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Synthesis of methyl 2-*O*-allyl-(and 3-*O*-allyl-)5-*O*-benzyl-β-D-ribofuranoside [1]

Trupti Desai, Jill Gigg, Roy Gigg *

Division of Lipid and General Chemistry, National Institute for Medical Research, Mill Hill, London NW7 1AA, UK

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Abstract

D-Ribose was converted into methyl 5-*O*-benzyl-β-D-ribofuranoside and this, on tin-mediated allylation, gave a mixture of the 2-*O*-allyl and 3-*O*-allyl derivatives which were separated by chromatography. The more polar isomer was characterised as the 3-*O*-allyl derivative after conversion via 3-*O*-allyl-5-*O*-benzyl-1,2-*O*-isopropylidene-α-D-ribofuranose (which was also synthesised from 3-*O*-allyl-1,2:5,6-di-*O*-isopropylidene-α-D-allofuranose) into the known 5-*O*-benzyl-1,2-*O*-isopropylidene-α-D-ribofuranose. Methyl 3-*O*-allyl-5-*O*-benzyl-β-D-ribofuranoside was converted into methyl 2-*O*-allyl-5-*O*-benzyl-β-D-ribofuranoside via methyl 2-*O*-allyl-5-*O*-benzyl-3-*O*-(prop-1-enyl)-β-D-ribofuranoside.

Keywords: Allyl ethers; Methyl 3-*O*-allyl-5-*O*-benzyl-β-D-ribofuranoside; Methyl 2-*O*-allyl-5-*O*-benzyl-β-D-ribofuranoside; 'Adenophostin' analogue; Inositol trisphosphate receptor; 'Glucositol trisphosphate'

1. Introduction

Japanese scientists reported recently [2,3] that the two compounds **1** and **2** ('adenophostins A and B'), isolated from the culture medium of *Penicillium brevicompactum*, were 100-fold [2] more active than 1D-*myo*-inositol 1,4,5-trisphosphate (IP_3, **5**) at the IP_3-receptor (IP_3R). We therefore synthesised [4] 2-hydroxyethyl α-D-glucopyranoside 2',3,4-trisphosphate (**3**, 'glucositol trisphosphate') which appears to be a minimal structure (analogous to the 'adenophostins') with respect to the three phosphate esters,

* Corresponding author.

[1] The Allyl Group for Protection in Carbohydrate Chemistry, Part 30. For Part 29, see ref. [1].

[2] A recent paper [*FEBS Lett.*, 368 (1995) 248–252] shows that in a different assay system the potency may be only 10 times that of IP_3.

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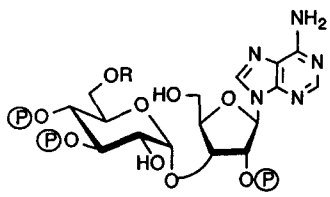
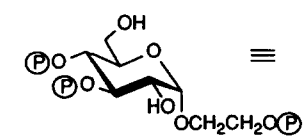
and this was shown [5] to be ca. 10-fold less active than IP_3 at the IP_3R; but nevertheless is the first synthetic compound [3], active at the IP_3R, which is not an inositol phosphate derivative. Like the 'adenophostins' [2], 'glucositol trisphosphate' **3** is resistant [5] to the enzymes 3-kinase and 5-phosphatase that normally metabolise IP_3 and it should be valuable for research on the IP_3R. If **3** is drawn as in **4**, the relationship to IP_3 (**5**) is more apparent and the molecule can be seen to fit the criteria for activity in the inositol phosphate series as outlined by Kozikowski et al. [6].

Since the activity of **3** at the IP_3R is considerably less than that reported for **1** and **2** we decided to synthesise a molecule more closely related to the 'adenophostins' and chose methyl 3-*O*-α-D-glucopyranosyl-β-D-ribofuranoside 2,3′,4′-trisphosphate (**6**) as our new model and for this purpose methyl 2-*O*-allyl-5-*O*-benzyl-β-D-ribofuranoside (**32**) was required as an intermediate.



1 R = H
2 R = Ac



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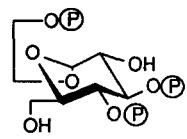

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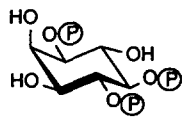

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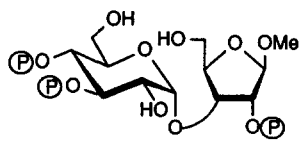

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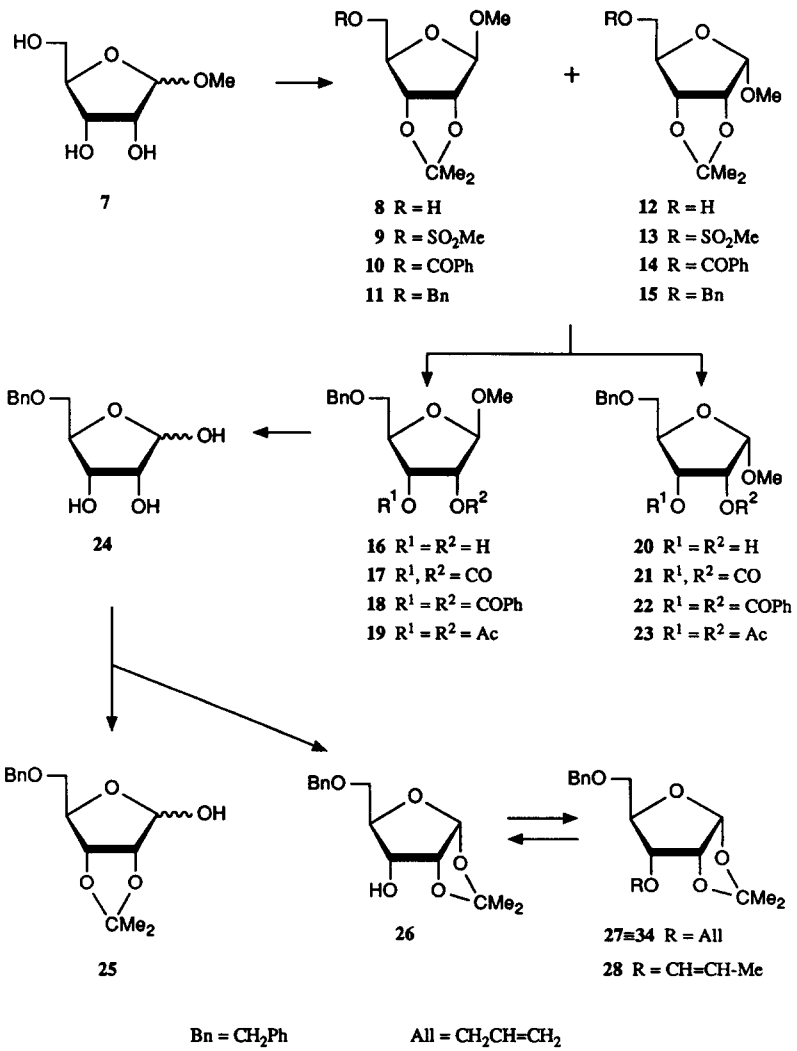
Ⓟ = $P(O)(O^-)_2$

2. Results and discussion

D-Ribose was converted into the mixture of methyl α- and β-ribofuranosides (**7**) essentially as described by Barker and Fletcher [7]. This mixture was treated with acetone and an acid catalyst to give a mixture of β (**8**, major isomer) and α (**12**) methyl 2,3-*O*-isopropylidene-D-ribofuranosides which were readily separated by column chromatography. Although the β-ribofuranoside **8** has been prepared on numerous occasions

