Synthesis and Structural Analysis of 5-Deoxy-5-*C*-(hydroxyphosphinyl)-D-xylo- and -glucopyranoses

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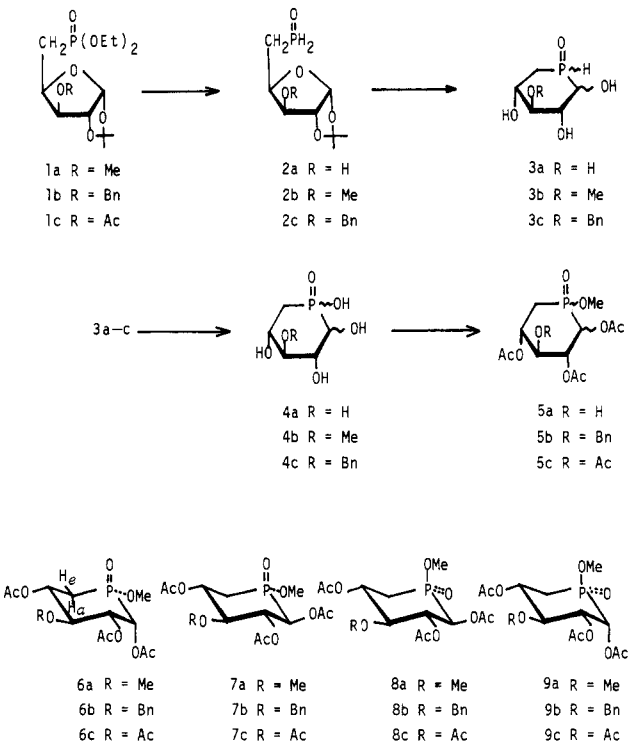
Treatment of 3-*O*-acetyl-5-deoxy-5-*C*-(diethoxyphosphinyl)-1,2-*O*-isopropylidene-α-D-xylofuranose (**1c**) with sodium dihydrobis(methoxyethoxy)aluminate, followed by the action of mineral acid and hydrogen peroxide, gave 5-deoxy-5-*C*-(hydroxyphosphinyl)-D-xylopyranose (**4a**). The 3-*O*-benzyl derivative **4c** was similarly obtained from the corresponding 3-*O*-benzyl-α-D-xylofuranose **1b**. Diazotization of 3-*O*-acetyl-6-amino-5,6-dideoxy-5-*C*-(dimethoxyphosphinyl)-1,2-*O*-isopropylidene-α-D-glucofuranose (**12**), followed by hydrolysis and then treatment with chlorotriphenylmethane in pyridine, afforded the corresponding 5-deoxy-6-*O*-triphenylmethyl derivative **17**. Similar ring enlargement of **17** exclusively yielded 5-deoxy-5-*C*-(hydroxyphosphinyl)-D-glucopyranose. The structures of these phosphorus sugar analogues were established on the basis of mass and 400-MHz ^{1}H NMR spectra of the per-*O*-acetyl-5-deoxy-5-*C*-(methoxyphosphinyl) derivatives **6–9** and **21–25**.

Various sugar analogues possessing a phosphorus atom in the hemiacetal ring have been prepared.[2-7] Such compounds are of interest for their physicochemical properties and potential biological activity. Although a large number of the analogues having an alkyl- or arylphosphinyl group in the hemiacetal ring, such as 5-deoxy-5-*C*-(ethylphosphinyl)-D-glucopyranoses[3,8] and 4-deoxy-4-*C*-(ethylphosphinyl)-D-ribofuranoses,[6] have been synthesized, only a few derivatives containing a hydroxyphosphinyl group in the ring have been reported: 4-deoxy-4-*C*-(hydroxyphosphinyl)-D-ribopyranose[7] and 5-deoxy-5-*C*-(hydroxyphosphinyl)-3-*O*-methyl-D-xylopyranose[9,10] (**4b**). The latter compound was synthesized from 5-deoxy-5-*C*-(diethoxyphosphinyl)-1,2-*O*-isopropylidene-3-*O*-methyl-α-D-xylofuranose (**1a**) by the sequence **1a** → **2b** → **3b** → **4b**, and the final product was characterized[10] as the four kinds of peracetates **6–9a** (see Scheme I). However, the fact that removing the 3-*O*-methyl group in **4b** to obtain the parent D-xylopyranose analogue **4a** turned out to be rather difficult by the usual method prompted us to take alternative approaches. We now describe[11] an efficient synthesis of **4a**, as well as of a D-glucose analogue **19** that is considered to be a representative example of 5-deoxy-5-*C*-(hydroxyphosphinyl)aldohexopyranoses.

Following a synthetic scheme analogous to that used to prepare **4b**, we attempted to prepare **4a** from the 3-*O*-benzyl derivative (**1b**), the latter compound being readily available by the Michaelis–Arbuzov reaction of 3-*O*-benzyl-5-deoxy-5-iodo-1,2-*O*-isopropylidene-α-D-xylofuranose[12] with triethyl phosphite. Protection of the 3-hydroxyl group was done to avoid the types of problems that occurred when analogous *xylo*-hexofuranoses were subjected to the key step reduction with sodium dihydrobis(2-methoxyethoxy)aluminate (SDMA) without protecting the 3-hydroxyl group.[13]

Thus, **1b** was reduced with SDMA to give the unstable intermediate 5-deoxy-5-*C*-phosphino compound, which was immediately oxidized with 1 equiv of hydrogen peroxide in 2-propanol to the 5-*C*-phosphinyl derivative **2c**. The acid-catalyzed deprotonation and ring enlargement of **2c** provided the 3-*O*-benzyl-5-deoxy-5-*C*-phosphinyl-D-xylopyranose (**3c**), oxidation of which with dilute hydrogen

Scheme I. Preparation of 5-Deoxy-5-*C*-(hydroxyphosphinyl)-D-xylopyranoses (Bn = CH_2Ph)



(1) (a) Okayama University. (b) Shizuoka University. (c) The University of Alberta.

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peroxide afforded the 3-*O*-benzyl-5-deoxy-5-*C*-(hydroxyphosphinyl) compound **4c** as a colorless syrup in 67% overall yield from **1b**.

The unambiguous structural assignment of **4c** was made by converting it into the 5-*C*-(methoxyphosphinyl) triacetates **5b** by treatment with ethereal diazomethane in 1:1 dimethyl sulfoxide–methanol and then with acetic anhydride–pyridine. Purification of the crude mixture by column chromatography on silica gel using ethyl acetate–hexane as the eluant gave four diastereomers: **6b** (3.4% overall yield from **1b**), **7b** (5.4%), and **8b** (4.7%) as pure components, and **9b** (1.6%) contaminated by a small amount of inseparable **8b**. The molecular composition of these compounds was confirmed by the CI (NH_3) mass spectra, which gave the (M + 18) ions at m/z 446 corresponding to ($C_{19}H_{24}O_9P$ + NH_4). The precise configurations and the $^4C_1(D)$ conformation of **6–9b** were established by complete analysis of their 400-MHz ^1H NMR spectra. A detailed discussion of the NMR spectra is presented later.

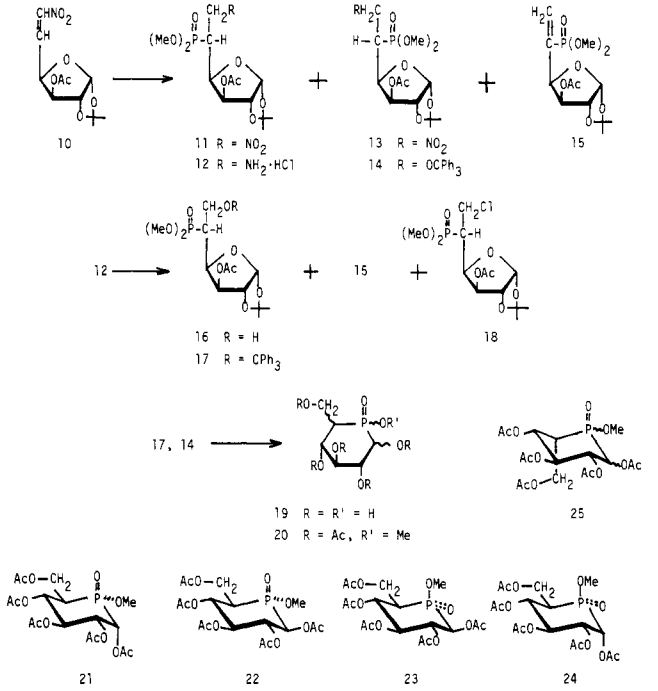
Debenzylation of **5b** by catalytic hydrogenation over 10% Pd/C in methanol in the presence of formic acid, however, proceeded sluggishly but provided 5-deoxy-5-*C*-(methoxyphosphinyl)-D-xylopyranose **5a**, which, on acetylation, afforded the tetraacetates **5c** (see below) in rather poor yield (25% from **5b**).

