Thermal Degradation of Designed Carbohydrate *N*-Oxides: A Single Methodology for the Synthesis of Ketoses, Enol Ethers, and Branched-Chain Sugars from *N*-Oxides Derived from D-Altrose Aminosugars†

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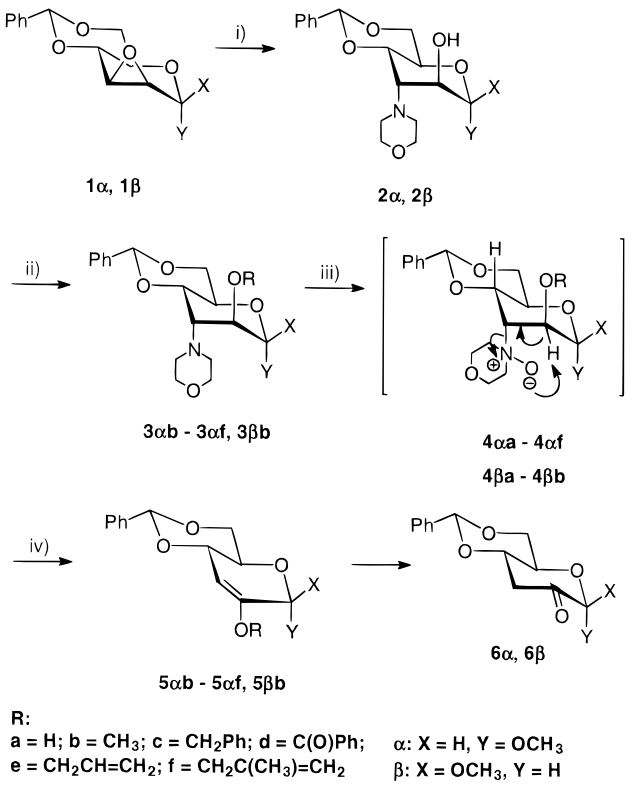
Introduction

Tertiary amine *N*-oxides undergo olefination reactions at elevated temperature (Cope reaction).[1,2] The success of the reaction depends on the availability of a suitably located *β*-hydrogen so that a five-membered transition state can be easily formed.[1b] Despite the familiarity with the general principle of this olefination procedure, no serious attempt[2] has been made to implement, by design, this methodology in the area of carbohydrates, although the procedure for accessing the starting materials, i.e., the tertiary aminosugars, by opening epoxides of carbohydrates was well documented.[3] In the few reported cases,[2b−d] (a) the yields of conversion of the *N*-oxides to the olefinic products varied between 38% and 76%[2b] or between 28% and 51%,[2c] (b) unwanted side products were formed,[2c] and/or (c) deoxygenated starting aminosugars were recovered[2c] in up to 60% yields. The inefficiencies of the above reactions could be attributed to the failure of the *N*-oxides of the conformationally flexible carbohydrates to form the required five-membered[1b] cyclic intermediates.

We envisaged that the *N*-oxides derived from the conformationally restricted methyl 4,6-*O*-(phenylmethylene)-3-deoxy-3-(4-morpholinyl)-D-*altro*-pyranosides **2**, namely, intermediates **4αa**−**4αf** and **4*β*a**−**4*β*b**, would undergo *syn*-elimination exclusively, resulting in the formation of enols **5** (Scheme 1). It is also expected that the enol ethers **5αe** and **5αf**, derived from the O-allylated products **3αe** and **3αf**, respectively, would undergo Claisen rearrangements[4] to produce branched-chain sugars. In this paper we report for the first time the synthesis of three varied classes of important synthons,[5] ketoses, enol ethers, and branched-chain sugars, through a single route starting from a single intermediate.

Scheme 1[a]



[a] Reagents: (i) morpholine/90−100 °C/9−60 h; (ii) alkylation/aroylation/allylation; (iii) mCPBA; (iv) pyridine/50−100 °C.

Results and Discussion

Methyl 4,6-*O*-(phenylmethylene)-3-deoxy-α-D- and -*β*-D-*erythro*-hexopyranoside-2-ulose (**6α** and **6*β***, respectively) have been used extensively in synthetic chemistry.[5−7] The enolic forms of such ketoses are known to be important synthetic intermediates,[7j,8] although the syntheses of such compounds are not always straightforward. Branched-chain carbohydrates,[4,5d,7d−g,k−l,n,9] on the other hand, constitute an important class of functionalized intermediates,[5] useful for further transformations.