[3] Since the submission of the manuscript another synthetic analogue of IP_3, not an inositol phosphate, has been described [*J. Am. Chem. Soc.*, 117 (1995) 3300–3301] as well as a further synthesis of compound **3** by a different method [*J. Chem. Soc., Chem. Commun.*, (1995) 1169–1170] and a synthesis of adenophostin A [*Tetrahedron Lett.*, 36 (1995) 5037–5040].

most preparations refer back to those of Levene and Stiller [8] or Leonard and Carraway [9] where **8** was isolated by distillation. There is little indication in the literature whether these preparations [8,9] of the methyl β-furanoside **8** were free from the methyl α-furanoside **12** (see refs. [10–12]) although **8** and **12** are readily distinguished by TLC. By contrast to the numerous publications describing **8**, the α anomer **12** has been little investigated. The mesylate **9** of the β-ribofuranoside **8** is crystalline and well characterised [13] whereas the syrupy mesylate **13** of the α-ribofuranoside **12** is characterised here for the first time. Likewise the crystalline benzoate **14** of the α-ribofuranoside **12** has been characterised [14] previously (being prepared together with the β anomer **10** on reaction of 5-*O*-benzoyl-2,3-*O*-isopropylidene-β-D-ribofuranosyl bromide with silver carbonate and methanol) but the syrupy **10** has not been fully characterised previously.



The alcohols **8** and **12** were individually converted into the benzyl ethers **11** and **15**, respectively. Compound **11** has been described on numerous occasions (see refs. [10] and [15]) whereas **15** has been characterised here for the first time. Hydrolysis of the isopropylidene group from either **11** or **15** in refluxing acidic methanol gave the same mixture (as observed by TLC) of β- and α-furanosides **16** and **20** in which the β-furanoside **16** predominated although it is reported [10] that 'the isopropylidene group could be removed selectively from **11** by heating in methanolic sulfuric acid' and the presence of **16** and **20** in the product was assumed [10] to be due to a mixture of **11** and **15** in the starting material.

The stability of the isopropylidene group (in **8** and **12**) in the presence of acetone and acidic methanol was made use of in the original preparation [8] of **8** by Levene and Stiller, and the hydrolysis of the isopropylidene groups from **11** and **15** does not go to completion in dry methanol; therefore water has been added [16] to the hydrolysis mixture to improve the yield of diols **16** and **20**. We find that azeotropic distillation of the dimethoxypropane formed in anhydrous methanolysis of the isopropylidene group allows the reaction to go to completion. Compounds **16** and **20** were separated on TLC and pure **16** was isolated by chromatography; a later fraction containing a mixture of **16** and **20** was used for the preparation of pure **20** and its derivatives.

The crystalline dibenzoate **18** of the β-ribofuranoside **16** has been described [17]. Both of the dibenzoates **18** and **22** were prepared here and were obtained as syrups which have been characterised.

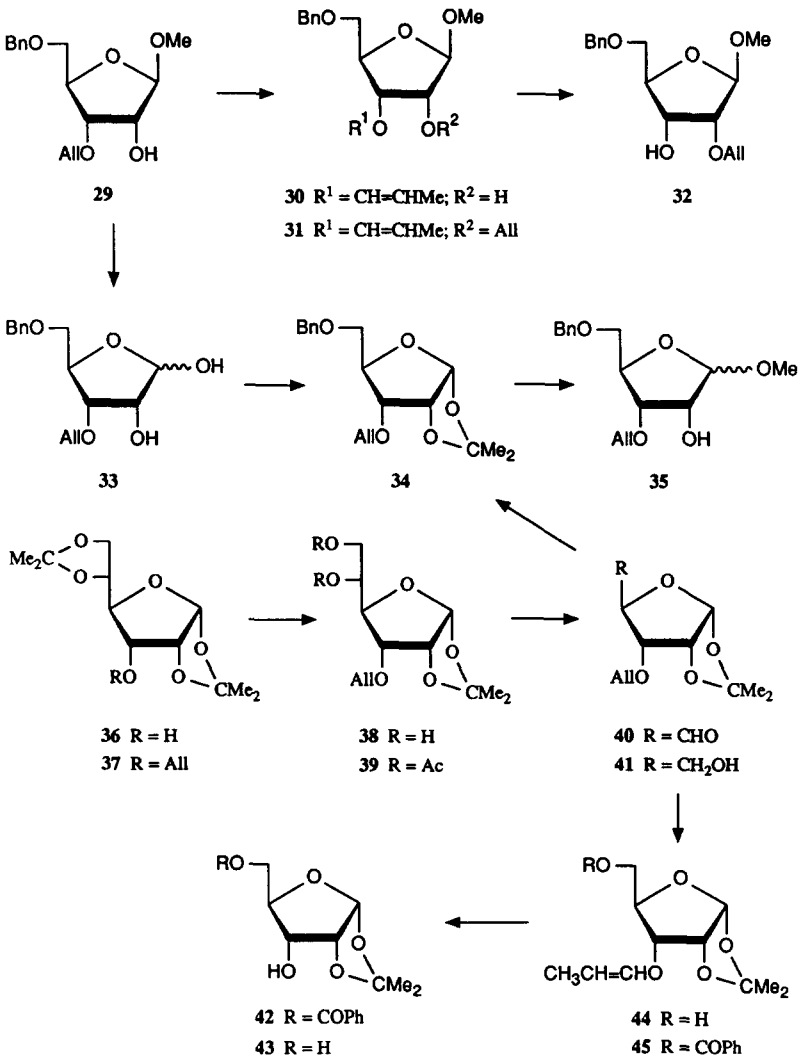
The crystalline carbonates **17** and **21** have also been described [10] and were prepared here for characterisation purposes by reaction of the diols **16** and **20** with ethylene carbonate and a trace of $NaHCO_3$ at 120 °C (cf. ref. [18]). The diacetates **19** and **23** were also characterised.

Treatment of the diol **16** with an excess of dibutyltin oxide and tetrabutylammonium bromide in refluxing allyl bromide–CH_3CN (1:1) in a Soxhlet apparatus containing 3 Å molecular sieves gave a mixture of the allyl ethers **29** and **32** in approximately equal amounts (TLC) and they were separated by chromatography. To distinguish between the isomers **29** and **32**, the more polar isomer **29** was hydrolysed to give the free ribofuranose derivative **33** and this on treatment with dimethoxypropane and an acid catalyst gave the *O*-isopropylidene derivative **34**, thus confirming that the 1- and 2-hydroxy groups were free and that the more polar isomer was the 3-allyl ether **29**.

For confirmation of the structure of compound **34** it was also prepared from 1,2:5,6-di-*O*-isopropylidene-α-D-allofuranose (**36**). The latter was converted into the allyl ether **37** and partial hydrolysis of **37** gave the diol **38** which on oxidation with periodate and subsequent reduction of the aldehyde **40** gave the alcohol **41**. Benzylation of the latter gave **34** identical with the material prepared as described above.

For confirmation of the structure of compound **41**, the allyl group was isomerised [19] to give the prop-1-enyl ether **44** which on benzoylation gave **45**. The prop-1-enyl group was removed by the action of $HgCl_2$–HgO in aqueous acetone [20] to give the benzoate **42** with properties similar to those reported [21]. Saponification of **42** gave the diol **43** with properties similar to those reported [22].