Therefore, we turned our attention to another approach for the preparation of **4a** from the 3-*O*-acetyl derivative (**1c**), although the acetyl group tends to be cleaved during the SDMA reduction.[8] The Michaelis–Arbuzov reaction of 3-*O*-acetyl-5-deoxy-5-iodo-1,2-*O*-isopropylidene-α-D-xylofuranose[14] with triethyl phosphite afforded the 3-*O*-acetyl-5-*C*-(diethoxyphosphinyl) derivative **1c**. When the same reaction scheme described for the preparation of 3-*O*-benzyl compounds was followed, **1c** was reduced with SDMA to give 5-deoxy-1,2-*O*-isopropylidene-5-*C*-phosphino-α-D-xylofuranose, which was either oxidized with hydrogen peroxide to the 5-*C*-phosphinyl derivative **2a** prior to the acid-catalyzed ring enlargement (to the 5-deoxy-5-*C*-phosphinyl-D-xylopyranose **3a**) or immediately hydrolyzed with hydrochloric acid in 2-propanol under nitrogen to give 5-deoxy-5-*C*-phosphino-D-xylopyranose (followed by the spontaneous air oxidation to afford **3a**). In the case of **1c**, the latter method provided a better overall yield (82% vs. 12%) of **3a** from **1c**. This was apparently because of the facile conversion of **2a** in the former case to its 5-*C*-(hydroxyphosphinyl)-α-D-xylofuranose derivative even under carefully controlled oxidation reaction with hydrogen peroxide. Oxidation of **3a** with hydrogen peroxide afforded the parent 5-*C*-(hydroxyphosphinyl)-D-xylopyranose **4a** as a colorless solid in 82% overall yield from **1c**.

The structure of **4a** was similarly established from the 5-*C*-(methoxyphosphinyl) tetraacetates **5c**, which were separated by column chromatography into four diastereomers: **6c** (5.0% overall yield from **1c**), **7c** (6.4%), and **8c** (6.8%) as pure components, and isomer **9c** (2.3%) contaminated with **8c**. The precise structures with the $^4C_1$(D) conformation of **6–9c** were derived from the mass and 400-MHz ^1H NMR spectra. A further discussion of the NMR spectra is presented later.

We then extended this synthetic scheme to the preparation of 5-deoxy-5-*C*-(hydroxyphosphinyl)aldohexopyranoses. For this purpose, 3-*O*-acetyl-5,6-dideoxy-1,2-*O*-isopropylidene-6-*C*-nitro-α-D-*xylo*-hex-5-enofuranose[15] (**10**) served as the starting material. This compound has

Scheme II. Preparation of (5*RS*)-5-Deoxy-5-*C*-(hydroxyphosphinyl)-D-*xylo*-hexopyranoses



been reported by Paulsen and Greve[16] to give a 43% yield of a 89:11 mixture of the 5,6-dideoxy-5-*C*-(dimethoxyphosphinyl)-α-D-gluco- and -β-L-ido-furanose (**11** and **13**) by the addition of dimethyl phosphonate in the presence of triethylamine. When this addition reaction was reinvestigated by using a stronger base, 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU), or without base, it was observed that a greater amount of the elimination product **15** was formed when 1 equiv of DBU was employed. Without base, more of the L-idofuranose **13** was produced. The yields of the products by the condensation under various conditions are described in the Experimental Section.

Catalytic hydrogenation of 6-*C*-nitro-D-glucofuranose **11** (obtained from **10** in 57% yield by a slightly modified method of Paulsen[16]) afforded the 6-amino-D-glucofuranose hydrochloride[16] **12**, which, on diazotization with nitrous acid, followed by hydrolysis, provided mainly 3-*O*-acetyl-5-deoxy-5-*C*-(dimethoxyphosphinyl)-1,2-*O*-isopropylidene-α-D-glucofuranose (**16**), besides small amounts of **15** and the 6-chloro compound **18** as byproducts. Compound **16** was then converted to the 6-*O*-triphenylmethyl derivative **17**, which was in turn reduced with SDMA. Acid hydrolysis and ring enlargement of the reaction product, followed by oxidation with 1.5% hydrogen peroxide, afforded (5*RS*)-5-deoxy-5-*C*-(hydroxyphosphinyl)-D-*xylo*-hexopyranoses (**19**) as a colorless syrup in 63% overall yield from **17**.

Compounds **19** were characterized by conversion into the 5-*C*-[(*RS*)-methoxyphosphinyl] pentaacetates **20** as before. The crude mixture was purified by chromatography on a silica gel column, giving four diastereomeric D-gluco compounds **21** (1.6% overall yield from **17**), **22** (4.8%), **23** (7.5%), and **24** (0.9%), and an extremely small amount of presumably the L-ido compound **25** which was contaminated by an inseparable mixture of **21–24** and unidentified other products (~2.9% total) (see Scheme II). The molecular composition of these compounds ($C_{17}H_{25}O_{12}P$) was confirmed from the EI and CI mass spectra, which also showed the general fragmentation

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Table I. Characteristic Features in the δ and J Values (Hz) for the 5-Deoxy-5-*C*-(methoxyphosphinyl)-D-aldopyranoses

ring proton		pyranose-$^4C_1$ (D) with P(=O_a)	pyranose-$^4C_1$ (D) with P(=O_e)
H_e-1	δ	5.6–5.7	5.64–5.73
	$J_{1,2}$	2.3–2.8	3.0
	$J_{1,P}$	14.2–14.8	15.0–15.5
	$J_{1,5e}$	2.0–2.4	2.0–2.3
H_a-1	δ	5.27–5.35	5.44–5.51
	$J_{1,2}$	10.4–10.5	10.2–10.8
	$J_{1,P}$	5.5–5.6	2.7–3.6
	$J_{1,5a}$	0.3–0.6	0–0.4
H-2	δ	5.41–5.58	5.04–5.21
H-4	δ	5.24–5.32[a]	4.94–5.09[a]
	δ	5.48–5.52[b]	5.35–5.36[b]
H_e-5	$J_{4,5e}$	4.5–4.8	4.5–4.8
	$J_{5e,P}$	21.8–23.4	21.5–23.5
H_a-5	$J_{4,5a}$	11.0–12.0	11.7–12.7
	$J_{5a,P}$	11.0–13.5	10.3–13.5
MeOP	δ	3.73–3.80	3.88–3.99
	$^3J_{POMe}$	11.0–11.3	10.5–10.7

[a] For 5-*C*-(methoxyphosphinyl)aldopentopyranoses. [b] For 5-*C*-(methoxyphosphinyl)aldohexopyranoses.

patterns[3,17] of P-in-ring sugar analogues. The D-gluco and L-ido structures of **21–25** with the $^4C_1$ conformation were established on the evidence of the 400-MHz ^{1}H NMR spectra, which closely resembled those of structurally related analogues such as per-*O*-acetyl-5-deoxy-5-*C*-(ethylphosphinyl)-D-glucopyranoses[3,8] and 5-*C*-(phenylphosphinyl)-L-iodopyranoses.[18,19]

When the L-idofuranose **13** was employed as the starting material and the same reaction scheme (via 6-*O*-triphenylmethyl-L-idofuranose **14**) was followed, almost the same ratio and the yields of **21–25** were obtained. Therefore, the predominant formation of D-glucopyranose analogues **21–24** over L-iodopyranose **25** can be explained in terms of the kinetically controlled ring closure of the key intermediates, (5*RS*)-5-deoxy-5-*C*-(phosphinyl)-6-*O*-triphenylmethyl-D-xylo-hexoses (which are formed by the SDMA reduction, followed by the acid hydrolysis), in a manner similar to the scheme proposed[3] for the formation of the 5-deoxy-5-*C*-(ethylphosphinyl)-D-glucopyranose peracetates.

^{1}H NMR Spectral Analysis of Peracetyl 5-Deoxy-5-*C*-(methoxyphosphinyl)aldopyranoses. ^{1}H NMR spectroscopy at 400 MHz has been highly effective for the establishment of the precise configurations, as well as the most probable conformations of various sugar analogues having a ring-phosphorus atom.[2] Some interesting features of the spectral data of the peracetylated 5-deoxy-5-*C*-(methoxyphosphinyl)aldopyranoses will be discussed here in detail. The values of these parameters can be used to determine the structures of other related analogues.

