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Carbohydrate Research 343 (2008) 1287–1296
Carbohydrate RESEARCH

Unusual addition of amines to C-2 of vinyl sulfone-modified-β-D-pent-2-enofuranosyl carbohydrates: synthesis of a new class of β-anomeric 2-amino-2,3-dideoxy-D-*threo*-pentofuranosides

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Received 18 January 2008; received in revised form 6 March 2008; accepted 13 March 2008
Available online 18 March 2008

Abstract—When 3-*C*-sulfonyl-pent-2-enofuranosides and 3-*C*-sulfonyl-hex-2-enofuranosides were reacted with primary and secondary amines, only the β-anomeric methoxy group of the pent-2-enofuranoside did not cause any hindrance to incoming nitrogen nucleophiles. This resulted in the 'unusual' addition of amines, in which the diastereoselectivity of the reaction was overwhelmingly in favor of amino sugars of the D-arabino configuration. Selected products were desulfonylated to obtain a new class of β-anomeric 2-amino-2,3-dideoxy-D-*threo*-pentofuranosides.

Keywords: Vinyl sulfone-modified carbohydrates; Amino sugars; Deoxyaminosugars; Diastereoselective Michael addition; Desulfonylation with Mg–MeOH–$NiBr_2$

1. Introduction

The amino groups present in the aminoglycoside antibiotics and polysaccharides play an important role in their biological activities.[1–3] The most important mechanism of resistance to aminoglycoside antibiotics among resistant bacteria arises from enzymatic N-acetylation, O-phosphorylation, and O-nucleotidylation of specific sites in the antibiotics. To avoid such deactivation processes, several semisynthetic aminoglycoside antibiotics have been designed where either the hydroxyl groups undergoing enzymatic phosphorylation have been removed and/or the amino groups susceptible to acetylation have been masked by acylation or alkylation.[3] We therefore considered it to be of interest to design general methodologies for the synthesis of modified new amino sugars having one or more deoxygenated centers and mono- or dialkylated amino groups at specific sites. In addition, an epimeric variation in the stereochemistry of the C–N bond might also lead to different types of responses by a biological system.[4]

Since we are interested in developing new methodologies for the synthesis of aminodeoxy sugars, we treated vinyl sulfone-modified hex-2-enopyranosides **1** and **2** (Fig. 1) with a wide range of amines. The addition of primary amines to C-2 of both **1** and **2** exclusively produced C-2 equatorial (gluco) products. Secondary amines on reactions with **2** produced only gluco derivatives but with **1** produced mixtures containing the gluco derivative as the major component.[4d] The strategy has been implemented in the synthesis of D-lividosamine

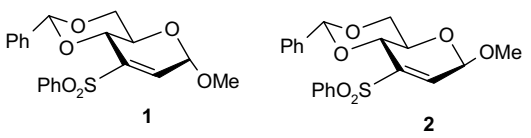

Figure 1. Vinyl sulfone-modified hex-2-enopyranosides.

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doi:10.1016/j.carres.2008.03.022

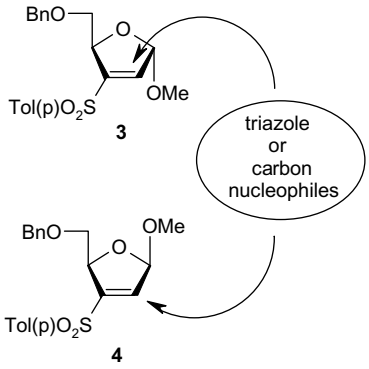


Figure 2. Attack of triazole[4f] or carbon nucleophiles[6] to C-2 of vinyl sulfone-modified pent-2-enofuranosides.

(2-amino-2,3-dideoxy-D-*ribo*-hexopyranose or '2-amino-2,3-dideoxy-D-glucose'), a constituent of aminoglycosides lividomycin-A, lividomycin-B, etc. Diastereoselective equatorial addition of ammonia to **1**, followed by the desulfonylation of the product at the C-3 site, produced a known intermediate for accessing D-lividosamine. Several partially and fully protected analogues of D-lividosamine could be synthesized using N-monoalkylated and N-dialkylated amines in a similar approach.[4c,d] Although most of the naturally occurring amino sugars have their C-2–N bond equatorially configured, there are some amino sugars, such as kasugamine where the C-2–N bond is axially oriented.[5]

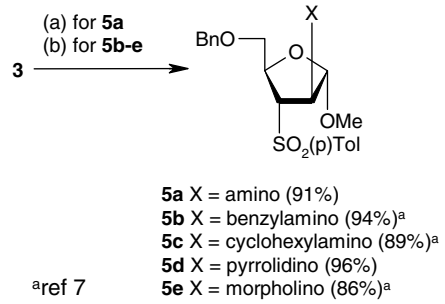
Since all of our earlier efforts to deliver primary amines effectively and exclusively from the β-face of the pyranose ring failed, it was necessary to develop a methodology for the delivery of amines from the β-face of the sugar ring. Since triazole[4f] and carbon nucleophiles[6] added to **3** and **4** from a direction opposite to the disposition of the anomeric methoxy group (Fig. 2), we presumed that the anomeric configurations would also influence the diastereoselctivity of addition of amines to C-2 of **3** and **4** in a similar fashion.[7]

2. Results and discussion

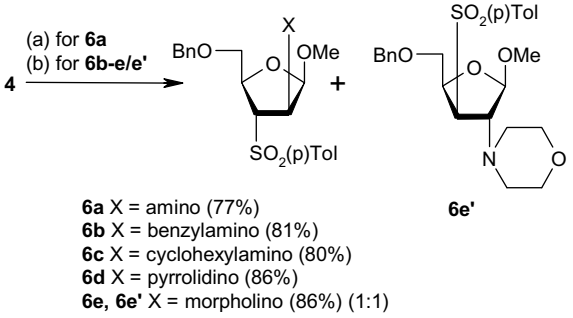
The addition of amines to the α-anomeric vinyl sulfone-modified carbohydrate **3** afforded single diastereomeric products **5a**–**e** with the expected D-arabino configurations (Scheme 1).[7] Formation of the expected products may be explained on the basis of the stereoelectronic repulsion of amines by the anomeric configuration of **3**.

Interestingly, vinyl sulfone **4** on reactions with 30% aqueous ammonia, neat benzylamine, cyclohexylamine, and pyrrolidine at ambient temperature produced single isomers **6a**–**d** in high yields (Scheme 2). In all these cases, the arabino derivatives were the sole products, which were isolated and identified unambiguously (see later). Morpholine, on the other hand, under similar conditions produced an inseparable mixture of compounds **6e/6e′** in a ratio of 1:1 (Scheme 2). It is well documented[8] that the coupling constant ($J_{1,2}$) values of authentic methyl β-D-ribofuranosides and β-D-xylofuranosides range between 0.0 and 2.0 Hz, which indicate a trans relationship between H-1 and H-2. The coupling constant ($J_{1,2}$) values for authentic methyl β-D-arabinofuranosides and β-D-lyxofuranosides range between 3.0 and 5.0 Hz, indicating a cis arrangement of H-1 and H-2. Excluding the possibility of any lyxo derivative formation for steric reasons, the coupling constant ($J_{1,2}$) values of compounds **6a**–**d**, which range between 4.1 and 4.4 Hz, indicate the presence of the D-arabino configuration in these compounds. Furthermore, single-crystal X-ray diffraction studies of compounds **6c** and **6d** confirm the arabino configuration, in line with the NMR data (Figs. 3 and 4, respectively). Following the trend of structures in the series **6a**–**d**, the inseparable morpholino derivatives **6e** and **6e′** were assigned D-arabino and D-xylo configurations, respectively.