Since the required 2-allyl ether **32** was thus established as the less polar isomer, the conversion of the more polar isomer **29** into **32** was also investigated. The allyl ether **29**



was isomerised [19] with potassium *tert*-butoxide in Me_2SO to give the prop-1-enyl ether **30** and this was allylated to give **31**. Hydrolysis [20] of the prop-1-enyl group from **31** with $HgCl_2$–HgO gave **32** identical with the material prepared as described above.

Since it was thus possible to convert **29** into the required 2-*O*-allyl derivative **32**, the route to **29** from the available D-allofuranose **36** via compounds **38**, **41**, and **34** was considered and a further route to **34** was also investigated. Thus acid hydrolysis of **16** or **20** (or a mixture of both) gave the known [23a] 5-*O*-benzyl-D-ribofuranose (**24**) which on treatment with dimethoxypropane and an acid catalyst in acetone gave a mixture of products from which the known [23] **26** was isolated in low yield by chromatography. The structure of **26** was confirmed as follows: isomerisation [19] of the allyl group in

(**34** ≡ **27**) gave the prop-1-enyl ether **28** and the prop-1-enyl group was removed by $HgCl_2$–HgO [20] to give **26** identical with the material prepared as described above from **24**. Thus allylation of **26** (prepared from **24**) would provide a further route to **34** ≡ **27**. However, acid methanolysis of **34** gave a mixture of anomers **35** (predominantly the β anomer **29** as observed by NMR) which were not separable on TLC and thus the route from **34** to **29** was not considered practical for a preparation of the pure β anomer.

3. Experimental

General.—The general methods were as described [24] except for optical rotations. NMR spectroscopy was carried out on a Jeol FX90Q instrument in $CDCl_3$ solution unless otherwise stated.

Methyl 2,3-O-isopropylidene-β-D-ribofuranoside (**8**) *and -α-D-ribofuranoside* (**12**).—D-Ribose was converted into the mixture of methyl α- and β-D-ribofuranosides (**7**) by a slight modification of the procedure of Barker and Fletcher [7]. Thus D-ribose (10 g) was dissolved in dry MeOH (200 mL) containing H_2SO_4 (0.92 g) and the solution was kept at 20 °C for 20 h. The solution was then stirred with an excess of Amberlite IR-45(OH) (prewashed with MeOH) until the solution was neutral. TLC (8:1 EtOAc–MeOH) showed two products (R_f 0.5 and 0.35, ca. 4:1; cf. ref. [25]). Triethylamine (5 mL) was added, the solution was concentrated, and toluene was evaporated from the residue. ^{1}H-NMR (CD_3COCD_3) then showed OMe peaks at δ 3.31 and 3.37 (ca. 4:1, respectively). The syrup was dissolved in dry acetone (300 mL) containing toluene-*p*-sulfonic acid (500 mg) and the solution was kept at 20 °C for 20 h. Triethylamine (5 mL) and $NaHCO_3$ (5 g) were added and the solution was concentrated. TLC (4:1 ether–light petroleum) then showed two products (R_f 0.7 and 0.3; ca. 4:1, for **8** and **12**, respectively). The ^{1}H-NMR spectrum of the mixture showed CMe_2 peaks at δ 1.31, 1.48 (for **8**) and 1.36, 1.57 (for **12**) (ca. 4:1, respectively) and OMe peaks at δ 3.42 (for **8**) and 3.47 (for **12**) (ca. 4:1, respectively).

The two anomers were separated by column chromatography. The β anomer (**8**, 8.53 g) was eluted with 2:1 ether–light petroleum and the α anomer (**12**, 2.45 g) with ether (i.e., β:α = 3.5:1 and total yield = 81%). The β anomer **8** had $[\alpha]_D^{19}$ −68.4° (*c* 2.2, $CHCl_3$) {lit. [26] $[\alpha]_D$ −75° (*c* 2, $CHCl_3$); lit. [9] $[\alpha]_D^{19}$ −82.2° (*c* 2, $CHCl_3$)}; ^{1}H-NMR data: δ 1.31, 1.48 (2 s, each 3 H, CMe_2), 3.15–3.30 (m, 1 H), 3.43 (s, 3 H, OMe), 3.58–3.71 (m, 2 H), 4.43 (t, 1 H, *J* 3.1 Hz), 4.58 (d, 1 H, *J* 5.5 Hz), 4.83 (d, 1 H, *J* 6.1 Hz), 4.97 (s, 1 H, H-1) (cf. ref. [9]). This gave a methanesulfonate **9**; mp 81–82.5 °C (from light petroleum, bp 60–80 °C); $[\alpha]_D^{19}$ −55.6° (*c* 1.87, $CHCl_3$) {lit. [13b] mp 82 °C, $[\alpha]_D^{20}$ −56.7° (*c* 1.2, MeOH); lit [13a] mp 78–79 °C, $[\alpha]_D^{24}$ −53.0° (*c* 1.86, $CHCl_3$)}; ^{1}H-NMR data: δ 1.32, 1.48 (2 s, each 3 H, CMe_2), 3.07 (s, 3 H, SMe), 3.34 (s, 3 H, OMe), 4.15–4.74 (m, 5 H, with major peaks at 4.15, 4.18, 4.24, 4.35, 4.63, and 4.67), 4.99 (s, 1 H, H-1). Compound **8** gave a syrupy benzoate **10** $[\alpha]_D^{20}$ −49.3° (*c* 2.5, $CHCl_3$); ^{1}H-NMR data: δ 1.34, 1.50 (2 s, each 3 H, CMe_2), 3.34 (s, 3 H, OMe), 4.30–4.82 (m, 5 H, with major peaks at 4.30, 4.33, 4.39, 4.47, 4.61, 4.68, 4.75, and

4.82), 5.02 (s, 1 H, H-1), 7.30–8.16 (m, 5 H, Ph) (cf. ref. [14]). Anal. Calcd for $C_{16}H_{20}O_6$: C, 62.33; H, 6.54. Found: C, 62.46; H, 6.45.

The α anomer **12** had $[\alpha]_D^{19}$ +83° (*c* 2.4, $CHCl_3$); ^{1}H-NMR data: δ 1.36, 1.57 (2 s, each 3 H, CMe_2), 3.48 (s, 3 H, OMe), 3.79 (m, 2 H), 4.16 (m, 1 H), 4.65–4.69 (m, 2 H), 4.93 (m, 1 H, H-1). Anal. Calcd for $C_9H_{16}O_5$: C, 52.93; H, 7.90. Found: C, 52.66; H, 7.65.

Compound **12** gave a crystalline benzoate **14**; mp 46–48 °C; $[\alpha]_D^{19}$ +48.5° (*c* 3, $CHCl_3$) {lit. [14] mp 44–45 °C, $[\alpha]_D^{20}$ +47.9° (*c* 2, $CHCl_3$)}; ^{1}H-NMR data: δ 1.38, 1.59 (2 s, each 3 H, CMe_2), 3.50 (s, 3 H, OMe), 4.40–4.52 (m, 3 H, with a major peak at 4.47), 4.64–4.83 (m, 2 H), 4.97 (d, 1 H, *J* 4.3 Hz, H-1) (cf. ref. [14]). Compound **12** gave a syrupy methanesulfonate **13**; $[\alpha]_D^{19}$ +64° (*c* 2.4, $CHCl_3$); ^{1}H-NMR data: δ 1.36, 1.57 (2 s, each 3 H, CMe_2), 3.07 (s, 3 H, SO_2Me), 3.48 (s, 3 H, OMe), 4.28–4.41 (m, 3 H, with a major peak at 4.36), 4.60–4.78 (m, 2 H), 4.94 (d, 1 H, *J* 4.3 Hz, H-1). Anal. Calcd for $C_{10}H_{18}O_7S$: C, 42.54; H, 6.43; S, 11.36. Found: C, 42.41; H, 6.53; S, 10.28.