In most cases, assignment of the signals of these compounds were readily made by employing first-order analysis with the aid of a decoupling technique, as exemplified by a part of the clearly resolved spectrum of **22** (Figure 1A). In the case of more complex spectra, a convenient simulation analysis[20] was employed to obtain reliable parameters, as seen in both the measured and calculated spectra of **21** (Figure 1B,C). In the spectral data (Experimental Section) there are some characteristic

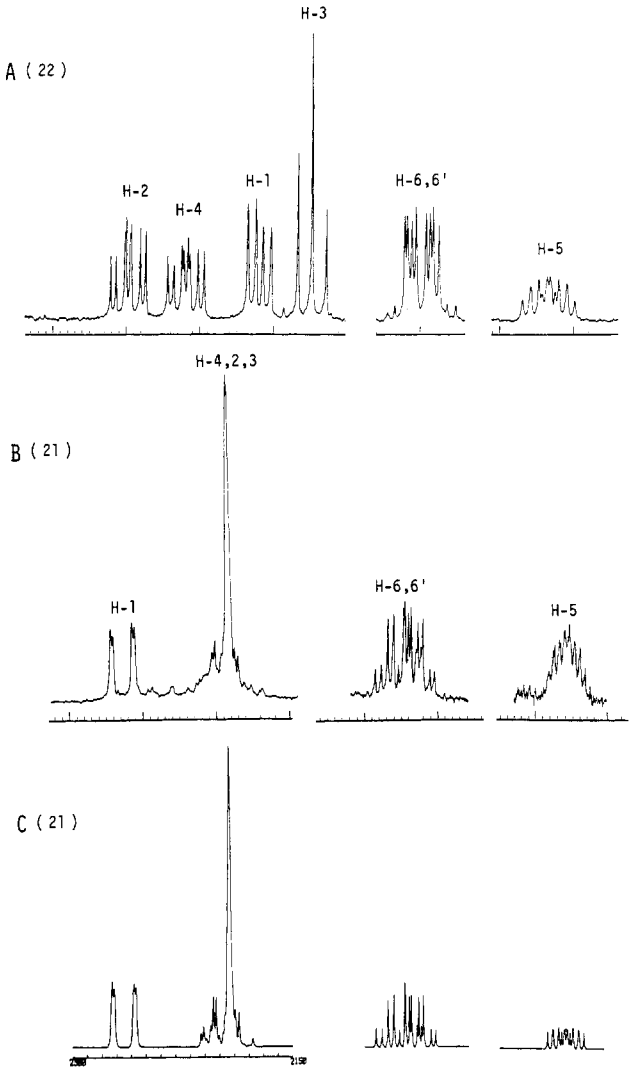

Figure 1. 400-MHz ^{1}H NMR spectra of peracetyl-5-deoxy-5-*C*-[(*R*)-methoxyphosphinyl]-β-D-glucopyranoses **22** (A, measured) and the α-anomer **21** (B, measured; C, calculated).

trends with regard to the chemical shifts and coupling constants of the ring protons and P–OMe group. The general trends of these values are summarized in Table I.

The large values of $J_{2,3}$ and $J_{3,4}$ indicate that these compounds exist predominantly in the $^4C_1$ (D) conformation. As were observed for 5-alkyl- or 5-aryl-phosphinyl analogues,[3,8] the values of the geminal P—*C*—H coupling constants ($J_{1,P}$ and $J_{5,P}$) of these methoxyphosphinyl compounds generally depend upon the magnitudes of their approximate O=P—*C*—H dihedral angles. Thus, the anti orientation of the O=P—*C*—H group exhibits a smaller coupling constant than the gauche orientation. It is noted, however, in the case of these 5-*C*-methoxyphosphinyl compounds that the magnitudes of $J_{1e,P}$ and $J_{5e,P}$ with equatorial orientation (*S*) of the ring P=O are much larger (Δ = ca. +5–7 Hz), whereas those of $J_{1a,P}$ and $J_{5a,P}$ are smaller (Δ = ca. −2–7 Hz), compared with those of 5-*C*-(alkyl- or -(arylphosphinyl)aldopento- and -hexopyranoses.

In general, the axial orientation (*R*) of the ring P=O group is observed from the downfield shift (0.2–0.4 ppm, compared with the equatorial P=O group) of the H-2 and H-4 signals (and a slight upfield shift of the P—OMe signal). The anomeric orientation of C-1 can be derived by considering the δ values of H-1, H-3, and H_a-5 and the magnitudes of $J_{1,2}$, $J_{1,P}$, and $J_{1,5e}$ (or $J_{1,5a}$). The configuration of C-5 of these aldohexopyranoses is readily established by the magnitude of $J_{4,5}$ and $J_{5,P}$; namely, the large

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(18) Inokawa, S.; Yamamoto, K.; Kawamoto, H.; Yamamoto, H.; Yamashita, M.; Luger, P. *Carbohydr. Res.* **1982**, *106*, 31.
(19) Yamamoto, H.; Yamamoto, K.; Kawamoto, H.; Inokawa, S.; Armour, M.-A.; Nakashima, T. T. *J. Org. Chem.* **1982**, *47*, 191.
(20) Satake, K.; Hara, Y.; Murata, H.; Yamamoto, H. *Kagaku (Kyoto)* **1984**, *39*, (3), A1.

values of $J_{4,5}$ (11–12 Hz) and the small values of $J_{5,P}$ (11–13.5 Hz) indicate the D-*gluco* configuration, whereas small values of $J_{4,5}$ (4–5 Hz) and the large values of $J_{5,P}$ (20–25 Hz) are compatible with the L-*ido* configuration.

Application of these principles to the structural analysis would permit establishment of the configurations of the ring carbon atoms and orientations of the protons thereon, along with the stereochemistry of the phosphorus atom, in other 5-deoxy-5-*C*-(alkoxyphosphinyl)aldopento- and -hexopyranoses.

Although improvement of the yields of some steps of these ring-enlargement reactions remains to be done, present work demonstrates an effective way for preparation of various 5-deoxy-5-*C*-hydroxy- and -methoxy-D-xylo- and -glucopyranoses from appropriate D-aldofuranoses.

Experimental Section

Melting points were determined with a Yanagimoto MP-S3 instrument and are uncorrected. All reactions were monitored by TLC (Merck silica gel 60F, 0.25 mm) with 2-propanol–AcOEt–water (5:3:1) as the eluant (unless otherwise stated). Column chromatography was performed by Wako C-200 silica gel or, when necessary, by using a Merck Lobar silica gel prepacked column (Size A). ^{1}H NMR spectra were recorded in $CDCl_3$ (unless otherwise stated). Chemical shifts are reported as δ values in parts per million relative to tetramethylsilane (δ 0.0) as the internal standard. The assignments of all signals were made by employing a first-order analysis with the aid of a decoupling technique or, when necessary, by a simulation analysis using an NEC 9801F personal computer.[20] All molecular formulas of the fragment ions shown in this section were supported by the accurate mass, derivation of which is normally within a range of ±3 ppm error from the calculated values.

3-*O*-Benzyl-5-deoxy-5-*C*-(diethoxyphosphinyl)-1,2-*O*-isopropylidene-α-D-xylofuranose (1b). A mixture of 3-*O*-benzyl-5-deoxy-5-iodo-1,2-*O*-isopropylidene-α-D-xylofuranose[12] (1.0 g) and triethyl phosphite (0.8 mL) was heated at 150 °C for 15 h with stirring under nitrogen; after 4 h, an additional amount of triethyl phosphite (0.4 mL) was added. After removal of an excess of phosphite and diethyl ethylphosphonate in vacuo, the residue was flash-distilled at ~150 °C (bath) (10^{-4} torr), to give **1b** as a colorless syrup: R_f 0.40 (3:1 AcOEt–hexane); 0.80 g (82%); ^{1}H NMR 1.30 [6 H, t, J = 6.9 Hz, P(OCCH$_3$)$_2$], 1.30, 1.48 (3 H each, s, CMe$_2$), 2.23 (1 H, $J_{5,P}$ = 20.0, $J_{5,5'}$ = 15.0, $J_{4,5}$ = 5.6 Hz, H-5), 2.30 (1 H, $J_{5',P}$ = 19.0, $J_{4,5'}$ = 7.5 Hz, H-5′), 4.10 [4 H, dq, $^3J_{H,P}$ = 7.0 Hz, P(OCH$_2$C)$_2$], 4.0–4.6 (3 H, m, H-2,3,4), 4.64 (2 H, bs, C$_6$CH$_2$O-3), 5.89 (1 H, d, $J_{1,2}$ = 4.2 Hz, H-1), 7.28 (5 H, bs, C$_6$H$_5$CO-3); LR MS, m/z 400 (M$^+$).