Synthesis of Ketoses and Enol Ethers. The starting amino alcohols **2α** and **2*β*** were synthesized in high yields, by reacting the known epoxides **1α**[10] and **1*β***,[11] respectively, with neat morpholine at elevated temperatures. In each case, as expected,[3] only the 3-deoxy-3-*N*-morpholino derivative was obtained. Compound **2α** was oxidized with mCPBA, and the crude product was heated

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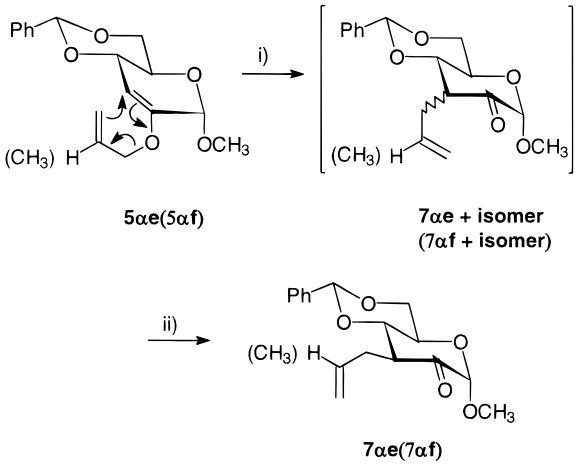
in pyridine at 90−100 °C. The only carbohydrate-based product that could be isolated on purification was the ketose derivative **6α**. The formation of this product validated our envision regarding the preferential intramolecular abstraction of the C-2 *equatorial* proton from the *N*-oxide intermediate **4αa** as discussed above. To broaden the scope of this reaction, compounds **3αb**, **3αc,** and **3αd** were synthesized from the single intermediate **2α** by methylation, benzylation, and benzoylation, respectively (see the Experimental Section). Each of these compounds was oxidized and heated in pyridine as described for the synthesis of compound **6α**. Compounds **3αb**, **3αc**, and **3αd** produced **5αb**, **5αc**, and **5αd**, respectively, in high yields. The *β*-isomers **6*β***[6,7] and **5*β*b** were obtained from compounds **2*β*** and **3*β*b** in similar fashion (Scheme 1).

Synthesis of Branched-Chain Derivatives. Compound **2α** on allylation with allyl bromide or 2-methylallyl chloride produced **3αe** and **3αf**, respectively. Compound **3αe** on oxidation followed by heating afforded the enolic form **5αe** (Scheme 1). Compound **5αe** rearranged[4] in situ to a mixture of isomers **7αe** at C-3. The mixture, however, was converted to the single compound **7αe** by brief treatment with silica gel (Scheme 2).[4b] Similarly, **3αf** was converted to **7αf** via **5αf**.

Compounds **5**, **6**, and **7** have so far been synthesized through completely unrelated routes. Each preparation required the synthesis of different starting materials and separate sets of reaction conditions. For example, **6α** was synthesized by regioselective (C-3) opening of epoxide **1α** by hydride followed by oxidation of the C-2 hydroxyl group.[6c] The best method for the synthesis of **6*β***, however, used the chlorination at C-3 of methyl 4,6-*O*-(phenylmethylene)-*β*-D-*gluco*-pyranoside by SO_2Cl_2 as the key step.[6e] Interestingly, this methodology was only applicable to *β*-glycosides because α-glycosides did not form chloro derivatives due to steric reasons.[12] We have synthesized **6α** from **1α** in 72% and **6*β*** from **1*β*** in 79% overall yields. According to the only report[8b] on the synthesis of **5αb**, methyl 4,6-*O*-benzylidene-2,3-di-*O*-methyl-α-D-hexopyranosides with D-*gluco*, D-*altro*, D-*allo*, and D-*manno* configurations were treated with *n*-butyllithium to produce the desired compound in 30%, 45%, 55%, and 0% yields, respectively. The D-*allo* derivative gave the best yield, but D-allose is one of the most expensive carbohydrates and normally accessed from D-glucose. In our case, the overall yield of **5αb** from **1α** is 61%. The related benzyl derivative **5αc** has been obtained[8k] from methyl 2-*O*-benzyl-3-*O*-trifluoromethane sulfonyl-4,6-*O*-(phenylmethylene)-α-D-*gluco*-pyranoside in 51% yield along with a side product (21%). Although **5αc** has been obtained[8k] from methyl 2-*O*-benzyl-3-*O*-trifluromethane sulfonyl-4,6-*O*-(phenylmethylene)-α-D-*allo*-pyranoside in 91% yield, accessing the starting material from expensive D-allose (or D-glucose) will certainly make the overall yield drop to a much lower value. By our method, **5αc** was synthesized in 71% overall yield from **1α**. The reported[4b] yield of **7αe** from **1α** was 55%; in our case the overall yield is 61%. The versatility of the method has been demonstrated further by synthesizing hitherto unknown benzoyl derivative **5α d**, methyl derivative **5*β*b**, and methylallyl derivative **7αf**.

