Pergamon

Tetrahedron, Vol. 53, No. 18, pp. 6539-6554, 1997
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0040-4020/97 $17.00 + 0.00

PII: S0040-4020(97)00309-8

Synthesis of 3",4"-Bisphosphate-Containing Analogs of Adenophostin A

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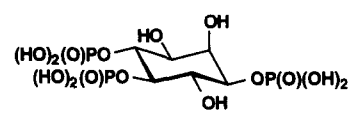
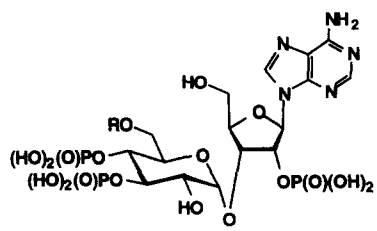
Abstract: Glycosylation of ethyl 3,4,6-tri-*O*-acetyl-2-*O*-benzyl-1-thio-α/β-D-glucopyranoside (**6**) with *tert*-butyldiphenylsilylglycol (**7**) or 1,2-di-*O*-*p*-methoxybenzyl-*sn*-glycerol (**16**) under the agency of *N*-iodosuccinimide/triflic acid afforded α-glucosides **8** and **17**, respectively. Protective group manipulations (**8** → **10** and **17** → **20**) and acetolysis of the methylthiomethyl functions yielded 2-*O*-(3,4,6-tri-*O*-acetyl-2-*O*-benzyl-α-D-glucopyranosyl)-1-*O*-acetoxymethylglycol (**11**) and 3-*O*-(3,4,6-tri-*O*-acetyl-2-*O*-benzyl-α-D-glucopyranosyl)-2-*O*-acetoxymethyl-1-*O*-*tert*-butyldiphenylsilyl-*sn*-glycerol (**21**). Vorbrüggen condensation with silylated 6-*N*-benzoyladenine (**22**), subsequent protective group manipulations on **23** and **29** followed by phosphorylation furnished, after purification, homogeneous glycol-based adenophostin A analog **4** and glycerol-based analog **5**. © 1997 Elsevier Science Ltd.

Introduction

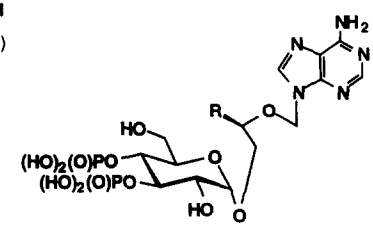
It has been firmly established[1] that Ca^{2+} release from intracellular stores is effected by the second messenger D-*myo*-inositol 1,4,5-trisphosphate (IP_3, **1**). Several important biological processes such as neuronal excitability, smooth muscle contractility and cell proliferation are controlled by IP_3-induced Ca^{2+} mobilization. In order to study in detail the biological function and metabolism of IP_3, an array of IP_3 analogs has been prepared.[2] The recent discovery of the naturally occurring adenophostins A (**2**) and B (**3**), which are full agonists for the IP_3 receptor[3] and show a 10-100 times higher binding affinity and Ca^{2+}-mobilizing activity in comparison with the native ligand IP_3, presented a new stimulus for inositol chemistry.



1 (IP_3)



2 R = H (adenophostin A)
3 R = Ac (adenophostin B)

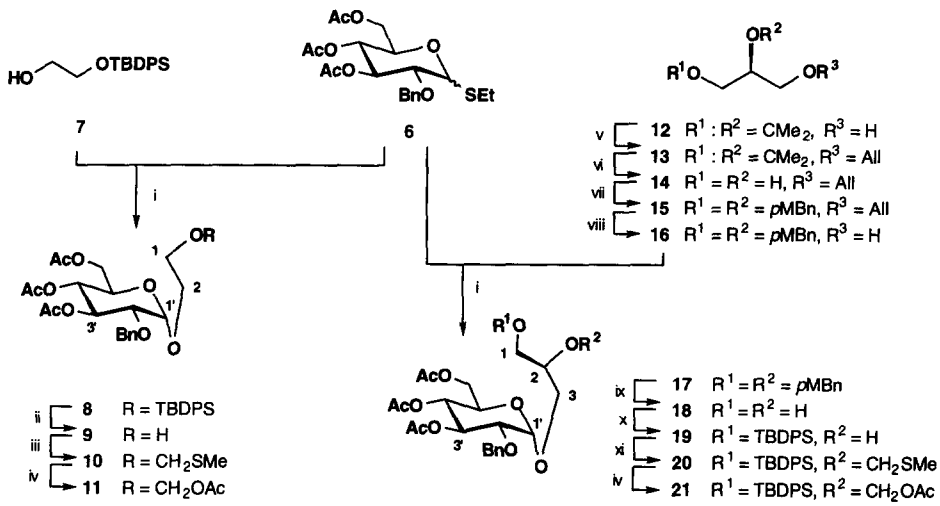


4 R = H
5 R = CH_2OH

It is evident[4,5] that the availability of structurally modified adenophostins would be of great value to study in detail the structure activity relationship of this new class of second messengers. We earlier prepared[6] two 2',3",4"-trisphosphate-containing analogs of adenophostin A. In this paper, we present the synthesis of two 3",4"-bisphosphate-containing adenophostin A analogs (*i.e.* **4** and **5**), in which the ribosyl-2-phosphate unit is replaced by either a glycol (*i.e.* **4**) or a glycerol (*i.e.* **5**) moiety.