On TLC (4:1 ether–light petroleum) the methanesulfonates **9** (R_f 0.55) and **13** (R_f 0.3) were well separated. TLC (1:1, ether–light petroleum) of the benzoates **10** (R_f 0.75) and **14** (R_f 0.5) also showed good separation.

*Methyl 5-O-benzyl-2,3-O-isopropylidene-β-*D*-ribofuranoside* (**11**) *and -α-*D*-ribofuranoside* (**15**).—The alcohols **8** and **12** were benzylated individually with NaH and benzyl bromide in DMF in the usual way. The syrupy β anomer (**11**) had $[\alpha]_D^{19}$ −53° (*c* 1.3, $CHCl_3$) {lit. [27] $[\alpha]_D^{17}$ −36° (*c* 1.3, $CHCl_3$); lit. [28] $[\alpha]_D^{21}$ −52.3° (*c* 1.59, benzene)}; ^{1}H-NMR data: δ 1.31, 1.48 (2 s, each 3 H, CMe_2), 3.28 (s, 3 H, OMe), 3.44 (d, 1 H), 3.52 (s, 1 H), 4.37 (t, 1 H, *J* 7.3 Hz), 4.55–4.71 (m, 4 H, with major peaks at 4.55, 4.58, and 4.65), 4.95 (s, 1 H, H-1), 7.32 (s, 5 H, Ph).

The syrupy α anomer (**15**) had $[\alpha]_D^{20}$ +39.0° (*c* 2.4, $CHCl_3$); ^{1}H-NMR data: δ 1.36, 1.57 (2 s, each 3 H, CMe_2), 3.49 (s, 3 H, OMe), 3.60 (d, 2 H, *J* 3.7 Hz), 4.26 (m, 1 H), 4.56 (s, 2 H), 4.67 (d, 2 H, *J* 3.1 Hz), 4.93–4.98 (d, 1 H, *J* 3.6 Hz, H-1), 7.32 (s, 5 H, Ph). Anal. Calcd for $C_{16}H_{22}O_5$: C, 65.29; H, 7.53. Found: C, 64.81; H, 7.30.

On TLC (1:2 ether–light petroleum), **11** (R_f 0.5) and **15** (R_f 0.2) were well separated.

*Methyl 5-O-benzyl-β-*D*-ribofuranoside* (**16**) *and -α-*D*-ribofuranoside* (**20**).—When the pure isopropylidene derivatives **11** and **15** were individually heated at reflux with 0.1 M H_2SO_4 in dry MeOH for 1 h they both gave the same mixture of anomers (**16** and **20**) as observed by TLC (EtOAc) in the ratio of β (**16**, R_f 0.6) to α (**20**, R_f 0.5 with streaking) of ca. 4:1.

For the preparative scale methanolysis, a solution of the pure β anomer (**11**, 4.83 g) in dry MeOH (100 mL) containing H_2SO_4 (0.46 g) (i.e., ca. 0.1 M H_2SO_4 in MeOH) was heated under reflux for 1.5 h during which time the solvent (150 mL) was allowed to distil off slowly whilst more dry MeOH (150 mL) was added dropwise, at the same rate, to the reaction mixture from a dropping funnel. After this time, TLC (1:2 ether–light petroleum) showed complete methanolysis of **11** (R_f 0.7) to a product (R_f 0) and TLC (EtOAc) showed the presence of **16** and **20** as described above. $NaHCO_3$ (10 g) was added to the cooled solution and after stirring for 1 h the solvent was evaporated and toluene was evaporated from the residue. The products were extracted from the residue with ether and column chromatography (ether) gave pure **16** (2.5 g,

60%) and a mixture of approximately equal amounts of **16** and **20** (1.2 g, 29%). The pure β anomer **16** had $[\alpha]_D^{20}$ −47.7° (*c* 2.4, $CHCl_3$) {lit. [16] $[\alpha]_D^{25}$ −49.6° (*c* 1.5, $CHCl_3$)}. Anal. Calcd for $C_{13}H_{18}O_5$: C, 61.40; H, 7.14. Found: C, 61.39; H, 7.13.

Compound **16** gave a syrupy diacetate (**19**); $[\alpha]_D^{19}$ −9.5° (*c* 2.2, $CHCl_3$); ^{1}H-NMR data for **19**: δ 2.02, 2.10 (2 s, each 3 H, 2 COMe), 3.35 (s, 3 H, OMe), 3.57 (d, 1 H, *J* 1.2 Hz), 3.63 (s, 1 H), 4.20–4.83 (m, 1 H), 4.59 (s, 2 H, CH_2Ph), 4.91 (d, 1 H, *J* 1.2 Hz, H-1), 5.18–5.39 (m, 2 H, H-2, H-3), 7.32 (s, 5 H, Ph). Anal. Calcd for $C_{17}H_{22}O_7$: C, 60.34; H, 6.55. Found: C, 59.67; H, 6.63.

Compound **16** also gave a syrupy dibenzoate **18**, $[\alpha]_D^{20}$ +49.8° (*c* 2.8, $CHCl_3$) {lit. [17] mp 68–69 °C, $[\alpha]_D^{25}$ +51° (*c* 0.5, $CHCl_3$)}; ^{1}H-NMR data: δ 3.42 (s, 3 H, OMe), 3.73 (d, 1 H, *J* 2.4 Hz), 3.78 (s, 1 H), 4.50–4.69 (m, 1 H), 4.62 (s, 2 H, CH_2Ph), 5.15 (s, 1 H, H-1), 5.59–5.78 (m, 2 H, H-2, H-3), 7.17–8.04 (m, 15 H, Ph). Anal. Calcd for $C_{27}H_{26}O_7$: C, 70.12; H, 5.67. Found: C, 70.10; H, 5.61.

The 2,3-carbonate **17** of **16** was prepared as follows. A mixture of **16** (170 mg), ethylene carbonate (120 mg), and $NaHCO_3$ (5 mg) was heated at 120 °C in an oil bath for 30 min. The mixture was cooled and distributed between ether (10 mL) and water (10 mL), and the ether solution was separated, dried ($MgSO_4$), and concentrated. TLC (ether) showed almost complete conversion of **16** (R_f 0.3) into a product (R_f 0.9). Column chromatography (2:1 ether–light petroleum) gave pure **17** (143 mg) as an oil which slowly crystallised; mp 47–49 °C (from EtOH); $[\alpha]_D^{20}$ −63.1° (*c* 1.75, EtOH) {lit. [10] mp 59–59.5 °C, $[\alpha]_D^{20}$ −54.5° (*c* 1.06, EtOH); lit. [29] mp 57–58 °C, $[\alpha]_D^{20}$ −53.6° (*c* 0.85, EtOH)}; ^{1}H-NMR data: δ 3.33 (s, 3 H, OMe), 3.48 (d, 1 H, *J* 4.9 Hz), 3.57 (d, 1 H, *J* 2.4 Hz), 4.46–4.62 (m, 1 H), 4.54 (s, 2 H, CH_2Ph), 5.03 (ABq, 2 H, H-2, H-3), 5.11 (s, 1 H, H-1), 7.34 (s, 5 H, Ph). Anal. Calcd for $C_{14}H_{16}O_6$: C, 59.99; H, 5.75. Found: C, 60.26; H, 5.60.