1,2,4-Tri-*O*-acetyl-3-*O*-benzyl-5-deoxy-5-*C*-[(*R*)-methoxyphosphinyl]-α-D-xylopyranose (6b), the β-Anomer 7b, and the 5-*C*-[(*S*)-Methoxyphosphinyl]-β,α-D-xylopyranoses 8b and 9b. A solution of SDMA (70% in toluene, 0.18 mL, 2.2 equiv) in dry benzene (1 mL) was slowly added at 0 °C to a stirred solution of **1b** (130 mg, 0.325 mmol) in dry benzene (3 mL) under argon, followed by stirring at 5 °C for ca. 1 h (until the starting material disappeared). Then water (1 mL) was added at 0 °C, and the mixture was stirred for 30 min and centrifuged to remove aluminum oxide; the precipitate was extracted with several portions of benzene. The organic layer was combined and evaporated in vacuo, giving labile 3-*O*-benzyl-5-deoxy-1,2-*O*-isopropylidene-5-*C*-phosphino-α-D-xylofuranose as a colorless syrup (R_f 0.91). This syrup was immediately dissolved in 2-propanol (3 mL) and titrated at 20 °C with 2% aqueous hydrogen peroxide (0.5 mL, ca. 1.0 equiv) until most of the phosphino compound disappeared, giving 3-*O*-benzyl-5-deoxy-1,2-*O*-isopropylidene-5-*C*-phosphinyl-α-D-xylofuranose (**2c**) as a colorless syrup (R_f 0.75).

Oxygen-free 0.5 M hydrochloric acid (3 mL) was immediately added to the above solution, and the mixture was heated at 100 °C (bath) for 1 h under argon. After cooling, the acid was neutralized by passing through a column of Amberlite IRA-45 anion exchange resin (weakly basic), which was washed with methanol. The eluant and washings were combined and evaporated in vacuo, to give 3-*O*-benzyl-5-deoxy-5-*C*-phosphinyl-D-xylopyranose (**3c**) as a colorless syrup (R_f 0.45–0.36). The syrup was dissolved in water (2 mL), and 30% aqueous hydrogen peroxide (0.05 mL) was added. The mixture was stirred at 20 °C for 1 day and then concentrated in vacuo to give 3-*O*-benzyl-5-deoxy-5-*C*-(hydroxyphosphinyl)-D-xylopyranose (**4c**) as a colorless syrup: R_f 0.19; 63 mg (67% yield from **1b**). This product (63 mg) was dissolved in dry methanol (4 mL) and treated with an excess of ethereal diazomethane at 0 °C. After concentration in vacuo, the residue was acetylated with acetic anhydride (1.5 mL) and pyridine (3 mL) at 20 °C for 1 day in the usual manner, giving a pale yellow syrup. This was chromatographed in a silica gel column with 1:1 AcOEt–hexane as the eluant. The fraction having R_f 0.55–0.40 (AcOEt) was collected and concentrated in vacuo, giving the per-*O*-acetates **5b** as a diastereomeric mixture: pale yellow syrup; 52 mg (55% from **1b**). This was then separated by rechromatography using a Merck Lobar silica gel column with the same eluant as above into four fractions, A–D.

Fraction A [R_f 0.53 (AcOEt)] gave **6b** as a colorless syrup: 4.8 mg (3.4% from **1b**); ^{1}H NMR (400 MHz) 1.97, 1.98, 2.22 (3 H each, all s, AcO-4, -2, -1), 2.15 (1 H, $J_{5a,5e}$ = −14.2, $J_{5a,P}$ = 13.0, $J_{4,5a}$ = 12.0 Hz, H$_a$-5), 2.47 (1 H, $J_{5e,P}$ = 23.0, $J_{4,5e}$ = 4.5, $J_{1,5e}$ = 2.0 Hz, H$_e$-5), 3.74 (3 H, d, J_{POMe} = 11.0 Hz, MeOP), 3.92 (1 H, $J_{2,3}$ = 10.0, $J_{3,4}$ = 9.3 Hz, H-3), 4.71, 4.73 (1 H each, $^2J_{H,H}$ = 12.0 Hz, PhCH_2), 5.31 (1 H, $J_{4,P}$ = 3.0 Hz, H-4), 5.50 (1 H, $J_{1,2}$ = 2.8, $J_{2,P}$ = 2.0 Hz, H-2), 5.64 (1 H, $J_{1,P}$ = 14.2 Hz, H-1), 7.11–7.38 (5 H, m, C$_6H_5$CH$_2$); CI MS, m/z 446 (100, M + 18), 429 (15, M + 1), 428 (11, M$^+$), 413 (20, M − CH$_3$); EI MS, m/z 386 (0.50, M − CH$_2$CO), 295 (1.23, M − CH$_2$CO − C$_7$H$_7$), 253 (5.39, M + 1 − 2CH$_2$CO − C$_7$H$_7$), 211 (4.87, M − 3CH$_2$CO − C$_7$H$_7$), 193 (7.98, M + 1 − 2CH$_2$CO − AcOH − C$_7$H$_7$), 151 (12.3, M + 1 − 3CH$_2$CO − AcOH − C$_7$H$_7$), 91 (100, C$_7$H$_7$); exact mass calcd for C$_{17}$H$_{23}$O$_8$P, (M − CH$_2$CO) 386.1131; found 386.1138.

Fraction B [R_f 0.47 (AcOEt)] gave **7b** as colorless needles: mp 206 °C (from AcOEt–hexane); 7.5 mg (5.4%); ^{1}H NMR (400 MHz) 1.93, 1.99, 2.13 (3 H each, all s, AcO-4, -2, -1), 1.95 (1 H, $J_{5a,5e}$ = −14.5, $J_{5a,P}$ = 12.0, $J_{4,5a}$ = 11.0, $J_{1,5a}$ = 0.3 Hz, H$_a$-5), 2.58 (1 H, $J_{5e,P}$ = 21.8, $J_{4,5e}$ = 4.5 Hz, H$_e$-5), 3.70 (1 H, $J_{2,3}$ = 8.8, $J_{3,4}$ = 8.7 Hz, H-3), 3.78 (3 H, d, J_{POMe} = 11.0 Hz, MeOP), 4.66, 4.71 (1 H each, $^2J_{H,H}$ = 12.0 Hz, PhCH_2), 5.29 (1 H, $J_{1,2}$ = 10.5 Hz, $J_{1,P}$ = 5.5 Hz, H-1), 5.31 (1 H, $J_{4,P}$ = 4.5 Hz, H-4), 5.54 (1 H, $J_{2,P}$ = 4.5 Hz, H-2), 7.11–7.38 (5 H, m, C$_6H_5$CH$_2$); CI MS, m/z 446 (100, M + 18), 429 (23), 428 (25), 413 (27); EI MS, m/z 386 (0.20), 295 (0.73), 253 (3.79), 211 (3.45), 193 (6.69), 151 (17.5), 91 (100); exact mass calcd for C$_{17}$H$_{23}$O$_8$P (M − CH$_2$CO), 386.1131; found 386.1141.

Fraction C [R_f 0.45 (AcOEt)] gave **8b** as a colorless syrup: 6.6 mg (4.7%); ^{1}H NMR (400 MHz) 1.92, 2.00, 2.13 (3 H each, all s, AcO-4, -2, -1), 1.95 (1 H, $J_{5a,5e}$ = −14.8, $J_{4,5a}$ = 12.0, $J_{5a,P}$ = 10.0, $J_{1,5a}$ = 0.4 Hz, H$_a$-5), 2.56 (1 H, $J_{5e,P}$ = 23.3, $J_{4,5e}$ = 4.5 Hz, H$_e$-5), 3.68 (1 H, $J_{3,4}$ = 9.5, $J_{2,3}$ = 9.2 Hz, H-3), 3.96 (3 H, d, J_{POMe} = 10.5 Hz, MeOP), 4.66, 4.73 (1 H each, $^2J_{H,H}$ = 12.0 Hz, PhCH_2), 5.09 (1 H, $J_{4,P}$ = 2.3 Hz, H-4), 5.34 (1 H, $J_{1,2}$ = 10.8, $J_{2,P}$ = 2.0 Hz, H-2), 5.47 (1 H, $J_{1,P}$ = 3.5 Hz, H-1), 7.11–7.38 (5 H, m, C$_6H_5$CH$_2$); CI MS, m/z 446 (62.4), 428 (100, M$^+$); Ei MS, m/z 386 (0.13), 295 (0.54), 253 (3.50), 211 (3.14), 193 (5.96), 151 (10.0), 91 (100); exact mass calcd for C$_{17}$H$_{23}$O$_8$P, (M − CH$_2$CO) 386.1131; found 386.1131.