Results and discussion

Recently, we reported[7] an expeditious route to the synthesis of adenophostin A based on *N*-iodosuccinimide (NIS)/triflic acid (TfOH)-mediated glycosylation of 1,2-*O*-isopropylidene-5-*O*-*tert*-butyldiphenylsilyl-α-D-ribofuranose with ethyl 3,4,6-tri-*O*-acetyl-2-*O*-benzyl-1-thio-α/β-D-glucopyranoside (**6**, Scheme 1) and introduction of the adenine moiety *via* a Vorbrüggen reaction. The excellent stereochemical outcome of the *O*-glycosylation and the high-yielding introduction of the adenine nucleobase were an incentive to exploit these features in the construction of the two target adenophostin A analogs **4** and **5**. The assembly of 9-{2-(α-D-glucopyranosyloxy 3,4-bisphosphate)ethoxymethyl}-adenine (**4**) and (2*R*)-9-[(1-{α-D-glucopyranosyl-oxy 3,4-bisphosphate}-3-hydroxy-2-propoxy)methyl]-adenine (**5**) comprises the following three stages: (i) condensation of the glucosyl donor **6** with the respective glycol and glycerol acceptors **7** and **16** (see Scheme 1), (ii) Vorbrüggen-type reaction of glycosyl donors **11** and **21** with silylated 6-*N*-benzoyladenine (**22**, Scheme 2) and (iii) phosphorylation of the glucosyl moiety in diols **25** and **31** (Scheme 2).



Reagents and conditions: (i) NIS/(*cat.*) TfOH, 1,2-DCE/Et_2O, **8**: 1/1, v/v, 0 °C, 5 min, 83%, **17**: 0/1, v/v, 0 °C, 2.5 h, 72%; (ii) TBAF/THF, 50 °C, 1 h, 89%; (iii) HOAc/Ac_2O/DMSO, 1/3/5, v/v/v, 16 h, 84%; (iv) AcOH, NIS, 1,2-DCE/THF, 1/1, v/v, 0 °C, 5 min, **11**: 73%, **21**: 85%; (v) AllBr, NaH, DMF, 4 h; (vi) AcOH/H_2O, 5/1, v/v, 1 h, 50 °C; (vii) *p*MBnCl, NaH, DMF, 16 h, 60 °C, 52% (based on **12**); (viii) $PdCl_2$/CuCl, O_2, DMF/H_2O, 10/1, v/v, 6 h, 75%; (ix) CAN, CH_3CN/H_2O, 10/1, v/v, 30 min, 87%; (x) TBDPSCl, pyr, DMAP, 48 h, 60 °C, 62%; (xi) $(CH_3)_2S$, 2,6-lutidine, BPO, CH_3CN, 1 h, 63%.

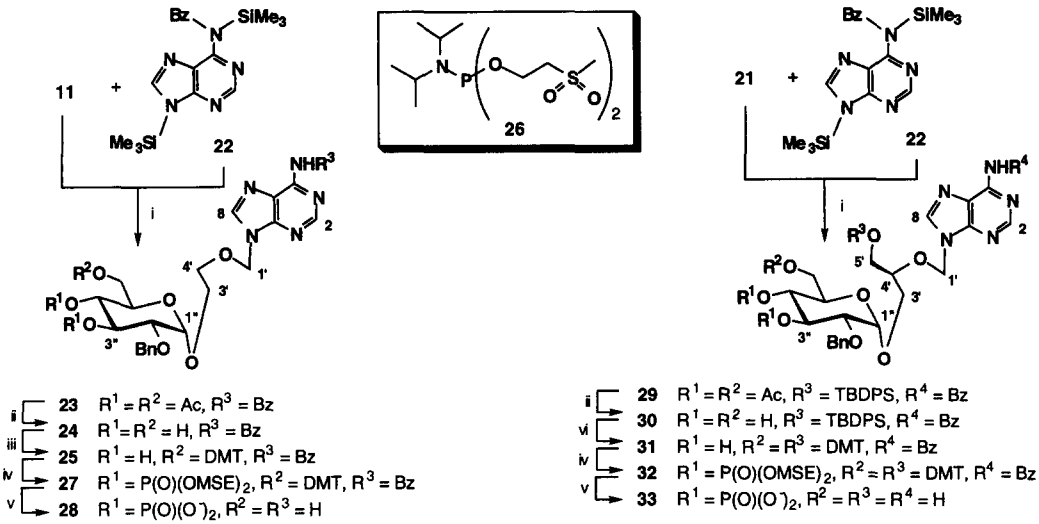
Scheme 1

The synthesis of the target glycol-based analog **4** commences with the glycosylation of *tert*-butyldiphenylsilyl (TBDPS)-glycol (**7**, Scheme 1) with ethyl 3,4,6-tri-*O*-acetyl-2-*O*-benzyl-1-thio-α/β-D-glucopyranoside (**6**). Thus, reaction of **6** with **7** under the agency of the promoter NIS/TfOH[8] led, as gauged by NMR analysis, to the exclusive formation of α-linked 2-*O*-(3,4,6-tri-*O*-acetyl-2-*O*-benzyl-α-D-glucopyranosyl)-1-*O*-*tert*-butyldiphenylsilylglycol (**8**) in 83% yield. It was anticipated[7] that the nucleobase could be smoothly installed by *N*-glycosylation of silylated 6-*N*-benzoyladenine (**22**) with 2-*O*-(3,4,6-tri-*O*-acetyl-2-*O*-benzyl-α-D-glucopyranosyl)-1-*O*-acetoxymethylglycol (**11**). To this end, compound **8** was desilylated and the resulting alcohol **9** was treated with a mixture of acetic acid/acetic anhydride/dimethyl sulfoxide[9] to give the methylthiomethyl (MTM) ether **10**. Reaction of **10** with acetic acid/NIS[10] furnished donor **11** in an overall yield of 55% based on **8**.