A portion of the mixture of **16** and **20** (500 mg) described above was acetylated with Ac_2O–pyridine in the usual way. TLC (2:1 ether–light petroleum) showed products at R_f 0.7 and 0.5, and these were readily separated by column chromatography in the same solvent mixture. The isomer R_f 0.7 (355 mg) was identical with the diacetate **19** described above. The isomer R_f 0.5 (295 mg) was the diacetate **23**; $[\alpha]_D^{19}$ +107.3° (*c* 2.6, $CHCl_3$); ^{1}H-NMR data: δ 2.11 (s, 6 H, 2 COMe), 3.43 (s, 3 H, OMe), 3.65, 3.69 (2 s, each 1 H), 4.16–4.27 (m, 1 H), 4.58 (s, 2 H, CH_2Ph), 4.95–5.32 (m, 3 H, with major doublet at 5.10, *J* 3.7 Hz, H-1, H-2, H-3), 7.32 (s, 5 H, Ph). Anal. Calcd for $C_{17}H_{22}O_7$: C, 60.34; H, 6.55. Found: C, 60.60; H, 6.21.

Saponification of the diacetate **23** gave methyl 5-*O*-benzyl-α-D-ribofuranoside (**20**); $[\alpha]_D^{20}$ +86.2° (*c* 2.4, $CHCl_3$) {lit. [16] $[\alpha]_D$ +96.5° (*c* 0.9, $CHCl_3$)}; ^{1}H-NMR data: δ 3.37 (broad s, 2 H, 2 OH), 3.42 (s, 3 H, OMe), 3.54, 3.58 (2 s, each 1 H), 3.88–4.14 (m, 3 H), 4.52 (s, 2 H, CH_2Ph), 4.88 (d, 1 H, *J* 4.3 Hz, H-1), 7.29 (s, 5 H, Ph). Anal. Calcd for $C_{13}H_{18}O_5$: C, 61.40; H, 7.14. Found: C, 61.25; H, 7.20.

Benzoylation of **20** with benzoyl chloride in pyridine in the usual way gave the syrupy dibenzoate **22**; $[\alpha]_D^{20}$ +70.3° (*c* 1.8, $CHCl_3$); ^{1}H-NMR data: δ 3.45 (s, 3 H, OMe), 3.75, 3.79 (2 s, each 1 H), 4.47 (m, 1 H), 4.62 (s, 2 H, CH_2Ph), 5.24–5.42 (m, 2 H, with major peak at 5.36), 5.70 (dd, 1 H, *J* 3.1 and 6.7 Hz), 7.13–8.15 (m, 15 H, Ph). Anal. Calcd for $C_{27}H_{26}O_7$: C, 70.12; H, 5.67. Found: C, 69.89; H, 5.28.

On TLC (1:1 ether–light petroleum) the dibenzoates **18** and **22** did not separate (R_f 0.75).

A further portion of the mixed anomers **16** and **20** (500 mg) was converted into the mixed carbonates **17** and **21** as described above for the preparation of **17**. TLC (2:1 ether–light petroleum) showed almost complete conversion of the starting materials (R_f 0 and 0.1) into two products R_f 0.6 and 0.8. Column chromatography in the same solvent mixture gave the product R_f 0.8 (252 mg) which was identical with the carbonate **17** described above. The carbonate **21** (R_f 0.6, 210 mg) was obtained as a syrup which slowly crystallised; mp 62–64 °C; $[\alpha]_D^{20}$ +105.1° (*c* 2.3, EtOH) {lit. [10] mp 62–63 °C, $[\alpha]_D$ +102.6° (*c* 2.5, EtOH)}; ^{1}H-NMR data: δ 3.45 (s, 3 H, OMe), 3.66, 3.71 (2 s, each 1 H), 4.32–4.41 (m, 1 H), 4.55 (s, 2 H, CH_2Ph), 4.90–4.95 (m, 2 H, H-2, H-3), 5.12–5.16 (m, 1 H, H-1), 7.32 (s, 5 H, Ph). Anal. Calcd for $C_{14}H_{16}O_6$: C, 59.99; H, 5.75. Found: C, 60.02; H, 5.55.

*Methyl 2-O-allyl- and 3-O-allyl-5-O-benzyl-β-*D*-ribofuranoside* (**32** *and* **29**).—A mixture of the diol **16** (1.14 g, 4.48 mmol), dibutyltin oxide (1.5 g, 6.03 mmol), tetrabutylammonium bromide (1.5 g, 4.65 mmol), allyl bromide (25 mL), and MeCN (25 mL) was heated under reflux with 3 Å molecular sieves (5 g) in a Soxhlet apparatus for 5 h. The solvents were evaporated, the residue was distributed between ether (50 mL) and water (50 mL), and the mixture was filtered through Celite. The ether layer was separated and stirred with satd aq $NaHCO_3$ (100 mL) for 4 h, the mixture was then filtered through Celite, and the ether layer was separated, dried (K_2CO_3), and concentrated to give the products (1.2 g). TLC (2:1 ether–light petroleum) showed two products (R_f 0.5 and 0.4) in approximately equal proportions. ^{1}H-NMR showed OMe peaks at δ 3.33 and 3.34, and H-1 peaks at δ 4.86 and 4.90. A portion of the mixture (200 mg) was partially separated by column chromatography in the same solvent mixture to give the less polar isomer **32** (71 mg), followed by a mixed fraction and then the more polar isomer **29** (72 mg).

Compound **32** had $[\alpha]_D^{21}$ +2.9° (*c* 2.2, $CHCl_3$); ^{1}H-NMR data: δ 2.64 (d, 1 H, *J* 8.5 Hz, OH), 3.34 (s, 3 H, OMe), 3.54–3.64 (m, 2 H), 3.74–3.81 (m, 1 H), 3.98–4.33 (m, 2 H), 4.60 (s, 2 H, CH_2Ph), 4.88 (s, 1 H, H-1), 5.15–5.42 (m, 2 H, =CH_2), 5.71–6.08 (m, 1 H, –CH=), 7.32 (s, 5 H, Ph). Anal. Calcd for $C_{16}H_{22}O_5$: C, 65.29; H, 7.53. Found: C, 65.77; H, 7.34.

The more polar isomer **29** had $[\alpha]_D^{21}$ −30.2° (*c* 2.2, $CHCl_3$); ^{1}H-NMR data: δ 2.78 (d, 1 H, *J* 2.4 Hz, OH), 3.32 (s, 3 H, OMe), 3.55, 3.62 (2 s, each 1 H), 3.94–4.55 (m, 3 H), 4.60 (s, 2 H, CH_2Ph), 4.86 (s, 1 H, H-1), 5.14–5.39 (m, 2 H, =CH_2), 5.68–6.11 (m, 1 H, –CH=), 7.33 (s, 5 H, Ph). Anal. Found: C, 65.24; H, 7.64.