Although the α-anomeric vinyl sulfone-modified carbohydrate **3** afforded the expected D-arabino derivative,[7] in contrary to our expectations, the β-anomeric vinyl sulfone-modified carbohydrate **4** on reactions with amines produced amino sugars **6a**–**e** with the D-arabino configuration as well. In order to establish the fact that the formation of **6a**–**e** was indeed the result of an 'unusual' addition reaction, we intended to examine



Scheme 1. Reagents and conditions: (a) 30% aqueous ammonia; (b) neat amines, rt, 5–13 h.



Scheme 2. Reagents and conditions: (a) 30% aqueous ammonia; (b) neat amines, rt, 5–13 h.

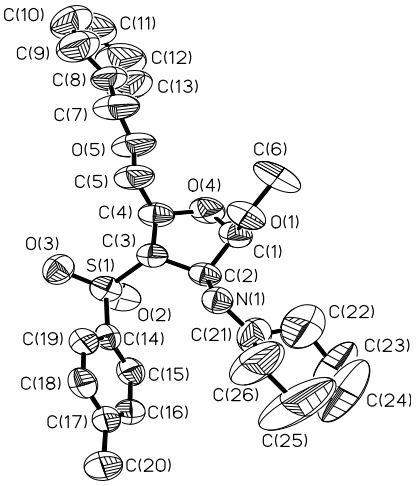


Figure 3. ORTEP diagram of compound **6c**.

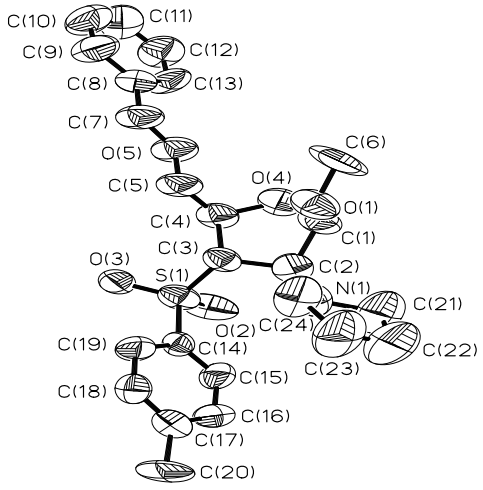
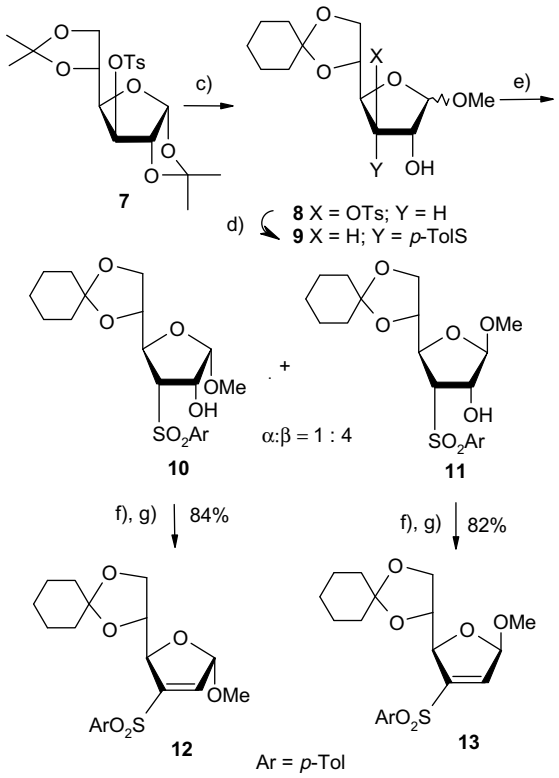


Figure 4. ORTEP diagram of compound **6d**.

the similar addition reaction patterns of related vinyl sulfone-modified hex-2-enofuranosides **12** and **13**. To start with it was necessary to develop strategies for the synthesis of these compounds. Thus, compound **7** on treatment with cyclohexanone, methanol, and concd H_2SO_4 generated a mixture of two anomers **8** in 65% yield. These cyclohexanone derivatives were reacted with the sodium salt of *p*-thiocresol in DMF at 110–120 °C to afford a mixture of two anomers **9** in 89% yield (Scheme 3). The mixture **9** was subjected to the magnesium monoperoxyphthalate (MMPP) mediated oxidation in MeOH for 6 h to produce **10** and **11** (1:4 from the ^{1}H NMR spectrum) in 91% yield. The anomers **10** and **11** were separated at this stage, and methanesulfonated (mesylated). The mesyl derivatives were then treated with DBU to afford vinyl sulfones **12** and **13**, respectively, in good yields.

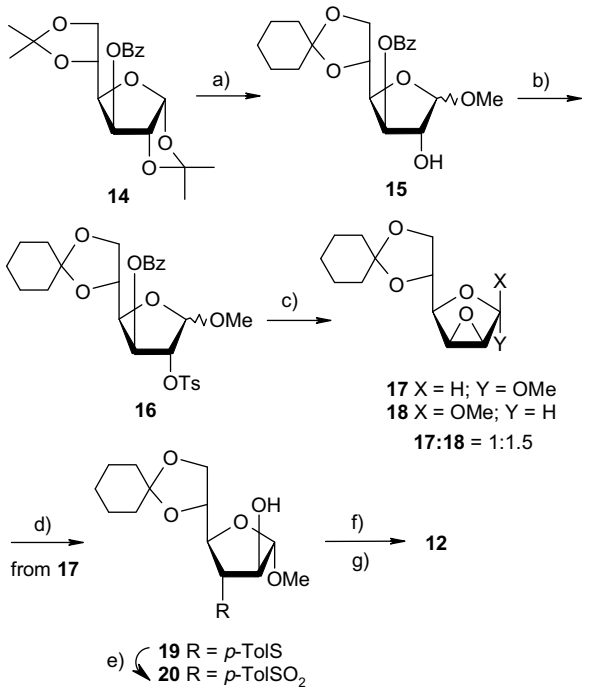
Since the α-anomer **10** was the minor component in the mixture of **10** and **11**, we studied another sequence of reactions to obtain **12** in large amount. Thus, the



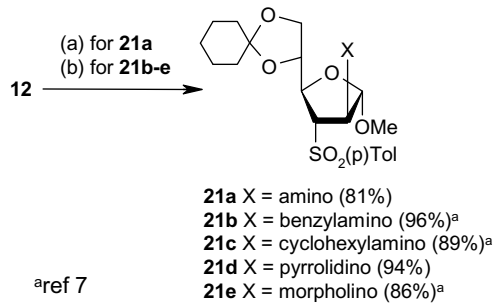
Scheme 3. Reagents and conditions: (c) cyclohexanone, MeOH, H_2SO_4, 80 °C, 2.5 h, 65%; (d) *p*-thiocresol, NaOMe, DMF, 110–120 °C, 4 h, 89%; (e) MMPP, MeOH, rt, 6 h, 91%; (f) MsCl, py, 0–4 °C, 24 h; (g) DBU, DCM, rt, 30 min.

known benzoyl derivative **14** was deprotected and glycosylated in the presence of cyclohexanone, MeOH, and concd H_2SO_4 to produce an anomeric mixture **15** of two diastereomers in a ratio of 1:1.5 (α:β) in 69% yield (Scheme 4). These compounds were treated with *p*-toluenesulfonyl chloride in pyridine at room temperature to afford a mixture of two anomers **16** in 94% yield. The mixture of tosylated derivatives **16** was then treated with NaOMe in MeOH to afford a mixture of epoxides **17** and **18** in 89% yield. Compounds **17** and **18** were separated at this stage. Compound **17** was reacted with the sodium salt of *p*-thiocresol in DMF at 110 °C to afford **19** in 90% yield, which was then subjected to oxidation with MMPP in MeOH to afford **20**. Sulfone derivative **20** was mesylated, and the mesylated derivative was treated with DBU to afford **12** in good overall yield. On the other hand, compound **18** under similar reaction conditions produced a complex mixture of products. It was probable that the ring opening of epoxide **18** was non-regioselective and therefore produced a mixture.

