a well-stirred solution of **20a** (0.4 g, 0.74 mmol) in dry THF (10 mL) was added LAH (5 equiv/mmol) at 0 °C under Ar, and the mixture was stirred at ambient temperature. After completion of the reaction (TLC), satd NH_4Cl solution was added, and the product was extracted with EtOAc (3 × 10 mL). The combined

organic layers were dried over anhyd Na_2SO_4 and filtered, and the filtrate was concentrated under reduced pressure to get a residue. The residue was benzylated to afford compound **23** (0.17 g, 58%). **Method B.** To a well-stirred solution of **20a** (0.3 g, 0.56 mmol) in dry MeOH (10 mL) was added Mg turnings (20 equiv/mmol) at 0 °C under Ar. Then the mixture was stirred at ambient temperature. Solvent was evaporated to dryness under reduced pressure. The resulting residue was dissolved in EtOAc (20 mL) and filtered. The filtrate was washed with water, dried over anhyd Na_2SO_4, and filtered, and the filtrate was concentrated under reduced pressure to get a residue. The residue was purified over silica gel column to afford compound **23** (0.09 g, 44%). Eluent: EtOAc/petroleum ether (1:2). Yellow oil. $[\alpha]^{29}_D$ −10.5 (*c* 0.65, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 0.98 (d, J = 6.5 Hz, 3H), 1.31 (s, 3H), 1.47 (s, 3H), 3.21 (m, 1H), 3.75 (d, J = 12.6 Hz, 1H), 3.98 (m, 2H), 4.05 (dd, J = 3.0, 9.1 Hz, 1H), 4.47 (d, J = 11.7 Hz, 1H), 4.65 (m, 2H), 5.92 (d, J = 3.8 Hz, 1H), 7.20−7.32 (m, 10H). ^{13}C NMR ($CDCl_3$): δ 15.6, 26.2, 26.6, 29.6, 51.4, 51.8, 71.7, 81.5, 81.7, 84.2, 104.7, 111.5, 126.7, 127.9, 128.0, 128.2, 128.3, 128.4, 137.1, 140.4. Anal. Calcd for $C_{23}H_{29}O_4N\cdot{}^1/_4H_2O$: C, 71.20; H, 7.66; N, 3.61. Found: C, 71.45; H, 7.57; N, 3.58.

5-Benzylamino-5,6-dideoxy-1,2-*O*-isopropylidene-3-*O*-methyl-β-L-ido-1,4-furanose 24. Compound **20b** (0.35 g, 0.76 mmol) was converted to **24** by LAH/THF (0.18 g, 78%) or by Mg/MeOH (0.12 g, 52%) following the procedure mentioned above. Eluent: EtOAc/petroleum ether (1:2). Yellow oil. $[\alpha]^{29}_D$ −31.3 (*c* 0.9, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 1.09 (d, J = 6.2 Hz, 3H), 1.31 (s, 3H), 1.47 (s, 3H), 3.10 (m, 1H), 3.39 (s, 3H), 3.64 (d, J = 3.1 Hz, 1H), 3.71 (d, J = 12.7 Hz, 1H), 3.89 (d, J = 12.9 Hz, 1H), 3.98 (dd, J = 3.0, 9.0 Hz, 1H), 4.57 (d, J = 3.9 Hz, 1H), 5.90 (d, J = 3.9 Hz, 1H), 7.24−7.32 (m, 5H). ^{13}C NMR ($CDCl_3$): δ 16.2, 26.7, 27.1, 51.8, 52.3, 57.9, 81.7, 84.4, 84.7, 105.2, 111.9, 127.2, 128.6, 128.8, 140.9. Anal. Calcd for $C_{17}H_{25}O_4N$: C, 66.43; H, 8.20; N, 4.56. Found: C, 66.07; H, 8.0; N, 4.77.