Vorbrüggen condensation[11] of methylene acetate **11** with the bis-trimethylsilyl derivative of 6-*N*-benzoyladenine (**22**, Scheme 2) in the presence of a catalytic amount of trimethylsilyl trifluoromethanesulfonate (TMSOTf) afforded 9-{2-(3,4,6-tri-*O*-acetyl-2-*O*-benzyl-α-D-glucopyranosyloxy)ethoxymethyl}-6-*N*-benzoyladenine (**23**). Dimer **23** was now subjected to short deacetylation to give 3",4",6"-triol **24**. Regioselective protection of the primary hydroxyl in **24** with a 4,4'-dimethoxytrityl (DMT) group afforded the partially protected 3",4"-diol **25**, the phosphorylation of which will lead to the modified adenophostin A derivative **4**.

The straightforward synthesis of diol derivative **25** encouraged us to adopt a similar approach towards the preparation of 3",4"-diol **31**, the precursor of the glycerol based adenophostin A analog **5**. The requisite *sn*-glycerol acceptor **16** was prepared by the following sequence of reactions. Regioselective allylation (see Scheme 1) of 1,2-*O*-isopropylidene-*sn*-glycerol (**12**) followed by deacetonation[12] of **13**, and then benzylation of **14** with *p*-methoxybenzyl chloride (*p*MBn-Cl) gave, after deallylation[13] of **15**, acceptor **16** in an overall yield of 53% over the four steps. It was established[14] that NIS/TfOH-mediated condensation of donor **6** with acceptor **16** in a mixture of 1,2-dichloroethane/diethyl ether (1/1, v/v) gave an anomeric mixture of **17** (α:β ratio of 4:1). On the other hand, glycosylation of **16** with **6** in diethyl ether resulted in the exclusive formation of α-linked 3-*O*-(3,4,6-tri-*O*-acetyl-2-*O*-benzyl-α-D-glucopyranosyl)-1,2-di-*O*-*p*-methoxybenzyl-*sn*-glycerol (**17**), which was converted into the methylene acetate derivative **21** by the following four-step procedure. Thus, demethoxybenzylation of **17** with ammonium cerium nitrate[15] (CAN) and regioselective silylation of the primary hydroxyl in **18** with TBDPS-Cl gave the partially protected derivative **19**. Methylthiomethylation of **19** with dimethyl sulfide and benzoyl peroxide[16] (BPO) in the presence of 2,6-lutidine proceeded smoothly[17] to yield **20**, which was converted with acetic acid under the agency of iodonium ions into the corresponding methylene acetate **21** in an overall yield of 29%. TMSOTf-assisted[11] glycosylation (see Scheme 2) of **21** with the silylated 6-*N*-benzoyladenine derivative **22** yielded (2*S*)-9-[(1-{3,4,6-tri-*O*-acetyl-2-*O*-benzyl-α-D-glucopyranosyloxy}-3-*tert*-butyldiphenylsilyloxy-2-propoxy)methyl]-6-*N*-benzoyladenine (**29**) in a yield of 52%. Deacetylation (**29** → **30**) and subsequent desilylation of **30** gave, after protection of the two primary hydroxyl functions with DMT-groups, the requisite 3",4"-diol derivative **31** in a yield of 92% over the three steps.

The final stage in the assembly of adenophostin A analogs **4** and **5** entails introduction of the phosphate monoesters. It was expected[7] that the reagent *N,N*-diisopropyl-bis-[2-(methylsulfonyl)ethyl] (MSE) phosphoramidite[18] (**26**) would be highly effective for the purposive phosphorylation of **25** and **31**.



Reagents and conditions: (i) TMSOTf, 1,2-dichloroethane, reflux, 16 h, **23**: 50%; **29**: 52%; (ii) KO*t*-Bu (1 M in MeOH)/1,4-dioxane, 2/1, v/v, 1 min, **24**: 70%, **30**: 96%; (iii) DMTCl, pyr, 3 h, 96%; (iv) a. **26**, 1*H*-tetrazole, CH_2Cl_2/CH_3CN, 1/1, v/v, 15 min; b. *t*-BuOOH, 0 °C, 15 min; (v) a. NaOH (4 M)/1,4-dioxane/MeOH, 1/14/5, v/v/v, 16 h; b. $HOAc/H_2O$, 4/1, v/v, 1 h; (vi) a. TBAF (1 M in THF)/1,4-dioxane, 1/5, v/v, 50 °C, 2 h; b. DMTCl, pyr, 3 h, 96% (2 steps).

Scheme 2

Indeed, phosphitylation of **25** and **31** with amidite **26** under the influence of 1*H*-tetrazole, and oxidation of the intermediate phosphite triesters to the corresponding phosphate triesters, proceeded smoothly to give the fully protected adenophostin A analogs **27** and **32**, respectively. Removal of the base-labile (MSE and benzoyl) groups and acid-labile (DMT) group gave partially protected **28** and **33**. Finally, hydrogenolysis (Pd-black, H_2) of **28** and **33** and purification of the individual compounds by gel-filtration (HW-40) yielded target adenophostin A analogs **4** and **5**, the analytical data of which - ^{13}C, ^{1}H and ^{31}P NMR spectroscopy as well as ESI-mass spectrometry- were in complete accordance with the proposed structures.

