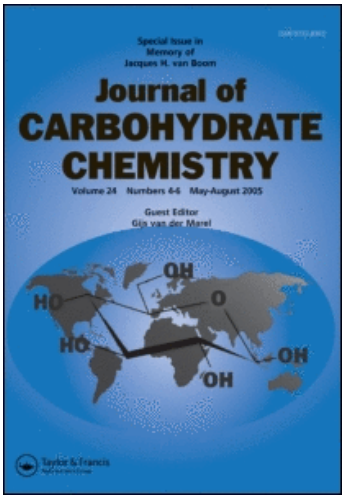

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A ROUTE TO 3,5-DIALKYLATED CARBOHYDRATES: THE CLAISEN REARRANGEMENT OF A 3-C-METHYLATED ALDOSE

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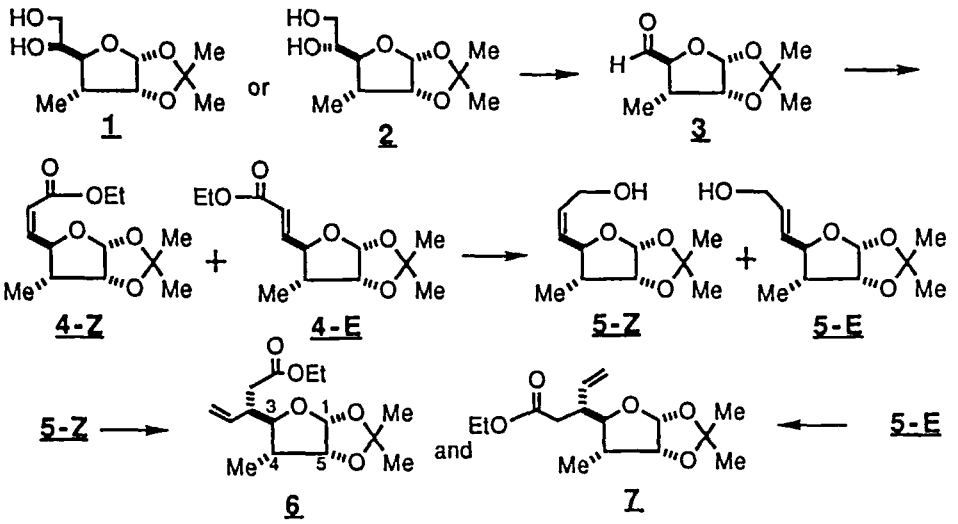
ABSTRACT

The thermal Claisen rearrangement of the *Z*-isomer (**5-Z**) of 3,5,6-trideoxy-1,2-*O*-isopropylidene-3-*C*-methyl-α-D-*ribo*-hept-5-eno-1,4-furanose with triethyl orthoacetate in the presence of propionic acid gave two rearrangement products with a high level of diastereoselectivity (approximately 8.5 to 1). On the other hand, the re-arrangement executed by using the *E*-isomer resulted in the formation of the products without significant stereoselectivity (approximately 1.6 to 1 ratio). The *S*-configuration for the newly introduced stereogenic center in the major product was secured by chemical correlation with our previously reported compound, which was the major rearrangement product of 5,6-dideoxy-1,2-*O*-isopropylidene-α-D-*ribo*-hept-5-eno-1,4-furanose. The transition state argument applied to the similar models accounts well for the stereoselectivity observed in the case of **5-Z**.