Scheme 2[a]



[a] Reagents: (i) pyridine/80−90 °C/3 h; (ii) pyridine/silica gel/80−90 °C/8−20 h.

Conclusion

We have reported for the first time a single methodology for the preparation of synthetically and biologically important carbohydrate molecules, such as ketoses, enol ethers, and branched-chain sugars, from a single amino alcohol intermediate prepared from D-glucose. The *N*-oxides derived from the conformationally restricted amino alcohols or various ethers and esters undergo *syn*-elimination exclusively to produce the aforementioned products.

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Experimental Section

General Methods. Melting points were determined in open-end capillary tubes and are uncorrected. Carbohydrates were obtained from commercial suppliers and were used without purification. Pyridine was dried over CaH_2. TLC was carried out on precoated plates (Merck silica gel 60, f_{254}), and the spots were visualized under UV or by using I_2 as the developing agent. Column chromatography was performed on silica gel (silica gel 60, 230−400 mesh). ^1H NMR spectra were recorded at 200 and 300 MHz in $CDCl_3$ using the residual $CHCl_3$ or TMS as the standard. ^{13}C NMR spectra were recorded at 50.3 and 75 MHz in $CDCl_3$ using the triplet centered at δ 77.0 as the standard. Optical rotation was recorded at 589 nm.

Methyl 4,6-*O*-(Phenylmethylene)-3-deoxy-3-(4-morpholinyl)-α-D-*altro*-pyranoside (2α). A solution of methyl 2,3-anhydro-4,6-*O*-(phenylmethylene)-α-D-mannopyranoside (**1α**) (1.65 g, 6.25 mmol) in neat morpholine (5−7 mL) was heated for 10 h at 90−100 °C. Morpholine was coevaporated with toluene under reduced pressure. The resulting syrup was purified over silica gel to yield a colorless solid, **2α** (1.95 g, 89%). Mp: 149−150 °C. $[\alpha]^{28.5}_D$ +96.3° (*c* 0.56, CH_2Cl_2). ^1H NMR ($CDCl_3$): δ 1.88 (br s, 1H), 2.81 (m, 2H), 3.03 (m, 3H), 3.42 (s, 3H), 3.71 (m, 5H), 4.23 (m, 4H), 4.58 (d, J = 1.9 Hz, 1H), 5.5 (s, 1H), 7.35−7.46 (m, 5H). ^{13}C NMR ($CDCl_3$): δ 52.8 (CH_2), 54.9, 59.4, 64.8, 67.2 (CH_2), 68.3, 69.4 (CH_2), 78.2, 101.1, 102.3, 125.9, 128.1, 128.8, 137.4. MS EI: *m*/*z* (%) 351 (M^+, 20), 320 ($M^+ - OCH_3$, 4). Anal. Calcd for $C_{18}H_{25}NO_6$: C, 61.52; H, 7.17; N, 3.99. Found: C, 61.15; H, 6.62; N, 3.94.