Vinyl sulfone **12** on reactions with 30% aqueous ammonia, neat benzylamine, cyclohexylamine, pyrrolidine, and morpholine at ambient temperature generated single isomers **21a–e** in high yields (Scheme 5).[7] Similarly, vinyl sulfone **13** on reaction with 30% aqueous ammonia, neat benzylamine, cyclohexylamine,



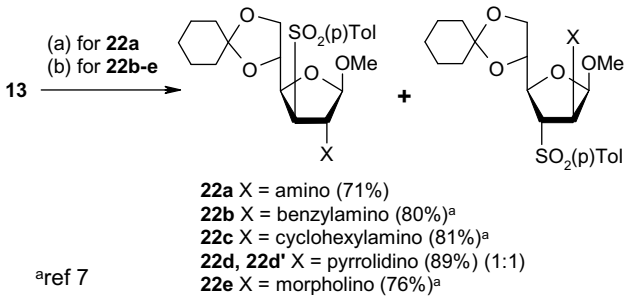
Scheme 4. Reagents and conditions: (a) cyclohexanone, MeOH, H_2SO_4, 80 °C, 2.5 h, 69%; (b) TsCl, py, DMAP, rt, 48 h, 94%; (c) NaOMe, MeOH, rt, 2.5 h, 89%; (d) *p*-thiocresol, NaOMe, DMF, 110 °C, 3.5 h, 90%; (e) MMPP, MeOH, rt, 6 h; (f) MsCl, py, 0–4 °C, 24 h; (g) DBU, DCM, rt, 30 min, 86% (yield in three steps).



Scheme 5. Reagents and conditions: (a) 30% aqueous ammonia; (b) neat amines, rt, 5–13 h.

morpholine, and pyrrolidine at ambient temperature generated single isomers **22a**–**c** and **22e** in high yields.[7] Only pyrrolidine under similar conditions afforded an inseparable mixture of compounds **22d**/**22d**′ in a ratio of 1:1 (Scheme 6).

It was therefore clear from these experiments that except for the formation of **22d**′, amino nucleophiles were always delivered to C-2 of **3**, **12**, and **13** from a direction opposite to that of the disposition of the anomeric methoxy group. It may therefore be emphasized that the addition pattern of amines to **4** was unusual in nature. Interestingly, in the case of another β-anomeric vinyl sulfone-modified carbohydrate **13**, at least one



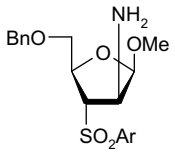
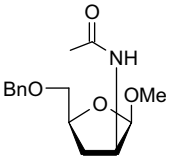
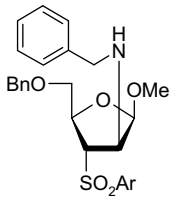
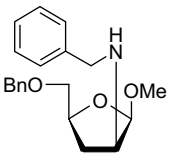
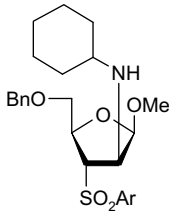
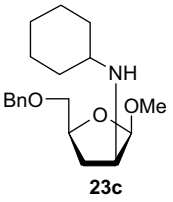
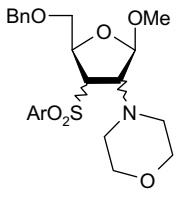
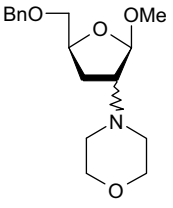
Scheme 6. Reagents and conditions: (a) 30% aqueous ammonia; (b) neat amines, rt, 5–13 h.

nucleophile showed the tendency of attacking C-2 in the unusual way.

Successful synthesis of deoxyamino sugars using carbohydrate vinyl sulfones would depend on the critical desulfonylation step.[9] We experimented with a large variety of desulfonylating agents available in the literature. However, none of these reagents were able to efficiently desulfonylate the amine Michael addition products of vinyl sulfone-modified carbohydrates. Since most of the conventional reagents or combination of reagents failed to deliver our desired products, we initiated a search for an alternative methodology for the desulfonylation. Reaction systems generating Ni(0) in situ[10] or making direct use of Raney nickel[11] for the reduction of sulfones to the corresponding carbon–hydrogen bonds have been reported. Although our compounds were either inert to Raney Ni or produced several products under the reaction conditions, our attention was drawn to a reported observation that the reduction of nickel halides with low-oxidation-potential metals such as magnesium produced finely divided Ni(0), which exhibited general, catalytic activity greater than commercial Raney nickel.[12] Compounds **6a**–**e**′ were subjected to desulfonylation by the Mg–MeOH–NiX_2 system to produce the aminodideoxy sugars **23a**, **23b**, **23c**, and an inseparable mixture **23e**/**23e**′ by the Mg–MeOH–NiX_2 system (Table 1).[7] Compound **6d** underwent extensive degradation. It is clear from Table 1 that $NiBr_2$ is a more efficient catalyst for the desulfonylation reaction.

In conclusion, we have established an efficient and new methodology for the synthesis of new amino sugars through the Michael addition of nitrogen nucleophiles to 3-*C*-sulfonyl-pent-2-enofuranosides **3** and **4** and 3-*C*-sulfonyl-pent-2-enofuranosides **12** and **13**. Amines added to C-2 of vinyl sulfones **3** (Scheme 1), **12** (Scheme 5), and **13** (Scheme 6) from a direction opposite to the dispositions of the anomeric methoxy groups. From the stereoelectronic consideration alone (Fig. 2), compound **4**, on reactions with amines, should have produced D-ribo- or D-xylo-derivatives. On the contrary, amines reacted with **4** to generate mostly ara-derivatives (Scheme 2) in an unusual fashion. A new and efficient

Table 1. Desulfonylation of amino sugars **6a**–**e**′[a]

Starting material	Product[b]	NiX_2 (Yield, %)
 **6a**	 **23a**	$NiCl_2$ (24) **$NiBr_2$(37)**
 **6b**	 **23b**	$NiCl_2$ (60) **$NiBr_2$(73)**
 **6c**	 **23c**	$NiCl_2$ (59) **$NiBr_2$(67)**
 **6e, 6e'**	 **23e, 23e'**	$NiCl_2$ (22) **$NiBr_2$(48)**

Ar = *p*-Tol.

