Palladium-Mediated Cyclization on Carbohydrate Templates. 1. Synthesis of Enantiopure Bicyclic Compounds

Jean-Flaubert Nguefack, Véronique Bolitt, and Denis Sinou*

Laboratoire de Synthèse Asymétrique, UMR 5622, CPE Lyon, Université Claude Bernard Lyon I, 43 boulevard du 11 Novembre 1918, 69622 Villeurbanne Cédex, France

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The bromo unsaturated carbohydrates **3a** and **9** were prepared from ethyl 4,6-di-*O*-acetyl-2,3-dideoxy-D-*erythro*-hex-2-enopyranoside (**1a**) and (**7**) by deacetylation followed by monosilylation with TBDMSCl and then alkylation with $BrCH_2CBr{=}CH_2$. The *threo* analogues **6** and **10** were obtained using the same methodology after inversion at C-4 *via* a Mitsunobu reaction. The *N*- and *C*-analogues **4b** and **5** were prepared by palladium alkylation of the carbonate **2d** with $TsNHCH_2$-$CBr{=}CH_2$ and $(CO_2Me)_2CHCH_2CBr{=}CH_2$, respectively. Treatment of the unsaturated carbohydrates **3a** and **9** with a catalytic amount of $Pd(OAc)_2/PPh_3$ in CH_3CN/H_2O in the presence of Bu_4NHSO_4 and NEt_3 afforded the bicyclic compound **14a**. The *N*- and *C*-analogues **14b** and **14c** were obtained using the same conditions and starting, respectively, from **4b** and **5**. On the other hand, treatment of the *threo* derivatives **6** and **10** under these conditions gave the furanic structure **15**. In the case of compound **3a**, performing the reaction in the presence of sodium formate yielded the bicyclic 2-deoxy carbohydrate **17**.

Introduction

Palladium-catalyzed cyclization processes constitute a widely used methodology for the stereospecific synthesis of carbocyclic as well as heterocyclic derivatives, sometimes *via* cascade reactions.[1] Most of these reactions are based on an intramolecular Heck reaction and allow the sequential formation of several carbon−carbon bonds in a single step, even in a diastereo- and enantioselective manner. This approach now competes well with the radical-initiated cascade cyclization.[2]

Carbohydrates provide an abundant source of optically active compounds with a variety of functional and stereochemical features. In addition, they can be modified to give versatile synthons. Although radical cyclization has been extensively studied in carbohydrate chemistry,[3] only a few examples of organometallic-induced reactions have been reported to date. Enantiopure functionalized cyclopentanes and their heterocyclic analogues were prepared *via* palladium-mediated cyclization of the appropriate glycals or pseudoglycals.[4] Recently, the Pauson−Khand reaction was applied to the synthesis of bis-annulated pyranosides.[5] A palladium-mediated [3 + 2] cycloaddition served as the key step in the synthesis of cyclopentenones and cyclopentadienes.[6]

We recently described an unexpected palladium-catalyzed Heck-type cyclization in carbohydrate chemistry, providing bicyclic glycals and occurring *via* a dealkoxypalladation pathway.[7] These highly functionalized and enantiomerically pure annulated glycals could be useful intermediates for further transformations. In the present paper, we report a more detailed investigation of this reaction.

Results and Discussion

Preparation of Unsaturated Starting Sugars. The 2,3-unsaturated glycosides **3**, **6**, **9**, **10**, and **13** used in this study were prepared from easily accessible derivatives of tri-*O*-acetyl-D-glucal. Deacetylation of ethyl 4,6-di-*O*-acetyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranoside (**1a**)[8] in methanol followed by selective monoprotection of the primary hydroxyl function with TBDMSCl, NEt_3, and imidazole gave the unsaturated compound **2a** in 80% yield (Scheme 1). Treatment of **2a** with NaH and 2,3-dibromopropene in THF at 60 °C led to the *O*-alkylated sugar **3a** in 70% yield. Subsequent desilylation of **3a** with Bu_4NF in THF gave compound **3d** in 85% yield. Starting from *tert*-butyl and *p-tert*-butylphenyl 4,6-di-*O*-acetyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranosides (**1b**[8]

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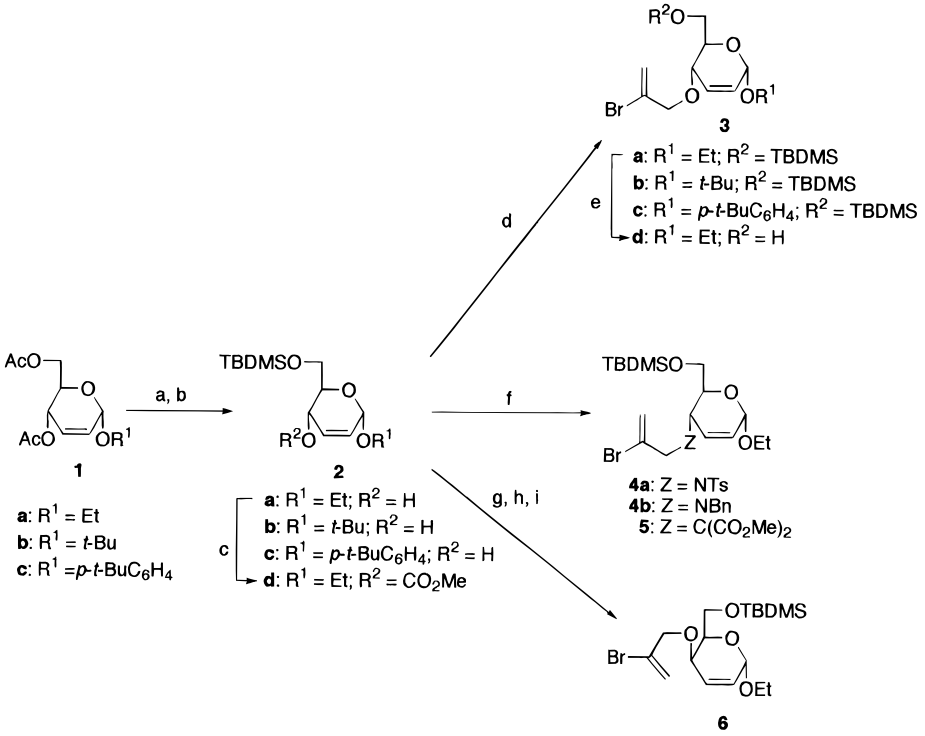
Scheme 1[a]



[a] Reagents and conditions: (a) cat. MeONa, MeOH, quant; (b) TBDMSCl, NEt_3, imidazole, CH_2Cl_2, rt, 24 h, 80%; (c) pyridine, DMAP $ClCO_2Me$, CH_2Cl_2, rt, 24 h, 75%; (d) NaH, $BrCH_2CBr{=}CH_2$, THF, 60 °C, 24 h, 70%; (e) Bu_4NF, THF, 25 °C, 1.5 h, 85%; (f) for compound **4a** (**4b**), $TsNHCH_2CBr{=}CH_2$), ($BnNHCH_2CBr{=}CH_2$), Pd_2dba_3, dppb, THF, 60 °C, 24 h, 87% (66%); for compound **5**, $(MeO_2C)_2CHCH_2CBr{=}CH_2$, Pd_2dba_3, dppb, THF, 60 °C, 6 h, 80%; (g) PPh_3, $ClCH_2CO_2H$, toluene, 0 °C, 15 min, then DEAD, 0 °C, 30 min, rt, 24 h; (h) cat. MeONa, MeOH, rt, 20 h, 62% (overall yield g + h); (i) NaH, $BrCH_2CBr{=}CH_2$, THF, 60 °C, 20 h, 65%.

and **1c**[9]), the same sequence led to the *O*-alkylated unsaturated carbohydrates **3b** and **3c**.