Methyl 4,6-*O*-(Phenylmethylene)-3-deoxy-3-(4-morpholinyl)-β-D-*altro*-pyranoside (2β). A solution of methyl 2,3-anhydro-4,6-*O*-(phenylmethylene)-β-D-mannopyranoside (**1β**) (0.65 g, 2.46 mmol) in neat morpholine (3−5 mL) was heated for 60 h at 90−100 °C. Morpholine was coevaporated with toluene. The resulting syrup was purified over silica gel to yield syrupy **2β** (0.81 g, 94%). $[\alpha]^{29}_D$ − 23.5° (*c* 0.2, CH_2Cl_2). ^1H NMR ($CDCl_3$): δ 2.70 (m, 3H), 3.00 (m, 3H), 3.56 (s, 3H), 3.72 (m, 5H), 4.08 (m, 2H), 4.32 (m, 2H), 4.81 (s, 1H), 5.49 (s, 1H), 7.35−7.57 (m, 5H). ^{13}C NMR ($CDCl_3$) δ 52.3 (CH_2), 56.4, 63.3, 63.5, 66.8 (CH_2), 68.0, 69.3 (CH_2), 77.3, 98.6, 102.1, 125.8, 127.9. 128.6, 137.2. MS EI: *m*/*z* (%) 351 (M^+, 11). Anal. Calcd for $C_{18}H_{25}NO_6$: C, 61.52; H, 7.17; N, 3.99. Found: C, 60.80; H, 7.08; N, 3.69.

General Procedure for the Oxidation and Thermal Degradation of 2 and 3. To a solution of **2** or **3** in dichloromethane (10 mL/mmol) was added mCPBA (50−60%, 2.5 equiv). The reaction mixture was stirred for 0.5 h at ambient temperature. Dichloromethane was evaporated under reduced pressure. The resulting crude *N*-oxide was dissolved in anhydrous pyridine (10 mL/mmol) and heated at 80−100 °C for 2−8 h (TLC). Pyridine was evaporated and coevaporated with toluene under reduced pressure. The resulting residue was dissolved in EtOAc and washed successively with saturated aqueous $NaHCO_3$ solution and water. The organic layer was dried over anhydrous Na_2SO_4, filtered, and evaporated to dryness under reduced pressure. The resulting residue was purified over silica gel.

Methyl 4,6-*O*-(Phenylmethylene)-3-deoxy-2-*O*-methyl-α-D-*erythro*-hex-2-enopyranoside (5αb).[8b] To a suspension of NaH (80% dispersion in oil, 0.42 g, 14.67 mmol) in anhydrous dioxane (10 mL) was added **2α** (1.72 g, 4.89 mmol) in anhydrous dioxane (15 mL). The reaction mixture was stirred under nitrogen atmosphere for 0.5 h at ambient temperature. Iodomethane (3.0 mL, 48.9 mmol) was added dropwise to the reaction mixture and stirred for a further 26 h at ambient temperature. The reaction mixture was poured into saturated aqueous NH_4Cl solution (50 mL) and extracted with dichloromethane (3 × 30 mL). The organic layer was dried over anhydrous Na_2SO_4, filtered, and evaporated under reduced pressure. The resulting residue was purified over silica gel to yield syrupy methyl 4,6-*O*-(phenylmethylene)-3-deoxy-2-*O*-methyl-3-(4-morpholinyl)-α-D-*altro*-pyranoside **3αb** (1.53 g, 86%). $[\alpha]^{30}_D$ +99.1° (*c* 2.2, $CHCl_3$). ^1H NMR ($CDCl_3$): δ 2.75 (m, 2H), 3.01 (m, 3H), 3.39 (s, 3H), 3.46 (s, 3H), 3.69 (m, 6H), 4.10 (dd, J = 4.0, 9.6 Hz, 1H), 4.30 (m, 2H), 4.61 (s, 1H), 5.48 (s, 1H), 7.33−7.47 (m, 5H). ^{13}C NMR ($CDCl_3$): δ 53.3 (CH_2), 54.9, 58.4, 59.1, 62.1, 67.3 (CH_2), 69.5 (CH_2), 78.4, 78.6, 99.0, 102.4, 126.1, 128.2, 128.9, 137.9. Anal. Calcd for $C_{19}H_{27}NO_6$: C, 62.44; H. 7.45; N, 3.83. Found: C, 62.46; H, 7.49; N, 3.50.

