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SYNTHESIS OF METHYL 4-DEOXY-3-*C*-[(*S*)-1,2-DIHYDROXYETHYL]-α-D-*xylo*-HEXOPYRANOSIDE AND METHYL 2,2'-ANHYDRO-3-*C*-[(*S*)-1,2-DIHYDROXYETHYL]-α-D-GLUCOPYRANOSIDE DERIVATIVES

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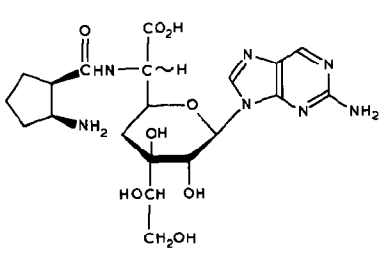
ABSTRACT

The title branched-chain sugars possessing a new type of two-carbon branch were synthesised from D-glucose. These compounds are important intermediates for a total synthesis of the nucleoside antibiotics, amipurimycin and miharamycin.

INTRODUCTION

Amipurimycin[1] (**1**) and miharamycin A (**2a**) and B (**2b**) (ref. 2) are novel 9-*N*-substituted 2-aminopurine nucleoside antibiotics that are active against rice-blast disease caused by *Pyricularia oryzae*. Although the absolute configurations at C-6' of these antibiotics remain to be established, the branched-chain moieties have closely related structures. The chain branches are the same two-carbon unit, namely, the (*S*)-1,2-dihydroxyethyl group, which has not heretofore been found as the side chain of naturally occurring branched-chain sugars. In this paper we describe the synthesis of the important intermediates (**22** and **32**) for a total synthesis of **1** and **2** from D-glucose.



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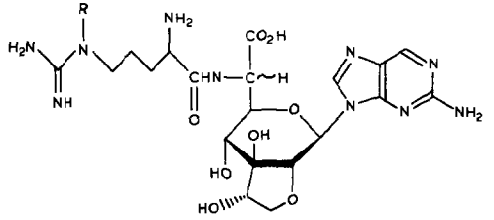

2a R = OH
2b R = H

RESULTS AND DISCUSSION

To construct the chain branch, Horner–Emmons alkenation of methyl 2-*O*-benzoyl-4,6-*O*-benzylidene-α-D-*ribo*-hexopyranosid-3-ulose[3] (**3**) was chosen, be-

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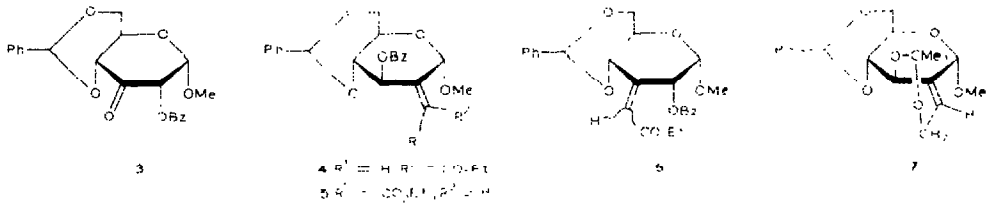
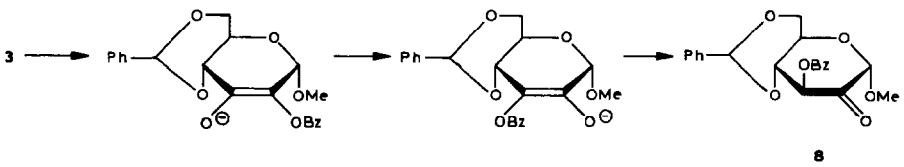
cause the undesired stereochemistry at C-3 was found[4] when alkyl metal carbanion was added. This method has the additional advantage that the configuration at the branching carbon and the side chain can be controlled at the same time by *cis*-dihydroxylation, if the (*E*) isomer is used. The alkenation of **3** with ethyl diethylphosphonoacetate in the presence of an equimolar amount of potassium *tert*-butoxide was complicated in that two 2-*C*-(ethoxycarbonylmethylene) isomers (**4** and **5**) were obtained in addition to a mixture of the two expected 3-*C*-(ethoxycarbonylmethylene) isomers (**6**). For example, the reaction in *N*,*N*-dimethylformamide (DMF) at −60° gave the products **4**, **5**, and **6** in 32, 11, and 27% yields, respectively. The mixture **6** could not be separated at this stage and the ratio of (*Z*)



and (*E*) isomers was proved to be 2.3 by the intensity of alkenic protons at δ 6.18 and 6.09, respectively, in the ^{1}H-n.m.r. spectrum at 500 MHz. The signals for the (*Z*) and (*E*) isomers were distinguished and assigned by the aid of ^{1}H-chemical-shift correlated 2D, n.m.r.[5] spectroscopy. The methylene signals in the ethyl group of the (*Z*) isomer show doubled quartets, which may be rationalized on the basis of hindered rotation of the ethyl group because of the neighboring benzoyl group.

The structures of the 2-*C*-alkylidene isomers **4** and **5** were confirmed by the fact that each H-1 proton is coupled with H-3, and each H-4 signal appears as triplet instead of a doublet because of the new proton at C-3. The configurations at C-3 were readily determined by the large values of $J_{3,4}$ (9.5 and 10.2 Hz), indicative of the *trans*-diaxial relationship. The geometrical structures of **4** and **5** were confirmed by the following chemical modifications. Each isomer was converted into the corresponding 2-hydroxyethylidene derivative by reduction of the ethoxycarbonyl group with lithium aluminium hydride in ether, followed by treatment with 2-methoxypropene and catalytic amount of pyridinium *p*-toluenesulfonate (PPTS) in DMF. The 2-hydroxyethylidene derivative from the minor (*E*) isomer **5** gave an *O*-isopropylidene derivative (**7**), whereas that from the major (*Z*) isomer **4** did not. A similar modification confirmed that the major component of **6** was the (*Z*) isomer, as shown later. These results indicate a rearrangement of **3** to the corresponding 3-*O*-benzoyl-D-*arabino*-hexopyranosid-2-ulose (**8**), *via* benzoyl migration of the 2,3-enediol derivative formed by proton abstraction with strong base, as shown in Scheme 1. This migration was suppressed considerably by addition of the less-polar tetrahydrofuran (THF) as cosolvent, as shown in Table 1. The best result was obtained in a mixture of DMF and THF, with a ratio of 4 to 5 that gave predominantly **6** in 72% yield. In contrast, the same alkenation with ethyl trimethyl-



Scheme 1.

silylacetate and lithium dicyclohexylamide[6] in THF gave only the 3-*C*-alkylidene derivative **6**, with a similar ratio of geometrical isomers, in 97% yield.

Conversion of **6** into the corresponding 3-*C*-(2-hydroxyethylidene) derivatives (**9** and **11**) was performed in the same manner as described for **4** and **5**. These geometrical isomers were first separated as their diacetates (**10** and **12**). Starting from the undesired but major (*Z*) isomer (**9**), the synthetic routes for the skeletal structures of **1** and **2** were established as follows.

Treatment of **9** with 2-methoxypropene and PPTS gave the 2,2[1]-*O*-isopropylidene derivative (**13**) in 91% yield, and this proved to have the (*Z*) configuration. Stereoselective *cis*-dihydroxylation from the exocyclic direction was performed by treatment of the alkene **13** with osmium tetraoxide and 4-methylmorpholine *N*-oxide[7] in *tert*-butyl alcohol–THF–water to give **14** in 62% yield. The stereochemistry of the 3,4-dihydroxy group was proved chemically to be *trans* by 3,4-anhydro ring formation, as will be mentioned here. In order to construct the skeletal structure of **1** from **14**, deoxygenation at C-4 and inversion of configuration in the chain branch were needed. At first the latter conversion was achieved by Swern oxidation[8] and subsequent reduction with sodium borohydride. The inverted product (**15**) was obtained as the 1[1]-acetate (**16**) in 72% yield. The *O*-debenzylidenated derivative (**17**) of **16**, obtained by hydrogenolysis in the presence of 20% palladium hydroxide, was treated with pivaloyl chloride in pyridine at 60° to afford the 6-*O*-pivaloyl derivative (**18**) in 87% yield. Formation of the 3,4-anhydro ring occurred readily with triflic anhydride in pyridine to give the D-*galacto* isomer (**20**) in 96% yield. However, even the secondary hydroxyl group of **18** resisted conventional sulfonylation with either *p*-toluenesulfonyl or methanesulfonyl chloride