[a] All reactions were carried out at room temperature using Mg–MeOH–NiX_2 in 6 h.

[b] Desulfonylated product of **6a** was isolated as the acetyl derivative **23a**.

reagent system Mg–MeOH–$NiBr_2$ desulfonylated **6a**–**c** and **6e**,**e**′ to yield a wide range of 2-amino-2,3-dideoxy-β-D-*threo*-pentofuranosides **23a**–**c** and **23e**,**e**′ for the first time. Research is in progress to identify the interactions responsible for the delivery of amines from the β-face of the vinyl sulfone-modified furanoside **4**.

3. Experimental

3.1. 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 standard procedures. TLC was carried out on precoated plates (E. Merck Silica Gel 60, F_{254}), and the spots were visualized with UV light or by charring the plates dipped in 5% H_2SO_4–MeOH solution or 5% H_2SO_4–vanillin–EtOH 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. Synthesis and spectroscopic data of compounds **5b**, **5c**, **5e**, **21b**, **21c**, **21e**, **22b**, **22c**, and **22e** were reported earlier.[7]

3.2. General procedure for the synthesis of sulfides 9 and 19

To a well-stirred solution of **8** or **17** 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 the 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 a silica gel column to afford sulfides **9** and **19**. Compounds **9** and **19** were taken directly for the oxidation reaction.

3.3. General procedure for the synthesis of sulfones 10, 11, and 20

To a well-stirred solution of sulfides **9** or **19** 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 **10**, **11**, and **20**.

3.4. General procedure for the synthesis of vinyl sulfone-modified carbohydrates 12 and 13

To a well-stirred solution of sulfones **10**, **11**, or **20** 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 24 h (TLC), the reaction mixture was poured into satd aq $NaHCO_3$, 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 residue. The residue in CH_2Cl_2 (10 mL) was treated with DBU at ambient temperature for 30 min. The solvent was evaporated under reduced pressure, and the resulting residue was purified over a silica gel column to afford **12** and **13**.

3.5. General procedure for the synthesis of 5a–e, 6a–e′, 21a–e, and 22a–e

A mixture of **3**, **4**, **12**, or **13** and the appropriate amine (30% aqueous ammonia or 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 a silica gel column to afford **5a**–**e**, **6a**–**e′**, **21a**–**e**, and **22a**–**e**.

3.6. General procedure for desulfonylation

To a well-stirred solution of **6a**, **6b**, **6c**, or **6e/6e′** in dry MeOH (10 mL) was added Mg turnings (15 mmol) and the appropriate nickel halide (10 mol % for primary amines and 20 mol % for secondary amines) at 0 °C under Ar. The mixture was stirred at ambient temperature. After 2–3 h another portion of Mg turnings (15 mmol) and dry MeOH (5 mL) were added. The mixture was stirred for an additional 2–3 h. The reaction mixture was filtered through Celite. The residue was washed thoroughly with MeOH. The filtrates were pooled together, and the liquid was concentrated under reduced pressure. The resulting residue was dissolved in EtOAc, and the solution was washed with satd aq NH_4Cl, dried over anhyd Na_2SO_4, and filtered. The filtrate was concentrated under reduced pressure to get a residue that was purified over a silica gel column to afford **23a**, **23b**, **23c**, or **23e**–**e′**.

3.7. Methyl 2-amino-5-*O*-benzyl-2,3-dideoxy-(3-*C*-*p*-tolylsulfonyl)-α-D-arabinofuranoside (5a)

Compound **3** (0.32 g, 0.85 mmol) was converted to **5a** following the general procedure (0.3 g, 91%). Eluent: 1:1 EtOAc–petroleum ether. White crystalline solid. Mp 99 °C. $[\alpha]_D^{29}$ +119.7 (*c* 0.11, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 2.44 (s, 3H), 3.29 (s, 3H), 3.36 (m, 1H), 3.63–3.75 (m, 3H), 4.45–4.52 (m, 3H), 4.73 (d, $J =$ 2.1 Hz, 1H), 7.26–7.34 (m, 7H), 7.74 (d, $J = 8.3$ Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 21.5, 55.2, 60.0, 69.3, 71.4, 73.4, 77.0, 110.4, 127.5, 128.27, 128.5, 129.8, 134.9, 137.5, 145.0. Anal. Calcd for $C_{20}H_{25}NO_5S{\cdot}0.25H_2O$: C, 60.67; H, 6.49; N, 3.54. Found: C, 60.66; H, 6.54; N, 3.06.

3.8. Methyl 5-*O*-benzyl-2,3-dideoxy-2-pyrrolidino-(3-*C*-*p*-tolylsulfonyl)-α-D-arabinofuranoside (5d)

Compound **3** (0.25 g, 0.67 mmol) was converted to **5d** following the general procedure (0.29 g, 96%). Eluent: 1:3 EtOAc–petroleum ether. Yellow gum. $[\alpha]_D^{29}$ +55.4 (*c* 0.26, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 1.67 (br m, 4H), 2.44 (s, 3H), 2.68 (br m, 4H), 3.19 (s, 3H), 3.43 (m, 1H), 3.70 (dd, $J = 1.9$, 11.1 Hz, 1H), 3.79–3.88 (m, 2H), 4.38–4.56 (m, 3H), 5.08 (s, 1H), 7.23–7.35 (m, 7H), 7.73 (d, $J = 8.3$ Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 21.6, 23.2, 49.6, 54.5, 64.6, 69.7, 69.8, 73.5, 77.7, 106.4, 127.6, 128.3, 128.9, 129.7, 135.3, 137.9, 144.9. Anal. Calcd for $C_{24}H_{31}NO_5S$: C, 64.69; H, 7.01; N, 3.14. Found: C, 64.71; H, 6.84; N, 3.26.

3.9. Methyl 2-amino-5-*O*-benzyl-2,3-dideoxy-(3-*C*-*p*-tolylsulfonyl)-β-D-arabinofuranoside (6a)

Compound **4** (0.22 g, 0.59 mmol) was converted to **6a** following the general procedure (0.18 g, 77%). Eluent: 1:1 EtOAc–petroleum ether. Amorphous solid. Mp 90 °C. $[\alpha]_D^{29}$ −110.9 (*c* 0.1, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 2.43 (s, 3H), 3.22–3.29 (m, 3H), 3.32 (s, 3H), 3.86 (m, 1H), 4.41–4.49 (m, 3H), 4.81 (d, $J = 4.4$ Hz, 1H), 7.22–7.34 (m, 7H), 7.74 (d, $J = 8.2$ Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 21.6, 54.7, 57.4, 70.3, 72.6, 73.12, 77.6, 103.6, 127.6, 128.2, 128.6, 129.9, 134.8, 137.7, 145.3. Anal. Calcd for $C_{20}H_{25}NO_5S$: C, 61.36; H, 6.44; N, 3.58. Found: C, 61.52; H, 6.41; N, 3.61.