Compound **3αb** (1.0 g, 2.74 mmol) was converted to a colorless solid, **5αb** (0.61 g, 80%), following the general procedure. Mp: 142−143 °C, lit.[8b] 147 °C. ^1H NMR ($CDCl_3$): δ 3.54 (s, 3H), 3.64 (s, 3H), 3.92 (m, 2H), 4.34 (m, 2H), 4.77 (s, 1H), 5.02 (d, J = 1.3 Hz, 1H), 5.59 (s, 1H), 7.35−7.57 (m, 5H). Anal. Calcd for $C_{15}H_{18}O_5$: C, 64.73; H, 6.52. Found: C, 65.14; H, 6.78.

Methyl 4,6-*O*-(Phenylmethylene)-3-deoxy-2-*O*-methyl-β-D-*erythro*-hex-2-enopyranoside (5βb). The procedure for the synthesis of **3αb** was used for the conversion of **2β** (0.7 g, 1.9 mmol) to syrupy methyl 4,6-*O*-(phenylmethylene)-3-deoxy-2-*O*-methyl-3-(4-morpholinyl)-β-D-*altro*-pyranoside (**3βb**) (0.59 g, 83%). $[\alpha]^{32}_D$ −33.4° (*c* 1.5, $CHCl_3$). ^1H NMR ($CDCl_3$): δ 2.69 (m, 2H), 2.97 (m, 3H), 3.50 (s, 6H), 3.75 (m, 6H), 4.00−4.39 (m, 3H), 4.90 (s, 1H), 5.45 (s, 1H), 7.35−7.55 (m, 5H). ^{13}C NMR ($CDCl_3$): δ 52.2 (CH_2), 56.6, 59.5, 62.3, 63.5, 66.8 (CH_2), 69.2 (CH_2), 76.9, 77.3, 99.3, 102.1, 125.7, 127.8, 128.5, 137.4. MS EI: *m*/*z* (%) 365 (M^+, 20), 334 ($M^+ - OCH_3$, 2). Anal. Calcd for $C_{19}H_{27}NO_6$: C, 62.44; H, 7.45; N, 3.83. Found: C, 62.07; H, 7.44; N, 3.61.

Compound **3βb** (0.39 g, 1.07 mmol) was converted to a colorless solid, **5βb** (0.23 g, 78%), following the general procedure. Mp: 143−144 °C. $[\alpha]^{26}_D$ −26.9° (*c* 1.13, $CHCl_3$). ^1H NMR ($CDCl_3$): δ 3.49 (s, 3H), 3.62 (s, 3H), 3.54−3.71 (m, 1H), 3.89 (t, J = 10.2 Hz, 1H), 4.40 (m, 2H), 5.12 (s, 1H), 5.23 (d, J = 1.8 Hz, 1H), 5.62 (s, 1H), 7.35−7.54 (m, 5H). ^{13}C NMR ($CDCl_3$): 54.2, 54.9, 68.5 (CH_2), 70.1, 74.6, 98.0, 98.6, 101.3, 125.9, 127.9, 128.7, 137.1, 152.8. MS EI: *m*/*z* (%) 278 (M^+, 18), 247 ($M^+ - OCH_3$, 8). Anal. Calcd for $C_{15}H_{18}O_5$: C, 64.73; H, 6.52. Found: C, 64.93; H, 6.28.

Methyl 4,6-*O*-(Phenylmethylene)-3-deoxy-2-*O*-benzyl-α-D-*erythro*-hex-2-enopyranoside (5αc).[8k] To a suspension of NaH (80% dispersion in oil, 0.103 g, 3.58 mmol) in anhydrous DMF (10 mL) was added **2β** (0.42 g, 1.19 mmol) in anhydrous DMF (10 mL). The reaction mixture was stirred under nitrogen atmosphere for 0.5 h at ambient temperature. Benzyl bromide (1.42 mL, 11.96 mmol) was added dropwise to the reaction mixture, and the mixture was stirred for a further 4.5 h at ambient temperature. After the usual workup as described for **3αb** the residue was purified over silica gel to yield syrupy methyl 4,6-*O*-(phenylmethylene)-3-deoxy-2-*O*-benzyl-3-(4-morpholinyl)-α-D-*altro*-pyranoside (**3αc**) (0.5 g, 94%). $[\alpha]^{31}_D$ +60.0° (*c* 0.33, $CHCl_3$). ^1H NMR ($CDCl_3$): 2.69 (m, 2H), 2.95 (m, 2H), 3.04 (s, 1H), 3.36 (s, 3H), 3.59−3.80 (m, 5H), 3.86 (s, 1H), 4.17−4.39 (m, 3H), 4.62−4.64 (m, 2H), 4.68 (s, 1H), 5.49 (s, 1H), 7.29−7.47 (m, 10H). ^{13}C NMR ($CDCl_3$): δ 52.9 (CH_2), 54.5, 58.9, 62.5, 66.9 (CH_2), 69.3 (CH_2), 72.3 (CH_2), 75.2, 78.2, 99.1, 102.2, 125.8, 126.5, 127.6, 127.9, 128.1, 128.6, 137.2, 137.5. MS EI: *m*/*z* (%) 441 (M^+, 11), 351 ($M^+ - CH_2Ph$, 28).