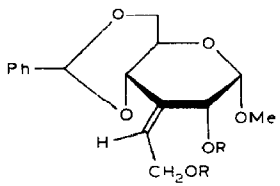
TABLE I

ETHOXYCARBONYLMETHYLENATION OF **3**

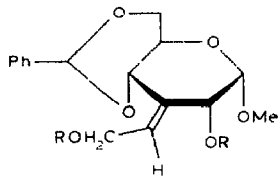
Carbanion sources	*Bases*	*Solvents (ratio)*	*Temperature[a] (degrees)*	*Products (%)*		
				4	**5** (Z/E)	**6** (Z/E)
$(EtO)_2POCH_2CO_2Et$	*tert*-BuOK	DMF	−60	32	11 (2.9)	27 (2.3)
$(EtO)_2POCH_2CO_2Et$	*tert*-BuOK	DMF–THF (5:2)	−78	38	6.8 (5.5)	45 (2.8)
$(EtO)_2POCH_2CO_2Et$	*tert*-BuOK	DMF–THF (4:5)	−78	18	5.8 (3.1)	72 (3.0)
$Me_3SiCH_2CO_2Et$	$(\bigcirc\!\!-)_2NLi$	THF	−78	—	—	97 (2.3)

[a]Reaction time was 2 h.

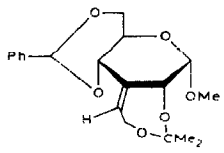
in pyridine at room temperature. The 4-*p*-toluenesulfonate **19** was first obtained, in 20% yield, when **18** was treated with *p*-toluenesulfonyl chloride in the presence of pyridine (6 equiv.) and 4-dimethylaminopyridine (1 equiv.) in dichloromethane under reflux for 7 days. The reaction in pyridine at 60° for 3 days gave **19** and **20** in 20 and 15% yields, respectively. The D-*galacto* configuration was considered much more probable than D-*allo*, considering the higher reactivity of the secondary hydroxyl group, and conclusive evidence was obtained by the next step, namely,



9 R = H
10 R = Ac



11 R = H
12 R = Ac



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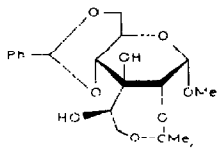

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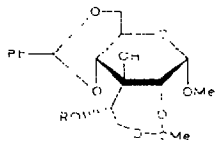
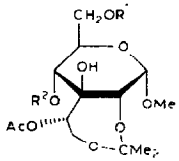
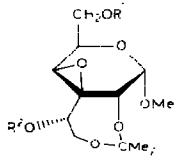


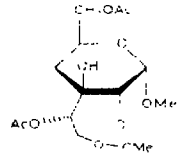
15 R = H
16 R = Ac



17 R = R' = H
18 R = COCMe$_3$, R' = H
19 R = COCMe$_3$, R' = Ts



20 R = COCMe$_3$, R' = Ac
21 R = R' = H



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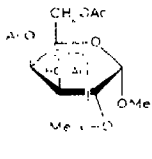

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reductive cleavage of the anhydro ring. Among various sets of conditions examined (Table II), the best selectivity for formation of the desired 4-deoxy sugar (**22**) was observed with lithium aluminium hydride in ether at 15° to give, after acetylation, the desired 4-deoxy sugar (**22**) and 3-deoxy sugar (**23**) in 68% yield in the ratio of 10 to 1. Reduction by diisobutylaluminium hydride and sodium bis(2-methoxyethoxy)aluminium hydride of the deacylated derivative **21** in the expectation, especially for the latter reagent, of higher regioselectivity (as shown in the formation of 1,3-diols from free allyl alcohol epoxides[9,10]), proved not to be effective. The structure of **23** was confirmed by the presence of three acetyl signals instead of two for **22**, together with appropriate coupling constants between ring protons: $J_{2,3}$ (11.8), $J_{3,4}$ (2.9), and $J_{4,5}$ (0 Hz), which were observed in the ^{1}H-n.m.r.

TABLE II

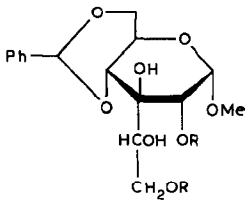
REDUCTIVE ANHYDRO-RING CLEAVAGE OF **20** AND **21**

Anhydro sugars	*Hydrides*	*Equivalents*	*Solvents*	*Temperature (degrees)*	*Reaction time (h)*	*Products*[a] *(%)* **(22/23)**[b]	*Recovery of anhydro sugar*[c]
20	$LiAlH_4$[d]	2.0	THF	reflux	6	57.2(68/32)	18.2
20	$LiAlH_4$	3.0	ether	15	42	68.0(91/9)	
20	$LiAlH_4$	8.0	ether	−25	240	37.5(91/9)	20.9
21	DIBAL[d]	5.0	THF	15	120	77.9(26/74)	
21	RedAl[e]	3.8	toluene	15	96	64.4(57/43)	

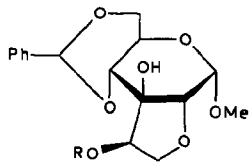
[a]Isolated after acetylation as a mixture of diacetate **22** and triacetate **23**. [b]Determined by ^{1}H-n.m.r. signals of methoxyl group. [c]Recovered as 6,1^1-diacetate of **21**. [d]Diisobutylaluminium hydride. [e]Sodium bis(2-methoxyethoxy)aluminium hydride.

spectrum at 500 MHz. Thus, a key intermediate **22** for the total synthesis of **1** was obtained from D-glucose by 16 steps in 9.6% overall yield.

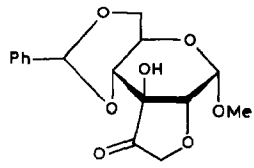
Dihydroxylation of the alkene **10** in the same manner as decribed for **13** gave the D-*gluco* isomer **24** selectively in 57% yield. Its *O*-deacetylated analog **25** was then cyclized with camphorsulfonyl chloride in pyridine at room temperature to give the 2,2^1-anhydro derivative **26** in 72% yield. The possibility of a four-membered cyclic ether structure was rejected by the fact that the H-1^1 signal was shifted to the lower field in the ^{1}H-n.m.r. spectrum of its acetate **27**. The configuration of the hydroxyl group at C-1^1 was inverted by the same oxidation–reduction method used for **14**. The intermediate glycosulose **28** was obtained by Swern oxidation in 72% yield and successive hydride reduction gave, in 95% yield, a diol



24 R = Ac
25 R = H



26 R = H
27 R = Ac



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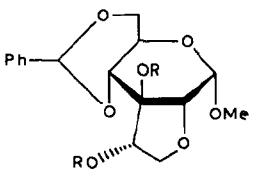
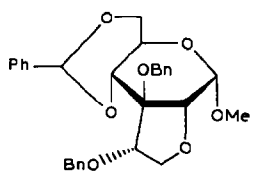


29 R = H
30 R = Ac



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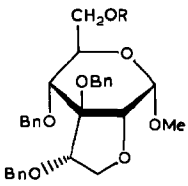

32 R = H
33 R = Ac

derivative (**29**) as a single product which was clearly different from **26**. The stereochemistry of **29** was confirmed by the following chemical conversion. Selective hydrolysis of **15** with 0.85M *p*-toluenesulfonic acid in 1:1 1,4-dioxane–water at room temperature gave the *O*-deisopropylidenated derivative, whose cyclization product using camphorsulfonyl chloride was fully consistent with the structure **29**. Furthermore, benzylation of **29** with sodium hydride and benzyl chloride in dimethyl sulfoxide gave the di-*O*-benzyl derivative (**31**), whose benzylidene group was cleavaged regioselectively with an equimolar mixture of lithium aluminium hydride and aluminium chloride in ether–dichloromethane to give the 3,4,1[1]-tri-*O*-benzyl derivative (**32**) in 82% yield. This compound is a key intermediate for modification both at C-1 and C-6, which is necessary for the synthesis of **2**, and was obtained from D-glucose by 14 steps in 2.6% overall yield.