Treatment of the carbonate **2d**, obtained from the unsaturated carbohydrate **2a**, with $TsNHCH_2CBr{=}CH_2$ or $BnNHCH_2CBr{=}CH_2$ in THF at 60 °C in the presence of tris(dibenzylideneacetone)dipalladium(0) and 1,4-bis-(diphenylphosphino)butane (dppb) led to the *N*-alkylated carbohydrates **4a** and **4b** in 87% and 66% yield, respectively. The *C*-alkylated analogue **5** was prepared in 80% yield using the same methodology and $(MeO_2C)_2CHCH_2$-$CBr{=}CH_2$ as the alkylating reagent (Scheme 1).

Compound **6** was synthesized from the pseudoglucal **2a** in a two-step sequence, involving inversion of configuration at C-4 of **2a** *via* a Mitsunobu reaction,[10] followed by alkylation of the resulting alcohol with 2,3-dibromopropene as previously described (Scheme 1).

Deacetylation of ethyl 4,6-di-*O*-acetyl-2,3-dideoxy-β-D-*erythro*-hex-2-enopyranoside (**7**), prepared from tri-*O*-acetyl-D-glucal by the method of Baer *et al.*,[11] using a catalytic amount of sodium methoxide in methanol afforded the diol, which was treated with TBDMSCl, NEt_3, and imidazole in CH_2Cl_2 to give the monosilylated carbohydrate **8** in 68% yield. Standard alkylation of this compound with 2,3-dibromopropene as already described gave ethyl 4-*O*-(2′-bromoprop-2′-enyl)-6-*O*-(*tert*-butyldimethylsilyl)-2,3-dideoxy-β-D-*erythro*-hex-2-enopyranoside (**9**) in 72% yield (Scheme 2). Inversion of configuration at C-4 of compound **8** using the Mitsunobu procedure,[10] followed by alkylation with 2,3-dibromopropene led to the epimerized analogue **10** in 52% yield (Scheme 2).

Deacetylation of 4,6-di-*O*-acetyl-1,5-anhydro-2,3-dideoxy-D-*erythro*-hex-2-enitol (**11**), obtained from **1a** according to Grynkiewicz's procedure,[12] in methanol in the presence of sodium methoxide followed by selective monosilylation of the diol as previously described gave compound **12** in 68% yield. The unsaturated carbohydrate **13** was prepared from **12** by alkylation with 2,3-dibromopropene in 80% yield (Scheme 3).

Palladium-Mediated Cyclization. As previously described,[7] an attempt to trap the transient bicyclic σ-alkylpalladium species resulting from a Heck reaction of carbohydrate **3a** in the presence of $Pd(OAc)_2$, PPh_3, Bu_4NBr, Na_2CO_3, and $NaBPh_4$ in acetonitrile−water failed, leading instead to the formation of the unexpected unsaturated bicycle **14a** (Scheme 4). Table 1 summarizes some of the results obtained in the improvement of this methodology. Firstly, it should be noticed that there is no reaction without base (Table 1, entry 1). Among the bases used, triethylamine gave the highest yields (compare Table 1, entries 2 and 3, 4 and 5). Both quaternary ammonium salts (bromide and hydrogenosulfate) were equally effective in this reaction. Most importantly, the nature of the phosphine seemed crucial for the cyclization reaction. While the diphosphines used gave very low yields (Table 1, entries 10−12), monophosphines gave chemical yields in **14a** of up to 77%, the most effective being trifurylphosphine (Table 1, entry 9). While there is no appreciable difference between triphenylphosphine and tris(2-methylphenyl)phosphine (Table 1, entries 5 and 7), the more basic tris(4-methoxyphenyl)phosphine gave a less efficient catalyst (Table 1, entry 8).

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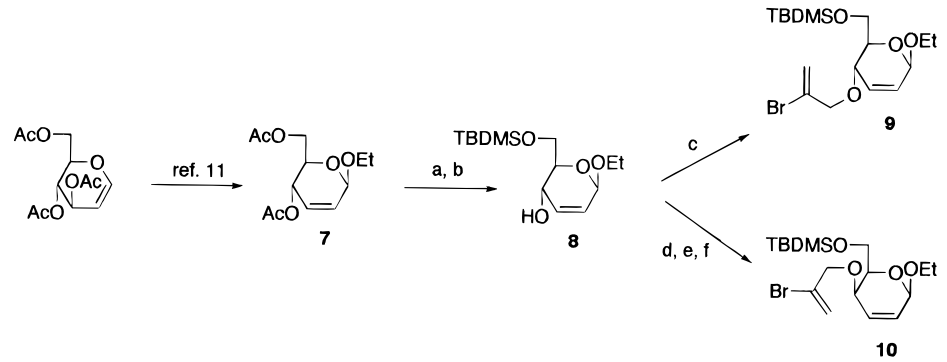
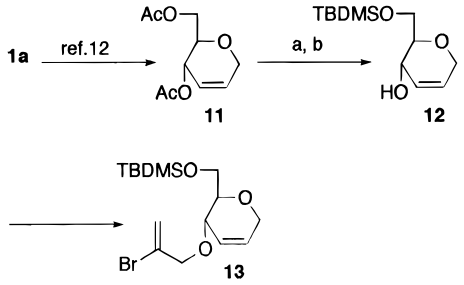
Scheme 2[a]



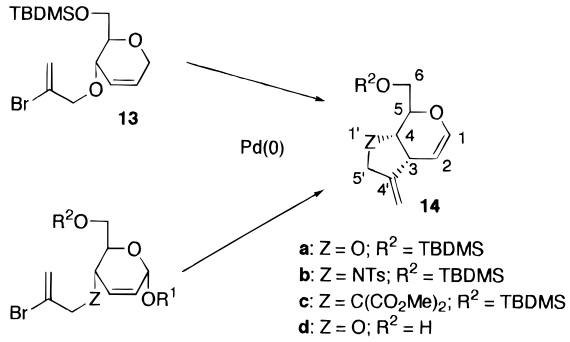
[a] Reagents and conditions: (a) cat. MeONa, MeOH, quant; (b) TBDMSCl, NEt_3, imidazole, CH_2Cl_2, rt, 1.5 h, 68%; (c) NaH, $BrCH_2CBr{=}CH_2$, THF, 60 °C, 24 h, 72%; (d) PPh_3, $ClCH_2CO_2H$, toluene, 0 °C, 15 min, then DEAD, 0 °C, 30 min, rt, 24 h; (e) cat. MeONa, MeOH, rt, 24 h, 56% (overall yield d + e); (f) NaH, $BrCH_2CBr{=}CH_2$, THF, 60 °C, 24 h, 76%.

Scheme 3[a]



[a] Reagents and conditions: (a) cat. MeONa, MeOH, quant; (b) TBDMSCl, NEt_3, imidazole, CH_2Cl_2, rt, 17 h, 77%; (c) NaH, $BrCH_2CBr{=}CH_2$, THF, 60 °C, 20 h, 80%.

Scheme 4



3a: Z = O; R^1 = Et; R^2 = TBDMS
3b: Z = O; R^1 = *t*-Bu; R^2 = TBDMS
3c: Z = O; R^1 = *p*-*t*-BuC_6H_4; R^2 = TBDMS
3d: Z = O; R^1 = Et; R^2 = H
4a: Z = NTs; R^1 = Et; R^2 = TBDMS
5: Z = $C(CO_2Me)_2$; R^1 = Et; R^2 = TBDMS

When the cyclization was performed under the standard conditions ($CH_3CN{-}H_2O$, Bu_4NHSO_4, NEt_3, 80 °C) on *tert*-butylglycoside **3b** and (*p*-*tert*-butylphenyl)glycoside **3c**, the same bicyclic derivative **14a** was also obtained, but in lower yields (20 and 30%, respectively), the reaction being in this case sluggish. The same bicyclic compound **14a** was also formed in 66% chemical yield by intramolecular cyclization of dihydropyran **13** under the same conditions.

Compound **14a** showed characteristic chemical shifts and coupling constants, particularly at δ 6.30 and 4.80 ppm for the olefinic protons H-1 and H-2, with coupling constants $J_{1,2}$ = 6.0 Hz, $J_{1,3}$ = 1.7 Hz, and $J_{2,3}$ = 4.3 Hz. The hydrogen atom H-4 appeared as a doublet of doublets at δ 4.10 ppm with $J_{3,4}$= 7.4 Hz and $J_{4,5}$ = 7.4 Hz, the former value being typical of *cis* stereochemistry in such bicyclic structures. Additional features of interest in compound **14a** are the ^{13}C chemical shifts of C-1, C-2, and C-3 at δ 143.16, 99.67, and 38.43, respectively.