Compound **3αc** (0.33 g, 0.75 mmol) was converted to a colorless solid, **5αc** (0.41 g, 85%), following the general procedure. Mp: 128−130 °C. $[\alpha]^{26}_D$ +84.1° (*c* 2.0, $CHCl_3$). ^1H NMR ($CDCl_3$): δ 3.50 (s, 3H), 3.82 (t, J = 7.3 Hz, 1H), 4.05 (m, 1H), 4.28 (m, 2H), 4.82 (m, 3H), 5.08 (s, 1H), 5.59 (s, 1H), 7.28−7.57 (m, 10H). ^{13}C NMR ($CDCl_3$): δ 56.2, 65.2, 69.3 (CH_2), 69.8 (CH_2), 77.9, 97.0, 98.5, 102.1, 126.5, 127.7, 128.2, 128.4, 128.6, 129.4, 136.3, 137.7, 153.2. MS EI: *m*/*z* (%) 263 ($M^+ - CH_2Ph$, 5). Anal. Calcd for $C_{21}H_{22}O_5$: C, 71.17; H, 6.26. Found: C, 71.63; H, 6.11.

Methyl 4,6-*O*-(Phenylmethylene)-3-deoxy-2-*O*-benzoyl-α-D-*erythro*-hex-2-enopyranoside (5αd). To a solution of **2α** (0.47 g, 1.34 mmol) in anhydrous pyridine (10 mL) at 0 to −5 °C was added benzoyl chloride (0.49 mL, 4.28 mmol) in anhydrous pyridine (5 mL) dropwise. The reaction mixture was stirred for 2 h at 0 °C. After the usual workup the residue was purified over silica gel to give syrupy methyl 4,6-*O*-(phenylmethylene)-3-deoxy-2-*O*-benzoyl-3-(4-morpholinyl)-α-D-*altro*-pyranoside (**3αd**) (0.51 g, 84%). $[\alpha]^{31}_D$ +3.0° (*c* 0.67, $CHCl_3$). ^1H NMR ($CDCl_3$): δ 2.86 (m, 2H), 3.01 (m, 3H), 3.44 (s, 3H), 3.78 (m, 5H), 4.20 (dd, J = 4.3, 9.7 Hz, 1H), 4.43−4.60 (m, 2H), 4.67 (s, 1H), 5.55 (s, 2H), 7.36−7.63 (m, 8H), 8.09 (dd, J = 1.4, 8.3 Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 52.9 (CH_2), 55.0, 58.9, 62.5, 67.1 (CH_2), 69.4 (CH_2), 70.5, 78.7, 98.6, 102.3, 125.9, 128.0, 128.3, 128.7, 129.5, 133.2, 137.5, 164.8.

Compound **3αd** (0.34 g, 0.747 mmol) was converted to a colorless solid, **5αd** (0.22 g, 80%), following the general procedure. Mp: 134−135 °C. $[\alpha]^{27}_D$ +67.9° (*c* 0.99, $CHCl_3$). ^1H NMR ($CDCl_3$): δ 3.45 (s, 3H), 3.86 (t, J = 10.2 Hz, 1H), 4.02 (m, 1H),

4.38 (m, 2H), 5.14 (s, 1H), 5.59 (s, 1H), 6.02 (s, 1H), 7.23−7.62 (m, 8H), 8.07 (dd, J = 1.4, 7.1 Hz, 2H). ^{13}C NMR ($CDCl_3$): δ 56.0, 64.2, 68.9 (CH_2), 74.8, 95.5, 101.8, 117.3, 126.1, 128.0, 128.3, 128.9, 129.9, 133.4, 137.1, 145.2, 164.1. Anal. Calcd for $C_{21}H_{20}O_6$: C, 68.47; H, 5.47. Found: C, 68.56; H, 5.45.