Conclusion

In summary, the results presented in this paper clearly indicate that ethyl 1-thio-α/β-D-glucopyranoside **6** is a very convenient donor for the construction of valuable analogs of adenophostin A (*i.e.* **4** and **5**). The biological activities of **4** and **5** with respect to the Ca^{2+}-mobilization and IP_3 receptor-binding affinity are currently under investigation and will be reported in due course.

Experimental

General methods and materials

Dichloromethane and toluene were dried by distillation from P_2O_5 (5 g L^{-1}) and stored over molecular sieves 4Å (Acros). Pyridine, diethyl ether, triethylamine and 2,6-lutidine were refluxed for 2 h in the presence of CaH_2 (5 g L^{-1}), subsequently distilled and pyridine, 2,6-lutidine and diethyl ether were stored over molecular sieves 4Å. *N,N*-Dimethylformamide (p.a. Baker), 1,2-dichloroethane (p.a. Rathburn), 1,4-dioxane (p.a. Baker), *iso*-propanol (p.a. Baker), dimethyl sulfoxide (p.a. Baker) and acetonitrile (p.a. Rathburn) were stored over molecular sieves 4Å, methanol (HPLC-grade, Rathburn) was stored over molecular sieves 3Å and all solvents were used without further purification. Acetic acid (p.a. Baker) and acetic anhydride (p.a. Baker) were used as received. Eluents for column chromatography were of technical grade and distilled before use. All reactions were performed under anhydrous conditions at room temperature unless stated otherwise. Reactions were followed by TLC analysis conducted at Schleicher and Schüll DC Fertigfolien (F 1500 LS 254). The following eluents were used: ethyl acetate/light petroleum, 1/3, v/v (System A), 1/1, v/v (System B), and 3/1, v/v (System C), methanol/dichloromethane, 5/95, v/v (System D), and 1/10, v/v (System E). Compounds were visualized by UV light and by spraying with 20% sulfuric acid in methanol followed by charring at 140 °C. Column chromatography was performed on silica gel 60, 0.036-0.200 mm (Baker). Gel-filtration was performed on Sephadex LH-20 (Pharmacia). Optical rotations were measured with a Propol polarimeter for solutions in chloroform (p.a. Baker) unless stated otherwise (20 °C). NMR spectra were recorded with a Jeol JNM-FX-200 (^1H, ^{13}C, and ^{31}P at 200, 50.1, and 80.7 MHz respectively), a Bruker WM-300 spectrometer equipped with an Aspect 2000 computer (^1H,^{13}C, and ^{31}P at 300, 75, and 121 MHz respectively), and a Bruker 600-DMX spectrometer (^1H, ^{13}C, and ^{31}P at 600, 150, and 242 MHz respectively). ^1H and ^{13}C-Chemical shifts are given in ppm (δ) relative to tetramethylsilane as an internal standard and ^{31}P-chemical shifts are given relative to 85% H_3PO_4 as an external standard. Mass spectra were recorded on a Finnigan MAT TSQ-70 equipped with a custom-made Electrospray Interface (ESI).

tert-Butyldiphenylsilylglycol (7)

To a mixture of ethylene glycol (15 mL) and pyridine (15 mL) was added *tert*-butyldiphenylsilyl chloride (7.8 mL, 30 mmol). After stirring for 1 h, TLC analysis (System B) showed the reaction to be complete. The mixture was diluted with ethyl acetate (100 mL) and poured in water (50 mL). The layers were separated and the organic phase was washed with aq. $NaHCO_3$ (10%, 50 mL) and water (50 mL), dried ($MgSO_4$), filtered, and concentrated *in vacuo*. The residual oil was applied onto a column of silica gel. Elution with ethyl acetate/light petroleum (1/9 to 1/1, v/v) and concentration of the appropriate fractions yielded pure **7**, which crystallized upon standing (9.0 g, 30 mmol, 99%); Rf 0.88; ^1H NMR ($CDCl_3$): δ 7.71-7.24 (m, 10H, H arom), 3.77-3.74 (m, 4H, H-1a, H-1b, H-2a, H-2b), 2.16 (bs, 1H, OH), 1.07 (s, 9H, CH_3 *t*-Bu); $^{13}C\{^1H\}$ NMR ($CDCl_3$): δ 133.2 (Cq Ph), 129.7, 127.7, 127.5 (CH arom), 65.0 (C-2), 63.6 (C-1), 26.8 (CH_3 *t*-Bu), 19.2 (Cq *t*-Bu).

2-*O*-(3,4,6-Tri-*O*-acetyl-2-*O*-benzyl-α-D-glucopyranosyl)-1-*O*-*tert*-butyldiphenylsilylglycol (8)