Table 1. Influence of Base, Added Salt and Phosphine on the Palladium(0)-Catalyzed Cyclization of 3a to 14a[a]

entry	base	added salt	phosphine	conversion (%)	time (h)	yield[b] (%)
1	no	Bu_4NBr	PPh_3	traces	48	0
2	Na_2CO_3	Bu_4NBr	PPh_3	100	24	43
3	NEt_3	Bu_4NBr	PPh_3	100	24	61
4	Na_2CO_3	Bu_4NHSO_4	PPh_3	100	24	39
5	NEt_3	Bu_4NHSO_4	PPh_3	100	10	72
6[c]	NEt_3	Bu_4NHSO_4	PPh_3	100	15	72
7	NEt_3	Bu_4NHSO_4	$P(C_6H_4\text{-}2\text{-}Me)_3$	100	15	70
8	NEt_3	Bu_4NHSO_4	$P(C_6H_4\text{-}4\text{-}OMe)_3$	100	40	63
9	NEt_3	Bu_4NHSO_4	P(2-furyl)$_3$	100	4	77
10	NEt_3	Bu_4NHSO_4	$Ph_2P(CH_2)_4PPh_2$	20	24	traces
11	NEt_3	Bu_4NHSO_4	$Ph_2P(CH_2)_3PPh_2$	30	24	10
12	NEt_3	Bu_4NHSO_4	dppf[d]	50	24	32

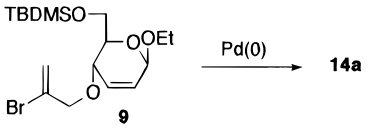
[a] Standard conditions: **3a** (0.50 mmol) in CH_3CN (15 mL) and H_2O (3 mL) in the presence of $Pd(OAc)_2$ (0.05 mmol), the phosphine (0.10 mmol for monophosphines or 0.05 mmol for diphosphines), the added salt (0.50 mmol), and the base (1.22 mmol) were heated at 80 °C for the indicated time. [b] Isolated yield after column chromatography on silica gel. [c] $Pd(acac)_2$ was used instead of $Pd(OAc)_2$. [d] 1,1′-Bis(diphenylphosphino)ferrocene.

A similar reaction performed with the unprotected carbohydrate **3d** gave the bicyclic compound **14d** in 68% yield; the coupling constant $J_{3,4}$ = 7.6 Hz is again in agreement with a *cis*-fused bicyclic structure.

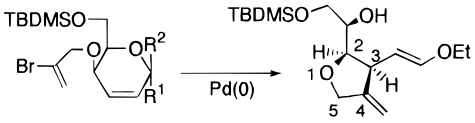
Whatever the conditions used, the *N*-benzyl derivative **4b** failed to give the cyclized product; this is probably due to the complexation of the σ-vinylpalladium intermediate by the nitrogen atom. However, the *N*-tosyl unsaturated carbohydrate **4a** gave the bicyclic aza-compound **14b** in 81% yield (Scheme 4); this different reactivity could be due to the unavailability of the nitrogen lone pair for coordination to the palladium as a result of its incorporation into a sulfonamide function. The ^1H NMR spectrum showed signals at δ 6.42 and 4.79 ppm for the vinylic protons H-1 (dd) and H-2 (dd) and at δ 2.43−2.40 ppm for H-3 with a coupling constant $J_{3,4}$ = 7.6 Hz, again characteristic of the *cis*-fused bicyclic structure. In the ^{13}C NMR spectrum the chemical shifts for C-1, C-2, and C-3 are found as expected at δ 144.07, 98.22, and 38.59 ppm, respectively.

Finally, the cyclization process was extended to the *C*-substituted analogue **5**, which gave the bicyclic compound **14c** in 80% chemical yield. This compound again

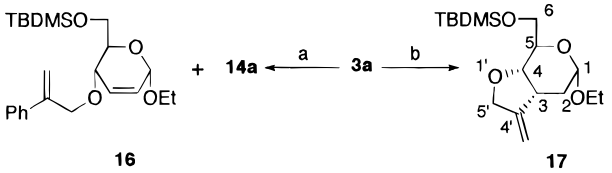
Scheme 5



Scheme 6



Scheme 7[a]



[a] Reagents and conditions: (a) NEt_3, Bu_4NHSO_4, $Pd(OAc)_2$, PPh_3, $NaBPh_4$, CH_3CN/H_2O 5/1, 60 °C, 24 h, 38% (**14**) and 20% (**16**); (b) NEt_3, Bu_4NHSO_4, $Pd(OAc)_2$, PPh_3, HCO_2Na, CH_3CN/H_2O 5/1, 80 °C, 24 h, 62%.

showed typical chemical shifts for both H-1 and H-2 at δ 6.12 and 4.55 ppm and a coupling constant $J_{3,4} = 9.1$ Hz (Scheme 4).

To study the mechanism of this intramolecular cyclization, we extended this reaction to three other substrates, **6**, **9**, and **10**.

Under the standard conditions of cyclization, the unsaturated β-glycoside **9** was transformed into the bicyclic compound **14a** in 50% chemical yield (Scheme 5).

On the other hand, both ethyl α- and β-4-*O*-(2′-bromoprop-2′-enyl)-6-*O*-(*tert*-butyldimethylsilyl)-2,3-dideoxy-D-*threo*-hex-2-enopyranoside (**6**) and (**10**) led to the formation of the same compound **15** in 57 and 67% yield, respectively, which has an *E* double bond configuration (Scheme 6). The ^{1}H NMR spectrum showed a doublet at δ 6.34 ppm and a doublet of doublets at δ 4.80 ppm for the hydrogen atoms −C*H*═C*H*OEt, the coupling constant $J = 12.7$ Hz being typical of an *E* configuration of the double bond.[13] The presence of the hydroxyl function is shown by the observation of a doublet at δ 2.40 ppm, and the *cis* stereochemistry of the two substituents of the tetrahydrofuran ring is in agreement with the coupling constant $J = 7.6$ Hz.

As previously stated, we expected to trap the bicyclic σ-alkylpalladium intermediate resulting from the carbopalladation of the unsaturated carbohydrate **3a**. Under the cyclization conditions, addition of 1.2 equiv of sodium tetraphenylborate resulted in the formation of a mixture of the cyclized compound **14a** (38%) and the unsaturated carbohydrate **16** (20%) (Scheme 7). The latter arose from the coupling of the first σ-vinylpalladium complex with $NaBPh_4$ *via* a transmetalation process. Increasing the amount of $NaBPh_4$ to 2 equiv gave only compound **16** in 43% yield. Substitution of sodium tetraphenylborate by phenyltributylstannane without base resulted in the formation of the same compound **16** in 40% yield.

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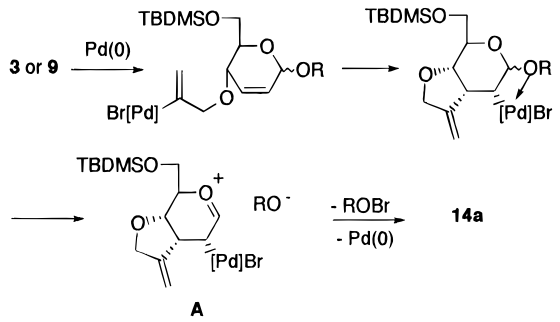
Scheme 8



However, using sodium formate, known as a good hydrogen donor, as the trapping reagent under the standard cyclization conditions led very nicely to the 2-deoxy carbohydrate **17** in 62% yield. This compound **17** showed characteristic chemical shifts and coupling constant values for the anomeric proton at δ 4.89 ppm and $J_{1,2} = 5.6$ Hz and $J_{1,3} = 6.9$ Hz. Additionnal characteristics are the ^{13}C NMR chemical shifts of C-1, C-2, and C-3 at δ 96.75, 31.43, and 39.10 ppm, respectively.