3.10. Methyl 5-*O*-benzyl-2-benzylamino-2,3-dideoxy-(3-*C*-*p*-tolylsulfonyl)-β-D-arabino-furanoside (6b)

Compound **4** (0.48 g, 1.28 mmol) was converted to **6b** following the general procedure (0.5 g, 81%). Eluent: 1:3 EtOAc–petroleum ether. White crystalline solid. Mp 103 °C. $[\alpha]_D^{29}$ −119.1 (*c* 0.22, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 2.41 (s, 3H), 3.25 (s, 3H), 3.42–3.49 (m, 3H), 3.59 (d, $J = 4.2$ Hz, 1H), 3.63–3.68 (m, 2H), 4.48 (s, 2H), 4.57 (m, 1H), 4.68 (d, $J = 4.3$ Hz, 1H), 7.11–7.36 (m, 12H), 7.69 (d, $J = 8.2$ Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 21.6, 52.4, 54.7, 62.9, 68.5, 73.1, 76.4, 102.1, 127.0, 127.6, 127.6, 128.0, 128.2, 128.7, 129.7, 135.2, 137.8, 139.6, 144.9. Anal. Calcd for $C_{27}H_{31}NO_5S$: C, 67.34; H, 6.49; N, 2.91. Found: C, 67.65; H, 6.09; N, 2.76.

3.11. Methyl 5-*O*-benzyl-2-cyclohexylamino-2,3-dideoxy-(3-*C*-*p*-tolylsulfonyl)-β-D-arabinofuranoside (6c)

Compound **4** (0.33 g, 0.88 mmol) was converted to **6c** following the general procedure (0.34 g, 80%). Eluent: 1:3 EtOAc–petroleum ether. White crystalline solid. Mp 133 °C. $[\alpha]_D^{29}$ −99.4 (*c* 0.11, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 0.87–1.60 (m, 10H), 2.26 (m, 1H), 2.42 (s,

3H), 3.32 (s, 3H), 3.35–3.43 (m, 3H), 3.72 (m, 1H), 4.47 (d, $J = 1.3$ Hz, 2H), 4.60 (m, 1H), 4.83 (d, $J = 4.4$ Hz, 1H), 7.26–7.30 (m, 7H), 7.76 (d, $J = 8.3$ Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 21.6, 24.8, 24.9, 25.8, 33.2, 34.3, 54.7, 55.7, 61.4, 68.9, 73.1, 76.1, 102.9, 127.6, 127.7, 128.2, 128.7, 129.5, 135.6, 137.8, 144.8. Anal. Calcd for $C_{26}H_{35}NO_5S$: C, 65.93; H, 7.45; N, 2.96. Found: C, 66.24; H, 7.78; N, 3.04.

3.12. Methyl 5-*O*-benzyl-2,3-dideoxy-2-pyrrolidino-(3-*C*-*p*-tolylsulfonyl)-β-D-arabinofuranoside (6d)

Compound **4** (0.19 g, 0.51 mmol) was converted to **6d** following the general procedure (0.2 g, 86%). Eluent: 1:3 EtOAc–petroleum ether. White crystalline solid. Mp 149 °C. $[\alpha]_D^{29}$ −84.9 (*c* 0.22, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 1.68 (br m, 4H), 2.41 (s, 3H), 2.65 (br m, 2H), 2.81 (br m, 2H), 3.32 (s, 3H), 3.34–3.46 (m, 2H), 3.79–3.81 (m, 2H), 4.37 (d, $J = 4.6$ Hz, 2H), 4.52 (m, 1H), 4.95 (d, $J = 4.1$ Hz, 1H), 7.17–7.32 (m, 7H), 7.74 (d, $J = 8.2$ Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 21.5, 23.3, 50.5, 54.9, 64.8, 65.4, 72.6, 72.9, 77.4, 105.1, 127.5, 128.1, 128.7, 129.5, 135.2, 137.7, 144.7. Anal. Calcd for $C_{24}H_{31}NO_5S$: C, 64.69; H, 7.01; N, 3.14. Found: C, 65.03; H, 6.73; N, 3.20.

3.13. Methyl 5-*O*-benzyl-2,3-dideoxy-2-morpholino-(3-*C*-*p*-tolylsulfonyl)-β-D-arabino- and xylofuranoside (6e and 6e′)

Compound **4** (0.27 g, 0.72 mmol) was converted to **6d** and **6d′**, an inseparable mixture of two diastereomers following the general procedure (0.25 g, 76%). Eluent: 1:2 EtOAc–petroleum ether. Amorphous solid.

3.14. Methyl 5,6-*O*-cyclohexylidene-3-deoxy-(3-*C*-*p*-tolylsulfonyl)-α-D-allopyranoside (10) and methyl 5,6-*O*-cyclohexylidene-3-deoxy-(3-*C*-*p*-tolylsulfonyl)-β-D-allopyranoside (11)

Compound **7** (5.0 g, 12.06 mmol) was gently heated under reflux at 80 °C with cyclohexanone (1.2 mL/mmol), MeOH (60 mL), and concd H_2SO_4 (0.1 mL) for 2.5 h.[13] After completion of the reaction (TLC), toluene (30 mL) was added, and the mixture was cooled to room temperature. MeOH was evaporated to dryness under reduced pressure to get a residue. The residue was neutralized with Et_3N, and the mixture was diluted with EtOAc (40 mL), washed with satd aq $NaHCO_3$, and then with H_2O. 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 a silica gel column (eluent: 1:1 EtOAc–petroleum ether) to obtain an inseparable mixture of two anomers **8** (3.4 g, 65%). The anomeric mixture **8** (3.4 g, 7.93 mmol) was converted to an inseparable mixture of two anomers **9** (2.7 g, 89%) following the general procedure. Eluent: 1:5 EtOAc–petroleum ether. Yellow gum. Compound **9** (2.0 g, 5.26 mmol) was converted to **10** and **11** (2.0 g, 91%) following the general procedure. The anomeric mixture can be separated at this stage (**10**:**11** = 1:4). Compound **10**: (0.33 g, 15%). Eluent: 1:3 EtOAc–petroleum ether. White crystalline solid. Mp 116 °C. $[\alpha]_D^{29}$ +131.4 (*c* 0.1, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 1.41–1.57 (m, 10H), 2.44 (s, 3H), 3.47 (s, 3H), 3.87 (dd, $J = 5.1$, 18.9 Hz, 1H), 4.05–4.13 (m, 2H), 4.29–4.37 (m, 2H), 4.79 (m, 1H), 4.92 (d, $J = 4.5$ Hz, 1H), 7.34 (d, $J = 8.0$ Hz, 2H), 7.83 (d, $J = 8.3$ Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 21.4, 23.3, 23.7, 24.9, 33.6, 35.6, 55.0, 63.4, 64.3, 72.4, 77.4, 77.5, 101.6, 110.1, 128.22, 129.4, 137.6, 144.5. Anal. Calcd for $C_{20}H_{28}O_7S$: C, 58.24; H, 6.84. Found: C, 57.93; H, 7.06. Compound **11**: (1.5 g, 69%). Eluent: 1:3 EtOAc–petroleum ether. White crystalline solid. Mp 74 °C. $[\alpha]_D^{29}$ −67.5 (*c* 0.26, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 1.38–1.56 (m, 10H), 2.46 (s, 3H), 3.31 (s, 3H), 3.77 (dd, $J = 4.9$, 15.5 Hz, 1H), 3.89–4.19 (m, 3H), 4.26 (d, $J = 5.1$ Hz, 1H), 4.72 (dd, $J = 6.1$, 14.5 Hz, 1H), 4.84 (d, $J = 0.6$ Hz, 1H), 7.36 (d, $J = 7.9$ Hz, 2H), 7.85 (d, $J = 8.3$ Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 21.4, 23.5, 23.7, 24.9, 34.4, 35.7, 54.9, 65.5, 67.5, 75.9, 76.8, 78.4, 108.4, 110.3, 128.3, 129.6, 136.1, 145.1. Anal. Calcd for $C_{20}H_{28}O_7S$: C, 58.24; H, 6.84. Found: C, 58.10; H, 6.94.