*3-O-Allyl-1,2:5,6-di-O-isopropylidene-α-*D*-allofuranose* (**37**).—1,2:5,6-Di-*O*-isopropylidene-α-D-allofuranose (**36**, 2.2 g, Janssen Chimica) was treated with an excess of NaH and allyl bromide in DMF and the product was isolated in the usual way. TLC (1:1 ether–light petroleum) showed conversion of **36** (R_f 0.1) into **37** (R_f 0.5). Column chromatography using the same solvent mixture gave **37** as a syrup (2.3 g, 93%); $[\alpha]_D^{20}$ +105.4° (*c* 1.7, $CHCl_3$); ^{1}H-NMR data: δ 1.36, 1.38, 1.46, 1.58 (4 s, each 3 H, 2 CMe_2), 3.81–4.50 (m, 7 H), 4.63 (t, 1 H, *J* 4.0 Hz, H-2), 5.16–5.43 (m, 2 H, =CH_2), 5.77 (d, 1 H, *J* 3.7 Hz, H-1), 5.75–6.21 (m, 1 H, –CH=). Anal. Calcd for $C_{15}H_{24}O_6$: C, 59.98; H, 8.06. Found: C, 60.30; H, 8.29.

3-O-Allyl-1,2-O-isopropylidene-α-D-allofuranose (**38**).—A solution of **37** (570 mg) in MeOH (75 mL), M HCl (13 mL), and water (42 mL) (i.e., ca. 0.1 M HCl) was kept at 20 °C for 6 h when TLC (EtOAc) showed almost complete conversion of **37** (R_f 0.95) into a major product (R_f 0.4) together with a trace product (R_f 0). An excess of triethylamine and $NaHCO_3$ were added and the solution was concentrated. Column chromatography (EtOAc) of the residue gave the diol **38** (360 mg, 73%) as a syrup; $[\alpha]_D^{21}$ +119.7° (*c* 2.1, $CHCl_3$); ^{1}H-NMR data: δ 1.35, 1.37 (2 s, each 3 H, CMe_2), 3.61–4.35 (m, 9 H), 4.63 (t, 1 H, *J* 3.7 Hz, H-2), 5.18–5.40 (m, 2 H, $=CH_2$), 5.77 (d, 1 H, *J* 3.7 Hz, H-1), 5.75–6.18 (m, 1 H, –CH=). Anal. Calcd for $C_{12}H_{20}O_6$: C, 55.37; H, 7.75. Found: C, 55.28; H, 8.01.

Diol **38** gave a syrupy diacetate **39**; ^{1}H-NMR data: δ 1.36, 1.57 (2 s, each 3 H, CMe_2), 2.05, 2.08 (2 s, each 3 H, 2 COMe), 3.80 (dd, 1 H, *J* 4.3 and 8.5 Hz), 3.96–4.48 (m, 5 H), 4.62 (t, 1 H, *J* 3.7 Hz, H-2), 5.18–5.42 (m, 3 H), 5.72 (d, 1 H, *J* 3.7 Hz, H-1), 5.70–6.19 (m, 1 H, –CH=).

3-O-Allyl-1,2-O-isopropylidene-α-D-ribofuranose (**41**).—Sodium metaperiodate (1.56 g, 7.29 mmol) was added to a solution of the diol **38** (1.26 g, 4.84 mmol) in water (23 mL) and the solution was kept at 20 °C for 1 h. After cooling in ice–water, a solution of $NaBH_4$ (916 mg, 24 mmol) in water (8 mL) was added dropwise during 5 min and the solution was kept at 20 °C for 4 h. The solution was extracted with CH_2Cl_2 (3 × 50 mL), and the extract dried (K_2CO_3) and concentrated to give the product as a syrup. TLC (ether) showed conversion of **38** (R_f 0.2) into the product (R_f 0.5) and column chromatography (ether) gave pure **41** as a syrup (1.2 g, 87%); $[\alpha]_D^{20}$ +127.6° (*c* 2.1, $CHCl_3$); ^{1}H-NMR data: δ 1.36, 1.59 (2 s, 3 H, CMe_2), 3.50–4.21 (m, 7 H), 4.63 (t, 1 H, *J* 3.7 Hz, H-2), 5.18–5.44 (m, 2 H, $=CH_2$), 5.76 (d, 1 H, *J* 3.7 Hz, H-1), 5.74–6.19 (m, 1 H, –CH=). Anal. Calcd for $C_{11}H_{18}O_5$: C, 57.38; H, 7.88. Found: C, 56.97; H, 7.90.

3-O-Allyl-5-O-benzyl-1,2-O-isopropylidene-α-D-ribofuranose (**34**).—(*a*) Compound **41** was treated with an excess of NaH and benzyl bromide in DMF, the product was isolated in the usual way, and column chromatography (2:1 ether–light petroleum) gave **34** as a syrup; $[\alpha]_D^{20}$ +83.55° (*c* 2, $CHCl_3$); ^{1}H-NMR data: δ 1.36, 1.57 (2 s, each 3 H, 2 CMe_2), 3.51–3.90 (m, 3 H, with major peaks at 3.51, 3.55, 3.63, 3.67, 3.73, 3.75, 3.80, 3.86, 3.88, 3.90), 4.03–4.23 (m, 3 H), 4.44–4.74 (m, 3 H, with ABq at 4.59 for CH_2Ph), 5.13–5.39 (m, 2 H, $=CH_2$), 5.72–6.14 (m, 2 H, –CH= and d, *J* 3.7 Hz, at 5.8 for H-1), 7.32 (s, 5 H, Ph). Anal. Calcd for $C_{18}H_{24}O_5$: C, 67.48; H, 7.55. Found: C, 67.52; H, 7.62.

(*b*) The more polar isomer **29** (72 mg) from the tin-mediated allylation of **16** was heated under reflux in acetone (8 mL) and M HCl (2 mL) for 1.5 h. The solution was cooled, water (10 mL) was added, and the solution was concentrated to remove the acetone. The aqueous residue (5 mL) was extracted with CH_2Cl_2 (3 × 25 mL), and the extract dried ($MgSO_4$) and concentrated. TLC (2:1 ether–light petroleum) showed almost complete conversion of **29** (R_f 0.5) into a major product **33** (R_f 0) and a minor product **34** (R_f 0.8). A solution of the crude product in acetone (10 mL) containing toluene *p*-sulfonic acid (20 mg) was kept at 20 °C for 30 min when TLC showed almost complete conversion of the product R_f 0 into the product R_f 0.8. Triethylamine (2 mL) was added and the solution was concentrated. Column chromatography (as in *a*) gave

the pure product which was identical with **34** described in (*a*). This established that the more polar isomer **29** was the 3-allyl ether.

5-O-Benzyl-1,2-O-isopropylidene-α-D-ribofuranose (**26**).—(*a*) The allyl ether (**27** ≡ **34**) was treated with potassium *tert*-butoxide in Me_2SO and the product isolated in the usual way [19]. TLC (1:1 ether–light petroleum) showed conversion of **27** (R_f 0.6) into the prop-1-enyl ether **28** (R_f 0.65). ^{1}H-NMR data for **28**: δ 1.34, 1.56 (2 s, each 3 H, 2 CMe_2), 1.58 (dd, 3 H, *J* 1.8 and 6.7 Hz, =CH*Me*), 3.33–4.33 (m, 4 H), 4.41–4.71 (m, 4 H, with ABq at 4.56 for CH_2Ph), 5.78 (d, 1 H, *J* 3.7 Hz, H-1), 6.02 (dd, 1 H, *J* 1.8 and 6.1 Hz, OCH=), 7.30 (s, 5 H, Ph). The prop-1-enyl group was removed with HgO–$HgCl_2$ in aq acetone in the usual way [20] to give the alcohol **26** (TLC, as above: R_f 0.2). Column chromatography (4:1 CH_2Cl_2–ether) gave the pure alcohol **26**; mp 85–87 °C (from light petroleum, bp 60–80 °C); $[\alpha]_D^{20}$ +37.3° (*c* 1.45, $CHCl_3$) {lit. [23a] mp 80–81 °C, $[\alpha]_D$ +42° (*c* 0.3, $CHCl_3$)}; ^{1}H-NMR data: δ 1.36, 1.56, (2 s, each 3 H, CMe_2), 2.26–2.49 (m, 1 H, OH), 3.52–4.11 (m, 4 H), 4.51–4.60 (m, 3 H, with major singlet at 4.60 for CH_2Ph), 5.83 (d, 1 H, *J* 3.7 Hz, H-1), 7.32 (s, 5 H, Ph).