Discussion

From a mechanistic point of view, the cyclization process starts with the formation of a σ-vinylpalladium intermediate by oxidative addition of compound **3** or **9** to the palladium(0) complex, followed by an association−insertion reaction leading to a new σ-alkylpalladium species (Scheme 8). We believe that the oxygen atom of the aglycon is coordinated to the metal; such hydroxyl or alkoxy coordination was recently proposed by Jeffery[14] and Cacchi *et al.*[15] In the case of derivative **9**, this complexation could prevent the *syn* relationship between the anomeric proton and the palladium fragment required for the usual β-hydride elimination and so could hamper this β-hydride elimination. Such an unsaturated compound arising from β-elimination was never observed in this case.

This complexation seems crucial for the next step, which is a dealkoxypalladation. There are few examples of dehydroxypalladation in the literature, including σ-bonded palladium(II) intermediates of tetrahydrofurans,[16] and, to our knowledge, only two cases of β-alkoxyelimination processes.[17] The main role of this chelation is demonstrated by comparing the results obtained with substrates **3a**, **3b**, and **3c**: the two last compounds gave lower yields, probably due to the difficulty of the complexation of the aglycon oxygen atom to the palladium. Chelating diphosphines performed poorly in our cyclization reaction, probably also by preventing the coordination of the aglycon to the palladium, resulting in poor cyclization yields. Finally, the fact that trifurylphosphine is more efficient than triphenylphosphine is in good agreement with our hypothesis;

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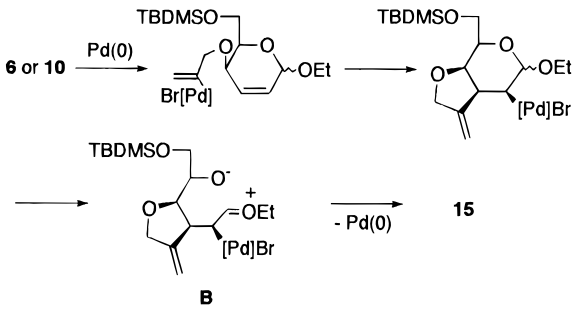
Scheme 9



as shown by Farina *et al.*,[18] the first ligand binds less tightly to the metal than the second one, promoting the reaction process by readily dissociating from palladium(II) and so allowing an easy complexation of the oxygen to the metal.

The next step, which is the β-dealkoxypalladation, may or may not be concerted. While the results concerning the cyclization of anomers **3** and **9** give no information concerning the mechanism, the obtention of only the *E* isomer **15** starting from **6** or **10** clearly indicates that this last step is an ionic and not a concerted mechanism. Effectively, in the case of a concerted process involving a *syn* (or eventually an *anti*) β-dealkoxypalladation, the two anomers **6** and **10** would afford two different stereoisomers. Thus, we propose for this transformation an ionic intermediate such as **A** in the cyclization of **3** and **9** and **B** in the case of **6** and **10**, leading to the formation of the unsaturated compounds **14a** and **15**, respectively, by the elimination of the palladium species (Schemes 8 and 9). The dissociation of the aglycon or of the carbohydrate moiety is facilitated by the coordination of the oxygen atom to the palladium. However, more work is needed to fully understand this reaction mechanism.

Conclusion

We have shown that various alkyl 4-*O*-bromoalkenyl-α-Δ^2-glycopyranosides and their *N*- and *C*-analogues undergo an unexpected palladium-mediated Heck-type cyclization under Jeffery's conditions. However, while the *erythro* structures afforded bicyclic glycals, *threo* derivatives led to the formation of a tetrahydrofuranic structure, indicating the crucial role of the configuration at C-4. On the other hand, the α or β configuration at the anomeric center has no influence on this cyclization process. In the presence of formiate as the hydride source, the bicyclic σ-alkylpalladium intermediate could be trapped to give a bicyclic 2-deoxyglucal.

Thus, we have demonstrated the efficiency and general scope of a new Heck-type cyclization reaction, leading to bicyclic carbohydrate-derivatized compounds that could be used as potential precursors for the synthesis of polycyclic natural products.

Experimental Section

General Methods and Materials. All reactions were monitored by thin-layer chromatography carried out on 0.25 mm silica gel plates (60 F-254, Merck). Compounds were visualized under UV light (254 nm) or by spraying with a H_2SO_4 solution and heating. Column chromatography was performed on silica gel 60 (40−63 mesh ASTM, Macherey-Nagel). NMR spectra were obtained in $CDCl_3$, and chemical shifts are given in ppm on the δ scale from internal tetramethylsilane. THF was distilled from sodium/benzophenone, purged, and kept under a nitrogen atmosphere. Reactions involving palladium complexes were carried out in a Schlenk tube under a nitrogen atmosphere. 3,4,6-Tri-*O*-acetyl-D-glucal, 2,3-dibromopropene, PPh_3, $P(C_6H_4\text{-}2\text{-}Me)_3$, $P(C_6H_4\text{-}4\text{-}OMe)_3$, $P(2\text{-furyl})_3$, $Ph_2P(CH_2)_4PPh_2$, $Ph_2P(CH_2)_3PPh_2$, dppf, $ClCH_2CO_2H$, DEAD, Bu_4NBr, Bu_4NHSO_4, TBDMSCl, $Bu_4NF\cdot 3H_2O$, DMAP, $Pd(OAc)_2$, and $Pd_2(dba)_3$ were purchased from Aldrich Chemical Co.

Benzyl(2-bromoprop-2-enyl)amine,[19] tosyl(2-bromoprop-2-enyl)amine,[20] 1,1-bis(methoxycarbonyl)-3-bromobut-3-ene,[21] ethyl 4,6-di-*O*-acetyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranoside (**1a**),[8] *tert*-butyl 4,6-di-*O*-acetyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranoside (**1b**),[8] *p*-*tert*-butylphenyl 4,6-di-*O*-acetyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranoside (**1c**),[9] ethyl 4,6-di-*O*-acetyl-2,3-dideoxy-β-D-*erythro*-hex-2-enopyranoside (**7**),[11] and 4,6-di-*O*-acetyl-1,5-anhydro-2,3-dideoxy-D-*erythro*-hex-2-enitol (**11**)[12] were prepared by known procedures.

Standard Preparation of 6-*O*-(*tert*-Butyldimethylsilyl) Derivatives 2a−c, 8, and 12. The corresponding diacetate (8.66 mmol) was treated by a catalytic amount of sodium methoxide in methanol (100 mL) at room temperature. After evaporation of the solvent, the free hydroxyl unsaturated glycoside was obtained in quantitative yield and used without further purification. This diol was treated with 1.25 equiv of TBDMSCl (1.62 g, 10.77 mmol), 1.3 equiv of NEt_3 (1.6 mL, 11.2 mmol), and 0.05 equiv of imidazole (30 mg, 0.43 mmol) in CH_2Cl_2 (30 mL) at room temperature for *ca.* 24 h (until TLC analysis showed no more starting material). After addition of 25 mL of water and extraction with 3 × 30 mL of CH_2Cl_2, the organic layer was dried. After evaporation of the solvent under reduced pressure, the residue was purified by column chromatography using petroleum ether/ethyl acetate as the eluent.

Ethyl 6-*O*-(*tert*-butyldimethylsilyl)-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranoside (2a): yield 80%; oil; R_f 0.54 (petroleum ether/ethyl acetate 5/1); $[\alpha]^{20}_D$ +22.1 (*c* 1.0, CH_2Cl_2); ^{1}H NMR (200 MHz) δ 5.95 (brd, 1H, J = 10.2 Hz), 5.75 (brdd, 1H, J = 2.3, 10.2 Hz), 4.96 (brs, 1H), 4.18 (ddd, 1H, J = 1.8, 3.8, 8.1 Hz), 3.95−3.69 (m, 4H), 3.54 (dq, 1H, J = 9.6, 7.1 Hz), 2.72 (d, 1H, J = 3.8 Hz), 1.14 (t, 3H, J = 7.1 Hz), 0.89 (s, 9H), 0.09 (s, 6H); ^{13}C NMR (50 MHz) δ 132.95, 125.94, 93.88, 70.59, 66.28, 64.91, 63.79, 25.81, 18.21, 15.26, −5.34, −5.30. Anal. Calcd for $C_{14}H_{28}O_4Si$: C, 58.29; H, 9.78. Found: C, 58.11; H, 9.84.