3.15. Methyl 5,6-*O*-cyclohexylidene-2,3-dideoxy-(3-*C*-*p*-tolylsulfonyl)-α-D-*erythro*-hex-2-enopyranoside (12)

Compound **10** (1.2 g, 2.91 mmol) was converted to **12** following the general procedure (0.97 g, 84%). Eluent: 1:5 EtOAc–petroleum ether. Yellow gum. $[\alpha]_D^{29}$ −5.8 (*c* 0.64, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 1.40–1.66 (m, 10H), 2.46 (s, 3H), 3.35 (s, 3H), 3.64 (m, 1H), 3.86 (m, 1H), 4.49 (m, 1H), 5.12 (m, 1H), 5.81 (d, $J = 4.5$ Hz, 1H), 6.52 (m, 1H), 7.37 (d, $J = 8.1$ Hz, 2H), 7.81 (d, $J = 8.1$ Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 21.6, 23.7, 23.8, 25.0, 34.6, 35.4, 54.7, 63.6, 75.4, 83.0, 106.9, 110.6, 128.2, 130.1, 135.6, 136.6, 145.5, 147.8. Anal. Calcd for $C_{20}H_{26}O_6S$: C, 60.89; H, 6.64. Found: C, 60.85; H, 6.48.

3.16. Methyl 5,6-*O*-cyclohexylidene-2,3-dideoxy-(3-*C*-*p*-tolylsulfonyl)-β-D-*erythro*-hex-2-enopyranoside (13)

Compound **11** (1.8 g, 4.36 mmol) was converted to **13** following the general procedure (1.4 g, 82%). Eluent: 1:5 EtOAc–petroleum ether. White crystalline solid. Mp 84 °C. $[\alpha]_D^{29}$ −172.0 (*c* 0.04, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 1.40–1.64 (m, 10H), 2.46 (s, 3H), 3.45 (s, 3H), 3.70 (dd, $J = 6.9$, 16.6 Hz, 1H), 3.92 (dd, $J = 5.9$, 16.8 Hz, 1H), 4.39 (m, 1H), 5.02 (m, 1H), 5.66 (m, 1H), 6.52 (m, 1H), 7.36 (d, $J = 7.9$ Hz, 2H), 7.79 (d, $J = 8.4$ Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 21.6, 23.7, 23.9, 25.1, 34.7, 35.7, 56.2, 63.7, 75.4, 83.6, 107.1,

110.2, 128.2, 130.0, 135.7, 136.3, 145.5, 147.5. Anal. Calcd for $C_{20}H_{26}O_6S$: C, 60.89; H, 6.64. Found: C, 60.51; H, 6.24.

3.17. Methyl 2,3-anhydro-5,6-*O*-cyclohexylidene-α-D-mannofuranoside (17) and methyl 2,3-anhydro-5,6-*O*-cyclohexylidene-β-D-mannofuranoside (18)

Compound **14** (6.0 g, 16.46 mmol) was gently refluxed at 80 °C with cyclohexanone (1.2 mL/mmol), MeOH (65 mL), and concd H_2SO_4 (0.1 mL) for 2.5 h.[13] After completion of the reaction (TLC), toluene (35 mL) was added, and the mixture was cooled to room temperature. MeOH was evaporated to dryness under reduced pressure to get a residue. The residue was neutralized with Et_3N, and the mixture was diluted with EtOAc (40 mL), washed with satd aq $NaHCO_3$, and then with H_2O. 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 a silica gel column (eluent: 1:1 EtOAc–petroleum ether) to obtain an inseparable mixture of two anomers **15** (4.3 g, 69%). The anomeric mixture **15** (4.3 g, 11.36 mmol) was then tosylated with TsCl (1.5 equiv/mmol), pyridine (10 mL/mmol), and DMAP (catalytic). After completion of the reaction (TLC), the reaction mixture was poured into an ice-cold solution of satd aq $NaHCO_3$, 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 a silica gel column (eluent: 1:3 EtOAc–petroleum ether) to afford **16** (5.7 g, 94%). Then compound **16** (5.7 g, 10.7 mmol) was stirred at ambient temperature with NaOMe (1.2 equiv/mmol) and MeOH (50 mL) for 2.5 h. After completion of the reaction (TLC), MeOH was evaporated to dryness under reduced pressure. The reaction mixture was then poured into satd aq NH_4Cl, 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 a silica gel column to afford **17** and **18** (2.4 g, 89%). The anomeric mixture was separated at this stage (**17**:**18** = 1:1.5). Compound **17**: 0.96 g, 35%. Eluent: 1:5 EtOAc–petroleum ether. Yellow oil. $[\alpha]_D^{26}$ +40.8 (*c* 10.0, $CHCl_3$). ^1H NMR ($CDCl_3$): δ 1.40–1.67 (m, 10H), 3.39 (s, 3H), 3.66 (d, $J = 2.6$ Hz, 1H), 3.83 (d, $J = 3.1$ Hz, 1H), 3.88–3.97 (m, 2H), 4.05–4.13 (m, 2H), 4.90 (s, 1H). ^{13}C NMR ($CDCl_3$): δ 23.3, 23.6, 24.7, 34.3, 36.2, 53.8, 54.7, 56.0, 66.5, 73.0, 76.8, 101.9, 109.3. Anal. Calcd for $C_{13}H_{20}O_5$: C, 60.92; H, 7.87. Found: C, 61.01; H, 7.63. Compound **18**: 1.4 g, 51%. Eluent: EtOAc/petroleum ether (1:5). Yellow oil. $[\alpha]_D^{26}$ −59.4 (*c* 9.8, $CHCl_3$). ^1H NMR ($CDCl_3$): δ 1.40–1.66 (m, 10H), 3.48 (s, 3H), 3.71–3.81 (m, 3H), 3.93 (m, 1H), 4.09 (m, 1H), 4.24 (m, 1H), 4.99 (s, 1H). ^{13}C NMR ($CDCl_3$): δ 23.3, 23.6, 24.7, 34.3, 36.2, 54.7, 55.5, 56.1, 66.3, 72.9, 76.8, 102.1, 109.3. Anal. Calcd for $C_{13}H_{20}O_5$: C, 60.92; H, 7.87. Found: C, 60.52; H, 8.02.

3.18. Methyl 5,6-*O*-cyclohexylidene-3-deoxy-(3-*C*-*p*-tolylsulfonyl)-α-D-mannopyranoside (19)

Compound **17** (1.2 g, 4.68 mmol) was converted to **19** (1.6 g, 90%) following the general procedure. Eluent: 1:4 EtOAc–petroleum ether. Yellow gum. ^1H NMR ($CDCl_3$): δ 1.41–1.64 (m, 10H), 2.32 (s, 3H), 3.40 (s, 3H), 3.45–3.52 (m, 2H), 4.00 (m, 1H), 4.17–4.22 (m, 2H), 4.42 (m, 1H), 4.93 (s, 1H), 7.13 (d, $J = 8.1$ Hz, 2H), 7.34 (d, $J = 8.1$ Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 20.7, 23.3, 23.6, 24.8, 33.8, 35.4, 52.1, 54.6, 64.9, 75.3, 80.5, 84.8, 109.6, 110.4, 129.7, 130.9, 131.6, 136.8. Anal. Calcd for $C_{20}H_{28}O_5S{\cdot}2H_2O$: C, 57.67; H, 7.74. Found: C, 57.54; H, 7.63.