INTRODUCTION

Over several years we have reported the Claisen rearrangement protocol applied to a number of carbohydrate derived substrates.[1] In many cases, the high levels of diastereoselectivity were realized by using the *Z*-allylic alcohol derivatives. One notable case was the rearrangement of (*Z*)-3-*O*-(*t*-butyldiphenylsilyl)-5,6-dideoxy-1,2-*O*-

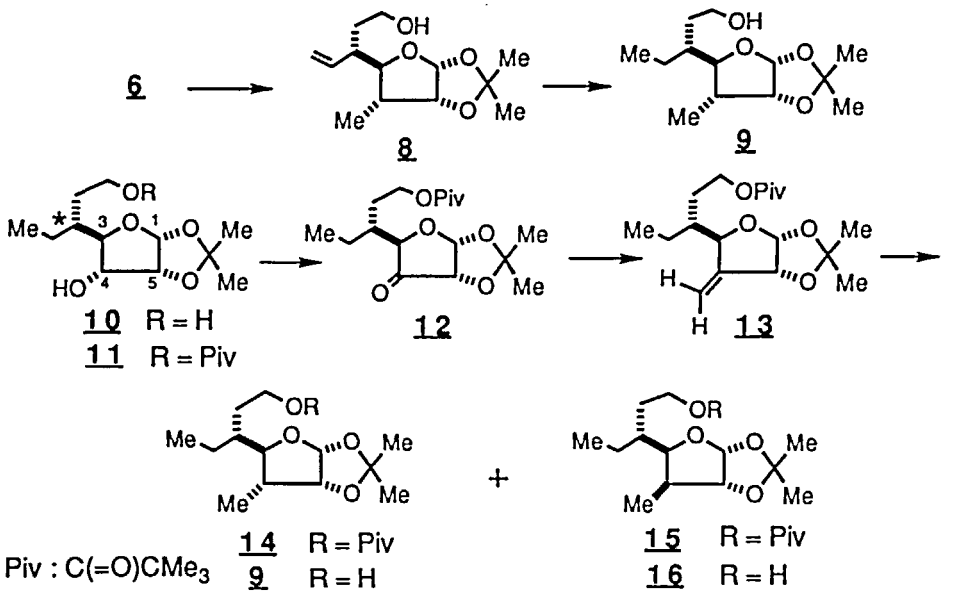


Scheme 1

isopropylidene-α-D-*ribo*-hept-5-eno-1,4-furanose with triethyl orthoacetate.[1c] The rearrangement products thus obtained with diastereoselectivity of 8 to 1 are 5-C-vinylated aldoheptonic acid derivatives, and the utility of these rearrangement products as chiral synthons is possible. In the course of our ongoing pursuit of providing utilizable enantiomerically pure building blocks by means of the Claisen rearrangement protocol, we report here the result of the Claisen rearrangement of (Z)-3,5,6-trideoxy-1,2-*O*-isopropylidene-3-*C*-methyl-α-D-*ribo*-hept-5-eno-1,4-furanose (**5-Z**) with triethyl orthoacetate. The rearrangement products consequently obtained are derivatives of 3,5-di-C-alkylated (or alkenylated) aldoheptonic acid, and may serve as versatile 1,3-dialkyl-2,4-dihydroxylated chiron equivalents.

RESULTS AND DISCUSSION

The substrate **5-Z** for our present study was prepared effectively from either 3-deoxy-1,2-*O*-isopropylidene-3-*C*-methyl-β-L-talo- (**1**)[2] or -α-D-allofuranose (**2**)[3] as follows (Scheme 1). Glycol cleavage of **1** or **2** with $NaIO_4$ gave a 5-*aldehydo*-furanose **3**, which was directly subjected to Wittig olefination with Ph_3P=CHCOOEt in MeOH. The *Z*- and *E*-isomers, **4-Z** and **4-E**, of the α,β-unsaturated esters were obtained as an inseparable mixture in combined yields of 82% (from **1**) or 84% (from **2**). The mixture was treated with diisobutylaluminum hydride (Dibal-H) in CH_2Cl_2 at



Scheme 2

-78 °C giving a mixture of allylic alcohols **5-Z** and **5-E**, which were almost separated by repeated chromatography on silica gel. The yields of **5-Z** and **5-E** were 63% and 28%, respectively.