Ethyl 6-*O*-(*tert*-butyldimethylsilyl)-2,3-dideoxy-β-D-*erythro*-hex-2-enopyranoside (8): yield 68%; oil; R_f 0.55 (petroleum ether/ethyl acetate 5/1); $[\alpha]^{20}_D$ +42.7 (*c* 1.05, CH_2Cl_2); ^{1}H NMR (200 MHz) δ 6.10 (ddd, 1H, J = 1.6, 2.9, 10.3 Hz), 5.90 (ddd, 1H, J = 1.5, 1.7, 10.3 Hz), 5.05 (brs, 1H), 4.04−3.99 (m, 1H), 3.94 (dq, 1H, J = 9.7, 7.1 Hz), 3.89−3.78 (m, 3H), 3.53 (dq, 1H, J = 9.7, 7.1 Hz), 2.81 (d, 1H, J = 4.0 Hz), 1.21 (t, 1H, J = 7.1 Hz), 0.92 (s, 9H), 0.08 (s, 6H); ^{13}C NMR (50 MHz) δ 132.87, 128.12, 96.59, 77.70, 66.10, 65.10, 63.45, 25.77, 18.13, 15.17, −5.53, −5.59. Anal. Calcd for $C_{14}H_{28}O_4Si$: C, 58.29; H, 9.78. Found: C, 58.32; H, 9.71.

6-*O*-(*tert*-Butyldimethylsilyl)-1,5-anhydro-2,3-dideoxy-D-*erythro*-hex-2-enitol (12): yield 77%; oil; R_f 0.23 (petroleum ether/ethyl acetate 2/1); $[\alpha]^{20}_D$ −29.3 (*c* 1.0, CH_2Cl_2); ^{1}H NMR (200 MHz) δ 5.83 (brd, 1H, J = 11.3 Hz), 5.75 (brd, 1H, J = 11.3 Hz), 4.23 (ddd, 1H, J = 2.6, 2.7, 7.9 Hz), 4.15 (brs, 2H), 3.95 (dd, 1H, J = 5.1, 9.8 Hz), 3.75 (dd, 1H, J = 7.8, 9.8 Hz), 3.42 (ddd, 1H, J = 5.1, 7.8, 7.9 Hz), 3.10 (d, 1H, J = 2.6 Hz), 0.87 (s, 9H), 0.08 (s, 6H); ^{13}C NMR (50 MHz) δ 128.74, 127.77, 77.74, 67.52, 66.34, 65.91, 26.56, 18.94, −5.31, −5.26. Anal. Calcd for $C_{12}H_{24}O_3Si$: C, 58.97; H, 9.83. Found: C, 59.43; H, 9.96.

General Procedure for Inversion of Configuration at C-4. To the 4-hydroxyl *erythro* compound **2a** or **8** (1.18 g, 4.09 mmol) in 40 mL of toluol was added 2.14 g (8.18 mmol) of PPh_3

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and 0.77 g (8.18 mmol) of $ClCH_2CO_2H$. The solution was stirred for 15 min at 0 °C, and 1.30 mL (8.18 mmol) of DEAD was injected. After the solution was stirred for 30 min at 0 °C and 24 h at room temperature, $OPPh_3$ was separated and the resulting solution was concentrated under vacuum. The resulting ester was directly treated with a catalytic amount of sodium methoxide in methanol (60 mL). After evaporation of the solvent and addition of 50 mL of CH_2Cl_2, the organic layer was washed with 0.1 M aqueous NH_4Cl and saturated aqueous NaCl. After drying, the solvent was removed under reduced pressure and the residue was purified by column chromatography on silica gel with petroleum ether/ethyl acetate as eluent to afford the corresponding 4-hydroxyl *threo* compound.

General Procedure for *O*-Alkylation. To the 4-hydroxyl compound (1.22 mmol) in 12 mL of dry THF was added 54 mg (1.34 mmol) of NaH (60%). The solution was stirred for 1 h at 60 °C, and 488 mg (2.44 mmol) of 2,3-dibromopropene was added. After being stirred at 60 °C for 14 h, the solution was cooled and the reaction quenched with 10 mL of H_2O and extracted with 3 × 15 mL of Et_2O. After drying, the solvent was removed under reduced pressure and the crude product was purified by column chromatography on silica gel with petroleum ether/ethyl acetate as the eluent to afford the *O*-alkylated compound.

Ethyl 4-*O*-(2′-bromoprop-2′-enyl)-6-*O*-(*tert*-butyldimethylsilyl)-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranoside (3a): yield 73%; oil; R_f 0.46 (petroleum ether/ethyl acetate 10/1); $[\alpha]^{20}_D$ +39.2 (*c* 1.1, CH_2Cl_2); ^{1}H NMR (200 MHz) δ 5.95 (brd, 1H, J = 10.3 Hz), 5.85 (dd, 1H, J = 1.5, 2.9 Hz), 5.71 (ddd, 1H, J = 2.2, 2.3, 10.3 Hz), 5.51 (dd, 1H, J = 0.9, 1.5 Hz), 4.89 (brs, 1H), 4.13 (brd, 1H, J = 13.9 Hz), 4.06 (brd, 1H, J = 13.9 Hz), 3.85−3.65 (m, 5H), 3.44 (dq, 1H, J = 9.7, 7.0 Hz), 1.14 (t, 3H, J = 7.0 Hz), 0.82 (s, 9H), 0.08 (s, 6H); ^{13}C NMR (50 MHz) δ 129.38, 130.22, 127.43, 117.91, 94.10, 72.96, 70.74, 70.47, 63.86, 62.95, 26.03, 18.47, 15.37, −5.09, −5.23.

Ethyl 4-*O*-(2′-bromoprop-2′-enyl)-6-*O*-(*tert*-butyldimethylsilyl)-2,3-dideoxy-α-D-*threo*-hex-2-enopyranoside (6): yield 65%; oil; R_f 0.46 (petroleum ether/ethyl acetate 10/1); $[\alpha]^{20}_D$ −105.9 (*c* 1.1, CH_2Cl_2); ^{1}H NMR (200 MHz) δ 6.17 (dd, 1H, J = 4.6, 10.1 Hz), 6.02 (dd, 1H, J = 2.9, 10.1 Hz), 5.94 (dd, 1H, J = 1.5, 3.0 Hz), 5.60 (brd, 1H, J = 1.5 Hz), 5.06 (d, 1H, J = 2.9 Hz), 4.26 (brd, 1H, J = 14.2 Hz), 4.17 (brd, 1H, J = 14.2 Hz), 4.09 (ddd, 1H, J = 2.4, 6.6, 6.6 Hz), 3.97−3.75 (m, 4H), 3.55 (dq, 1H, J = 9.7, 7.1 Hz), 1.24 (t, 3H, J = 7.1 Hz), 0.89 (s, 9H), 0.09 (s, 6H); ^{13}C NMR (50 MHz) δ 129.81, 130.34, 126.63, 117.50, 93.84, 73.17, 71.10, 67.57, 63.56, 62.19, 25.89, 18.25, 15.30, −5.34, −5.60. Anal. Calcd for $C_{17}H_{31}O_4BrSi$: C, 50.11; H, 7.66. Found: C, 50.23; H, 7.69.