3.19. Methyl 5,6-*O*-cyclohexylidene-2,3-dideoxy-(3-*C*-*p*-tolylsulfonyl)-α-D-*erythro*-hex-2-enopyranoside (12)

Compound **19** (0.8 g, 2.1 mmol) was converted to sulfone derivative **20** following the general procedure. Then the sulfone derivative **20** was converted to vinyl sulfone-modified carbohydrate **12** (0.71 g, 86%) following the general procedure. Eluent: 1:5 EtOAc–petroleum ether. Yellow gum.

3.20. Methyl 2-amino-5,6-*O*-cyclohexylidene-2,3-dideoxy-(3-*C*-*p*-tolylsulfonyl)-α-D-mannopyranoside (21a)

Compound **12** (0.5 g, 1.27 mmol) was converted to **21a** following the general procedure (0.42 g, 81%). Eluent: 1:1 EtOAc–petroleum ether. Yellow crystalline solid. Mp 90 °C. $[\alpha]_D^{29}$ −12.7 (*c* 0.06, $CHCl_3$). ^1H NMR ($CDCl_3$): δ 1.40–1.94 (m, 10H), 2.45 (s, 3H), 3.25 (s, 3H), 3.50 (m, 1H), 3.76 (m, 1H), 3.88–4.08 (m, 2H), 4.39 (m, 1H), 4.56 (m, 1H), 4.79 (s, 1H), 7.37 (d, $J = 8.1$ Hz, 2H), 7.82 (d, $J = 8.1$ Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 21.5, 23.5, 23.8, 24.9, 33.9, 35.6, 55.1, 60.1, 64.4, 72.4, 75.8, 77.9, 110.3, 110.5, 128.8, 129.8, 135.2, 144.9. Anal. Calcd for $C_{20}H_{29}NO_6S$: C, 58.37; H, 7.10; N, 3.40. Found: C, 58.20; H, 7.19; N, 3.51.

3.21. Methyl 5,6-*O*-cyclohexylidene-2,3-dideoxy-2-pyrrolidino-(3-*C*-*p*-tolylsulfonyl)-α-D-mannopyranoside (21d)

Compound **12** (0.4 g, 1.01 mmol) was converted to **21d** following the general procedure (0.44 g, 94%). Eluent: 1:3 EtOAc–petroleum ether. Yellow gum. $[\alpha]_D^{29}$ +33.0 (*c* 0.4, $CHCl_3$). ^1H NMR ($CDCl_3$): δ 1.40–1.72 (m, 14H), 2.44 (s, 3H), 2.53 (br m, 4H), 3.22 (s, 3H), 3.66 (m, 1H), 3.74 (m, 1H), 4.02 (d, $J = 6.0$ Hz, 2H), 4.24

(m, 1H), 4.41 (m, 1H), 4.99 (s, 1H), 7.34 (d, $J = 8.2$ Hz, 2H), 7.80 (d, $J = 8.2$ Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 21.5, 23.1, 23.6, 23.9, 25.0, 34.4, 35.7, 50.8, 54.8, 65.4, 67.4, 70.8, 75.6, 78.8, 106.8, 110.3, 129.3, 129.5, 135.3, 144.8. Anal. Calcd for $C_{24}H_{35}NO_6S$: C, 61.91; H, 7.58; N, 3.01. Found: C, 61.84; H, 7.86; N, 3.01.

3.22. Methyl 2-amino-5,6-*O*-cyclohexylidene-2,3-dideoxy-(3-*C*-*p*-tolylsulfonyl)-β-D-gluco-pyranoside (22a)

Compound **13** (0.25 g, 0.63 mmol) was converted to **22a** following the general procedure (0.18 g, 71%). Eluent: 1:1 EtOAc–petroleum ether. White crystalline solid. Mp 115 °C. $[\alpha]_D^{29}$ −96.3 (*c* 0.13, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 1.14–1.76 (m, 10H), 2.44 (s, 3H), 3.36 (s, 3H), 3.76–3.86 (m, 3H), 3.89–3.97 (m, 2H), 4.38 (m, 1H), 4.85 (d, $J = 2.8$ Hz, 1H), 7.36 (d, $J = 8.0$ Hz, 2H), 7.81 (d, $J = 8.2$ Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 21.6, 23.5, 23.9, 25.0, 34.4, 35.7, 55.8, 59.9, 66.1, 68.2, 76.3, 79.2, 110.2, 110.3, 128.5, 129.7, 136.5, 144.9. Anal. Calcd for $C_{20}H_{29}NO_6S{\cdot}0.25\,H_2O$: C, 57.75; H, 7.14; N, 3.37. Found: C, 57.69; H, 7.23; N, 3.48.

3.23. Methyl 5,6-*O*-cyclohexylidene-2,3-dideoxy-2-pyrrolidino-(3-*C*-*p*-tolylsulfonyl)-β-D-gluco- and mannopyranoside (22d and 22d′)

Compound **13** (0.25 g, 0.63 mmol) was converted to **22d** and **22d′** an inseparable mixture of two diastereomers following the general procedure (0.26 g, 89%). Eluent: 1:3 EtOAc–petroleum ether. Amorphous solid.

3.24. Methyl 2-acetylamino-5-*O*-benzyl-2,3-dideoxy-β-D-*threo*-pentofuranoside (23a)

Compound **6a** (0.12 g, 0.31 mmol) was desulfonylated following the general procedure. The residue obtained was acetylated to afford **23a** (0.03 g, 37%, $NiBr_2$), (0.02 g, 24%, $NiCl_2$). Eluent: 1:3 EtOAc–petroleum ether. White crystalline solid. Mp 112 °C. $[\alpha]_D^{29}$ +16.8 (*c* 0.06, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 1.49 (m, 1H), 1.96 (s, 3H), 2.39 (m, 1H), 3.34 (s, 3H), 3.43 (d, $J = 8.7$ Hz, 2H), 4.33 (m, 1H), 4.44 (m, 1H), 4.54 (s, 2H), 4.76 (d, $J = 4.5$ Hz, 1H), 5.92 (br d, $J = 7.6$ Hz, 1H), 7.25–7.42 (m, 5H). ^{13}C NMR ($CDCl_3$): δ 23.2, 32.1, 51.9, 54.5, 73.3, 73.9, 77.3, 101.7, 127.6, 128.3, 138.1, 169.8. Anal. Calcd for $C_{15}H_{21}NO_4.1H_2O$: C, 60.59; H, 7.79; N, 4.71. Found: C, 60.19; H, 7.70; N, 4.90.