Fraction D [R_f 0.42 (AcOEt)] gave **9b** as a colorless syrup which contained a small proportion of **8b**: 2.2 mg (1.6%); ^{1}H NMR (400 MHz) 1.98, 2.02, 2.22 (3 H each, all s, AcO-4, -2, -1), 2.26 (1 H, $J_{5a,5e}$ = −14.8, $J_{5a,P}$ = 12.0, $J_{4,5a}$ = 12.0 Hz, H$_a$-5), 2.52 (1 H, $J_{5e,P}$ = 22.0, $J_{4,5e}$ = 4.8, $J_{1,5e}$ = 2.2 Hz, H$_e$-5), 3.86 (1 H, $J_{2,3}$ = 10.0, $J_{3,4}$ = 9.7 Hz, H-3), 3.90 (3 H, d, J_{POMe} = 10.7 Hz, MeOP), 4.70, 4.72 (1 H each, $^2J_{H,H}$ = 12.0 Hz, PhCH_2), 5.06 (1 H, $J_{4,P}$ = 2.0 Hz, H-4), 5.15 (1 H, $J_{1,2}$ = 3.0, $J_{2,P}$ = 2.2 Hz, H-2), 5.70 (1 H, $J_{1,P}$ = 15.3 Hz, H-1), 7.11–7.38 (5 H, m, C$_6H_5$CH$_2$); CI MS, m/z 446 (100, M + 18).

Debenzylation and Acetylation of 5b. The diastereomeric mixture **5b** (180 mg) was dissolved in methanol (5 mL) and hydrogenated in the presence of 10% Pd on carbon (180 mg) and formic acid (0.02 mL, 1.3 equiv). After 2 days, the catalyst was filtered off, and the filtrate was concentrated in vacuo, giving 1,2,4-tri-*O*-acetyl-5-deoxy-5-*C*-(methoxyphosphinyl)-D-xylopyranose (**5a**) as a colorless syrup [R_f <0.05 (AcOEt)]. Without addition of formic acid, no reduction proceeded.

The reduction product was acetylated with acetic anhydride (1 mL) and pyridine (3 mL) in the usual manner. The crude product was chromatographed on a silica gel column with AcOEt

as the eluant, giving the tetraacetate **5c** (by NMR; see below) as a colorless syrup [R_f 0.6–0.4 (AcOEt)]: 40 mg (25% yield from **5b**).

3-*O*-Acetyl-5-deoxy-5-*C*-(diethoxyphosphinyl)-1,2-*O*-isopropylidene-α-D-xylofuranose (1c). With use of the same procedures as for **1b**, a mixture of 3-*O*-acetyl-5-deoxy-5-iodo-1,2-*O*-isopropylidene-α-D-xylofuranose[14] (13.0 g) was treated with triethyl phosphite (8 mL) at 150 °C for 20 h, giving **1c** as a colorless syrup: R_f 0.38 (3:1 AcOEt–hexane); bp 134–136 °C (10^{-4} torr); 11.3 g (87%); ^{1}H NMR 1.32 [6 H, t, J = 6.9 Hz, P(OCCH$_3$)$_2$], 1.32, 1.50 (3 H each, s, CMe$_2$), 2.10 (3 H, s, AcO-3), 2.16 (1 H, $J_{5,P}$ = 18.9, $J_{5,5'}$ = 15, $J_{4,5}$ = 6.8 Hz, H-5), 2.28 (1 H, $J_{5',P}$ = 18.0, $J_{4,5'}$ = 7.5 Hz, H-5′), 4.13 [4 H, dq, $^3J_{H,P}$ = 7.0 Hz, P(OCH$_2$C)$_2$], 4.40 (1 H, m, H-4), 4.50 (1 H, d, $J_{1,2}$ = 3.9 Hz, H-2), 5.16 (1 H, d, $J_{3,4}$ = 3.0 Hz, H-3), 5.90 (1 H, d, H-1); LR MS, m/z 352 (M$^+$).

1,2,3,4-Tetra-*O*-acetyl-5-deoxy-5-*C*-[(*R*)-methoxyphosphinyl]-α-D-xylopyranose (6c), the β-Anomer 7c, the [(*S*)-Methoxyphosphinyl]-β-D-xylopyranose 8c, and the α-Anomer 9c. Procedures similar to those for the preparation of **6–9b** were used (unless otherwise described in detail). Acetyl compound **1c** (560 mg) was reduced with SDMA (70% in toluene, 1.2 mL), to give 5-deoxy-1,2-*O*-isopropylidene-5-*C*-phosphino-α-D-xylofuranose as a colorless liquid (R_f 0.88). The liquid was immediately treated with 1:1 2-propanol–0.25 M sulfuric acid (10 mL) at 90–95 °C for 1 h under nitrogen, giving mostly 5-deoxy-5-*C*-phosphino-D-xylopyranose (R_f 0.60). After cooling, the product was neutralized with aqueous barium hydroxide and barium carbonate. The precipitate was filtered through an active carbon bed, and the filtrate was passed through a column of Amberlite IRC-50. The eluant was concentrated in vacuo to give the 5-*C*-phosphinyl compound **3a** (R_f 0.36), which was dissolved in water (3 mL) and further oxidized with 30% aqueous hydrogen peroxide (0.22 mL, 1.5 equiv) at 20 °C for 1 day, giving 5-deoxy-5-*C*-(hydroxyphosphinyl)-D-xylopyranose (**4a**) as an amber solid: R_f 0.17; 252 mg (82% overall yield from **1c**).

Oxidation of the 5-deoxy-1,2-*O*-isopropylidene-5-*C*-phosphino-α-D-xylofuranose (see above) with hydrogen peroxide to the 5-*C*-(phosphinyl) derivative **2a**, followed by the acid-catalyzed ring enlargement, resulted in a 12% overall yield of **4a** from **1c**, mainly because of the facile, further oxidation of **2a** presumably to 5-deoxy-5-*C*-(hydroxyphosphinyl)-1,2-*O*-isopropylidene-α-D-xylofuranose (R_f 0.10).

Compound **4a** (252 mg) was methylated with ethereal diazomethane in a 1:1 Me$_2$SO–MeOH (4 mL) at 0 °C. When the reaction mixture became turbit, it was concentrated in vacuo and repeatedly treated with ethereal diazomethane in the same mixed solvent. The solvent was evaporated in vacuo at below 30 °C (10^{-3} torr), and the residue was triturated with dry CH$_2$Cl$_2$, giving 5-deoxy-5-*C*-(methoxyphosphinyl)-D-xylopyranose (R_f 0.45). This product was acetylated with acetic anhydride (2.5 mL) and pyridine (5 mL), giving a mixture of peracetates **5c**: 280 mg (58% overall yield from **1c**). The crude product was purified on a column of silica gel with AcOEt–hexane as before.

Fraction A [R_f 0.53 (AcOEt)] gave **6c** as an amorphous solid: 29 mg (5.0% overall yield from **1c**); ^{1}H NMR (400 MHz) 1.99, 2.01, 2.02, 2.22 (3 H each, all s, AcO-4, -3, -2, -1), 2.20 (1 H, $J_{5a,5e}$ = −14.2, $J_{5a,P}$ = 13.2, $J_{4,5a}$ = 12.0 Hz, H$_a$-5), 2.47 (1 H, $J_{5e,P}$ = 23.4, $J_{4,5e}$ = 4.6, $J_{1,5e}$ = 2.4 Hz, H$_e$-5), 3.73 (3 H, d, J_{POMe} = 11.2 Hz, MeOP), 5.32 (1 H, $J_{3,4}$ = 10.0, $J_{4,P}$ = 2.0 Hz, H-4), 5.48 (1 H, $J_{2,3}$ = 10.0, $J_{1,2}$ = 2.3, $J_{2,P}$ = ∼0 Hz, H-2), 5.49 (1 H, H-3), 5.64 (1 H, $J_{1,P}$ = 14.4 Hz, H-1); EI MS, m/z 381 (3.35, M + 1), 380 (4.65, M$^+$), 338 (20.4, M − CH$_2$CO), 321 (29.2, M + 1 − AcOH), 296 (19.7, M − 2CH$_2$CO), 279 (49.9), 278 (98.7, M − CH$_2$CO − AcOH), 237 (41.3), 236 (100, M − 2CH$_2$CO − AcOH), 219 (98.3), 218 (39.9, M − CH$_2$CO − 2AcOH), 194 (47.8, M − 3CH$_2$CO − AcOH), 193 (42.2), 177 (88.0), 176 (46.1, M − 2CH$_2$CO − 2AcOH); exact mass calcd for C$_{14}$H$_{21}$O$_{10}$P, (M$^+$) 380.0872; found 380.0875.