(*b*) The α,β-mixture of diols **16** and **20** (934 mg) was heated under reflux with acetone (10 mL) and M HCl (10 mL) for 1.5 h. Sodium acetate (700 mg) was added to the cooled solution which was concentrated (to ca. 3 mL) to remove the acetone. Ethyl acetate (50 mL), $NaHCO_3$ (1 g), and $MgSO_4$ (10 g) were added, and the mixture was filtered and concentrated. The residual syrup was dissolved in acetone (10 mL) and 2,2-dimethoxypropane (5 mL) containing toluene *p*-sulfonic acid (100 mg). After 30 min, triethylamine (1 mL) and $NaHCO_3$ (1 g) were added and the mixture was concentrated. TLC (1:1 ether–light petroleum) showed a major product (R_f 0.5) and minor products (R_f 0.8 and 0.2); the most polar product (R_f 0.2) co-chromatographed with the product **26** from (*a*). Column chromatography with the same solvent mixture gave the product R_f 0.8 (200 mg, the ^{1}H-NMR of which indicated it was the 1-methyl-1-methoxyethyl ether of the product R_f 0.5), the product R_f 0.5 (590 mg, which is probably **25**—see ref. [23a]), and the product R_f 0.2 (100 mg). The latter crystallised and was identical with **26** described in (*a*).

Conversion of 3-O-allyl-1,2-O-isopropylidene-α-D-ribofuranose (**41**) *into 5-O-benzoyl-1,2-O-isopropylidene-α-D-ribofuranose* (**42**) *and 1,2-O-isopropylidene-α-D-ribofuranose* (**43**).—The allyl ether **41** was converted into the prop-1-enyl ether **44** by treatment with potassium *tert*-butoxide in Me_2SO at 50 °C and the product isolated in the usual way [19]. TLC (ether) showed conversion of **41** (R_f 0.5) into **44** (R_f 0.6). ^{1}H-NMR data for **44**: δ 1.37, 1.59 (2 s, each 3 H, CMe_2), 1.57–1.66 (dd, 3 H, *J* 1.2 and 7.3 Hz, =CH*Me*), 3.56–4.20 (m, 4 H), 4.41–4.71 (m, 2 H), 5.79 (d, 1 H, *J* 3.7 Hz, H-1), 6.04–6.13 (m, 1 H, OCH=). The crude product was treated with benzoyl chloride in pyridine and the product isolated in the usual way to give the benzoate **45** as a syrup. TLC (1:1 ether–light petroleum) showed conversion of **44** (R_f 0.25) into **45** (R_f 0.8). ^{1}H-NMR data for **45**: δ 1.38, 1.62 (2 s, each 3 H, $2CMe_2$), 1.56–1.66 (dd, 3 H, *J* 1.8 and 6.7 Hz, =CH*Me*), 3.96 (dd, 1 H, *J* 3.7 and 8 Hz), 4.31–4.82 (m, 5 H), 5.83 (d, 1 H, *J* 3.7 Hz, H-1), 6.02–6.10 (m, 1 H, OCH=), 7.26–8.11 (m, 5 H, Ph). The crude product was treated with $HgCl_2$–HgO in aq acetone and the product isolated in the usual way [20] to give the alcohol **42**. TLC (as above) showed conversion of **45** into **42** (R_f 0.3). Column chromatography (2:1 ether–light petroleum) gave the pure alcohol **42**; mp

81–83 °C; $[\alpha]_D^{20}$ +31.2° (*c* 1.87, $CHCl_3$) {lit. [21a] mp 78–79 °C, $[\alpha]_D^{26}$ +20.05° (*c* 1, $CHCl_3$); lit. [21b] mp 81–82 °C, $[\alpha]_D^{26}$ +32° (*c* 1, $CHCl_3$); lit. [21c] mp 76.5–77.5 °C, $[\alpha]_D^{23}$ +25.5° (*c* 1, $CHCl_3$)}; ^{1}H-NMR data: δ 1.38, 1.59 (2 s, each 3 H, CMe_2), 2.53 (d, 1 H, *J* 9.8 Hz, OH), 3.79–4.19 (m, 2 H), 4.35–4.80 (m, 3 H), 5.85 (d, 1 H, *J* 3.7 Hz, H-1), 7.32–8.11 (m, Ph).

Saponification of the benzoate **42** gave the diol **43**; mp 88–90 °C; $[\alpha]_D^{20}$ +45.4° (*c* 1.6, $CHCl_3$) {lit. [22a] mp 86–87 °C, $[\alpha]_D^{25}$ +37° (*c* 0.59, $CHCl_3$); lit. [22b] mp 85.5–86 °C, $[\alpha]_D^{22}$ +65° (*c* 1, EtOH); lit. [22c] mp 85–86 °C, $[\alpha]_D$ +39.5° (*c* 1, $CHCl_3$); lit. [22d] mp 84–86 °C, $[\alpha]_D^{25}$ +38° (H_2O)}; ^{1}H-NMR data: δ 1.38, 1.57 (2 s, each 3 H, CMe_2), 3.67–4.03 (m, 4 H), 4.58 (t, 1 H, *J* 4.3 Hz, H-2), 5.82 (d, 1 H, *J* 3.7 Hz, H-1).

Conversion of methyl 3-O-allyl-5-O-benzyl-β-D-ribofuranoside (**29**) *into methyl 2-O-allyl-5-O-benzyl-β-D-ribofuranoside* (**32**).—A solution of the 3-allyl ether **29** (285 mg) and potassium *tert*-butoxide (500 mg) in dry Me_2SO (20 mL) was kept at 50 °C for 2 h. TLC (1:1 ether–light petroleum) showed complete conversion of **29** (R_f 0.35) into the prop-1-enyl ether **30** (R_f 0.5) which was isolated in the usual way. ^{1}H-NMR data for **30**: δ 1.58 (dd, 3 H, *J* 1.5 and 7 Hz, =CH*Me*), 2.66 (s, 1 H, OH), 3.34 (s, 3 H, OMe), 3.58, 3.62 (2 s, each 1 H), 4.08–4.67 (m, 4 H), 4.58 (s, 2 H, CH_2Ph), 4.87 (s, 1 H, H-1), 5.93–6.05 (m, 1 H with a major dd at 5.99, *J* 1.5 and 6 Hz, OCH=), 7.32 (s, 5 H, Ph).