A mixture of ethyl 1-thioglucosyl donor **6** (0.22 g, 0.50 mmol) and glycol acceptor **7** (0.15 g, 0.50 mmol) in a mixture of 1,2-dichloroethane/diethyl ether (1/1, v/v, 5 mL) was stirred for 30 min under a blanket of argon in

the presence of activated molecular sieves (4Å). The mixture was cooled (0 °C) and NIS (0.11 g, 0.50 mmol) and a catalytic amount of TfOH (8 mg, 0.05 mmol) were added. Stirring was continued for 5 min, after which TLC analysis (System A) revealed complete conversion of both donor and acceptor into one product. The reaction mixture was quenched with triethylamine (1 mL), diluted with dichloromethane (15 mL), and molecular sieves were removed by filtration. The filtrate was washed with aq. $Na_2S_2O_3$ (20%, 10 mL), aq. $NaHCO_3$ (10%, 10 mL) and water (10 mL). The combined organic layers were dried ($MgSO_4$), filtered, and concentrated. Purification by silica gel column chromatography (eluent: ethyl acetate/light petroleum, 1/9 to 1/3, v/v) afforded α-linked **8** as an oil (0.28 g, 0.42 mmol, 83%); Rf 0.32; ^{1}H NMR ($CDCl_3$): δ 7.73-7.28 (m, 15H, H arom), 5.54 (t, 1H, H-3', $J_{2,3}$, $J_{3,4}$ 9.6 Hz), 5.00 (t, 1H, H-4', $J_{4,5}$ 9.2 Hz), 4.86 (d, 1H, H-1', $J_{1,2}$ 3.6 Hz), 4.67-4.53 (AB, 2H, CH_2 Bn), 4.26-3.76 (m, 7H, H-1a, H-1b, H-2a, H-2b, H-5', H-6a', H-6b'), 3.59 (dd, 1H, H-2'), 2.06, 2.01, 1.96 (3x s, 9H, 3x CH_3 Ac), 1.05 (s, 9H, CH_3 *t*-Bu); ^{13}C{^{1}H} NMR ($CDCl_3$): δ 169.9, 169.4, 169.2 (3x C(O) Ac), 137.5 (Cq Bn), 135.3-127.3 (CH arom) 132.8, 132.7 (2x Cq Ph), 96.2 (C-1', $J_{C\text{-}1',H\text{-}1'}$ 170.0 Hz), 76.6, 71.5, 68.3, 66.6 (C-2', C-3', C-4', C-5'), 72.3 (CH_2 Bn), 68.7 (C-2), 62.5 (C-1), 61.6 (C-6'), 26.4 (CH_3 *t*-Bu), 20.4, 20.2, 20.1 (3x CH_3 Ac), 18.7 (Cq *t*-Bu); ESI-MS: $[M+Na]^+$ 701; Anal. Calcd. for $C_{37}H_{46}O_{10}Si$ (678.29): C, 65.46; H, 6.83; Si, 4.14. Found: C, 65.48; H, 6.88, Si, 4.10.

2-*O*-(3,4,6-Tri-*O*-acetyl-2-*O*-benzyl-α-D-glucopyranosyl)glycol (9)

To a solution of 2-*O*-(3,4,6-tri-*O*-acetyl-2-*O*-benzyl-α-D-glucopyranosyl)-1-*O*-*tert*-butyldiphenylsilylglycol (**8**, 1.4 g, 2.1 mmol) in THF (10 mL) were subsequently added pyridine.HCl (0.25 g, 2.1 mmol) and tetrabutylammonium fluoride (4.2 mL, 1 M in THF). After stirring for 1 h at 50 °C, TLC analysis (System C) showed complete conversion of **8** into a more polar product. The reaction mixture was diluted with ethyl acetate (25 mL) and washed with aq. $NaHCO_3$ (10%, 10 mL). The organic layer was washed with water (10 mL), dried ($MgSO_4$), filtered, and concentrated. Purification of the crude product was accomplished by silica gel column chromatography. Elution with ethyl acetate/light petroleum (1/1 to 1/0, v/v) and concentration of the appropriate fractions gave **9** (0.83 g, 1.9 mmol, 89%) as a colorless oil; Rf 0.41; ^{1}H NMR ($CDCl_3$, 300 MHz, HH-COSY): δ 7.38-7.27 (m, 5H, H arom), 4.46 (t, 1H, H-3', $J_{2,3}$, $J_{3,4}$ 9.7 Hz), 4.97 (t, 1H, H-4', $J_{4,5}$ 9.9 Hz), 4.83 (d, 1H, H-1', $J_{1,2}$ 3.6 Hz), 4.68-4.57 (AB, 2H, CH_2 Bn), 4.25 (dd, 1H, H-6a', $J_{5,6a}$ 4.5 Hz, $J_{6a,6b}$ 12.3 Hz), 4.09 (ddd, 1H, H-5', $J_{5,6a}$ 4.3 Hz, $J_{5,6b}$ 2.2 Hz), 4.04 (dd, 1H, H-6b', $J_{5,6b}$ 2.3 Hz), 3.81-3.71 (m, 3H, H-1a, H-1b, H-2a), 3.59 (dd, 1H, H-2'), 3.56 (dd, 1H, H-2b, $J_{1,2a}$ 3.2 Hz, $J_{2a,2b}$ 13.8 Hz), 3.12 (bs, 1H, OH), 2.07, 2.00 (2x s, 9H, 3x CH_3 Ac); ^{13}C{^{1}H} NMR ($CDCl_3$): δ 170.4, 169.9, 169.6 (3x C(O) Ac), 137.2 (Cq Bn), 97.1 (C-1'), 76.7, 71.7, 68.4, 67.2 (C-2', C-3', C-4', C-5'), 73.1 (CH_2 Bn), 70.5 (C-2), 61.8, 61.2 (C-1, C-6'), 20.6, 20.5, 20.4 (3x CH_3 Ac); ESI-MS: $[M+Na]^+$ 463.