Methyl 4,6-*O*-(Phenylmethylene)-3-deoxy-α-D-*erythro*-hexopyranoside-2-ulose (6α).[6c] Compound **1α** (1.0 g, 3.78 mmol) was converted to **2α** as described above. The crude syrup was oxidized directly, and the *N*-oxide was heated in pyridine. The usual workup and purification produced **6α** (0.72 g, 72%). Mp: 112−114 °C, lit.[6c] 114 °C. IR: ν_{max} ($CHCl_3$) 1737 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ 2.92 (m, 2H), 3.52 (s, 3H), 3.84 (m, 2H), 4.18 (m, 1H), 4.42 (m, 1H), 4.61 (s, 1H), 5.57 (s, 1H), 7.36−7.54 (m, 5H). Anal. Calcd for $C_{14}H_{16}O_5$: C, 63.62; H, 6.10. Found: C, 63.37; H, 6.30.

Methyl 4,6-*O*-(Phenylmethylene)-3-deoxy-β-D-*erythro*-hexopyranoside-2-ulose (6β).[6e] Compound **1**β was converted to a white solid **6**β following a procedure similar to that described for the synthesis of **6**α. Yield: 0.41 g, 84%. Mp: 165 °C, lit.[6e] 153−155 °C. IR: ν_{max} ($CHCl_3$) 1744 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ 2.67 (dd, J = 15.5, 11.8 Hz, 1H), 3.05 (dd, J = 5.48, 10.3 Hz, 1H), 3.56 (s, 3H), 3.81 (m, 2H), 4.07 (m, 1H), 4.48 (m, 1H), 4.73 (s, 1H), 5.55 (s, 1H), 7.23−7.57 (m, 5H). MS EI: m/z (%) 264 (M^+, 2).

General Procedure for the Synthesis of 7αe and 7αf. To a solution of **3αe** and **3αf** in dichloromethane (10 mL/mmol) was added mCPBA (50−60%, 2.5 equiv). The reaction mixture was stirred for 0.5 h at ambient temperature. Dichloromethane was evaporated under reduced pressure. The crude *N*-oxide was dissolved in anhydrous pyridine (10 mL/mmol), and the solution was heated at 80−90 °C for 3 h. Silica gel (1.5 g/mmol) was added to the solution, and the mixture was heated further for 8−20 h at the same temperature. Pyridine was evaporated and coevaporated with toluene. The resulting residue was purified over silica gel to obtain **7αe** and **7αf**.

Methyl 3-*C*-Allyl-4,6-*O*-(phenylmethylene)-α-D-*arabino*-hexopyranosid-2-ulose (7αe).[4b] To a suspension of NaH (80% dispersion in oil, 0.103 g, 3.58 mmol) in anhydrous DMF (10 mL) was added **2α** (0.42 g, 1.19 mmol) in anhydrous DMF (10 mL). The reaction mixture was stirred under nitrogen atmosphere for 0.5 h at ambient temperature. Allyl bromide (1.04 mL, 11.96 mmol) was added dropwise to the reaction mixture, and the mixture was stirred for a further 4.5 h at ambient temperature. After the usual workup as described for **3αb** the residue was purified over silica gel to yield syrupy methyl 4,6-*O*-(phenylmethylene)-3-deoxy-2-*O*-allyl-3-(4-morpholinyl)-α-D-*altro*-pyranoside (**3αe**) (0.41 g, 85%). $[\alpha]^{31}_D$ +48.1° (*c* 0.09, CH_2Cl_2). ^{1}H NMR ($CDCl_3$): δ 2.75 (m, 2H), 2.99 (m, 3H), 3.38 (s, 3H), 3.69−3.83 (m, 6H), 4.09−4.30 (m, 3H), 4.34 (m, 2H), 4.59 (s, 1H), 5.22 (d, J = 1.1 Hz, 1H), 5.28 (m, 1H), 5.49 (s, 1H), 5.91 (m, 1H), 7.35−7.47 (m, 5H). ^{13}C NMR ($CDCl_3$): δ 53.5 (CH_2), 55.2, 59.4, 63.0, 67.6 (CH_2), 69.8 (CH_2), 71.9 (CH_2), 75.8, 79.0, 99.8, 102.6, 118.0 (CH_2), 126.4, 128.4, 129.1, 134.5, 138.2.