EXPERIMENTAL

General methods. — Melting points are uncorrected. Solutions were concentrated under diminished pressure at <50° (bath). Optical rotations were measured with a Carl Zeiss LEP-Al or a JASCO DIP-4 polarimeter. I.r. spectra were recorded with a Hitachi EPI-G2 grating spectrometer. ^{1}H-N.m.r. spectra were recorded at 100 MHz with a JEOL PS-100 spectrometer, unless otherwise stated, for solutions in $CDCl_3$ (internal Me_4Si). Bruker AM-500 and Varian XL-400 spectrometers were also used for the measurement of certain compounds, at 500 MHz and 400 MHz, respectively. ^{13}C-N.m.r. spectra were recorded at 22.5 MHz with a JEOL FX-90 spectrometer for solutions in $CDCl_3$, unless otherwise stated. Chromatography was performed on Wakogel C-200, flash chromatography on Wakogel C-300, and preparative t.l.c. on silica gel 60 (Merck). Ethyl diethylphosphonoacetate and ethyl trimethylsilylacetate were purchased from Tokyo Kasei Kogyo Co. Ltd. and Aldrich Chemical Co., respectively.

Reaction of **3** *with ethyl diethylphosphonoacetate and potassium* tert-*butoxide.* — To a solution of **3** (50 g, 0.13 mol) in a mixture of DMF (300 mL) and THF (400 mL) was added dropwise at −78° during 1 h a solution of the carbanion[11] prepared from ethyl diethylphosphonoacetate (58.3 g, 0.26 mol) and potassium *tert*-butoxide (29.2 g, 0.26 mmol) in a mixture of DMF (100 mL) and THF (100 mL). After being kept for 2 h at −78°, the solution was poured into saturated aqueous ammonium chloride, and extracted with ethyl acetate. The extract was washed with water, dried with magnesium sulfate, and evaporated to give a syrup that was separated on a column of silica gel with 6:1 hexane–ethyl acetate to give **4** (10.7 g, 18%), **6** (42.8 g, 72%) and **5** (3.4 g, 5.8%).

Compound **4**, a syrup, had $[\alpha]_D$ −3.4° (*c* 1.0, $CHCl_3$); ^{1}H-n.m.r.: δ 5.89 (d, H-1), 6.27 (dd, $J_{1,3}$ 2.0 Hz, $J_{3,4}$ 10.2 Hz, H-3), 3.82 (t, $J_{4,5}$ 9.6 Hz, H-4), 4.21 (dt, $J_{5,6a}$ 9.9 Hz, $J_{5,6b}$ 4.9 Hz, H-5), 3.81 (t, $J_{6a,6b}$ 10.3 Hz, H-6a), 4.36 (dd, H-6b), 6.48 (s, H-1[1]), 1.27 (t, Me in Et), 4.18 (q, J_{Me,CH_2} 7.3 Hz, CH_2 in Et), 3.53 (s, OMe), and 5.55 (s, PhCH); ^{13}C-n.m.r.: δ 96.06 (d, C-1), 139.19 (s, C-2), 70.71 (d, C-3), 81.38

(d, C-4), 63.23 (d, C-5), 68.92 (t, C-6), 120.66 (d, C-1^1), 164.71 (s, C-2^1), 14.09 (q, Me in Et), 54.37 (q, OMe), 60.63 (t, CH_2 in Et), 101.54 (d, PhCH), 126.13, 128.08, 128.52, 128.89, 129.87 and 133.34 (each d, Ph), 129.38 and 137.08 (each s, Ph), and 164.87 (s, Bz).

Anal. Calc. for $C_{25}H_{26}O_8$: C, 66.07; H, 5.77. Found: C, 65.78; H, 5.94.

Compound **5** had m.p. 146–148°, $[\alpha]_D$ −2.9° (*c* 0.9, $CHCl_3$); ^{1}H-n.m.r. (500 MHz): δ 5.97 (d, $J_{1,3}$ 2.3 Hz, H-1), 6.46 (dd, $J_{3,4}$ 9.5 Hz, H-3), 3.87 (t, $J_{4,5}$ 9.5 Hz, H-4), 4.13 (dt, $J_{5,6a}$ 10.3 Hz, $J_{5,6b}$ 5.0 Hz, H-5), 3.80 (t, $J_{6a,6b}$ 10.3 Hz, H-6a), 4.35 (dd, H-6b), 5.02 (s, H-1^1), 5.52 (s, PhCH), 3.40 and 3.73 (each dq, J_{AB} 10.8 Hz, $J_{Me,CH}$ 7.3 Hz, CH_2 in Et), 1.28 (t, Me in Et), and 3.45 (s, OMe); ^{13}C-n.m.r.: δ 101.37 and 102.89 (d, C-1 and PhCH), 139.19 (s, C-2), 70.00 (d, C-3), 81.11 (d, C-4), 63.39 (d, C-5), 68.92 (t, C-6), 120.66 (d, C-1^1), 164.71 and 166.11 (each s, C-2^1), 13.87 (q, Me in Et), 54.94 (q, OMe), 61.06 (t, CH_2 in Et), 126.03, 128.08, 128.03, 128.84, 129.87 and 133.23 (each d, Ph), 129.49 and 137.02 (each s, Ph).

Anal. Calc. for $C_{25}H_{26}O_8$: C, 66.07; H, 5.77. Found: C, 65.82; H, 5.51.

Compound **6** was a mixture of the (*Z*) and (*E*) isomers in 2.3 ratio; ^{1}H-n.m.r. (500 MHz), (*Z*) isomer: δ 4.93 (d, $J_{1,2}$ 4.0 Hz, H-1), 5.92 (dd, $J_{2,1'}$ 2.1 Hz, H-2), 4.12 (dd, $J_{4,5}$ 9.5 Hz, $J_{4,1'}$ 1.6 Hz, H-4), 3.97 (dt, $J_{5,6a}$ 9.8 Hz, $J_{5,6b}$ 4.7 Hz, H-5), 3.8 (H-6a), 4.36 (dd, $J_{6a,6b}$ 10.4 Hz, H-6b), 6.18 (dd, H-1^1), 5.64 (s, PhCH), 3.54 and 3.80 (each dq, J_{AB} 10.7 Hz, $J_{Me,CH}$ 7.3 Hz, CH_2 in Et), 0.93 (t, Me in Et) and 3.44 (s, OMe); (*E*) isomer: 5.06 (d, $J_{1,2}$ 3.9 Hz, H-1), 5.64 (dd, $J_{2,1'}$ 1.8 Hz, H-2), 4.29 (dd, $J_{4,5}$ 9.3 Hz, $J_{4,1'}$ 1.8 Hz, H-4), 4.00 (dt, $J_{5,6a}$ 10.0 Hz, $J_{5,6b}$ 4.3 Hz, H-5), 3.8 (H-6a), 4.34 (dd, H-6b), 6.09 (dd, H-1^1), 5.60 (s, PhCH), 3.75 (q, *J* 7.2 Hz, CH_2 in Et), 0.93 (t, Me in Et), and 3.44 (s, OMe).

Anal. Calc. for $C_{25}H_{26}O_8$: C, 66.07; H, 5.77. Found: C, 66.52; H, 5.70.

*Methyl 2-O-benzoyl-4,6-O-benzylidene-3-C-(ethoxycarbonylmethylene)-α-*D-ribo-*hexopyranoside* (**6**). — To a solution of dicyclohexylamine (363 mg, 2 mmol) in THF (10 mL) was added, under an atmosphere of argon dropwise with stirring at −78°, a 1.6M THF solution of butyllithium (1.25 mL, 2 mmol) and ethyl trimethylsilylacetate (320 mg, 2 mmol) and then a solution of **3** (384 mg, 1.0 mmol) in THF (5 mL) during 10 min. The solution was kept at −78°, at −25°, and then at 0° each for 1 h, poured into saturated aqueous sodium chloride, and extracted with ethyl acetate. Conventional treatment of the extract gave a syrupy residue that was purified by flash chromatography on silica gel with 3:1 hexane–ethyl acetate to give **6** (440 mg, 97%), which was identical with the mixture just described. The ratio of (*Z*) and (*E*) isomers was 2.3.