2-*O*-(3,4,6-Tri-*O*-acetyl-2-*O*-benzyl-α-D-glucopyranosyl)-1-*O*-methylthiomethylglycol (10)

Partially protected **9** (0.83 g, 1.9 mmol) was dissolved in a mixture of acetic acid/acetic anhydride/dimethyl sulfoxide (11/35/54, v/v/v, 10 mL) and stirred for 16 h. The mixture was diluted with ethyl acetate (25 mL) and poured into water (10 mL). Separation of the layers and cautious washing of the organic phase with aq. $NaHCO_3$ (10%, 10 mL), followed by drying ($MgSO_4$), filtration, and concentration under reduced pressure afforded crude **10**. Application of **10** on a silica gel column and elution with ethyl acetate/light petroleum (1/1, v/v) yielded methylthiomethyl-containing **10** as an oil (0.79 g, 1.6 mmol, 84%); Rf 0.73 (System C); ^{1}H NMR

($CDCl_3$): δ 7.31-7.28 (m, 5H, H arom), 5.46 (t, 1H, H-3', $J_{2,3}$, $J_{3,4}$ 9.9 Hz), 4.97 (t, 1H, H-4', $J_{4,5}$ 9.7 Hz), 4.85 (d, 1H, H-1', $J_{1,2}$ 3.6 Hz), 4.67 (s, 2H, CH_2 MTM), 4.64-4.61 (AB, 2H, CH_2 Bn), 4.26 (dd, 1H, H-6a', $J_{5,6a}$ 4.5 Hz, $J_{6a,6b}$ 12.2 Hz), 4.14-4.02 (m, 2H, H-6b', H-5'), 3.82-3.63 (m, 4H, H-1a, H-1b, H-2a, H-2b), 3.57 (dd, 1H, H-2'), 2.14 (s, 3H, CH_3 MTM), 2.07, 2.02, 2.01 (3x s, 9H, 3x CH_3 Ac); $^{13}C\{^1H\}$ NMR ($CDCl_3$): δ 169.8, 169.3, 169.1 (3x C(O) Ac), 127.8, 127.3, 127.1 (CH arom), 96.1 (C-1'), 76.2, 71.1, 68.0, 66.5 (C-2', C-3', C-4', C-5'), 74.6 (CH_2 MTM), 72.0 (CH_2 Bn), 66.6, 65.9 (C-1, C-2), 61.3 (C-6'), 20.1, 20.0, 19.9 (3x CH_3 Ac), 13.0 (CH_3 MTM); ESI-MS: $[M+Na]^+$ 523.

1-*O*-Acetoxymethyl-2-*O*-(3,4,6-tri-*O*-acetyl-2-*O*-benzyl-α-D-glucopyranosyl)glycol (11)

Compound **10** (0.79 g, 1.6 mmol) was dissolved in 1,2-dichloroethane (2.5 mL) and stirred for 30 min under a nitrogen atmosphere in the presence of activated molecular sieves (4Å). A solution of acetic acid (0.12 mL, 2.0 mmol) in THF (2.5 mL) was dried by stirring for 1 h under a nitrogen atmosphere in the presence of activated molecular sieves (4Å). To this solution, NIS (0.46 g, 2.0 mmol) was added and the acetic acid/NIS mixture was subsequently added to the cooled (0 °C) solution of **10** in 1,2-dichloroethane. TLC analysis (System C) after 5 min revealed complete conversion of starting sugar material. The mixture was diluted with dichloromethane (25 mL) and filtered. The filtrate was washed with aq. $Na_2S_2O_3$ (20%, 10 mL), aq. $NaHCO_3$ (10%, 10 mL), and water (10 mL). The combined organic layers were dried ($MgSO_4$), filtered, and concentrated. The oily product obtained was purified by silica gel column chromatography (eluent: ethyl acetate/light petroleum, 1/3 to 1/1, v/v). Concentration of the appropriate fractions furnished acetate **11** as a colorless oil (0.60 g, 1.2 mmol, 73%); Rf 0.70; ^1H NMR ($CDCl_3$): δ 7.38-7.26 (m, 5H, H arom), 5.44 (t, 1H, H-3', $J_{2,3}$, $J_{3,4}$ 10.0 Hz), 5.32-5.24 (AB, 2H, OCH_2O), 4.97 (t, 1H, H-4', $J_{4,5}$ 10.2 Hz), 4.83 (d, 1H, H-1', $J_{1,2}$ 3.6 Hz), 4.69-4.55 (AB, 2H, CH_2 Bn), 4.23 (dd, 1H, H-6a', $J_{5,6a}$ 3.7 Hz, $J_{6a,6b}$ 12.0 Hz), 4.14-4.00 (m, 2H, H-6b', H-5'), 3.87-3.66 (m, 4H, H-1a, H-1b, H-2a, H-2b), 3.58 (dd, 1H, H-2'), 2.10, 2.07, 2.02, 2.00 (4x s, 12H, 4x CH_3 Ac); $^{13}C\{^1H\}$ NMR ($CDCl_3$): δ 169.9, 169.4, 169.2 (4x C(O) Ac), 137.4 (Cq Bn), 128.0, 127.4, 127.2 (CH arom), 96.3 (C-1'), 88.5 (OCH_2O), 76.2, 71.2, 68.1, 66.7 (C-2', C-3', C-4', C-5'), 72.2 (CH_2 Bn), 68.6, 66.8 (C-1, C-2), 61.4 (C-6'), 20.4, 20.3, 20.2, 20.0 (4x CH_3 Ac); ESI-MS: $[M+NH_4]^+$ 530; Anal. Calcd. for $C_{24}H_{32}O_{12}$ (512.19): C, 56.25; H, 6.29. Found: C, 56.23; H, 6.33.