Fraction B [R_f 0.48 (AcOEt)] gave **8c** as colorless prisms: mp 150–151 °C (from AcOEt–hexane): 40 mg (6.8%); ^{1}H NMR (400 MHz) 2.02, 2.04, 2.06, 2.14 (3 H each, all s, AcO-4, -3, -2, -1), 2.05 (1 H, $J_{5a,5e}$ = −14.8, $J_{4,5a}$ = 12.0, $J_{5a,P}$ = 10.3, $J_{1,5a}$ = ∼0 Hz, H$_a$-5), 2.57 (1 H, $J_{5e,P}$ = 23.5, $J_{4,5e}$ = 4.5 Hz, H$_e$-5), 3.97 (3 H, d, J_{POMe} = 10.5 Hz, MeOP), 5.09 (1 H, $J_{3,4}$ = 10.0, $J_{4,P}$ = 1.5 Hz, H-4), 5.24 (1 H, $J_{2,3}$ = 10.0 Hz, H-3), 5.32 (1 H, $J_{1,2}$ = 10.2, $J_{2,P}$ = 1.8 Hz, H-2), 5.53 (1 H, $J_{1,P}$ = 3.2 Hz, H-1); EI MS, m/z 381 (2.30, M + 1), 338 (8.95), 321 (4.42), 296 (16.5), 279 (65.1), 278 (100), 237 (32.2), 236 (64.2), 219 (80.9), 218 (79.5), 194 (45.0), 193 (33.4), 177 (87.7), 176 (92.0); exact mass calcd for C$_{14}$H$_{22}$O$_{10}$P, (M + 1) 381.0950; found 381.0942.

Fraction C [R_f 0.47 (AcOEt)] gave a colorless syrup which consisted mainly of **9c** (but contained a minor proportion of **8c**); **9c**, 13 mg (2.3%); ^{1}H NMR (400 MHz) 2.02, 2.06, 2.08, 2.26 (3 H each, all s, AcO-4, -3, -2, -1), 2,34 (1 H, $J_{5a,5e}$ = −14.8, $J_{5a,P}$ = 12.3, $J_{4,5a}$ = 11.7 Hz, H$_a$-5), 2.54 (1 H, $J_{5e,P}$ = 22.5, $J_{4,5e}$ = 4.8, $J_{1,5e}$ = 2.3 Hz, H$_e$-5), 3.93 (3 H, d, J_{POMe} = 10.5 Hz, MeOP), 5.05 (1 H, $J_{3,4}$ = 10.3, $J_{4,P}$ = 1.3 Hz, H-4), 5.13 (1 H, $J_{2,3}$ = 10.6, $J_{1,2}$ = 3.0, $J_{2,P}$ = ∼0 Hz, H-2), 5.46 (1 H, H-3), 5.71 (1 H, $J_{1,P}$ = 15.3 Hz, H-1).

Fraction D [R_f 0.45 (AcOEt)] gave **7c** as colorless needles: mp 183 °C (from AcOEt–hexane): 37 mg (6.4%); ^{1}H NMR (400 MHz) 2.02, 2.04, 2.05, 2.16 (3 H each, all s, AcO-4, -3, -2, -1), 2.02 (1 H, $J_{5a,5e}$ = −14.7, $J_{5a,P}$ = 13.5, $J_{4,5a}$ = 11.3, $J_{1,5a}$ = 0.3 Hz, H$_a$-5), 2.61 (1 H, $J_{5e,P}$ = 22.5, $J_{4,5e}$ = 4.5 Hz, H$_e$-5), 3.80 (3 H, d, J_{POMe} = 11.2 Hz, MeOP), 5.24 (1 H, $J_{3,4}$ = 9.7, $J_{2,3}$ = 9.3 Hz, H-3), 5.32 (1 H, $J_{4,P}$ = 4.5, H-4), 5.35 (1 H, $J_{1,2}$ = 10.5, $J_{1,P}$ = 5.5 Hz, H-1), 5.54 (1 H, $J_{2,P}$ = 3.2 Hz, H-2); EI MS, m/z 381 (2.73, M + 1), 338 (6.45), 321 (2.97), 296 (9.80), 279 (45.7), 278 (100), 237 (28.8), 236 (41.2), 219 (76.7), 218 (33.7), 194 (30.1), 193 (24.0), 177 (85.2), 176 (56.2); exact mass calcd for C$_{14}$H$_{22}$O$_{10}$P, (M + 1) 381.0950; found 381.0950.

3-*O*-Acetyl-5,6-dideoxy-5-*C*-(dimethoxyphosphinyl)-1,2-*O*-isopropylidene-6-*C*-nitro-α-D-gluco- and -β-L-idofuranose (11 and 13) and -α-D-*xylo*-hex-5-enofuranose (15). A mixture of **10**[15] (170 mg) and dimethyl phosphonate (1 mL) was heated at 100 °C for 2 h under nitrogen with stirring. The excess phosphonate was distilled off at ca. 30 °C (10^{-3} torr). The residue was diluted with CH$_2$Cl$_2$, and washed with water. The organic layer was dried (Na$_2$SO$_4$), concentrated in vacuo, and purified by a column of silica gel with AcOEt–hexane as an eluant, giving a 1:3 mixture of the *gluco* compound[16] **11** and the *ido* compound (**13**), the ratio being determined by ^{1}H NMR: R_f 0.52 (AcOEt); 168 mg (79%).

From this mixture, pure **11** crystallized out on seeding. Removal of **11** by filtration and washing with AcOEt–hexane gave almost pure **13** as a colorless syrup: ca. 1.0 g (47%); ^{1}H NMR 1.29, 1.50 (3 H each, s, CMe$_2$), 2.10 (3 H, s, AcO-3), 3.5 (1 H, m, H-5), 3.77 [6 H, d, $^3J_{P,H}$ = 18.0 Hz, P(OMe)$_2$], 4.46 (1 H, d, $J_{1,2}$ = 3.6 Hz, H-2), 4.4–4.9 (3 H, m, H-4,6,6′), 5.23 (1 H, d, $J_{3,4}$ = 3.3 Hz, H-3), 5.87 (1 H, d, H-1); LR MS, m/z 382 (M$^+$).

The condensation of **10** and dimethyl phosphonate in the presence of triethylamine was carried out essentially by following the procedures of Paulsen and Greve[16] but with a slight modification: triethylamine (0.40 mL, 2.77 mmol) was dropwise added at 0 °C to a mixture of **10** (1.80 g, 5.08 mmol) and dimethyl phosphonate (10 mL), and then the resultant reaction mixture was stirred at 20 °C for 3 h. The same workup as above afforded a 9:1 mixture of **11** and **13** [2.27 g (75%)]. Recrystallization from AcOEt–hexane gave **11** as colorless prisms: 1.72 g (57%); mp 108–109 °C (ref 16, 108–110 °C, 43% yield); ^{1}H NMR of **11** was identical with that in ref 16.

The same condensation in the presence of DBU was conducted in a manner similar to that described above. For example, **10** (181 mg, 0.663 mmol), dimethyl phosphonate (1 mL), and DBU (0.03 mL, 0.20 mmol) gave, after the column chromatography, [besides **11** (140 mg, 55% yield)], **15** as a colorless syrup: 58 mg (26%); R_f 0.44 (AcOEt); ^{1}H NMR 1.31, 1.52 (3 H each, s, CMe$_2$), 1.99 (3 H, s, AcO-3), 3.72 [6 H, d, $^3J_{P,H}$ = 10.8 Hz, P(OMe)$_2$], 4.50 (2 H, d, $J_{1,2}$ = 3.9 Hz, H-2), 4.90 (1 H, $J_{4,P}$ = 2.0 Hz, H-4), 5.28 (1 H, d, $J_{3,4}$ = 3.0 Hz, H-3), 5.96 (1 H, d, H-1), 6.22 [1 H, bdt, $J_{6,P}$ = 34, $J_{6,6'}$ = 2.0, $J_{4,6}$ = 1.0 Hz, (*Z*)H-6], 6.42 [1 H, bdt, $J_{6',P}$ = 37.2, $J_{4,6'}$ = 1.5 Hz, (*E*)H-6′]; LR MS, m/z 336. When one equivalent of DBU was employed for the above condensation, a 16% yield of **11** and a 62% yield of **15** were isolated.