Methyl 4,6-O-benzylidene-2-C-[(E)*-2-hydroxyethylidene]-3,2'-O-isopropylidene-α-*D-arabino-*hexopyranoside* (**7**). — Compound **5** was converted first into the corresponding 2-*C*-(2-hydroxyethylidene) derivative and then into its 3,2^1-diacetate in the same manner as described for **9** and **10**. The diacetate was purified on a column of silica gel with 3:1 hexane–ethyl acetate and deacetylated with sodium methoxide in methanol. The diol obtained thus was further treated with 2-methoxypropene in the presence of PPTS, as described for **13**, to give **7** (265 mg,

72%), m.p. 158–160°, $[\alpha]_D$ −4.0° (*c* 1.3, $CHCl_3$); ^{1}H-n.m.r.: δ 4.94 (s, H-1), 4.86 (m, H-3), 3.5–4.1 (m, H-4 and H-5), 4.31 (dd, $J_{5,6a}$ 4.4 Hz, $J_{6a,6b}$ 9.8 Hz, H-6a), 3.65 (t, $J_{5,6b}$ 9.8 Hz, H-6b), 5.74 (ddd, $J_{1',2'a}$ 4.0 Hz, $J_{1',2'b}$ 6.0 Hz, $J_{1',3}$ 1.8 Hz, H-1'), 4.56 (ddd, $J_{2'a,2'b}$ 17.0 Hz, $J_{3,2'a}$ 2.6 Hz, H-2'a), 3.96 (ddd, $J_{3,2'b}$ 3.6 Hz, H-2'b), 1.45 and 1.50 (each s, Me_2C), 3.36 (s, OMe), 5.56 (s, PhCH), and 7.3–7.6 (m, Ph); ^{13}C-n.m.r.: δ 101.22 (d, C-1), 137.53 (s, C-2), 70.38 (d, C-3), 80.28 (d, C-4), 61.94 (d, C-5), 69.21 (t, C-6), 128.75 and 130.70 (each d, C-1' and Ph), 59.93 (t, C-2'), 24.16 and 24.26 (each q, Me), 54.52 (q, OMe), 102.05 (s and d, Me_2C and PhCH, respectively), 126.06 and 128.07 (each d, Ph), and 137.53 (s, Ph).

Anal. Calc. for $C_{10}H_{24}O_6$: C, 66.50; H, 6.94. Found: C, 66.84; H, 7.20.

*Methyl 2,2'-di-O-acetyl-4,6-O-benzylidene-3-C-[(Z)-2-hydroxyethylidene]-α-*D-ribo-*hexopyranoside* (**10**). — To an ice-cold suspension of lithium aluminium hydride (344 mg, 9.07 mmol) in dry ether (35 mL) was added dropwise with stirring a solution of **6** (1.75 g, 3.81 mmol) in dry ether (20 mL). Stirring was continued at room temperature for 30 min. To the mixture was added dropwise ethyl acetate (20 mL) and water (1 mL). Undissolved materials were filtered off using filter aid, and the filtrate was extracted with chloroform. The mixture was evaporated and the residue, dried over phosphorus pentaoxide, was acetylated conventionally with acetic anhydride in pyridine. Only the major isomer (**10**) was obtained, as crystals (940 mg, 63%), after purification by column chromatography on silica gel with 2:1 hexane–ethyl acetate; the minor isomer (**12**) was not obtained by this treatment. Compound **10** had m.p. 116–117° (from EtOH), $[\alpha]_D$ +127.8° (*c* 1.0, $CHCl_3$); ^{1}H-n.m.r.: δ 4.84 (d, $J_{1,2}$ 3.9 Hz, H-1), 5.40–5.52 (m, H-2), 3.6–4.4 (m, H-4, H-5, H-6a, and H-6'b), 5.73 (t, $J_{1',2'}$ 6.0 Hz, H-1'), 4.82–4.96 (m, H-2'a, H-2'b), 2.02 and 2.18 (each s, Ac), 3.38 (s, OMe), 5.54 (s, PhCH), 7.2–7.5 (m, Ph); ^{13}C-n.m.r.: δ 98.65 (d, C-1), 72.54 (d, C-2), 130.46 (s, C-3), 78.50 (d, C-4), 65.87 (d, C-5), 69.34 (t, C-6), 118.32 (d, C-1'), 69.34 (t, C-2'), 20.86 and 21.02 (each q, Ac), 55.36 (q, OMe), 101.69 (d, PhCH), 126.39, 128.29 and 129.16 (each d, Ph), 137.34 (s, Ph), 169.63 and 170.82 (each s, Ac).

Anal. Calc. for $C_{20}H_{24}O_8$: C, 61.22; H, 6.17. Found: C, 61.25; H, 6.14.

In a separate experiment, the reaction mixture was poured into M hydrochloric acid and extracted with chloroform. The dried residue obtained by evaporation of the extract was acetylated and the products were fractionated on a column of silica gel with hexane–ethyl acetate to give **10** (370 mg, 52%) and **12** (120 mg, 17%). Compound **12** had ^{1}H-n.m.r.: δ 4.79 (d, $J_{1,2}$ 4.0 Hz H-1), 5.72 (d, H-2), 3.6–4.4 (m, H-4, H-5, H-6a, and H-6b), 5.48 (t, $J_{1',2'}$ 6.0 Hz, H-1'), 4.6–4.8 (m, H-2'a and H-2'b), 2.04 and 2.16 (each s, Ac), 3.40 (s, OMe), 5.50 (s, PhCH), 7.2–7.6 (m, Ph); ^{13}C-n.m.r.: δ 96.64 (C-1, d), 72.08 (d, C-2), 128.07 (s, C-3), 79.21 (d, C-4), 63.64 (d, C-5), 69.06 (t, C-6), 119.96 (t, C-1'), 60.32 (t, C-2'), 55.15 (q, OMe), 60.32 and 69.06 (each q, Ac), 101.66 (d, PhCH), 126.12, 128.16, and 128.94 (each d, Ph), 137.29 (s, Ph), 169.65 and 170.18 (each s, Ac).

Anal. Calc. for $C_{20}H_{24}O_8$: C, 61.22; H, 6.17. Found: C, 61.09; H, 6.11.

Methyl 4,6-O-benzylidene-3-C-[(Z)-2-hydroxyethylidene]-2,2'-O-isopropyl-

*idene-α-*D*-ribo-hexopyranoside* (**13**). — To a solution of **9** (290 mg, 1.0 mmol) in DMF (3 mL) was added 2-methoxypropene (5 mL) and PPTS (30 mg). The solution was kept overnight at room temperature, poured into saturated aqueous sodium hydrogencarbonate, and extracted with ethyl acetate. The extract was dried and evaporated to a syrup that was purified by flash chromatography with 1:1 hexane–ethyl acetate to give **13** as crystal, yield 317 mg (92%); m.p. 154–155°, $[\alpha]_D$ +23.0° (*c* 0.6, $CHCl_3$); ^{1}H-n.m.r.: δ 4.48–4.80 (m, 3 H, H-1, H-2, and H-2^{1}a), 4.28 (d, $J_{4,5}$ 6.0 Hz, H-4), 3.6–4.0 (m, 4 H, H-5, H-6a, H-6b, and H-2^{1}b), 5.92 (m, H-1^1), 1.48 (s, 3 H, CMe_2), 3.44 (s, 3 H, OMe), 5.54 (s, PhCH), 7.2–7.56 (m, 5 H, Ph); ^{13}C-n.m.r.: δ 99.48 (d, C-1), 71.30 (d, C-2), 135.40 (s, C-3), 77.64 (d, C-4), 63.23 (d, C-5), 135.40 (s, C-3), 69.64 (t, C-6), 122.45 (d, C-1^1), 59.22 (t, C-2^1), 23.68 and 25.30 (q, Me in CMe_2), 55.32 (q, OMe), 101.75 (d, PhCH), 101.91 (s, CMe_2), 128.14, 126.24 and 128.95 (d, Ph).

Anal. Calc. for $C_{19}H_{24}O_6$: C, 65.50; H, 6.94. Found: C, 65.52; H, 7.10.

*Methyl 4,6-*O*-benzylidene-3-*C*-[(*R*)-1,2-dihydroxyethyl]-2,2^1-*O*-isopropylidene-α-*D*-glucopyranoside* (**14**). — Compound **13** (200 mg, 0.547 mmol) and 4-methylmorpholine *N*-oxide (135 mg, 1 mmol) were dissolved in a mixture of *tert*-butyl alcohol (3 mL), tetrahydrofuran (3 mL), and water (1.5 mL). To the solution was added a 0.13M solution of osmium tetraoxide (0.47 mL, 0.06 mmol) in *tert*-butyl alcohol and stirring was continued overnight at room temperature under exclusion of light. The mixture was poured into water and extracted with chloroform. The extract was washed with water, dried, and evaporated. The residue was purified by flash chromatography with 4:1 hexane–ethyl acetate to give **14** as a syrup (136 mg, 62%), $[\alpha]_D$ 0° (*c* 0.65, $CHCl_3$); ^{1}H-n.m.r.: δ 4.77 (d, $J_{1,2}$ 3.2 Hz, H-1), 4.04 (d, H-2), 3.50–4.40 (m, 7 H), 1.38 and 1.46 (each s, 3 H, CMe_2), 3.40 (s, 3 H, OMe), 5.14 (s, PhCH), 7.08–7.44 (m, 5 H, Ph); ^{13}C-n.m.r.: δ 98.34 (d, C-1), 75.47 (d, C-2), 74.71 (s, C-3), 85.28 (d, C-4), 62.04 (d, C-5), 69.79 (t, C-6), 69.87 (d, C-1^1), 64.58 (each t, C-2^1), 24.00 and 25.63 (each q, CMe_2), 56.13 (q, OMe), 101.86 (s, CMe_2), 102.35 (d, PhCH), 125.97, 128.30 and 129.22 (each d, Ph), and 136.97 (s, Ph).