1,2-*O*-Isopropylidene-3-*O*-allyl-*sn*-glycerol (13)

To a cooled (0 °C) solution of 1,2-*O*-isopropylidene-*sn*-glycerol (**12**, 6.2 mL, 50 mmol) in DMF (50 mL) was added sodium hydride (2.7 g, 60% in oil, 86 mmol). After stirring for 15 min, allyl bromide (5.1 mL, 60 mmol) was added and the mixture was allowed to warm to room temperature. TLC analysis (System B) after 4 h showed complete conversion of starting material into a higher-running product. Methanol (10 mL) was added and the mixture was diluted with diethyl ether/light petroleum (1/1, v/v, 350 mL). The organic solution was washed with water (100 mL), dried ($MgSO_4$), filtered, and concentrated (temperature of the water bath did not exceed 20 °C). Purification by silica gel column chromatography (eluent: ethyl acetate/light petroleum, 0/1 to 1/1, v/v) furnished **13** as a colorless oil; Rf 0.76; ^1H NMR ($CDCl_3$): δ 5.89 (ddt, 1H, C*H*=CH_2, $J_{H,H}$ 5.6 Hz, $J_{H,H}$ 10.3 Hz, $J_{H,H}$ 17.2 Hz), 5.28 (dd, 1H, CH=CH_2, $^2J_{H,H}$ 1.5 Hz), 5.20 (dd, 1H, CH=CH_2) 4.30 (m, 1H, H-2), 4.07-4.01 (m, 3H, H-3a, OCH_2 All), 3.74 (m, 1H, H-3b), 3.57-3.41 (m, 2H, H-1a, H-1b), 1.42, 1.37 (2x s, 6H, 2x CH_3 isoprop); $^{13}C\{^1H\}$ NMR ($CDCl_3$): δ 134.3 (*C*H=CH_2), 116.1 (CH=*C*H_2), 108.6 (Cq isoprop), 74.3 (C-2), 71.8, 70.7, 66.4 (C-1, C-3, OCH_2 All), 26.2, 24.9 (2x CH_3 isoprop).

3-*O*-Allyl-*sn*-glycerol[12] (14)

1,2-*O*-Isopropylidene-3-*O*-allyl-*sn*-glycerol (**13**, 50 mmol) was stirred at 50 °C in a mixture of acetic acid/water (5/1, v/v, 240 mL). TLC analysis (System C) after 1 h indicated complete removal of the acetonide function. The mixture was diluted with toluene (25 mL) and concentrated to a smaller volume. The residual oil was repeatedly diluted with toluene (5x 25 mL) and concentrated under reduced pressure to furnish crude **14**, which was used without further purification.

3-*O*-Allyl-1,2-di-*O*-*p*-methoxybenzyl-*sn*-glycerol (15)

To a solution of glycerol derivative **14** (50 mmol) in DMF (200 mL) was added sodium hydride (5.2 g, 60% in oil, 130 mmol). After stirring for 15 min, *p*-methoxybenzyl chloride (6.6 mL, 130 mmol) and a catalytic amount of TBAI were added and the mixture was allowed to warm to room temperature. After stirring for 16 h at 60 °C, TLC analysis (System C) revealed almost complete consumption of starting material. Methanol (25 mL) was added and the mixture was diluted with diethyl ether/light petroleum (1/1, v/v, 200 mL). The organic solution was washed with water (100 mL) and aq. $NaHCO_3$ (10%, 100 mL), dried ($MgSO_4$), filtered, and concentrated. The residue was applied onto a column of silica gel. Elution with ethyl acetate/light petroleum (1/3 to 1/1, v/v) and subsequent concentration of the appropriate fractions gave **15** as an oil (9.0 g, 26 mmol, 52% based on **12**); Rf 0.73; ^{1}H NMR ($CDCl_3$): δ 7.29-6.83 (4x d, 8H, H arom), 5.85 (ddt, 1H, C*H*=CH_2, $J_{H,H}$ 5.5 Hz), 5.24 (dd, 1H, CH=C*H*$_2$, $^2J_{H,H}$ 1.5 Hz, $J_{H,H}$ 17.2 Hz), 5.17 (dd, 1H, CH=C*H*$_2$, $J_{H,H}$ 10.5 Hz), 4.61, 4.46 (2x s, 4H, 2x CH_2 *p*MBn), 3.98 (dd, 2H, OCH_2 All, $^2J_{H,H}$ 1.3 Hz, $J_{H,H}$ 4.1 Hz), 3.80, 3.79 (2x s, 6H, 2x OCH_3), 3.74 (m, 1H, H-2), 3.56-3.53 (m, 4H, H-1a, H-1b, H-3a, H-3b); ^{13}C {^{1}H} NMR ($CDCl_3$): δ 158.2 (2x *C*OCH_3), 134.6 (*C*C=CH_2), 130.6, 130.1 (2x Cq *p*MBn), 129.0, 128.9, 113.4 (CH arom), 116.3 (CH=*C*H_2), 76.6 (C-2), 72.6, 71.9, 71.5, 70.1, 69.8 (2x CH_2 *p*MBn, OCH_2 All, C-1, C-3), 54.8 (OCH_3).