3.25. Methyl 5-*O*-benzyl-2-benzylamino-2,3-dideoxy-β-D-*threo*-pentofuranoside (23b)

Compound **6b** (0.1 g, 0.21 mmol) was converted to **23b** following the general procedure (0.07 g, 73%, $NiBr_2$), (0.06 g, 60%, $NiCl_2$). Eluent: 1:2 EtOAc–petroleum ether. Yellow oil. $[\alpha]_D^{29}$ −80.9 (*c* 0.36, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 1.43 (m, 1H), 2.28 (m, 1H), 3.25 (m, 1H), 3.32 (s, 3H), 3.38–3.53 (m, 2H), 3.79 (s, 2H), 4.22 (m, 1H), 4.58 (s, 2H), 4.74 (d, $J = 4.2$ Hz, 1H), 7.18–7.50 (m, 10H). ^{13}C NMR ($CDCl_3$): δ 32.7, 52.4, 54.4, 61.1, 73.3, 74.7, 76.8, 101.9, 127.0, 127.6, 127.7, 128.2, 128.3, 128.4, 138.2, 140.1. Anal. Calcd for $C_{20}H_{25}NO_3{\cdot}0.5H_2O$: C, 71.40; H, 7.78; N, 4.16. Found: C, 71.45; H, 7.80; N, 4.10.

3.26. Methyl 5-*O*-benzyl-2-cyclohexylamino-2,3-dideoxy-β-D-*threo*-pentofuranoside (23c)

Compound **6c** (0.22 g, 0.46 mmol) was converted to **23c** following the general procedure (0.1 g, 67%, $NiBr_2$), (0.09 g, 59%, $NiCl_2$). Eluent: 1:2 EtOAc–petroleum ether. Yellow oil. $[\alpha]_D^{29}$ −40.6 (*c* 0.22, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 1.02–1.84 (m, 11H), 2.25 (m, 1H), 2.44 (m, 1H), 3.33 (s, 3H), 3.35–3.52 (m, 3H), 4.20–4.28 (m, 1H), 4.58 (s, 2H), 4.76 (d, $J = 4.2$ Hz, 1H), 7.25–7.40 (m, 5H). ^{13}C NMR ($CDCl_3$): δ 24.9, 26.0, 33.0, 33.6, 33.8, 54.4, 55.0, 58.5, 73.3, 74.7, 76.9, 102.4, 127.5, 127.7, 128.3, 138.2. Anal. Calcd for $C_{19}H_{29}NO_3$: C, 71.44; H, 9.15; N, 4.38. Found: C, 71.04; H, 9.50; N, 4.0.

3.27. Methyl 5-*O*-benzyl-2,3-dideoxy-2-morpholino-β-D-*erythro*- and *threo*-pentofuranoside (23e and 23e′)

Compounds **6e** and **6e′** (0.18 g, 0.39 mmol) were converted to **23e** and **23e′**, an inseparable mixture of two diastereomers following the general procedure (0.05 g, 48%, $NiBr_2$), (0.03 g, 22%, $NiCl_2$). Eluent: 1:1 EtOAc–petroleum ether. Yellow oil. ^{1}H NMR of the mixture ($CDCl_3$): δ 1.63–2.24 (m, 4H), 2.47–2.51 (m, 8H), 2.59–2.65 (m, 2H), 3.30 (s, 6H), 3.31–3.59 (m, 4H), 3.67–3.78 (m, 8H), 4.36 (m, 2H), 4.56 (s, 4H), 4.83/4.92 (each d, 2H), 7.28–7.34 (m, 10H).

Acknowledgment

The authors thank the Indo-French Centre for the Promotion of Advanced Research, New Delhi for funding (Project No. 3405-1).

Supplementary data

Complete crystallographic data for the structural analysis have been deposited with the Cambridge Crystallographic Data Centre, CCDC Nos. 670145 and 670146. Copies of this information may be obtained free of charge from the Director, Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge, CB21EZ, UK. (fax: +44-1223-336033, e-mail: deposit@ccdc.cam.

ac.uk or via: www.ccdc.cam.ac.uk), and spectra of **5a**, **5d**, **6a–e′**, **10–13**, **17–19**, **21a**, **21d**, **22a**, **22d/d′**, **23a–c**, **23e/23e′** all new compounds. Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.carres.2008.03.022.

References

1. McAuliffe, J. C.; Hindsgaul, O. *Chem. Ind. (London)* **1997**, 170–175.
2. Kondo, S.; Hotta, K. *J. Infect. Chemother.* **1999**, *5*, 1–9.
3. Wong, C.-H. *Acc. Chem. Res.* **1999**, *32*, 376–385.
4. (a) Ravindran, B.; Pathak, T. *J. Org. Chem.* **1999**, *64*, 9715–9718; (b) Ravindran, B.; Sakthivel, K.; Suresh, C. G.; Pathak, T. *J. Org. Chem.* **2000**, *65*, 2637–2641; (c) Ravindran, B.; Pathak, T. *Ind. J. Chem.* **2001**, *B40*, 1114–1120; (d) Ravindran, B.; Deshpande, S. G.; Pathak, T. *Tetrahedron* **2001**, *57*, 1093–1098; (e) Suresh, C. G.; Ravindran, B.; Pathak, T.; Narasimha Rao, K.; Sasidhar Prasad, J. S.; Lokanath, N. K. *Carbohydr. Res.* **2002**, *337*, 1507–1512; (f) Sanki, A. K.; Pathak, T. *Synlett* **2002**, 1241–1244; (g) Sanki, A. K.; Pathak, T. *Tetrahedron* **2003**, *59*, 7203–7214.
5. Hanessian, S.; Masse, R. *Carbohydr. Res.* **1974**, *35*, 175–185.
6. Sanki, A. K.; Suresh, C. G.; Falgune, U. D.; Pathak, T. *Org. Lett.* **2003**, *5*, 1285–1288.
7. Das, I.; Pathak, T. *Org. Lett.* **2006**, *8*, 1303–1306.
8. (a) Casini, G.; Goodman, L. *J. Am. Chem. Soc.* **1964**, *86*, 1427–1431; (b) Montgomery, J. N.; Thorpe, M. C.; Clayton, S. D.; Thomas, H. J. *Carbohydr. Res.* **1974**, *32*, 404–407; (c) Bock, K.; Pederson, C. *Carbohydr. Res.* **1979**, *73*, 85–91; (d) Liptak, A.; Neszmelyi, A.; Kovac, P.; Hirsch, J. *Tetrahedron* **1981**, *37*, 2379–2382; (e) Su, T.-L.; Klein, R. S.; Fox, J. J. *J. Org. Chem.* **1981**, *46*, 1790–1792; (f) Kawana, M.; Kuzuhara, H.; Emoto, S. *Bull. Chem. Soc. Jpn.* **1981**, *54*, 1492–1504; (g) Kawana, M.; Koresawa, T.; Kuzuhara, H. *Bull. Chem. Soc. Jpn.* **1983**, *56*, 1095–1100.
9. Najera, C.; Yus, M. *Tetrahedron* **1999**, *55*, 10547–10658.
10. Chan, M. C.; Cheng, K. M.; Ho, K. M.; Ng, C. T.; Yam, T. M.; Wang, B. S. L.; Luh, T. Y. *J. Org. Chem.* **1988**, *53*, 4466–4471.
11. (a) Oikawa, M.; Oikawa, H.; Ichthara, A. *Tetrahedron Lett.* **1993**, *34*, 4797–4800; (b) Oikawa, M.; Oikawa, H.; lchihara, A. *Tetrahedron* **1995**, *51*, 6237–6254; (c) Gamble, M. P.; Giblin, G. M. P.; Taylor, R. J. K. *Synlett* **1995**, 779–780.
12. Mauret, P.; Alphonse, P. *J. Org. Chem.* **1982**, *47*, 3322–3323.
13. Kawana, M.; Kuzuhara, H. *Synthesis* **1995**, 544–552.