3-*O*-Benzyl-6-deoxy-1,2-*O*-isopropylidene-5-*O*-tosyl-β-L-ido-1,4-furanose 27. 3-*O*-Benzyl-6-deoxy-1,2-*O*-isopropylidene-β-L-ido-1,4-furanose[16c] (0.8 g, 2.72 mmol) was tosylated to afford compound **27** (1.12 g, 92%). Eluent: EtOAc/petroleum ether (1:5). Yellow gum. $[\alpha]^{29}_D$ −4.1 (*c* 0.25, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 1.26 (d, J = 6.7 Hz, 3H), 1.28 (s, 3H), 1.55 (s, 3H), 2.41 (s, 3H), 3.82 (d, J = 3.3 Hz, 1H), 4.08 (dd, J = 3.4, 8.5 Hz, 1H), 4.4 (d, J = 11.7 Hz, 1H), 4.5 (d, J = 3.9 Hz, 1H), 4.6 (d, J = 11.7 Hz, 1H), 4.84 (m, 1H), 5.74 (d, J = 3.9 Hz, 1H), 7.18−7.41 (m, 7H), 7.82 (d, J = 8.3 Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 17.2, 21.5, 26.1, 26.6, 71.5, 78.2, 81.2, 81.4, 81.6, 104.9, 111.6, 127.9, 128.0, 128.1, 128.5, 129.3, 134.1, 136.4, 144.1. Anal. Calcd for $C_{23}H_{28}O_7S$: C, 61.59; H, 6.29. Found: C, 62.02; H, 5.97.

3-*O*-Benzyl-5-benzylamino-5,6-dideoxy-1,2-*O*-isopropylidene-α-D-gluco-1,4-furanose 28. A mixture of **27** (0.3 g, 0.26 mmol) and neat benzylamine was heated in an oil bath at 100 °C for 14 h. After usual workup and purification, compound **28** was isolated (0.2 g, 78%). Eluent: EtOAc/petroleum ether (1:3). Yellow oil. $[\alpha]^{29}_D$ −56.2 (*c* 0.45, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 1.25 (d, J = 6.4 Hz, 3H), 1.31 (s, 3H), 1.47 (s, 3H), 3.20 (m, 1H), 3.67 (d, J = 13.0 Hz, 1H), 3.88 (m, 2H), 4.05 (d, J = 3.2 Hz, 1H), 4.49 (d, J = 11.7 Hz, 1H), 4.62 (d, J = 3.9 Hz, 1H), 4.69 (d, J = 11.7 Hz, 1H), 5.91 (d, J = 3.9 Hz, 1H), 7.18−7.27 (m, 10H). ^{13}C NMR ($CDCl_3$): δ 17.7, 26.2, 26.6, 50.7, 51.0, 71.7, 81.4, 81.8, 84.4, 104.7, 111.3, 126.8, 127.7, 127.8, 127.9, 128.3, 128.4, 137.3, 140.4. Anal. Calcd for $C_{23}H_{29}O_4N$: C, 72.04; H, 7.62; N, 3.65. Found: C, 72.05; H, 7.71; N, 3.71.

3-*O*-Benzyl-5-benzylamino-5,6-dideoxy-1,2-*O*-isopropylidene-β-L-ido-1,4-furanose 23. A mixture of **25**[16a] (0.26 g, 0.58 mmol) and neat benzylamine was heated in an oil bath at 100 °C for 13 h. After usual workup and purification, compound **23** was isolated (0.15 g, 69%).

5-Benzylamino-5,6-dideoxy-1,2-*O*-isopropylidene-3-*O*-methyl-β-L-ido-1,4-furanose 24. A mixture of **26** (0.28 g, 0.75 mmol) and neat benzylamine was heated in an oil bath at 100 °C for 10 h. After usual workup and purification, compound **24** was isolated (0.09 g, 40%).

Crystal data of 20h: $C_{22}H_{33}NO_6S$, M = 439.56, monoclinic, a = 13.948(5) Å, b = 11.955(5) Å, c = 14.073(6) Å, β = 95.826(9)°, U = 2334(2) Å^3, T = 295(2) K, space group $P2_1$(No. 4), Z = 2, μ(Mo Kα) = 0.175 mm^{-1}, 7863 reflections processed, 5717 unique (R_{int} = 0.028), which were used in refinement, $wR(F^2)$ was 0.0786 for all data. The compound crystallized in monoclinic cell with two molecules in the asymmetric unit. The two molecules in the asymmetric unit differ only slightly.

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Supporting Information Available: Crytallographic information file for **20h**. This material is available free of charge via the Internet at http://pubs.acs.org.

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