The thermal Claisen rearrangement of the *Z*-isomer **5-Z** was executed in triethyl orthoacetate with a catalytic amount of propionic acid at 135 °C for 10 h. The ^{1}H NMR (400 MHz) spectrum of the crude reaction mixture revealed that the diastereomeric ratio of two rearrangement products **6** and **7** was approximately 9 to 1. In fact, compounds **6** and **7** were isolated in 70% and 8% yields, respectively, after separation on silica gel. On the other hand, the rearrangement of the *E*-isomer **5-E** under the analogous reaction conditions used for **5-Z** gave **6** and **7** in 41% and 26% yields, respectively (5 h of reaction time was sufficient in this case). As anticipated from the previous results,[1c] the *Z*-allylic alcohol **5-Z** reacted with a high level of diastereoselectivity.

The configuration of the newly introduced stereogenic center in the major rearrangement product **6** was established as follows (Scheme 2). The vinylated ester **6** was converted into the saturated primary alcohol **9** via **8** in an overall yield of 85% by 1) $LiAlH_4$ reduction, and 2) catalytic hydrogenation. Independently, we prepared the C-ethylated heptose derivative **10** according to our previously reported procedure.[1c] The

stereochemistry of the C-ethylated carbon (shown with asterisk) in **10**, which was introduced by the Claisen rearrangement protocol, had been unambiguously determined by chemical modifications.[1c] The conversion of the hydroxyl group at C-4 in **10** into a methyl group was next carried out for direct comparison with **9**.

The primary hydroxyl group in **10** was selectively protected as a pivaloyl ester **11** in 92% yield. Pyridinium chlorochromate (PCC) oxidation[4] of **11** followed by Wittig methylenation of 4-keto derivative **12** with $Ph_3P{=}CH_2$ in THF provided the 3-C-methylene derivative **13** in an overall yield of 88%. Catalytic hydrogenation of **13** in the presence of Pd/C under atmospheric hydrogen, followed by $LiAlH_4$ reduction of the resulting mixture (**14** and **15**) gave the 3-C-methyl derivatives **9** and **16** in 79% and 18% yields, respectively, after separation on silica gel. The previous observations[5] demonstrated that hydride addition or hydrogen addition to the sp^2 carbons at C-3 (C=O or C=C) of 1,2-*O*-isopropylidene-α-D-aldofuranose derivatives, which correspond to C-4 in **13**, took place predominantly from the β-face of the 2,6,8-trioxabicyclo[3.3.0]octane skeleton. Therefore the major product **9**, obtained by hydrogen addition to **13**, was a 3-C-methyl-D-ribo type derivative. This was confirmed by the fact that compound **9** obtained from **13** was identical with that obtained from **6** (mentioned above) in all respects (TLC, ^1H NMR, IR, and $[\alpha]_D$). In conclusion, the new stereogenic centers in **6** and **7** are *S*- and *R*-configurations, respectively. This high level of diastereoselectivity realized by the Claisen rearrangement of **5-Z** coincides with our previous results achieved by the rearrangement of the 3-OH derivatives, and the plausible account for the preferable transition state of the rearrangement seems to be similar to that adopted for the latter.[1c] The synthon **9** could be obtained from both **6** and **10**. Comparing each overall yield, the route to **9** from **6** is superior to that from **10** owing to the less stereoselective hydrogenation of **13**.

EXPERIMENTAL

General Procedures. Reactions were carried out at room temperature unless otherwise described. Melting points are uncorrected. Specific rotations were measured with a JASCO DIP-4 polarimeter ($CHCl_3$ solution) in a 10-mm cell. Column chromatography was performed with silica gel (Katayama Chemicals, K070), and thin-layer chromatography (TLC) with plates coated with Kieselgel 60 GF_{254} (Merck). ^1H NMR spectra were recorded ($CDCl_3$ solution) at 90 MHz with a Varian EM-390 spectrometer or at 400 MHz with a JEOL JNM-GX 400 FT spectrometer.