Compound **3αe** (0.38 g, 0.97 mmol) was converted to a white solid, **7αe** (0.24 g, 81%), following the general procedure. Mp: 97−98 °C, lit.[4b] 100−101 °C. IR: ν_{max} ($CHCl_3$) 1738 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ 2.53 (m, 2H), 3.12 (m, 1H), 3.50 (s, 3H), 3.57−3.83 (m, 2H), 4.25 (m, 1H), 4.40 (m, 1H), 4.61 (s, 1H), 5.15−5.20 (m, 2H), 5.50 (s, 1H), 5.87 (m, 1H), 7.38−7.53 (m, 5H). Anal. Calcd for $C_{17}H_{20}O_5$: C, 67.09; H, 6.62. Found: C, 67.02; H, 6.76.

Methyl 3-*C*-(2-Methylallyl)-4,6-*O*-(phenylmethylene)-α-D-*arabino*-hexopyranosid-2-ulose (7αf). Compound **2α** (0.4 g, 1.2 mmol) was allylated with 2-methylallyl chloride using a method described for the synthesis of **3αe** to obtain syrupy methyl 4,6-*O*-(phenylmethylene)-3-deoxy-2-*O*-2-methylallyl-3-(4-morpholinyl)-α-D-*altro*-pyranoside (**3αf**) (0.43 g, 84%). $[\alpha]^{31}_D$ +72.9° (*c* 0.11, $CHCl_3$). ^{1}H NMR ($CDCl_3$): δ 1.79 (s, 3H), 2.77 (m, 2H), 2.98 (m, 3H), 3.35 (s, 4H), 3.47−4.34 (m, 10H), 4.56 (s, 1H), 4.95 (m, 2H), 5.46 (s, 1H), 7.24−7.43 (m, 5H). ^{13}C NMR ($CDCl_3$): δ 19.5, 53.3 (CH_2), 55.0, 59.1, 62.8 (CH_2), 67.0 (CH_2), 69.6 (CH_2), 74.5, 75.0, 78.4, 99.2, 102.5, 113.3 (CH_2), 126.1, 128.2, 128.9, 137.8, 141.5. MS EI: m/z (%) 405 (M^+, 5), 374 (M^+ − OCH_3, 5), 350 (M^+ − methylallyl, 28).

Compound **3αf** (0.49 g, 1.21 mmol) was converted to a white solid, **7αf** (0.30 g, 78%), following the general procedure. Mp: 76−77 °C. $[\alpha]^{27}_D$ +56.9° (*c* 1.2, $CHCl_3$). IR: ν_{max} ($CHCl_3$) 1733 cm^{-1}. ^{1}H NMR ($CDCl_3$; ^{1}H−^{1}H COSY): δ 1.72 (s, 3H, CH_3), 2.47 (m, 2H, methylallyl CH_2), 3.23 (m, 1H, H-3), 3.47 (s, 4H, OCH_3 and H-4), 3.74 (t, J = 10.3 Hz, 1H, H-6), 4.22 (m, 1H, H-5), 4.36 (m, 1H, H-6), 4.60 (s, 1H, H-1), 4.67 (s, 1H, =CH_2), 4.75 (s, 1H, =CH_2), 5.48 (s, 1H, PhCH), 7.24−7.48 (m, 5H, aromatic). ^{13}C NMR ($CDCl_3$): δ 23.3, 31.1 (CH_2), 49.9, 55.6, 64.6, 69.0 (CH_2), 81.2, 101.1, 101.2, 111.6 (CH_2), 126.1, 128.3, 129.1, 137.3, 143.0, 199.7. MS EI: m/z (%) 318 (M^+, 6). Anal. Calcd for $C_{18}H_{22}O_5$: C, 67.91; H, 6.97. Found: C, 67.40; H, 6.80.

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Supporting Information Available: Copies of both ^{1}H and ^{13}C NMR spectra of **2α**, **2**β, **5**β**b**, **5αd**, and **7αf**. This material is available free of charge via the Internet at http://pubs.acs.org.

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