Anal. Calc. for $C_{19}H_{26}O_8$: C, 59.67; H, 6.85. Found: C, 59.47; H, 7.10.

*Methyl 4,6-*O*-benzylidene-3-*C*-[(*S*)-1,2-dihydroxyethyl]-2,2^1-*O*-isopropylidene-α-*D*-glucopyranoside* (**15**). — Under an atmosphere of argon, to a solution of dimethyl sulfoxide (2.11 g, 27.0 mmol) in dichloromethane (30 mL) was added at −78° oxalyl chloride (3.63 mL, 27.0 mmol) and then, after stirring for 10 min, a solution of **14** (2.58 g, 6.75 mmol) in dichloromethane (50 mL). To this solution was added after 1 h triethylamine (7.1 mL, 54 mmol), and the temperature was raised and kept for 1 h at room temperature. After addition of water, the organic layer was separated and the aqueous layer extracted with chloroform. The organic layer and the extract were combined, washed with water, dried, and evaporated to give the crude, syrupy glycosulose. To a chilled solution of the latter in methanol (30 mL) was added with stirring sodium borohydride (255 mg, 6.75 mmol) and then, after 1 h, acetone (10 mL). The residue obtained by evaporation of the

solvent was purified on a column of silica gel with hexane–ethyl acetate to give **15** (1.86 g, 72%) as a syrup, $[\alpha]_D$ +45.9° (*c* 1.2, $CHCl_3$); ^{1}H-n.m.r.: δ 4.60 (d, $J_{1,2}$ 3.6 Hz, H-1), 3.40–4.32 (m, 9 H), 4.46 (dd, H-1'), 1.32 and 1.40 (each s, 3 H, CMe_2), 3.32 (s, 3 H, OMe), 5.36 (s, PhCH), 7.12–7.48 (m, 5 H, Ph); ^{13}C-n.m.r.: δ 100.18 (d, C-1), 75.80 (d, C-2), 73.58 (s, C-3), 84.63 (d, C-4), 61.77 (d, C-5), 69.13 (t, C-6), 73.69 (d, C-1'), 66.37 (t, C-2'), 26.33 and 26.87 (each q, CMe_2), 55.64 (q, OMe), 101.64 (d, PhCH), 107.44 (s, CMe_2), 126.46, 128.14 and 129.00 (each d, Ph), 137.62 (s, Ph).

Conventional acetylation of **15** gave its 1'-acetate (**16**), m.p. 136–137°, $[\alpha]_D$ +32.7° (*c* 3.5, $CHCl_3$); ^{1}H-n.m.r.: δ 5.13 (d, $J_{1,2}$ 4.0 Hz, H-1), 4.78 (d, H-2), 3.46–4.38 (m, 7 H), 4.65 (dd, $J_{1',2'a}$ 5.0 Hz, $J_{1',2'b}$ 9.8 Hz, H-1'), 1.40 and 1.50 (each s, 3 H, CMe_2), 2.13 (s, 3 H, Ac), 3.40 (s, 3 H, OMe), 5.50 (s, PhCH), 7.24–7.64 (m, 5 H, Ph); ^{13}C-n.m.r.: δ 97.96 (d, C-1), 75.79 (d, C-2), 72.00 (s, C-3), 84.79 (d, C-4), 61.60 (d, C-5), 68.97 (t, C-6), 73.08 (d, C-1'), 66.32 (t, C-2'), 20.81 (q, Ac), 26.28 and 26.93 (each q, CMe_2), 55.54 (q, OMe), 101.64 (d, PhCH), 107.82 (s, CMe_2), 126.40, 128.08 and 129.00 (each d, Ph), 137.51 (s, Ph), 169.48 (s, Ac).

Anal. Calc. for $C_{21}H_{28}O_9$: C, 59.42; H, 6.65. Found: C, 59.14; H, 6.76.

*Methyl 1'-O-acetyl-3-C-[(S)-1,2-dihydroxyethyl]-2,2'-O-isopropylidene-α-*D*-glucopyranoside* (**17**). — Compound **16** (107 mg, 0.25 mmol) in ethanol (50 mL) was hydrogenolyzed at atmospheric pressure in the presence of 20% palladium hydroxide on charcoal and two drops of acetic acid for 44 h at room temperature. Undissolved material was filtered off, the filtrate made neutral with sodium hydrogen carbonate, and evaporated to a syrup. Purification by flash chromatography with 1:1 hexane–ethyl acetate gave **17** quantitatively, $[\alpha]_D$ +29.5° (*c* 0.95, $CHCl_3$); ^{1}H-n.m.r.: δ 4.82 (d, $J_{1,2}$ 4.0 Hz, H-1), 3.3–4.3 (m, 9 H), 4.92 (t, $J_{1',2'a}$ 4.0 Hz, H-1'), 1.12 (s, 3 H, Ac), 1.44 (s, 6 H, CMe_2), 2.80 (bs, OH), 3.40 (s, 3 H, OMe); ^{13}C-n.m.r.: δ 97.09 (d, C-1), 77.42 and 77.75 (each d, C-2 and C-4), 72.65 (s, C-3), 71.63 (d, C-5), 62.15 (t, C-6), 74.34 (d, C-1'), 66.15 (t, C-2'), 20.75 (q, Ac), 25.90 and 26.44 (each q, CMe_2), 108.80 (s, CMe_2), 169.75 (s, Ac).

Anal. Calc. for $C_{14}H_{24}O_9$: C, 49.99; H, 7.19. Found: C, 49.94; H, 7.63.

*Methyl 1'-O-acetyl-3-C-[(S)-1,2-dihydroxyethyl]-2,2'-O-isopropylidene-6-O-pivaloyl-α-*D*-glucopyranoside* (**18**). — To a solution of **17** (73 mg, 0.23 mmol) in pyridine (7 mL) was added pivaloyl chloride (33 mg, 0.27 mmol). The solution was heated for 24 h at 60°, poured into water, and extracted with chloroform. The extract was washed with water, dried, and evaporated to give a residue that was purified by flash chromatography with 2:1 hexane–ethyl acetate to give **18** in 87% yield. The starting compound **17** was recovered in 12% yield. Compound **18**, a syrup, had $[\alpha]_D$ +108.2° (*c* 1.3, $CHCl_3$); ^{1}H-n.m.r. (500 MHz): δ 4.93 (d, $J_{1,2}$ 4.0 Hz, H-1), 4.79 (d, H-2), 3.62 (t, $J_{4,5}$ 10.4 Hz, $J_{4,OH}$ 10.4 Hz, H-4), 3.89 (ddd, $J_{5,6a}$ 2.1 Hz, $J_{5,6b}$ 6.1 Hz, H-5), 4.28 (dd, $J_{6a,6b}$ 11.9 Hz, H-6), 4.48 (dd, H-6b), 4.86 (dd, $J_{1',2'a}$ 5.8 Hz, $J_{1',2'b}$ 8.6 Hz, H-1'), 4.19 (dd, $J_{2'a,2'b}$ 8.6 Hz, H-2'a), 4.09 (t, H-2'b), 1.23 (s, 9 H, CMe_3), 1.41 and 1.44 (each s, 3 H, CMe_2), 2.11 (s, 3 H, Ac), 3.38 (s, 3 H, OMe), 3.98 (d, OH); ^{13}C-n.m.r.: δ 96.88 (d, C-1), 77.37 (d, C-2), 72.60 (s,

C-3), 76.01 (d, C-4), 69.62 (d, C-5), 63.72 (each t, C-6), 73.96 (d, C-1^1), 66.21 (t, C-2^1), 20.70 (q, Ac), 25.90 and 26.49 (each q, CMe_2), 27.20 (q, CMe_3), 38.85 (s, CMe_3), 55.37 (q, OMe), 108.90 (s, CMe_2), 169.42 (s, Ac), 177.98 (s, $COCMe_3$).