Compound **30** was treated with an excess of allyl bromide and NaH in DMF; TLC (as above) showed complete conversion of **30** into **31** (R_f 0.8) and the product was isolated in the usual way. ^{1}H-NMR data for **31**: δ 1.59 (dd, 3 H, *J* 1.5 and 7 Hz, =CH*Me*), 3.35 (s, 3 H, OMe), 3.57–3.64 (m, 2 H), 3.81–3.87 (m, 1 H), 4.08–4.54 (m, 5 H), 4.59 (s, 2 H, CH_2Ph), 4.89 (d, 1 H, *J* 1.8 Hz, H-1), 5.11–5.40 (m, 2 H, $=CH_2$), 5.71–6.13 (m, 2 H with a major dd at 5.97, *J* 1.8 and 6.1 Hz, OCH= and C*H*$=CH_2$), 7.32 (s, 5 H, Ph). Compound **31** was treated with $HgCl_2$–HgO in aq acetone and the product isolated in the usual way [20]. TLC (as above) showed complete conversion of **31** into **32** (R_f 0.4) which co-chromatographed with the 2-allyl ether **32** prepared as described above. Column chromatography (2:1 ether–light petroleum) gave pure **32** identical with the material prepared as described above.

Acid methanolysis of 3-O-allyl-5-O-benzyl-1,2-O-isopropylidene-α-D-ribofuranose (**34**).—A solution of the allyl ether **34** (58 mg) in 0.1 M H_2SO_4 in dry MeOH (20 mL) was heated under reflux for 1.5 h. Triethylamine (2 mL), H_2O (5 mL), and K_2CO_3 (2 g) were added to the cooled solution which was then concentrated. The residue was extracted with ether and the extract dried (K_2CO_3) and concentrated to give **35** (52 mg). TLC (ether) showed a single product (R_f 0.8) which co-chromatographed with the 3-allyl ether **29**. The ^{1}H-NMR spectrum showed that the product was predominantly the β anomer **29**, but extra singlets at δ 3.46 (OMe) and 3.54 and 3.58 indicated that ca. 20% of the α anomer of **29** was also present.

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References

[1] T. Desai, J. Gigg, R. Gigg, and E. Martín-Zamora, *Carbohydr. Res.*, 262 (1994) 59–77.
[2] M. Takahashi, T. Kagasaki, T. Hosoya, and S. Takahashi, *J. Antibiot.*, 46 (1993) 1643–1647; S. Takahashi, T. Kinoshita, and M. Takahashi, *ibid.*, 47 (1994) 95–100; M. Takahashi, K. Tanzawa, and S. Takahashi, *J. Biol. Chem.*, 269 (1994) 369–372; S. Takahashi, M. Takahashi, K. Tanzawa, K. Ogawa, and T. Hosoya, Europ. Patent Appl., EP 527646, 1993; *Chem. Abstr.*, 119 (1993) 93689.
[3] A. Chaudhary and G.D. Prestwich, *Chemtracts – Org. Chem.*, 7 (1994) 111–114.
[4] T. Desai, J. Gigg, and R. Gigg, *Abstr. Papers*, Roy. Soc. Chem. Carbohydr. Group, Leeds, UK, April 19–21, 1995; *Abstr. Papers*, 8th Europ. Carbohydr. Symp., Seville, Spain, July 2–7, 1995, A-14.
[5] R.A. Wilcox, C. Erneux, W.U. Primrose, R. Gigg, and S. Nahorski, *Mol. Pharmacol.*, 47 (1995) 1204–1211.
[6] A.P. Kozikowski, V.I. Ognyanov, A.H. Fauq, S.R. Nahorski, and R.A. Wilcox, *J. Am. Chem. Soc.*, 115 (1993) 4429–4434.
[7] R. Barker and H.G. Fletcher, Jr., *J. Org. Chem.*, 26 (1961) 4605–4609.
[8] P.A. Levene and E.T. Stiller, *J. Biol. Chem.*, 104 (1934) 299–306.
[9] N.J. Leonard and K.L. Carraway, *J. Heterocycl. Chem.*, 3 (1966) 485–489.
[10] G.M. Tener and H.G. Khorana, *J. Am. Chem. Soc.*, 79 (1957) 437–441.
[11] N. Berg and O. Kjølberg, *Carbohydr. Res.*, 57 (1977) 65–71.
[12] J. Yoshimura, S. Kondo, M. Ihara, and H. Hashimoto, *Carbohydr. Res.*, 99 (1982) 129–142.
[13] (a) H.M. Kissman and B.R. Baker, *J. Am. Chem. Soc.*, 79 (1957) 5534–5540; (b) N.F. Taylor and P.W. Kent, *J. Chem. Soc.*, (1958) 872–875.
[14] K. Bock and S. Refn, *Acta Chem. Scand., Ser. B*, 42 (1988) 324–327.
[15] L. Chan and G. Just, *Tetrahedron*, 46 (1990) 151–162.
[16] M. Kawana, H. Kuzuhara, and S. Emoto, *Bull. Chem. Soc. Jpn.*, 54 (1981) 1492–1504.
[17] S. Nilsson, M. Bengtsson, and T. Norberg, *J. Carbohydr. Chem.*, 11 (1992) 265–285; correction 11 (1992) 1067.
[18] J. Cunningham and R. Gigg, *J. Chem. Soc.*, (1965) 1553–1554; P.A. Gent, R. Gigg, and R. Conant, *J. Chem. Soc., Perkin Trans. 1*, (1972) 248–254.
[19] J. Gigg and R. Gigg, *J. Chem. Soc., C*, (1966) 82–86.
[20] R. Gigg and C.D. Warren, *J. Chem. Soc., C*, (1968) 1903–1911.
[21] (a) K. Oka and H. Wada, *Yakugaku Zasshi*, 83 (1963) 890–891; *Chem. Abstr.*, 60 (1964) 1825d; (b) I. Watanabe, T. Tsuchiya, T. Takase, S. Umezawa, and H. Umezawa, *Bull. Chem. Soc. Jpn.*, 50 (1977) 2369–2374; (c) Y. Ishido, N. Sakairi, M. Sekiya, and N. Nakazaki, *Carbohydr. Res.*, 97 (1981) 51–79.
[22] (a) N.A. Hughes and P.R.H. Speakman, *Carbohydr. Res.*, 1 (1965) 171–175; (b) H. Tsutsumi, Y. Kawai, and Y. Ishido, *ibid.*, 73 (1979) 293–296; (c) G.O. Aspinall and R.R. King, *Can. J. Chem.*, 51 (1973) 394–401; (d) J. Kiss, R. D'Souza, and P. Taschner, *Helv. Chim. Acta*, 58 (1975) 311–317.
[23] (a) J.S. Brimacombe and O.A. Ching, *J. Chem. Soc., C*, (1969) 964–967; *Carbohydr. Res.*, 8 (1968) 374–376; (b) P. Ching and A. Orlando, *Bol. Soc. Quim. Peru*, 36 (1970) 60–69.
[24] T. Desai, A. Fernandez-Mayoralas, J. Gigg, R. Gigg, and S. Payne, *Carbohydr. Res.*, 205 (1990) 105–123.
[25] R.R. Schmidt and A. Gohl, *Chem. Ber.*, 112 (1979) 1689–1704.
[26] J.S. Brimacombe, J. Minshall, and L.C.N. Tucker, *Carbohydr. Res.*, 52 (1976) 31–47.
[27] G.W. Kenner, C.W. Taylor, and A.R. Todd, *J. Chem. Soc.*, (1949) 1620–1624.
[28] M. Taniguchi, K. Koga, and S. Yamada, *Tetrahedron*, 30 (1974) 3547–3552.
[29] A. Klemer, R. Lemmes, and K. Cimander, *Carbohydr. Res.*, 68 (1979) 375–383.