***Z* and *E* Isomers of 3,5,6-Trideoxy-1,2-O-isopropylidene-3-C-methyl-α-D-*ribo*-hept-5-eno-1,4-furanose (5-Z and 5-E).** From **1**. To a

stirred solution of **1** (3.33 g, 15.3 mmol) in MeOH (60 mL) was added an aqueous solution (15 mL) of $NaIO_4$ (3.94 g, 18.4 mmol) at 0 °C. The mixture was stirred for 15 min. The resulting precipitates were removed by filtration, and washed well with MeOH. The combined filtrate and washings were concentrated *in vacuo*. The residue was partitioned between AcOEt (150 mL) and H_2O (150 mL), and the aqueous phase was extracted with AcOEt (150 mL x 2). The combined organic phases were dried (Na_2SO_4) and concentrated *in vacuo* to give **3** (2.84 g), which was used for the next step directly.

A mixture of **3** (2.84 g) and Ph_3P=CHCOOEt (6.92 g, 19.9 mmol) in MeOH (60 mL) was stirred for 30 min. The solvent was removed by concentration *in vacuo*. The residue was triturated with petroleum ether and stirred for 30 min. The insoluble Ph_3P=O was removed by filtration, washed well with petroleum ether, and the combined filtrate and washings were concentrated *in vacuo*. The residue was chromatographed on silica gel (AcOEt/hexane, 1/10) to give an inseparable mixture of the α,β–unsaturated esters (**4-Z** and **4-E**) (3.22 g) (TLC, R_f 0.42 AcOEt/hexane, 1/4) as a colorless oil.

The mixture of **4-Z** and **4-E** (3.22 g) was dissolved in CH_2Cl_2 (50 mL), and Dibal-H (1.5 M solution in toluene, 25.1 mL, 37.7 mmol) was added to the solution at -78 °C under an argon atmosphere. The mixture was stirred at -78 °C for 30 min, and the reaction was quenched with H_2O (1 mL). After warming the mixture to room temperature, the resulting gels were removed by filtration and washed well with CH_2Cl_2. The combined filtrate and washings were concentrated in vacuo. The residue was partitioned between AcOEt (150 mL) and H_2O (150 mL), and the aqueous phase was extracted with AcOEt (150 mL x 2). The combined organic phases were dried (Na_2SO_4) and concentrated *in vacuo*. The residue was chromatographed on silica gel (AcOEt/hexane, 2/3) repeatedly to give 1.69 g (52% from **1**) of **5-Z**, 0.761 g (23%) of **5-E**, and 0.019 g (0.6%) of the mixture. **5-Z** as colorless needles, mp 77.5-78.5 °C: TLC, R_f 0.31 (AcOEt/hexane, 1/1); $[\alpha]_D^{24}$ +1.05° (*c* 1.05); IR (KBr) 3480, 2980, 2960, 2940, 2860, 1450, 1380, 1255, 1215, 1170 cm^{-1}; ^1H NMR (400 MHz) δ 1.01 (d, 3H, J=6.8 Hz), 1.34, 1.54 (2s, 6H), 1.77 (ddq, 1H, J=4.4, 10.0, and 6.8 Hz), 1.75 (br s, 1H), 4.13-4.19, 4.30-4.36 (2m, 2H), 4.49 (ddd, 1H, J=1.0, 8.8, and 1.0 Hz), 4.57 (dd, 1H, J=3.7 and 4.4 Hz), 5.45 (ddt, 1H, J=8.8, 11.2, and 1.5 Hz), 5.82 (d, 1H, J=3.7 Hz), 5.88 (dddd, 1H, J=1.0, 5.9, 7.3, and 11.2 Hz).

Anal. Calcd for $C_{11}H_{18}O_4$: C, 61.66; H, 8.47. Found: C, 61.59; H, 8.28.