Ethyl 4-*O*-(2′-bromoprop-2′-enyl)-6-*O*-(*tert*-butyldimethylsilyl)-2,3-dideoxy-β-D-*erythro*-hex-2-enopyranoside (9): yield 72%; oil; R_f 0.46 (petroleum ether/ethyl acetate 10/1); $[\alpha]^{20}_D$ +26.9 (*c* 0.8, CH_2Cl_2); ^{1}H NMR (200 MHz) δ 6.06 (ddd, 1H, J = 1.5, 3.4, 10.3 Hz), 5.94 (brd, 1H, J = 1.6 Hz), 5.87 (ddd, 1H, J = 1.5, 1.5, 10.3 Hz), 5.62 (brs, 1H), 5.08 (dd, 1H, J = 1.5, 3.4 Hz), 4.26 (d, 1H, J = 13.9 Hz), 4.16 (d, 1H, J = 13.9 Hz), 4.85−3.98 (m, 1H), 3.91 (dq, 1H, J = 9.6, 7.1 Hz), 3.85−3.76 (m, 3H), 3.55 (dq, 1H, J = 9.6, 7.1 Hz), 1.22 (t, 3H, J = 7.1 Hz), 0.90 (s, 9H), 0.08 (s, 6H); ^{13}C NMR (50 MHz) δ 129.57, 129.40, 127.63, 117.90, 95.02, 76.55, 73.04, 69.32, 63.30, 62.97, 25.90, 18.31, 15.25, −5.27, −5.31. Anal. Calcd for $C_{17}H_{31}O_4BrSi$: C, 50.11; H, 7.66. Found: C, 50.06; H, 8.11.

Ethyl 4-*O*-(2′-bromoprop-2′-enyl)-6-*O*-(*tert*-butyldimethylsilyl)-2,3-dideoxy-β-D-*threo*-hex-2-enopyranoside (10): yield 76%; oil; R_f 0.46 (petroleum ether/ethyl acetate 10/1); $[\alpha]^{20}_D$ −63.2 (*c* 0.75, CH_2Cl_2); ^{1}H NMR (200 MHz) δ 6.13 (ddd, 1H, J = 1.3, 4.8, 10.1 Hz), 5.96 (brd, 1H, J = 1.5 Hz), 5.92 (brd, 1H, J = 10.1 Hz), 5.59 (brd, 1H, J = 1.5 Hz), 5.08 (brd, 1H, J = 1.3 Hz), 4.26 (brd, 1H, J = 13.8 Hz), 4.19 (brd, 1H, J = 13.8 Hz), 4.02−3.72 (m, 5H), 3.63 (dq, 1H, J = 9.6, 7.1 Hz), 1.24 (t, 1H, J = 7.1 Hz), 0.90 (s, 9H), 0.09 (s, 6H); ^{13}C NMR (50 MHz) δ 129.89, 132.58, 127.66, 117.39, 97.53, 75.89, 73.09, 68.47, 63.77, 62.13, 25.91, 18.28, 15.27, −5.28, −5.34. Anal. Calcd for $C_{17}H_{31}O_4BrSi$: C, 50.11; H, 7.66. Found: C, 50.27; H, 7.60.

4-*O*-(2′-Bromoprop-2′-enyl)-6-*O*-(*tert*-butyldimethylsilyl)-1,5-anhydro-2,3-dideoxy-D-*erythro*-hex-2-enitol (13): yield 80%; oil; R_f 0.42 (petroleum ether/ethyl acetate 5/1); $[\alpha]^{20}_D$ +57.3 (*c* 1.0, CH_2Cl_2); ^{1}H NMR (200 MHz) δ 6.25 (brd, 1H, J = 1.5 Hz), 5.93 (brd, 1H, J = 10.3 Hz), 5.87 (brd, 1H, J = 10.3 Hz), 5.58 (dd, 1H, J = 0.8, 1.5 Hz), 4.30−4.13 (m, 4H), 4.11 (brdd, 1H, J = 2.5, 7.7 Hz), 3.92 (dd, 1H, J = 2.7, 11.3 Hz), 3.85 (dd, 1H, J = 4.8, 11.3 Hz), 3.45 (ddd, 1H, J = 2.7, 4.8, 7.7 Hz), 0.91 (s, 9H), 0.08 (s, 6H); ^{13}C NMR (50 MHz) δ 130.29, 129.51, 125.93, 118.93, 78.03, 73.81, 71.13, 65.94, 63.88, 26.71, 19.16, −4.68, −4.79. Anal. Calcd for $C_{15}H_{27}O_3BrSi$: C, 49.58; H, 7.47. Found: C, 49.14; H, 7.48.

Ethyl 4-*O*-(2′-Bromoprop-2′-enyl)-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranoside (3d). The silyl derivative **3a** (1.1 g, 2.71 mmol) in 20 mL of THF was treated with 871 mg (2.71 mmol) of $Bu_4NF{\cdot}3H_2O$. The solution was stirred at room temperature for 1.5 h and then concentrated under vacuum. The residue was dissolved in 20 mL of Et_2O and the solution washed with 3 × 30 mL of a saturated aqueous solution of NaCl and dried. After removal of the solvent under reduced pressure, the residue was purified by column chromatography on silica gel with petroleum ether/ethyl acetate 1/1 as the eluent to give 0.67 g (85%) of **3d** as an oil: R_f 0.25; $[\alpha]^{20}_D$ +58.7 (*c* 0.5, CH_2Cl_2); ^{1}H NMR (200 MHz) δ 6.07 (brd, 1H, J = 10.3 Hz), 5.93 (brd, 1H, J = 1.6 Hz), 5.79 (ddd, 1H, J = 2.2, 2.3, 10.3 Hz), 5.63 (d, 1H, J = 1.6 Hz), 5.01 (brs, 1H), 4.24 (brd, 1H, J = 14.2 Hz), 4.16 (brd, 1H, J = 14.2 Hz), 4.09 (brd, 1H, J = 9.1 Hz), 3.95−3.75 (m, 4H), 3.54 (dq, 1H, J = 9.6, 7.1 Hz), 1.90 (t, 1H, J = 5.8 Hz), 1.24 (t, 3H, J = 7.1 Hz); ^{13}C NMR (50 MHz) δ 129.13, 129.90, 127.02, 118.38, 94.18, 72.96, 70.42, 69.51, 64.01, 62.09, 15.25. Anal. Calcd for $C_{11}H_{17}O_4Br$: C, 45.06; H, 5.84. Found: C, 44.80; H, 5.94.

General Procedure for *N*- and *C*-Alkylation. To a solution of 2.0 g (6.94 mmol) of **2a** in 60 mL of CH_2Cl_2 at room temperature was added 170 mg (1.4 mmol) of DMAP, 2.8 mL (34.7 mmol) of pyridine, and 2.7 mL (34.7 mmol) of methyl chloroformate. The mixture was stirred for 24 h at room temperature. After addition of 60 mL of a water solution of $CuSO_4.5\ H_2O$, the solution was extracted with 4 × 50 mL of Et_2O. The organic layer was dried, the solvent was removed under reduced pressure, and the product was purified by column chromatography on silica gel with petroleum ether/ethyl acetate 3/1 as the eluent to give 1.8 g (75%) of the carbonate **2d**. To a solution of this carbonate **2d** (500 mg, 1.44 mmol) in 10 mL of dry THF was added 838 mg (2.89 mmol) of $TsNHCH_2CBr{=}CH_2$, 659 mg (2.89 mmol) of $BnNHCH_2$-$CBr{=}CH_2$, or 726 mg (2.89 mmol) of $(MeO_2C)_2CHCH_2$-$CBr{=}CH_2$ and the catalytic system obtained by reacting $Pd_2(dba)_3$ (33 mg, 0.036 mmol) and dppb (31 mg, 0.072 mmol) in 10 mL of THF. The mixture was stirred at 60 °C for 24 h and quenched with 10 mL of H_2O. After extraction with 3 × 15 mL of Et_2O, the organic layer was dried. The solvent was removed under reduced pressure to give an oil that was purified by column chromatography on silica gel using petroleum ether/ethyl acetate as the eluent.