Anal. Calc. for $C_{19}H_{32}O_{10}$: C, 54.27; H, 7.67. Found: C, 54.59; H, 7.65.

Methyl 1^1-O-acetyl-3-C-[(S)-1,2-dihydroxyethyl]-2,2^1-O-isopropylidene-6-O-pivaloyl-4-O-p-tolylsulfonyl-α-D-glucopyranoside (**19**). — To a solution of **18** (108 mg, 0.27 mmol) in dichloromethane (1 mL) was added with stirring pyridine (260 μL, 3.2 mmol), 4-dimethylaminopyridine (39.6 mg, 0.27 mmol), and *p*-toluenesulfonyl chloride (509 mg, 2.7 mmol). The solution was heated at 40° for 7 d, and processed conventionally. The syrup obtained was fractionated by flash chromatography on silica gel with 5:1 hexane–ethyl acetate to give **19** (29 mg, 20%) and unreacted **18** (60 mg, 56%).

Compound **19** was a syrup, $[\alpha]_D$ +74.6° (*c* 0.6, $CHCl_3$); ^{1}H-n.m.r.: δ 5.04 (d, $J_{1,2}$ 3.6 Hz, H-1), 3.80–4.88 (m, 8 H), 3.40 (s, 3 H, OMe), 2.44 (s, 3 H, Me in Ts), 2.10 (s, 3 H, Ac), 1.32 (s, 6 H, CMe_2), 1.24 (s, 9 H, CMe_3), and 7.34 and 7.88 (each d, 4 H, *J* 8.8 Hz, Ts); ^{13}C-n.m.r.: δ 96.77 (d, C-1), 75.64 and 80.30 (each d, C-2 and C-4), 72.76 (s, C-3), 67.78 (d, C-5), 62.15 (t, C-6), 72.28 (d, C-1^1), 65.99 (t, C-2^1), 20.81 and 21.61 (each q, Me in Ac and Ts), 25.79 and 26.82 (each q, CMe_2), 27.20 (q, CMe_3), 38.90 (s, CMe_3), 55.70 (q, OMe), 108.15 (s, CMe_2), 128.14 and 129.60 (each d, Ts), 133.50 and 145.09 (each s, Ts), 169.26 (s, Ac), and 177.98 (s, $COCMe_3$).

Anal. Calc. for $C_{26}H_{38}O_{12}S$: C, 54.03; H, 6.63. Found: C, 54.32; H, 6.69.

Methyl 1^1-O-acetyl-3,4-anhydro-3-C-[(S)-1,2-dihydroxyethyl]-2,2^1-O-isopropylidene-6-O-pivaloyl-α-D-galactopyranoside (**20**). — To a solution of **18** (500 mg, 1.2 mmol) in pyridine (10 mL) was added trifluoromethanesulfonic anhydride (1 mL, 6.0 mmol) under strictly dry conditions. After being kept overnight at room temperature, the syrup obtained conventionally was purified by flash chromatography with 3:1 hexane–ethyl acetate to give **20** (443 mg, 93%), $[\alpha]_D$ +78.5° (*c* 0.9, $CHCl_3$); ^{1}H-n.m.r. (500 MHz): δ 4.93 (d, $J_{1,2}$ 3.2 Hz, H-1), 4.80 (d, H-2), 3.48 (s, $J_{4,5}$ 0 Hz, H-4), 4.22–4.36 (m, 3 H, H-5, H-6a, and H-6b), 4.49 (t, $J_{1^1,2^1a}$ 6.4 Hz, $J_{1^1,2^1b}$ 6.4 Hz, H-1^1), 4.08 (dd, $J_{2^1a,2^1b}$ 8.4 Hz, H-2^{1}a), 3.90 (dd, H-2^{1}b), 1.24 (s, 9 H, CMe_3), 1.35 (s, 6 H, CMe_2), 2.16 (s, 3 H, Ac), 3.40 (s, 3 H, OMe); ^{13}C-n.m.r.: δ 94.28 (d, C-1), 65.45 (d, C-2), 57.87 (s, C-3), 53.64 (d, C-4), 67.51 (d, C-5), 62.90 (t, C-6), 72.00 (d, C-1^1), 65.94 (t, C-2^1), 20.81 (q, Ac), 25.63 (q, 2 C, CMe_2), 27.14 (q, 3 C, CMe_3), 38.19 (s, CMe_3), 56.02 (q, OMe), 109.88 (s, CMe_2), 169.58 (s, Ac), 178.04 (s, $COCMe_3$).

Anal. Calc. for $C_{19}H_{30}O_9$: C, 56.71; H, 7.51. Found: C, 56.28; H, 7.40.

Methyl 6,1^1-di-O-acetyl-4-deoxy-3-C-[(S)-1,2-dihydroxyethyl]-2,2^1-O-isopropylidene-α-D-xylo-hexopyranoside (**22**) *and methyl 4,6,1^1-tri-O-acetyl-3-deoxy-3-C-[(R)-1,2-dihydroxyethyl]-2,2^1-O-isopropylidene-α-D-galactopyranoside* (**23**). — To a chilled suspension of lithium aluminium hydride (17 mg, 0.44 mmol) in ether (3 mL) was added with stirring an ethereal solution (3 mL) of **21** (80 mg, 0.20 mmol) which was prepared as described for the next experiment. After stirring for

42 h at room temperature, the mixture was evaporated with additions of small amounts of water. The residue was dried over phosphorus pentaoxide under diminished presssure at 50°, and acetylated conventionally to give a mixture of **22** and **23** (49 mg, 68%, ratio 10:1 by ^{1}H-n.m.r.) after purification by flash chromatography. The two isomers were separated by preparative t.l.c., with double development by 7:2:1 benzene–hexane–acetone. Compound **22** was a syrup, $[\alpha]_D$ +88.9° (*c* 0.2, $CHCl_3$); ^{1}H-n.m.r.: δ 4.84 (d, $J_{1,2}$ 3.8 Hz, H-1), 5.02 (d, H-2), 1.68 (t, $J_{4a,5}$ 12.8 Hz, $J_{4a,4b}$ 13.2 Hz, H-4a), 2.22 (dd, $J_{4b,5}$ 2.1 Hz, H-4b), 4.03 (dddd, $J_{5,6a}$ 5.6 Hz, $J_{5,6b}$ 4.0 Hz, H-5), 4.13 (dd, $J_{6a,6b}$ 11.7 Hz, H-6a), 4.16 (dd, H-6b), 4.61 (dd, $J_{1',2'a}$ 8.4 Hz, $J_{1',2'b}$ 5.9 Hz, H-1'), 3.98 (t, $J_{2'a,2'b}$ 8.6 Hz, H-2'a), 4.09 (dd, H-2'b), 1.39 and 1.40 (each s, 3 H, CMe_2), 2.10 (s, 6 H, Ac), 3.37 (s, 3 H, OMe); ^{13}C-n.m.r.: δ 97.58 (d, C-1), 76.72, 65.23 and 73.90 (each d, C-2, C-5 and C-1'), 70.54 (s, C-3), 38.41 (t, C-4), 65.34 and 65.83 (each t, C-6 and C-2'), 55.48 (q, OMe), 20.81 and 20.91 (each q, Ac), 107.71 (s, *C*Me$_2$), 169.91 and 170.78 (each s, Ac).

Anal. Calc. for $C_{16}H_{26}O_9$: C, 53.03; H, 7.23. Found: C, 52.80; H, 7.32.