5-E as a colorless oil: TLC, R_f 0.23 (AcOEt/hexane, 1/1); $[\alpha]_D^{24}$ +9.9° (*c* 1.03); IR (neat) 3425, 2990, 2940, 2890, 1455, 1380, 1340, 1305, 1255, 1220, 1175, 1150 cm^{-1}; ^1H NMR (400 MHz) δ 1.03 (d, 3H, J=6.8 Hz), 1.34, 1.54 (2s, 6H), 1.56 (br s,

1H), 1.75-1.78 (m, 1H), 4.12-4.18 (m, 3H), 4.57 (dd, 1H, J=3.7 and 4.4 Hz), 5.65 (ddt, 1H, J=7.3, 15.1, and 1.5 Hz), 5.82 (d, 1H, J=3.7 Hz), 5.92-5.99 (m, 1H).

Anal. Calcd for $C_{11}H_{18}O_4$: C, 61.66; H, 8.47. Found: C, 61.61; H, 8.23.

From **2**. By the same procedure described for **1**, 310 mg of **2** was converted into **5-Z** (152 mg, 51% from **2**) and **5-E** (68 mg, 23%), which were separated by silica-gel chromatography, and the mixture (4 mg, 1%).

(1*R*,3*R*,4*R*,5*R*)-3-[(1*S*)- and (1*R*)-1-(Ethoxycarbonyl)methyl-2-propenyl]-4,7,7-trimethyl-2,6,8-trioxabicyclo[3.3.0]octanes[6] (6 and 7). From **5-Z**. A solution of **5-Z** (1.17 g, 5.5 mmol) in freshly distilled triethyl orthoacetate (10 mL) was heated at 135 °C in the presence of 36 μL of distilled propionic acid under an argon atmosphere. The mixture was heated for 10 h with a distilling reservoir for collecting EtOH, while each 40 μL aliquot of propionic acid was added at intervals of 2 h. After cooling to room temperature, the mixture was concentrated *in vacuo* with the aid of toluene. The residue was chromatographed on silica gel (AcOEt/hexane, 1/10) repeatedly to give **6** (1.09 g, 70%) and **7** (0.121 g, 8%), **6** as a colorless oil: TLC, R_f 0.38 (AcOEt/hexane, 1/4); $[\alpha]_D^{27}$ +34.3° (*c* 1.01); IR (neat) 2990, 2940, 2880, 1735, 1640, 1460, 1420, 1370, 1335, 1290, 1250, 1220 cm^{-1}; ^1H NMR (400 MHz) δ 1.08 (d, 3H, J=6.8 Hz), 1.24 (t, 3H, J=7.3 Hz), 1.32, 1.50 (2s, 6H), 1.81 (ddq, 1H, J=4.4, 10.0, and 6.8 Hz), 2.34 (dd, 1H, J=9.5 and 15.1 Hz), 2.64 (dd, 1H, J=4.4 and 15.1 Hz), 2.69-2.76 (m, 1H), 3.72 (dd, 1H, J=5.6 and 10.0 Hz), 4.11 (q, 2H, J=7.3 Hz), 4.53 (dd, 1H, J=3.9 and 4.4 Hz), 5.08 (dd, 1H, J=1.5 and 9.3 Hz), 5.14 (ddd, 1H, J=1.0, 1.5, and 17.1 Hz), 5.74 (d, 1H, J=3.9 Hz), 5.78 (ddd, 1H, J=8.8, 9.3, and 17.1 Hz).

Anal. Calcd for $C_{15}H_{24}O_5$: C, 63.36; H, 8.51. Found: C, 63.14; H, 8.30.