Ethyl 6-*O*-(*tert*-butyldimethylsilyl)-4-[*N*-tosyl-*N*-(2′-bromoprop-2′-enyl)amino]-2,3,4-trideoxy-α-D-*erythro*-hex-2-enopyranoside (4a): yield 87%; oil; R_f 0.45 (petroleum ether/ethyl acetate 5/1); $[\alpha]^{20}_D$ +65.4 (*c* 0.75, CH_2Cl_2); ^{1}H NMR (300 MHz) δ 7.73 (d, 2H, J = 8.1 Hz), 7.32 (d, 2H, J = 8.1 Hz), 5.99 (ddd, 1H, J = 1.5, 1.7, 1.7 Hz), 5.85 (ddd, 1H, J = 2.7, 2.7, 10.2 Hz), 5.63 (dd, 1H, J = 2.1, 2.5 Hz), 5.14 (brdd, 1H, J = 1.8, 10.2 Hz), 4.91 (d, 1H, J = 3.0 Hz), 4.36 (ddd, 1H, J = 1.8, 3.0, 9.7 Hz), 4.21 (brd, 1H, J = 17.1 Hz), 3.94 (ddd, 1H, J = 1.9, 6.5, 9.7 Hz), 3.86 (dd, 1H, J = 1.9, 11.3 Hz), 3.81 (dq, 1H, J = 9.7, 7.1 Hz), 3.76 (brd, 1H, J = 17.1 Hz), 3.60 (dd, 1H, J = 6.5, 11.3 Hz), 3.48 (dq, 1H, J = 9.7, 7.1 Hz), 2.44 (s, 3H), 1.19 (t, 3H, J = 7.1 Hz), 0.88 (s, 9H), 0.06 (s, 3H), 0.05 (s, 3H); ^{13}C NMR (75 MHz) δ 144.10, 137.08, 131.12, 127.45, 129.73, 129.98, 126.44, 119.60, 93.67, 86.45, 68.71, 63.69, 63.18, 53.48, 26.07, 21.73, 18.51, 15.30, −5.03, −5.16. Anal. Calcd for $C_{24}H_{38}O_5BrSiSN$: C, 51.41; H, 6.81; N, 2.49. Found: C, 51.65; H, 6.73; N, 2.79.

Ethyl 6-*O*-(*tert*-butyldimethylsilyl)-4-[1′,1′-bis(methoxycarbonyl)-3′-bromobut-3′-enyl]-2,3,4-trideoxy-α-D-*erythro*-hex-2-enopyranoside (5): yield 80%; oil; R_f 0.46 (petroleum

ether/ethyl acetate 5/1); $[\alpha]^{20}_D$ +50.5 (*c* 0.8, CH_2Cl_2); ^{1}H NMR (300 MHz) δ 5.94 (brd, 1H, *J* = 10.5 Hz), 5.76 (ddd, 1H, *J* = 1.7, 1.7, 10.5 Hz), 5.68 (d, 1H, *J* = 1.9 Hz), 5.55 (d, 1H, *J* = 1.9 Hz), 5.02 (brs, 1H), 4.20−4.13 (m, 1H), 3.77−3.65 (m, 3H), 3.69 (s, 3H), 3.67 (s, 3H), 3.44 (dq, 1H, *J* = 9.8, 7.1 Hz), 3.24 (d, 1H, *J* = 15.9 Hz), 3.15 (d, 1H, *J* = 15.9 Hz), 3.76−2.79 (m, 1H), 1.50 (t, 3H, *J* = 7.1 Hz), 0.89 (s, 9H), 0.08 (s, 3H), 0.07 (s, 3H); ^{13}C NMR (50 MHz) δ 170.21, 169.47, 127.23, 129.86, 126.77, 122.03, 92.69, 72.66, 64.14, 63.33, 60.06, 52.74, 52.45, 43.47, 37.12, 25.83, 18.21, 15.30, −5.31, −5.40. Anal. Calcd for $C_{22}H_{37}O_7BrSi$: C, 50.66; H, 7.15. Found: C, 50.44; H, 7.14.

Standard Palladium(0)-Mediated Cyclization Procedure. A solution of 1.01 mmol of the 2,3-unsaturated glycoside **3a**−**d**, **4a**, **5**, **6**, **9**, **10**, or **13** in CH_3CN (15 mL) and H_2O (3 mL) was heated in the presence of $Pd(OAc)_2$ (11 mg, 0.05 mmol), PPh_3 (26.5 mg, 0.10 mmol), Bu_4NHSO_4 (1.0 mmol), and NEt_3 (700 μl, 2.5 mmol) at 80 °C for 24 h. The progress of the reaction was monitored by TLC. When the starting material was no longer present, the reaction was quenched with 10 mL of water, and the mixture was extracted with 3 × 30 mL of Et_2O. Evaporation of the solvent under reduced pressure gave an oil that was purified by column chromatography on silica gel to give the pure product.

1,2,3,4-Tetradeoxy-2′,3′,4′,5′-tetrahydro-6-*O*-(*tert*-butyldimethylsilyl)-4′-methylene-D-*ribo*-hex-1-enopyranoso-[4,3-*b*]furan (14a): yield 75%; oil; R_f 0.56 (petroleum ether/ethyl acetate 10/1); $[\alpha]^{20}_D$ +145.5 (*c* 1.3, CH_2Cl_2); ^{1}H NMR (200 MHz) δ 6.30 (dd, 1H, *J* = 1.7, 6.0 Hz), 4.92 (ddd, 2H, *J* = 2.6, 2.7, 2.7 Hz), 4.80 (dd, 1H, *J* = 4.3, 6.0 Hz), 4.43 (brd, 1H, *J* = 13.8 Hz), 4.37 (brd, 1H, *J* = 13.8 Hz), 4.10 (dd, 1H, *J* = 7.4, 7.4 Hz), 3.85 (dd, 1H, *J* = 3.5, 11.4 Hz), 3.75 (dd, 1H, *J* = 5.1, 11.4 Hz), 3.50 (ddd, 1H, *J* = 3.5, 5.1, 7.4 Hz), 3.10−3.00 (m, 1H), 0.90 (s, 9H), 0.09 (s, 6H); ^{13}C NMR (50 MHz) δ 150.71, 143.16, 105.63, 99.67, 74.91, 70.70, 69.95, 62.45, 38.43, 25.96, 18.50, −5.29, −5.33.

1,2,3,4-Tetradeoxy-2′,3′,4′,5′-tetrahydro-6-*O*-(*tert*-butyldimethylsilyl)-4′-methylene-1′-*N*-tosyl-D-*ribo*-hex-1-enopyranoso)[4,3-*b*]pyrrole (14b): yield 81%; oil; R_f 0.68 (petroleum ether/ethyl acetate 3/1); $[\alpha]^{20}_D$ +64.9 (*c* 1.1, CH_2Cl_2); ^{1}H NMR (300 MHz) δ 7.72 (d, 2H, *J* = 8.1 Hz), 7.32 (d, 2H, *J* = 8.1 Hz), 6.42 (dd, 1H, *J* = 1.5, 6.1 Hz), 5.03 (ddd, 1H, *J* = 2.0, 2.1, 2.1 Hz), 4.88 (ddd, 1H, *J* = 2.0, 2.3, 2.3 Hz), 4.79 (dd, 1H, *J* = 4.7, 6.1 Hz), 4.26 (dd, 1H, *J* = 2.3, 11.8 Hz), 4.01 (brd, 1H, *J* = 14.9 Hz), 3.90 (brd, 1H, *J* = 14.9 Hz), 3.84 (dd, 1H, *J* = 7.4, 11.8 Hz), 3.77 (dd, 1H, *J* = 7.6, 9.8 Hz), 3.47 (ddd, 1H, *J* = 2.3, 7.4, 9.8 Hz), 2.44 (s, 3H), 2.43−2.40 (m, 1H), 0.94 (s, 9H), 0.12 (s, 6H); ^{13}C NMR (50 MHz) δ 144.67, 134.52, 129.59, 127.59, 147.69, 144.07, 109.41, 98.22, 75.59, 63.25, 56.52, 51.63, 38.59, 25.06, 21.59, 18.54, −5.03, −5.17.