Compound **23** was a syrup, $[\alpha]_D$ +68.9° (*c* 0.3, $CHCl_3$); ^{1}H-n.m.r.: δ 4.86 (d, $J_{1,2}$ 3.5 Hz, H-1), 5.41 (dd, $J_{2,3}$ 11.8 Hz, H-2), 2.52 (ddd, $J_{3,4}$ 2.9 Hz, $J_{3,4'}$ 4.0 Hz, H-3), 5.32 (d, $J_{4,5}$ 0 Hz, H-4), 4.10 (dd, $J_{5,6a}$ 13.2 Hz, $J_{5,6b}$ 5.5 Hz, H-5), 3.99 (dd, $J_{6a,6b}$ 13.2 Hz, H-6a), 4.13 (dd, H-6b), 4.16 (dt, $J_{1',2'a}$ 7.0 Hz, $J_{1',2'b}$ 7.0 Hz, H-1'), 3.87 (dd, $J_{2'a,2'b}$ 8.0 Hz, H-2'a), 3.91 (dd, H-2'b), 1.23 and 1.33 (each s, 3 H, CMe_2), 2.05, 2.07 and 2.10 (each s, 3 H, Ac), 3.43 (s, 3 H, OMe); ^{13}C-n.m.r.: δ 96.77 (d, C-1), 67.62 (2C), 69.24 and 74.77 (each d, C-2, C-4, C-5, and C-1'), 39.61 (d, C-3), 62.57 (t, C-6), 67.62 (t, C-2'), 55.26 (q, OMe), 20.75, 20.91 and 21.13 (each q, Ac), 24.33 and 26.11 (each q, CMe_2), 109.12 (s, *C*Me$_2$), 170.35 (s, 3 C, Ac).

Anal. Calc. for $C_{18}H_{28}O_{10}$: C, 53.46; H, 6.98. Found: C, 52.96; H, 7.02.

Reduction of **21** *with diisobutylaluminium hydride (DIBAL) or sodium bis(2-methoxyethoxy)aluminium hydride (RedAl).* — Compound **20** was first deacylated with sodium methoxide in methanol in the conventional manner to give **21** quantitatively, whose homogeneity was ascertained only by ^{13}C-n.m.r.: δ 96.34 (d, C-1), 66.33 and 67.01 (each d, C-2 and C-5), 57.84 (s, C-3), 53.94 (d, C-4), 62.67 (t, C-6), 72.57 (d, C-1'), 65.74 (t, C-2'), 109.47 (s, *C*Me$_2$), 55.79 (q, OMe), 25.62 and 25.96 (each q, CMe_2). Reduction of **21** with DIBAL or RedAl was carried out according to conditions shown in Table II, and the mixture was processed as just described.

*Methyl 2,2'-di-*O*-acetyl-4,6-*O*-benzylidene-3-*C*-[(*R*)-1,2-dihydroxyethyl]-α-*D*-glucopyranoside* (**24**). — Compound **10** (1.0 g, 2.6 mmol) was hydroxylated in the same manner as described for **14** and the product was purified on a column of silica gel with 1:1 hexane–ethyl acetate to give **24** (1.1 g, 57%), $[\alpha]_D$ +120.9° (*c* 1.0, $CHCl_3$, ^{1}H-n.m.r. (400 MHz): δ 4.80 (d, $J_{1,2}$ 4.0 Hz, H-1), 5.11 (d, H-2), 3.79 (d, $J_{4,5}$ 9.8 Hz, H-4), 4.02 (dt, $J_{5,6a}$ 4.8 Hz, $J_{5,6b}$ 10.0 Hz, H-5), 4.36 (dd, $J_{6a,6b}$ 9.8 Hz, H-6a), 3.77 (dd, H-6b), 4.31 (dd, $J_{1',2'a}$ 11.8 Hz, $J_{1',2'b}$ 6.9 Hz, H-1'), 4.63 and 4.66 (each dd, H-2'a and H-2'b), 3.44 (s, OMe), 2.10 and 2.15 (each s, Ac); ^{13}C-n.m.r.: δ 98.39 (d, C-1), 74.09 (d, C-2), 74.38 (s, C-3), 86.73 (d, C-4), 62.28 (d, C-5), 69.45 (t, C-6), 71.06 (d, C-1'), 66.23 (t, C-2'), 21.13 and 21.28 (each q, Ac), 56.03 (q,

OMe), 102.74 (d, PhCH), 126.51, 128.80 and 129.77 (each d, Ph), 137.19 (s, Ph), 170.28 and 171.50 (each s, Ac).

Anal. Calc. for $C_{20}H_{26}O_{10}$: C, 56.34; H, 6.15. Found: C, 56.32; H, 6.12.

Methyl 2,2^1-anhydro-4,6-O-benzylidene-3-C-[(R)-1,2-dihydroxyethyl]-α-D-glucopyranoside (**26**). — Compound **24** (0.26 g, 0.61 mmol) was deacetylated conventionally with sodium methoxide in methanol to give **25** quantitatively, which was treated with camphorsulfonyl chloride (0.15 g, 0.35 mmol) in pyridine (5 mL) at room temperature for 20 h. The solution was poured into saturated aqueous sodium chloride, and extracted with chloroform. The residue obtained by evaporation of the dried extract was purified on a silica gel column with 1:2 hexane–ethyl acetate to give **26** (0.14 g, 72%), $[\alpha]_D$ +74.7° (*c* 1.1, $CHCl_3$); ^{1}H-n.m.r. (500 MHz): δ 4.71 (d, $J_{1,2}$ 5.2 Hz, H-1), 4.08 (d, H-2), 3.88 (d, $J_{4,5}$ 9.6 Hz, H-4), 3.78 (ddd, $J_{5,6a}$ 9.6 Hz, $J_{5,6b}$ 4.6 Hz, H-5), 3.73 (t, $J_{6a,6b}$ 9.6 Hz, H-6a), 4.30 (dd, H-6b), 4.82 (dd, $J_{1^1,2^1a} = J_{1^1,2^1b}$ 7.8 Hz, H-1^1), 4.25 (dd, $J_{2^1a,2^1b}$ 7.8 Hz, H-2^{1}a), 3.66 (dd, H-2^{1}b), 3.39 (s, OMe), 5.52 (s, PhCH), 7.34–7.46 (m, Ph); ^{13}C-n.m.r.: δ 100.87 (d, C-1), 83.40 (d, C-2), 77.34 (s, C-3), 84.28 (d, C-4), 60.40 (d, C-5), 70.15 (t, C-6), 72.21 (d, C-1^1), 73.61 (t, C-2^1), 56.23 (q, OMe), 103.55 (d, PhCH), 127.69, 129.93 and 130.85 (each d, Ph), 138.84 (s, Ph).

Anal. Calc. for $C_{16}H_{20}O_7$: C, 59.26; H, 6.22. Found: C, 59.35; H, 6.22.

Conventional acetylation of **26** gave its 1^1-acetate (**27**), syrup, $[\alpha]_D$ +2.7° (*c* 1.2, $CHCl_3$), ^{1}H-n.m.r.: δ 4.82 (d, $J_{1,2}$ 5.5 Hz, H-1), 4.17 (d, H-2), 3.77–4.13 (m, H-4, H-5, H-6a and H-2b), 4.29–4.50 (m, H-6b), 5.50 (dd, $J_{1^1,2^1a} = J_{1^1,2^1b}$ 7.6 Hz, H-1^1), 4.54 (t, $J_{2^1a,2^1b}$ 7.6 Hz, H-2^{1}a), 2.65 (s, Ac), 3.50 (s, OMe), 5.64 (s, PhCH), 7.26–7.72 (m, Ph); ^{13}C-n.m.r.: δ 99.32 (d, C-1), 81.94 (d, C-2), 76.92 (s, C-3), 82.33 (d, C-4), 59.30 (d, C-5), 69.06 (t, C-6), 71.79 (d, C-1^1), 72.18 (t, C-2^1), 20.50 (q, Ac), 55.64 (q, OMe), 102.40 (d, PhCH), 126.26; 128.07 and 129.14 (each d, Ph), 137.24 (s, Ph), 169.31 (s, Ac).

Anal. Calc. for $C_{18}H_{22}O_8$: C, 59.02; H, 6.05. Found: C, 58.96; H, 6.13.

Methyl 2,2^1-anhydro-4,6-O-benzylidene-3-C-hydroxyacetyl-α-D-glucopyranoside (**28**). — Swern oxidation of **26** (0.16 g, 0.48 mmol) was performed as described for **15** and the product was purified on a column of silica gel with 2:1 hexane–ethyl acetate to give **28** (0.12 g, 78%), syrup, $[\alpha]_D$ +6.1° (*c* 1.2, $CHCl_3$); ^{1}H-n.m.r.: δ 4.92 (s, $J_{1,2}$ 5.6 Hz, H-1), 4.44 (d, H-2), 3.72–4.68 (m, 7 H), 3.42 (s, OMe), 5.64 (s, PhCH), 7.32–7.64 (m, Ph); ^{13}C-n.m.r.: δ 100.18 (d, C-1), 79.86 (d, C-2), 76.18 (s, C-3), 58.79 (d, C-4), 80.24 (d, C-5), 68.97 (t, C-6), 158.58 (s, C-1^1), 72.00 (t, C-2^1), 55.76 (q, OMe), 101.97 (d, PhCH), 125.97, 128.30 and 129.33 (each d, Ph), 137.95 (s, Ph).