7 as a colorless oil: TLC, R_f 0.45 (AcOEt/hexane, 1/4); $[\alpha]_D^{25}$ +18.1° (*c* 1.15); IR (neat) 2990, 2940, 2880, 1735, 1640, 1460, 1420, 1380, 1370, 1355, 1300, 1255, 1235, 1215 cm^{-1}; ^1H NMR (400 MHz) δ 1.03 (d, 3H, J=6.8 Hz), 1.24 (t, 3H, J=7.1 Hz), 1.32, 1.59 (2s, 6H), 1.84 (ddq, 1H, J=4.7, 10.3, and 6.8 Hz), 2.50-2.62 (m, 2H), 2.69-2.75 (m, 1H), 3.79 (dd, 1H, J=2.5 and 10.3 Hz), 4.12 (q, 2H, J=7.1 Hz), 4.50 (dd, 1H, J=3.7 and 4.7 Hz), 5.07-5.13 (m, 2H), 5.71 (d, 1H, J=3.7 Hz), 5.66-5.75 (m, 1H).

Anal. Calcd for $C_{15}H_{24}O_5$: C, 63.36; H, 8.51. Found: C, 63.37; H, 8.58.

From **5-E**. By the analogous procedure and work-up described for **5-Z**, 111 mg (0.52 mmol) of **5-E** with 1 mL of triethyl orthoacetate was converted to **6** (61 mg, 41%) and **7** (38 mg, 26%), which were separated by silica-gel chromatography (5 h-heating was enough for completion of the rearrangement in this case).

(1*R*,3*R*,4*R*,5*R*)-3-[(1*S*)-1-(2-Hydroxyethyl)-2-propenyl]-4,7,7-trimethyl-2,6,8-trioxabicyco[3.3.0]octane (8). To a stirred solution of **6** (69 mg, 0.24 mmol) in THF (1 mL) was added $LiAlH_4$ (14 mg, 0.38 mmol) at 0 °C. After being stirred for 20 min at room temperature, the reaction was quenched with 0.05 mL of H_2O. The resulting gels were removed, and washed with THF. The combined filtrate and washings were concentrated *in vacuo*. The residue was partitioned between AcOEt (20 mL) and H_2O (20 mL), and the aqueous phase was extracted with AcOEt (20 mL x 2). The combined organic phases were dried (Na_2SO_4) and concentrated *in vacuo*. The residue was chromatographed on silica gel (AcOEt/hexane, 1/2) to give **8** (52 mg, 89%) as a colorless oil: TLC, R_f 0.49 (EtOH/toluene, 1/5); $[\alpha]_D^{26}$ +66.1° (*c* 0.99); IR (neat) 3420, 2990, 2940, 2880, 1640, 1460, 1420, 1380, 1370, 1335, 1240, 1220 cm^{-1}; ^1H NMR (90 MHz) δ, 1.06 (d, 3H, J=6.8 Hz), 1.32, 1.50 (2s, 6H), 1.55-2.10 (m, 4H), 2.17-2.51 (m, 1H), 3.44-3.90 (m, 3H), 4.52 (t, 1H, J=4.0 Hz), 4.95-5.25 (m, 2H), 5.74 (d, 1H, J=4.0 Hz), 5.52-6.04 (m, 1H).

Anal. Calcd for $C_{13}H_{22}O_4$: C, 64.44; H, 9.15. Found: C, 64.31; H, 9.07.

(1*R*,3*R*,4*R*,5*R*)-3-[(1*R*)-1-Ethyl-3-hydroxypropyl]-4,7,7-trimethyl-2,6,8-trioxabicyclo[3.3.0]octane (9). A solution of **8** (33 mg, 0.14 mmol) in EtOH (1 mL) was hydrogenated in the presence of Raney Ni T-4 catalyst under an atmospheric hydrogen for 2 h. The catalyst was removed through a Celite pad, and washed well with EtOH. The combined filtrate and washings were concentrated *in vacuo*. The residue was chromatographed on silica gel (AcOEt/hexane, 1/2) to give **9** (31 mg, 95%) as a colorless oil: TLC, R_f 0.49 (EtOH/toluene, 1/5); $[\alpha]_D^{33}$ +39.2° (*c* 1.04); IR (neat) 3420, 2960, 2940, 2880, 1460, 1380, 1370, 1335, 1305, 1240 cm^{-1}; ^1H NMR (400 MHz) δ 0.95 (t, 3H, J=7.3 Hz), 1.04 (d, 3H, J=6.8 Hz), 1.33, 1.50 (2 s, 6H), 1.46-1.70 (m, 5H), 1.89-1.95 (m, 1H), 2.12 (br s, 1H), 3.57-3.62 (m, 1H), 3.69-3.75 (m, 1H), 3.83 (dd, 1H, J=2.4 and 10.3 Hz), 4.54 (dd, 1H, J=3.9 and 4.4 Hz), 5.74 (d, 1H, J=3.9 Hz).