1,2,3,4-Tetradeoxy-6-*O*-(*tert*-butyldimethylsilyl)-1′,1′-bis(methoxycarbonyl)-4′-methylene-D-*ribo*-hex-1-enopyranoso)[4,3-*b*]cyclopentane (14c): yield 80%; oil; R_f 0.70 (petroleum ether/ethyl acetate 5/1); $[\alpha]^{20}_D$ +101.2 (*c* 1.0, CH_2Cl_2); ^{1}H NMR (300 MHz) δ 6.12 (dd, 1H, *J* = 2.3, 6.3 Hz), 4.97 (brs, 2H), 4.55 (brdd, 1H, *J* = 2.7, 6.3 Hz), 4.39 (ddd, 1H, *J* = 1.5, 6.1, 6.5 Hz), 3.79 (dd, 1H, *J* = 6.5, 10.5 Hz), 3.72 (s, 3H), 3.70 (s, 3H), 3.65 (dd, 1H, *J* = 6.1, 10.5 Hz), 3.45 (dddd, 1H, *J* = 1.8, 2.3, 2.3, 16.9 Hz), 3.31 (brd, 1H, *J* = 9.1 Hz), 3.14 (brd, 1H, *J* = 9.1 Hz), 2.58 (ddd, 1H, *J* = 2.3, 2.3, 16.9 Hz), 0.91 (s, 9H), 0.09 (s, 3H), 0.08 (s, 3H); ^{13}C NMR (75 MHz) δ 172.12, 171.31, 150.36, 140.98, 107.52, 103.02, 73.23, 63.78, 59.99, 52.74, 52.82, 43.30, 40.40, 36.46, 25.88, 18.33, −5.27, −5.41.

1,2,3,4-Tetradeoxy-2′,3′,4′,5′-tetrahydro-4′-methylene-D-*ribo*-hex-1-enopyranoso)[4,3-*b*]furan (14d): yield 68%; oil; R_f 0.37 (petroleum ether/ethyl acetate 5/1); $[\alpha]^{20}_D$ +205.3 (*c* 1.1, CH_2Cl_2); ^{1}H NMR (300 MHz) δ 6.37 (dd, 1H, *J* = 1.8, 5.9 Hz), 5.00−4.96 (m, 2H), 4.93 (dd, 1H, *J* = 4.5, 5.9 Hz), 4.38 (brd, 1H, *J* = 13.0 Hz), 4.29 (brd, 1H, *J* = 13.0 Hz), 4.12 (dd, 1H, *J* = 7.6, 8.7 Hz), 3.85 (dd, 1H, *J* = 3.4, 11.9 Hz), 3.76 (dd, 1H, *J* = 5.8, 11.9 Hz), 3.46 (ddd, 1H, *J* = 3.4, 5.8, 8.7 Hz), 3.18−3.14 (m, 1H), 2.67 (brs, 1H); ^{13}C NMR (75 MHz) δ 149.93, 142.87, 105.97, 99.94, 74.28, 73.67, 69.84, 61.96, 38.53.

(2*R*,3*S*,1′*R*) 2-[1′-Hydroxy-2′-[(*tert*-butyldimethylsilyl)-oxy]ethyl]-3-(*E*)-(2′-ethoxyethenyl)-4-methylenetetrahydrofuran (15): yield 67%; oil; R_f 0.26 (petroleum ether/ethyl acetate 10/1); $[\alpha]^{20}_D$ −30.9 (*c* 0.9, CH_2Cl_2); ^{1}H NMR (300 MHz) δ 6.34 (d, 1H, *J* = 12.7 Hz), 4.93 (brd, 2H, *J* = 2.2 Hz), 4.80 (dd, 1H, *J* = 9.9, 12.7 Hz), 4.54 (ddd, 1H, *J* = 1.9, 1.9, 13.0 Hz), 4.38 (brd, 1H, *J* = 13.0 Hz), 3.93 (dd, 1H, *J* = 3.8, 7.6 Hz), 3.85−3.59 (m, 5H), 3.26 (brdd, 1H, *J* = 7.6, 9.9 Hz), 2.40 (d, 1H, *J* = 3.8 Hz), 1.29 (t, 3H, *J* = 7.0 Hz), 0.89 (s, 9H), 0.07 (s, 6H); ^{13}C NMR (75 MHz) δ 152.41, 148.57, 103.84, 100.77, 81.29, 72.06, 71.45, 64.72, 64.33, 45.78, 25.89, 18.29, 14.66, −5.36, −5.38. Anal. Calcd for $C_{17}H_{32}O_4Si$: C, 62.15; H, 9.81. Found: C, 62.56; H, 9.69.

Standard Tandem Palladium(0)-Mediated Cyclization/Ion-Capture Procedure. Compound **3a** (410 mg, 1.01 mmol) was allowed to react under the previously described conditions for palladium(0)-catalyzed cyclization in the presence of added $NaBPh_4$ (691 mg, 1.21 mmol) or HCO_2Na (75 mg, 1.11 mmol), respectively, for 15 h at 60 °C or 24 h at 80 °C. The usual workup gave the pure product after column chromatography on silica gel.

Ethyl 6-*O*-(*tert*-butyldimethylsilyl)-4-*O*-(2′-phenylprop-2′-enyl)-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranoside (16): yield 40%; oil; R_f 0.36 (petroleum ether/ethyl acetate 10/1); $[\alpha]^{20}_D$ +104.3 (*c* 1.2, CH_2Cl_2); ^{1}H NMR (200 MHz) δ 7.60−7.30 (m, 5H), 6.04 (brd, 1H, *J* = 10.2 Hz), 5.76 (ddd, 1H, *J* = 2.2, 2.3, 10.2 Hz), 5.52 (d, 1H, *J* = 1.1 Hz), 5.34 (d, 1H, *J* = 1.1 Hz), 4.99 (s, 1H), 4.55 (d, 1H, *J* = 12.6 Hz), 4.35 (d, 1H, *J* = 12.6 Hz), 4.01−3.45 (m, 6H), 1.23 (t, 3H, *J* = 7.1 Hz), 0.91 (s, 9H), 0.08 (s, 3H), 0.06 (s, 3H). Anal. Calcd for $C_{23}H_{36}O_4Si$: C, 68.27; H, 8.96. Found: C, 67.82; H, 8.69.

Ethyl 2,3,4-trideoxy-2′,3′,4′,5′-tetrahydro-6-*O*-(*tert*-butyldimethylsilyl)-4′-methylene-α-D-*ribo*-hexopyranosido-[4,3-*b*]furan (17): yield 62%; oil; R_f 0.47 (petroleum ether/ethyl acetate 10/1); $[\alpha]^{20}_D$ +197.7 (*c* 1.5, CH_2Cl_2); ^{1}H NMR (200 MHz) δ 4.99 (dd, 2H, *J* = 1.9, 4.0 Hz), 4.89 (dd, 1H, *J* = 5.6, 6.9 Hz), 4.47 (ddd, 1H, *J* = 1.8, 3.7, 13.2 Hz), 4.28 (brd, 1H, *J* = 13.2 Hz), 3.98−3.65 (m, 5H), 3.46 (dq, 1H, *J* = 9.6, 7.1 Hz), 2.80−2.67 (m, 1H), 2.02 (ddt, 1H, *J* = 5.6, 5.6, 14.3 Hz), 1.72 (ddd, 1H, *J* = 6.9, 11.1, 14.3 Hz), 1.19 (t, 3H, *J* = 7.1 Hz), 0.91 (s, 9H), 0.08 (s, 6H); ^{13}C NMR (50 MHz) δ 150.13, 104.88, 96.75, 77.01, 71.41, 70.87, 64.38, 62.58, 39.10, 31.43, 25.95, 18.43, 15.16, −5.26, −5.36. Anal. Calcd for $C_{16}H_{31}O_4Si$: C, 60.91; H, 9.90. Found: C, 60.47; H, 10.17.

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Supporting Information Available: Full data for all new compounds described in this paper, including ^{1}H and ^{13}C NMR spectra, with complete peak assignments and copies of ^{1}H and ^{13}C NMR spectra for new compounds having microanalyses that do not come within 0.4% for C and/or H calculated values (34 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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