3-*O*-Acetyl-6-amino-5,6-dideoxy-5-*C*-(dimethoxyphosphinyl)-1,2-*O*-isopropylidene-α-D-glucofuranose Hydrochloride (12). The literature procedure[16] was followed except that the reaction time was longer (15 h), giving **12** as colorless needles: 1.48 g (91%); R_f 0.51; mp 228–230 °C dec (ref 16, mp 230 °C dec, 79% yield); ^{1}H NMR (in Me$_2$SO-d_6) 1.26, 1.45 (3 H each, s, CMe$_2$), 2.10 (3 H, s, AcO-3), 3.73, 3.76 [3 H each, 2 d, $^3J_{P,H}$ = 10.2 Hz, P(OMe)$_2$], 2.7–4.0 (3 H, m, H-5,6,6′), 4.1–4.6 (1 H, m, H-4), 4.60 (1 H, d, $J_{1,2}$ = 4.2 Hz, H-2), 5.03 (1 H, d, $J_{3,4}$ = 3.3 Hz, H-3), 5.93 (1 H, d, H-1), 8.30 (3 H, m, H$_3$N$^+$-6, D$_2$O exchangeable).

3-O-Acetyl-5-deoxy-5-C-(dimethoxyphosphinyl)-1,2-O-isopropylidene-α-D-glucofuranose (16) and Its 6-Chloro Derivative 18. To a solution of **12** (1.17 g) in water (20 mL) was added, at 0 °C, acetic acid (0.7 mL) and then sodium nitrite (1.10 g). After 2 h, nitrogen gas was led into the reaction mixture to remove an excess of nitrous acid, and the mixture was extracted with three portions of CH_2Cl_2. The combined organic layers were washed with aqueous $NaHCO_3$ and then with water, dried (Na_2SO_4), and concentrated in vacuo. The residue was chromatographed in a column of silica gel with AcOEt–hexane as an eluant, mainly giving two fractions A and B.

Fraction A [R_f 0.44 (AcOEt)] gave, besides **15** as a colorless syrup (151 mg, 15%), **18** as colorless crystals: 56 mg (5%); mp 129–130 °C (from AcOEt–hexane); ^{1}H NMR 1.30, 1.53 (3 H each, s, CMe_2), 2.09 (3 H, s, AcO-3), 2.4–3.1 (1 H, m, H-5), 3.76, 3.83 [3 H each, d, $^3J_{P,H}$ = 10.8 Hz, $P(OMe)_2$], 3.8, 4.27 (1 H each, m, H-6,6′), 4.49 (1 H, d, $J_{1,2}$ = 3.6 Hz, H-2), 4.60 (1 H, m, H-4), 5.28 (1 H, d, $J_{3,4}$ = 2.4 Hz, H-3), 5.89 (1 H, d, H-1). Anal. Calcd for $C_{13}H_{22}O_8PCl$: C 41.87, H 5.95%. Found: C 42.16, H 6.13%.

Fraction B [R_f 0.23 (AcOEt)] gave **16** as colorless prisms: 666 mg (63%); mp 78–79 °C (from AcOEt–hexane); ^{1}H NMR 1.29, 1.51 (3 H each, s, CMe_2), 2.09 (3 H, s, AcO-3), 2.52 (1 H, $J_{5,P}$ = 20, $J_{4,5}$ = 9.8, $J_{5,6}$ = 5.5, $J_{5,6'}$ = 4.5 Hz, H-5), 3.45 (1 H, bt, J = 6.5 Hz, HO-6, D_2O exchangeable), 3.73, 3.79 (3 H each, d, $^3J_{P,H}$ = 10.8 Hz, $P(OMe)_2$], 3.85, 4.20 (1 H each, m, H-6,6′), 4.45 (1 H, d, $J_{1,2}$ = 4.2 Hz, H-2), 4.47 (1 H, H-4), 5.20 (1 H, $J_{3,4}$ = 2.7 Hz, H-3), 5.87 (1 H, d, H-1); LR MS, m/z 354 (M^+).

3-O-Acetyl-5-deoxy-5-C-(dimethoxyphosphinyl)-1,2-O-isopropylidene-6-O-(triphenylmethyl)-α-D-gluco- and -β-L-idofuranose (17 and 14). A solution of **16** (602 mg, 1.70 mmol) and chlorotriphenylmethane (1.45 g, 5.60 mmol) in dry pyridine (10 mL) was stirred at 60 °C for 30 h. The mixture was cooled, diluted with water (3 mL), stirred at 20 °C for 1 h, and then concentrated in vacuo. The residue was dissolved in CH_2Cl_2 and washed with water. The organic layer was dried (Na_2SO_4) and concentrated in vacuo. The residue was chromatographed in a column of silica gel with AcOEt–hexane as the eluant, giving **17** as a colorless syrup: R_f 0.63 (AcOEt); 445 mg (45%); ^{1}H NMR 1.31, 1.52 (3 H each, s, CMe_2), 2.02 (3 H, s, AcO-3), 2.40 (1 H, $J_{5,P}$ = 20.5, $J_{4,5}$ = 10.5, $J_{5,6}$ = 3.0, $J_{5,6'}$ = 2.5 Hz, H-5), 3.4–4.2 (2 H, m, H-6,6′), 3.57, 3.68 [3 H each, d, $^3J_{P,H}$ = 11.4 Hz, $P(OMe)_2$], 4.50 (1 H, d, $J_{1,2}$ = 3.8 Hz, H-2), 4.95 (1 H, dt, $J_{3,4}$ = $J_{4,P}$ = 2.5 Hz, H-4), 5.33 (1 H, d, H-3), 5.85 (1 H, bd, H-1), 7.25–7.55 (15 H, m, CPh_3).

With the same procedures described above, **13** was similarly converted into **14** in three steps, and the product was purified on a column of silica gel with AcOEt–hexane as the eluant: colorless prisms; R_f 0.53 (AcOEt); 25% overall yield from **13**; mp 148–149 °C (from AcOEt–hexane); ^{1}H NMR 1.27, 1.52 (3 H each, s, CMe_2), 1.80 (3 H, s, AcO-3), 2.2–3.0 (1 H, m, H-5), 3.2–4.1 (2 H, m, H-6,6′), 3.80, 3.85 [3 H each, d, $^3J_{P,H}$ = 10.8 Hz, $P(OMe)_2$], 4.37 (1 H, dd, $J_{1,2}$ = 3.6, $J_{2,3}$ 1.8 Hz, H-2), 4.60 (1 H, $J_{3,4}$ = 0.5 Hz, H-3), 4.78 (1 H, $J_{4,5}$ = 9.0, $J_{4,P}$ = 2.6 Hz, H-4), 5.86 (1 H, d, H-1), 7.25–7.55 (15 H, m, CPh_3).

1,2,3,4,6-Penta-O-acetyl-5-deoxy-5-C-[(*R*)-methoxyphosphinyl]-α-D-glucopyranose (21), the β-Anomer 22, the [(*S*)-Methoxyphosphinyl]-β-D-glucopyranose (23), the α-Anomer 24, and 5-C-(Methoxyphosphinyl)-L-idopyranoses (25). Procedures similar to those used for the preparation of **6–9c** were employed. Thus, **17** (740 mg, 1.24 mmol) dissolved in dry benzene (5 mL) was reduced with SDMA (70% in toluene, 0.99 mL, 3.2 equiv), to give 5-deoxy-1,2-O-isopropylidene-5-C-phosphino-α-D-*xylo*-hexofuranose as a colorless liquid (R_f 0.92). The liquid was immediately treated with 1:1 2-propanol–0.25 M sulfuric acid (10 mL) at 90 °C for 1 h under nitrogen, giving mostly (5*RS*)-5-deoxy-5-C-phosphino-D-*xylo*-hexopyranose as a colorless syrup (R_f 0.62), which was spontaneously oxidized to the 5-C-phosphinyl derivative (R_f 0.37) during the workup. This product was further oxidized with hydrogen peroxide, to give (5*RS*)-5-deoxy-5-C-(hydroxyphosphinyl)-D-*xylo*-hexopyranoses (**19**) as an amorphous solid: 232 mg (82% yield from **17**; R_f 0.23).

The oxidation product was methylated with diazomethane in Me_2SO–MeOH, to give the 5-C-(methoxyphosphinyl) derivative (R_f 0.43), which, on acetylation with acetic anhydride–pyridine, afforded (5*RS*)-5-deoxy-5-C-[(*RS*)-methoxyphosphinyl]-D-*xylo*-hexopyranose peracetates **20**: 190 mg (41% overall yield from **17**). This crude product was twice purified by a column of silica gel with AcOEt–hexane.