Anal. Calcd for $C_{13}H_{24}O_4$: C, 63.91; H, 9.90. Found: C, 63.72; H, 9.63.

(1*R*,3*R*,4*R*,5*R*)-4-Hydroxy-3-[(1*R*)-1-ethyl-3-[(2,2-dimethylpropionyl)oxy]propyl]-7,7-dimethyl-2,6,8-trioxabicyclo[3.3.0]octane (11). To a stirred solution of **10**[1c] (114 mg, 0.46 mmol) in a mixture of CH_2Cl_2 (1 mL) and pyridine (2 mL) was added pivaloyl chloride (115 μL, 0.93 mmol) at 0 °C. After being stirred at room temperature for 4 h, 20 mL of CH_2Cl_2 was added to the mixture. This was washed with H_2O (20 mL), and the aqueous phase was extracted with CH_2Cl_2 (20 mL x 2). The combined organic phases were dried (Na_2SO_4) and concentrated *in vacuo*. The residue was chromatographed on silica gel (AcOEt/hexane 1/5) to give **11** (140 mg, 92%) as a colorless oil: TLC, R_f 0.69 (EtOH/toluene, 1/5); $[\alpha]_D^{33}$ +30.0° (*c*

1.20) ; IR (neat) 3480, 2960, 2940, 2880, 1720, 1480, 1460, 1395, 1380, 1370, 1280, 1215 cm^{-1}; ^1H NMR (400 MHz) δ 0.95 (t, 3H, J=7.1Hz), 1.19 (s, 9H), 1.37, 1.56 (2 s, 6H), 1.39-1.47 (m, 1H), 1.57-1.69 (m, 3H), 1.83 (td, 1H, J=7.3 and 9.3 Hz), 2.40 (d, 1H, J=10.3 Hz), 3.70-3.80 (m, 2H), 4.12 (t, 2H, J=6.6 Hz), 4.54 (dd, 1H, J=3.9 and 4.4 Hz), 5.78 (d, 1H, J=3.9 Hz).

Anal. Calcd for $C_{17}H_{30}O_6$: C, 61.80; H, 9.15. Found: C, 61.46; H, 8.97.

(1*R*,3*R*,5*R*)-3-[(1*R*)-1-Ethyl-3-[(2,2-dimethylpropionyl)oxy]propyl]-7,7-dimethyl-4-methylene-2,6,8-trioxabicyclo[3.3.0]octane (13). A mixture of **11** (99 mg, 0.30 mmol), PCC (369 mg, 1.7 mmol) and molecular sieves (4A, powder, 283 mg) in CH_2Cl_2 (2 mL) was stirred for 23 h. The mixture was applied to a short silica-gel column, and the column was eluted with Et_2O to give 4-keto derivative **12** (94 mg) after concentration of the eluate [TLC, R_f 0.68 (AcOEt/hexane, 1/2)], which was used for the next step without further purification.