Anal. Calc. for $C_{16}H_{18}O_7$: C, 59.63; H, 5.63. Found: C, 59.47; H, 5.82.

Methyl 2,2^1-anhydro-4,6-O-benzylidene-3-C-[(S)-1,2-dihydroxyethyl)-α-D-glucopyranoside (**29**). — The compound **28** (59 mg, 0.18 mmol) was reduced with sodium borohydride as described for **15** and the product was purified on a column of silica gel with 1:2 hexane–ethyl acetate to give **29** (57 mg, 95%), syrup $[\alpha]_D$ +57.6° (*c* 0.9, $CHCl_3$); ^{1}H-n.m.r. (500 MHz): δ 4.77 (d, $J_{1,2}$ 5.0 Hz, H-1), 4.14 (d,

H-2), 3.95 (d, $J_{4,5}$ 10 Hz, H-4), 3.86 (dt, $J_{5,6a}$ 10 Hz, $J_{5,6b}$ 5.0 Hz, H-5), 3.84 (t, $J_{6a,6b}$ 9.6 Hz, H-6a), 4.34 (dd, H-6b), 4.96 (dd, $J_{1',2'a} = J_{1',2'b}$ 7.8 Hz, H-1'), 4.32 (t, $J_{2'a,2'b}$ 7.8 Hz, H-2'a), 3.74 (t, H-2'b), 3.43 (s, OMe), 5.57 (s, PhCH), 7.26–7.45 (m, Ph); ^{13}C-n.m.r.: δ 99.32 (d, C-1), 81.94 (d, C-2), 76.92 (s, C-3), 82.33 (d, C-4), 59.30 (d, C-5), 69.06 (t, C-6), 71.79 (d, C-1'), 72.18 (t, C-2'), 20.50 (q, Ac), 55.64 (q, OMe), 102.40 (d, PhCH), 126.26, 128.07 and 129.14 (each d, Ph), 137.24 (s, Ph), 169.31 (s, Ac).

Anal. Calc. for $C_{16}H_{20}O_7$: C, 59.26; H, 6.22. Found: C, 59.13; H, 6.23.

Conventional acetylation of **29** gave its 1'-acetate (**30**), syrup, $[\alpha]_D$ +55.3° (*c* 1.0, $CHCl_3$); ^{1}H-n.m.r.: δ 4.73 (d, $J_{1,2}$ 5.2 Hz, H-1), 4.07 (d, H-2), 3.55–3.98 (m, H-4, H-5, H-6a and H-2'b), 4.16–4.31 (m, H-6b), 5.83 (dd, $J_{1',2'a} = J_{1',2'b}$ 7.7 Hz, H-1'), 4.42 (t, $J_{2'a,2'b}$ 7.7 Hz, H-2'a), 1.90 (s, Ac), 3.43 (s, OMe), 5.45 (s, PhCH), 7.25–7.48 (m, Ph); ^{13}C-n.m.r.: δ 99.48 (d, C-1), 81.81 (d, C-2), 77.05 (s, C-3), 82.52 (d, C-4), 59.38 (d, C-5), 69.19 (t, C-6), 71.95 (d, C-1'), 71.41 (t, C-2'), 20.59 (q, Ac), 55.75 (q, OMe), 102.56 (d, PhCH), 126.35, 128.19 and 129.28 (each d, Ph), 137.30 (s, Ph), 169.48 (s, Ac).

Anal. Calc. for $C_{18}H_{22}O_8$: C, 59.02; H, 6.05. Found: C, 59.01; H, 6.16.

Methyl 2,2'-anhydro-3,1'-di-O-benzyl-4,6-O-benzylidene-3-C-[(S)-1,2-dihydroxyethyl]-α-D-glucopyranoside (**31**). — To a suspension of sodium hydride (0.42 g, 17.5 mmol) in Me_2SO, which had been stirred for 4 h at 40°, was added with stirring a solution of **29** (1.03 g, 3.2 mmol) in Me_2SO (5 mL), and then, after 2 h, benzyl chloride (1.46 mL, 12.7 mmol). After 2 h the mixture was poured into saturated aqueous sodium chloride and extracted with ether. Conventional isolation and purification on a column of silica gel gave **31** (1.4 g, 87%), syrup, $[\alpha]_D$ +18.6° (*c* 0.84, $CHCl_3$); ^{1}H-n.m.r.: δ 3.60–4.82 (m, 11 H), 3.37 (s, OMe), 4.98 and 5.14 (ABq, CH_2 in Bn, J_{AB} 12.0 Hz), 5.44 (s, PhCH), 7.12–7.60 (m, Ph, 15 H); ^{13}C-n.m.r.: δ 98.99 (d, C-1), 81.49 (d, C-2), 81.76 (s, C-3), 82.68 (d, C-4), 59.98 (d, C-5), 68.59 (t, C-6), 79.81 (d, C-1'), 69.51 (t, C-2'), 55.59 (q, OMe), 72.60 and 73.04 (each t, CH_2 in Bn), 101.80 (d, PhCH), 127.16, 127.38, 128.14 and 128.95 (each d, Ph), 137.30, 138.54 and 139.90 (each s, Ph).

Anal. Calc. for $C_{30}H_{32}O_7$: C, 71.42; H, 6.34. Found: C, 71.42; H, 6.39.

Methyl 2,2'-anhydro-3,4,1'-tri-O-benzyl-3-C-[(S)-1,2-dihydroxyethyl]-α-D-glucopyranoside (**32**). — To a chilled suspension of $LiAlH_4$ (510 mg, 1.3 mmol) in a mixed solution of dry ether (10 mL) and dichloromethane (10 mL) was added dropwise a solution of **31** (0.55 g, 1.3 mmol) and then aluminium trichloride (0.18 g, 1.3 mmol) in dry ether (10 mL). The mixture was heated under reflux for 3 h, mixed carefully with water, and extracted with ether and chloroform. The residue obtained by evaporation of the dried extract was purified on a column of silica gel with 1:1 hexane–ethyl acetate to give **32** (0.46 g, 82%), syrup, $[\alpha]_D$ +59.4° (*c* 0.9 $CHCl_3$); ^{1}H-n.m.r.: δ 3.40–4.76 (m, 11 H), 3.30 (s, OMe), 4.96 (t, CH_2 in Bn), 7.13–7.68 (m, Ph, 15 H); ^{13}C-n.m.r.: δ 98.73 (d, C-1), 80.04 (d, C-2), 86.04 (s, C-3), 80.48 (d, C-4), 67.69 (d, C-5), 62.47 (t, C-6), 76.87 (d, C-1'), 66.96 (t, C-2'), 55.05 (q, OMe), 73.26, 74.09 and 74.38 (each t, CH_2 in Bn), 126.75, 127.19, 127.48, 128.11 and 128.31 (each d, Ph), 138.42, 138.61 and 139.29 (each s, Ph).

Anal. Calc. for $C_{30}H_{34}O_7$: C, 71.13; H, 6.77. Found: C, 70.80; H, 6.84.

Conventional acetylation of **32** gave **33**, $[\alpha]_D$ +64.1° (*c* 2.2, $CHCl_3$); ^{1}H-n.m.r.: δ 3.86–5.14 (m, 15 H), 1.96 (s, Ac), 3.36 (s, OMe), 7.04–7.56 (m, Ph, 15 H); ^{13}C-n.m.r.: δ 98.72 (d, C-1), 80.02 (d, C-2), 86.15 (s, C-3), 80.46 (d, C-4), 65.61 (d, C-5), 63.55 (t, C-6), 76.29 (d, C-1^1), 67.18 (t, C-2^1), 20.70 (q, Ac), 55.10 (q, OMe), 73.36 and 74.17 (each t, CH_2 in Bn), 127.27, 127.43, 127.65, 128.19 and 128.41 (each d, Ph), 138.16, 138.54 and 139.25 (each s, Ph), 170.56 (s, Ac).

Anal. Calc. for $C_{32}H_{36}O_8$: C, 70.06; H, 6.61. Found: C, 70.08; H, 6.84.

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