Fraction A [R_f 0.59 (AcOEt)] gave **21** as a colorless syrup: 9.1 mg (1.6% overall yield from **17**); ^{1}H NMR (400 MHz) 2.01, 2.03, 2.07, 2.09, 2.24 (3 H each, all s, AcO-6, -4, -3, -2, -1), 2.70 (1 H, $J_{4,5}$ = 12.0, $J_{5,P}$ = 12.0, $J_{5,6}$ = 5.8, $J_{5,6'}$ = 4.3 Hz, H-5), 3.80 (3 H, d, J_{POMe} = 11.3 Hz, MeOP), 4.39 (1 H, $J_{6',P}$ = 13.0, $J_{6,6'}$ = −11.6 Hz, H-6′), 4.445 (1 H, $J_{6,P}$ = 16.8 Hz, H-6), 5.49 (1 H, $J_{2,3}$ = 10.0, $J_{3,4}$ = 8.0 Hz, H-3), 5.51 (1 H, $J_{1,2}$ = 2.5, $J_{2,P}$ = 0.2 Hz, H-2), 5.52 (1 H, $J_{4,P}$ = 3.0 Hz, H-4), 5.68 (1 H, $J_{1,P}$ = 14.8 Hz, H-1); CI MS, m/z 470 (100, M + 18), 453 (1.7, M + 1), 452 (6.8, M^+), 437 (12.1, M − CH_3), 422 (5.6, M − CH_2O), 410 (3.3, M − CH_2CO); EI MS, m/z 439 (1.23, M + 1 − CH_2), 410 (5.9, M − CH_2CO), 393 (2.27, M + 1 − AcOH), 380 (10.2, M − CH_2CO − CH_2O), 368 (7.2, M − AcOH − CH_2), 351 (19.1, M + 1 − CH_2CO − AcOH), 321 (34.5, M + 1 − CH_2O − CH_2CO − AcOH), 309 (66.9), 308 (100, M − $2CH_2CO$ − AcOH), 280 (45.1, M − CH_2O − AcOH − $2CH_2CO$), 267 (18.9, M + 1 − $3CH_2CO$ − AcOH), 249 (45.3, M + 1 − $2CH_2CO$ − 2AcOH), 230 (39.0, M − CH_2CO − 3AcOH), 207 (50.6, M + 1 − $3CH_2CO$ − 2AcOH), 188 (61.6, M − $2CH_2CO$ − 3AcOH); exact mass calcd for $C_{16}H_{24}O_{12}P$, (M + 1 − CH_2) 439.1005; found 439.1013.

Fraction B [R_f 0.54 (AcOEt)] gave **24** as a colorless syrup: 4.6 mg (0.9%); ^{1}H NMR (400 MHz) 1.99, 2.02, 2.05, 2.05, 2.24 (3 H each, all s, AcO-6, -4, -3, -2, -1), 2.78 (1 H, $J_{5,P}$ = 13.5, $J_{4,5}$ = 12.0, $J_{5,6}$ = 4.5, $J_{5,6'}$ = 3.0 Hz, H-5), 3.96 (3 H, d, J_{POMe} = 10.5 Hz, MeOP), 4.28 (1 H, $J_{6',P}$ = 10.0, $J_{6,6'}$ = −12.0 Hz, H-6′), 4.66 (1 H, $J_{6,P}$ = 22.5 Hz, H-6), 5.21 (1 H, $J_{2,3}$ = 10.5, $J_{1,2}$ = 3.0 Hz, $J_{2,P}$ = 2.8 Hz, H-2), 5.35 (1 H, $J_{3,4}$ = 10.0, $J_{4,P}$ = 2.0 Hz, H-4), 5.45 (1 H, H-3), 5.73 (1 H, $J_{1,P}$ = 15.5 Hz, H-1); CI MS, m/z 470 (100, M + 18), 453 (7.3), 452 (7.1), 437 (9.0), 410 (5.8); EI MS, m/z, 439 (3.29), 410 (1.61), 393 (5.24), 380 (14.1), 368 (9.12), 351 (20.0), 321 (40.8), 309 (57.8), 308 (100), 280 (38.4), 267 (37.0), 249 (55.3), 230 (48.8), 207 (70.3), 189 (54.18), 188 (86.7), 177 (37.8), 164 (49.7); exact mass calcd for $C_{16}H_{24}O_{12}P$, (M + 1 − CH_2) 439.1005; found 439.1002.

Fraction C [R_f 0.52 (AcOEt)] gave **23** as a colorless syrup: 42 mg (7.5%); ^{1}H NMR (400 MHz) 2.00, 2.00, 2.04, 2.06, 2.14 (3 H each, all s, AcO-6, -4, -3, -2, -1), 2.48 (1 H, $J_{4,5}$ = 12.0, $J_{5,P}$ = 11.0, $J_{5,6}$ = 5.0, $J_{5,6'}$ = 3.8 Hz, H-5), 3.99 (3 H, d, J_{POMe} = 10.5 Hz, MeOP), 4.29 (1 H, $J_{6',P}$ = 11.0, $J_{6,6'}$ = −12.0 Hz, H-6′), 4.64 (1 H, $J_{6,P}$ = 20.0 Hz, H-6), 5.235 (1 H, $J_{2,3}$ = 9.9, $J_{3,4}$ = 9.6 Hz, H-3), 5.355 (1 H, $J_{4,P}$ = 2.0 Hz, H-4), 5.375 (1 H, $J_{1,2}$ = 10.5, $J_{2,P}$ = 1.8, H-2), 5.51 (1 H, $J_{1,P}$ = 2.7 Hz, H-1); CI MS, m/z 470 (100, M + 18), 453 (7.3), 452 (12.8), 437 (14.4), 410 (3.3); EI MS, m/z 422 (1.32), 410 (2.21), 393 (5.02), 380 (4.62), 368 (7.02), 351 (18.0), 321 (15.7), 309 (54.8), 308 (100), 280 (34.4), 267 (33.6), 249 (48.6), 248 (32.2), 230 (51.0), 207 (58.1), 206 (55.0), 188 (82.1); exact mass calcd for $C_{16}H_{23}O_{11}P$, (M − CH_2O) 422.0978; found 422.0961.

Fraction D [R_f 0.49 (AcOEt)] gave **22** as colorless prisms: 27 mg (4.8%); mp 167–168 °C (from AcOEt–hexane); ^{1}H NMR (400 MHz) 2.02, 2.03, 2.08, 2.11, 2.17 (3 H each, all s, AcO-6, -4, -3, -2, -1), 2.48 (1 H, $J_{5,P}$ = 13.0, $J_{4,5}$ = 11.0, $J_{5,6'}$ = 5.8 Hz, $J_{5,6}$ = 5.0, $J_{1,5}$ = 0.6 Hz, H-5), 3.88 (3 H, d, J_{POMe} = 11.0 Hz, MeOP), 4.44 (1 H, $J_{6',P}$ = 15.5, $J_{6,6'}$ = −12.0 Hz, H-6′), 4.465 (1 H, $J_{6,P}$ = 13.8 Hz, H-6), 5.26 (1 H, $J_{2,3}$ = $J_{3,4}$ = 9.6 Hz, H-3), 5.35 (1 H, $J_{1,2}$ = 10.4, $J_{1,P}$ = 5.6 Hz, H-1), 5.48 (1 H, $J_{4,P}$ = 4.2 Hz, H-4), 5.58 (1 H, $J_{2,P}$ = 3.6 Hz, H-2); CI MS, m/z 470 (100, M + 18), 453 (9.7, M + 1), 452 (5.4), 437 (10.6), 410 (9.0); EI MS, m/z, 453 (0.46), 410 (0.82), 393 (3.18), 368 (4.30), 351 (23.3), 321 (5.42), 309 (76.6), 308 (79.1), 291 (20.3), 280 (47.7), 267 (24.4), 249 (69.7), 248 (35.0), 230 (41.8), 207 (83.6), 206 (53.3), 189 (74.4), 188 (100), 177 (40.4), 164 (40.2); exact mass calcd for $C_{17}H_{26}O_{12}P$, (M + 1) 453.1162; found, 453.1155.

Fraction E [R_f 0.48–0.46 (AcOEt)] gave **25** as a colorless syrup that was contaminated by **22**, **23**, **24**, and unidentified other products: 16 mg (2.9% total); ^{1}H NMR (400 MHz) 2.82 (1 H, $J_{5,P}$ = 25, $J_{5,6}$ = 6.0, $J_{4,5}$ = 4.5, $J_{5,6'}$ = 3.5 Hz, H-5) (signals other than these are uncertain, because of overlapping with signals of the inseparable products); CI MS, m/z 470 (100, M + 18), 453 (5.5, M + 1), 452 (5.0).

When **14** was subjected to the same procedures for the ring-enlargement reaction, **21–25** were also obtained in similar yields to those described above.