To a stirred solution of **12** (94 mg) in THF (2 mL) was added 0.5 M solution of $Ph_3P{=}CH_2$ in THF (2.95 mL, 1.48 mmol), prepared from Ph_3PCH_3Br with $NaNH_2$. The mixture was stirred for 10 min, and the reaction was quenched with 10% aqueous NH_4Cl solution (30 mL). This was extracted with AcOEt (30 mL). The organic phase was washed with 10% aqueous NH_4Cl (30 mL x 2), then dried (Na_2SO_4), and concentrated *in vacuo*. The residue was chromatographed on silica gel (AcOEt/hexane, 1/20) to give **13** (86 mg, 88%) as a colorless oil: TLC, R_f 0.52 (AcOEt/hexane, 1/4); $[\alpha]_D^{28}$ +147.4° (*c* 0.97); IR (neat) 2960, 2940, 2880, 1725, 1480, 1455, 1395, 1380, 1370, 1280, 1230, 1210 cm^{-1}; ^1H NMR (400 MHz) δ 0.99 (t, 3H, J=7.3 Hz), 1.19 (s, 9H), 1.37, 1.51 (2s, 6H), 1.46-1.69 (m, 5H), 4.01-4.12 (m, 2H), 4.87-4.89 (m, 2H), 5.09 (t, 1H, J=1.7 Hz), 5.45 (dd, 1H, J=1.5 and 2.0 Hz), 5.80 (d, 1H, J=3.9 Hz).

Anal. Calcd for $C_{18}H_{30}O_5$: C, 66.23; H, 9.26. Found: C, 65.92; H, 9.09.

(1*R*,3*R*,4*R*,5*R*)- and (1*R*,3*R*,4*S*,5*R*)-3-[(1*R*)-1-Ethyl-3-hydroxypropyl]-4,7,7-trimethyl-2,6,8-trioxabicyclo[3.3.0]octanes (9 and 16). A solution of **13** (68 mg, 0.21 mmol) in EtOH (2 mL) was hydrogenated in the presence of 10% Pd on charcoal under an atmospheric hydrogen for 2 h. The catalyst was removed through a Celite pad and washed well with EtOH. The combined filtrate and washings were concentrated *in vacuo* to give a mixture of **14** and **15** (68 mg) [TLC, R_f 0.52 (AcOEt/hexane 4/1)], which was used for the next step directly.

To a stirred solution of the mixture (68 mg) in THF (2 mL) was added $LiAlH_4$ (15 mg, 0.40 mmol) at 0 °C. After being stirred at room temperature for 30 min, the reaction was quenched with 0.02 mL of H_2O. The resulting gels were filtered and washed well with THF. The combined filtrate and washings were concentrated *in vacuo*. The residue was partitioned between AcOEt (20 mL) and H_2O (20 mL), and the

aqueous phase was extracted with AcOEt (20 mL x 2). The combined organic phases were dried (Na_2SO_4) and concentrated *in vacuo*. The residue was chromatographed on silica gel (AcOEt/hexane 3/1) to give **9** (40 mg, 79%) and **16** (9 mg, 18%). The TLC mobility, $[\alpha]_D$, and spectral data (^1H NMR and IR) of **9** was completely identical with those of the sample obtained from **6**. **16** as a colorless oil: TLC, R_f 0.46 (AcOEt/hexane,1/1); $[\alpha]_D^{30}$ +2.9° (*c* 0.42); IR (neat) 3440, 2960, 2940, 2880, 1460, 1380, 1370, 1300, 1255, 1215 cm^{-1}; ^1H NMR (400 MHz) δ 0.84 (d, 3H, J=7.3 Hz), 0.93 (t, 3H, J=7.6 Hz), 1.30, 1.50 (2s, 6H), 1.15-1.73 (m, 4H), 1.79-1.85 (m, 1H), 2.26-2.29 (m, 1H), 2.75 (br s, 1H), 3.63-3.67 (m, 1H), 3.74-3.79 (m, 1H), 3.98 (dd, 1H, J=3.7 and 10.5 Hz), 4.35 (d, 1H, J=3.7 Hz), 5.78 (d, 1H, J=3.7 Hz).

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6. The carbohydrate derived compounds **6** through **16** were named as derivatives of 2,6,8-trioxabicyclo[3.3.0]octane to avoid ambiguity arising from the carbohydrate nomenclature.