1,2-di-*O*-*p*-Methoxybenzyl-*sn*-glycerol (16)

Air was bubbled through a mixture of glycerol derivative **15** (0.37 g, 1.0 mmol), $PdCl_2$ (18 mg, 1.0 mmol), and CuCl (99 mg, 1.0 mmol) in DMF/water (10/1, v/v, 11 mL). TLC analysis (System B) after 6 h indicated the reaction to be complete. The mixture was diluted with diethyl ether (10 mL) and filtered over a bed of Hyflo.® The filtrate was washed with water (5 mL) and the layers were separated. The organic phase was dried ($MgSO_4$), filtered, and concentrated *in vacuo*. The residual oil was purified by silica gel column chromatography (eluent: ethyl acetate/light petroleum, 1/3 to 1/1, v/v) to afford pure acceptor **16** (0.24 g, 0.75 mmol, 75%); $[\alpha]_D$ -21.3° (*c* 1.0); Rf 0.46; ^{1}H NMR ($CDCl_3$): δ 7.28, 7.23, 6.89, 6.85 (2x d, 8H, H arom), 4.59-4.48 (AB, 2H, CH_2 *p*MBn), 4.46 (s, 2H, CH_2 *p*MBn), 3.80, 3.79 (2x s, 6H, 2x OCH_3), 3.57-3.52 (m, 5H, H-1a, H-1b, H-2, H-3a, H-3b); ^{13}C{^{1}H} NMR ($CDCl_3$): δ 158.9 (2x *C*OCH_3), 130.6, 130.2 (2x Cq *p*MBn), 129.2, 129.0, 113.5 (CH arom), 78.3 (C-2), 72.7, 71.3, 69.8, 62.1 (2x CH_2 *p*MBn, C-1, C-3), 54.8 (OCH_3); ESI-MS: $[M+H]^+$ 333; Anal. Calcd. for $C_{19}H_{24}O_5$ (332.16): C, 68.66; H, 7.28. Found: C, 68.64; H, 7.32.

3-*O*-(3,4,6-Tri-*O*-acetyl-2-*O*-benzyl-α-D-glucopyranosyl)-1,2-di-*O*-*p*-methoxybenzyl-*sn*-glycerol (17)

A solution of ethyl 3,4,6-tri-*O*-acetyl-2-*O*-benzyl-1-thio-α/β-D-glucopyranoside (**6**, 0.95 g, 2.2 mmol) and 1,2-di-*O*-*p*-methoxybenzyl-*sn*-glycerol (**16**, 0.43 g, 1.8 mmol) in diethyl ether (20 mL) was stirred for 30 min in the presence of activated molecular sieves (4Å) under a blanket of argon. The mixture was cooled (0 °C) and NIS (0.54 g, 2.4 mmol) and TfOH (33 mg, 0.22 mmol) were added. After stirring for 15 min, an extra amount of NIS (0.1 g, 0.44 mmol) and TfOH (33 mg, 0.22 mmol) were added. The mixture was stirred for 2 h at ambient temperature, after which TLC analysis (System B) indicated almost complete reaction. Triethylamine (1 mL) was added and the molecular sieves were removed by filtration. The filtrate was diluted with diethyl ether (25 mL), washed with aq. $Na_2S_2O_3$ (20%, 10 mL), and aq. $NaHCO_3$ (10%, 10 mL), dried ($MgSO_4$), filtered, and concentrated. Purification by silica gel column chromatography (eluent: ethyl acetate/light petroleum, 1/9 to 1/3, v/v) furnished α-linked dimer **17** (0.92 g, 1.3 mmol, 72%); Rf 0.63; ^{1}H NMR ($CDCl_3$): δ 7.28-6.86 (m, 13H, H arom), 5.46 (t, 1H, H-3', $J_{2,3}$, $J_{3,4}$ 9.6 Hz), 5.30 (d, 1H, H-1', $J_{1,2}$ 3.1 Hz), 5.01 (t, 1H, H-4', $J_{4,5}$ 9.8 Hz), 4.63, 4.60, 4.59 (3x s, 6H, 3x CH_2 (*p*M)Bn), 4.29-3.61 (m, 9H, H-1a, H-1b, H-2, H-3a, H-3b, H-2', H-5', H-6a', H-6b'), 3.81, 3.80 (2x s, 6H, 2x OCH_3), 2.02, 2.01, 2.00 (3x s, 9H, 3x CH_3 Ac); $^{13}C\{^1H\}$ NMR ($CDCl_3$): δ 170.1, 169.7, 169.4 (3x C(O) Ac), 158.9 (2x $COCH_3$), 137.5 (Cq Bn), 130.2, 129.9 (2x Cq *p*MBn), 128.9-127.3 (CH arom), 113.4 (CH arom *p*MBn), 96.7 (C-1', $J_{C\text{-}1',H\text{-}1'}$ 170.3 Hz), 76.5, 75.7, 71.6, 68.3, 66.8 (C-2, C-2', C-3', C-4', C-5'), 72.7, 72.3, 71.3, 68.9, 68.4 (3x CH_2 (*p*M)Bn, C-1, C-3), 61.6 (C-6'), 54.8 (OCH_3), 20.5, 20.3 (3x CH_3 Ac); ESI-MS: $[M+NH_4]^+$ 729; Anal. Calcd. for $C_{38}H_{46}O_{13}$ (710.29): C, 64.21; H, 6.52. Found: C, 64.16; H, 6.54.

3-*O*-(3,4,6-Tri-*O*-acetyl-2-*O*-benzyl-α-D-glucopyranosyl)-*sn*-glycerol (18)

To a cooled (0 °C) solution of dimer **17** (0.43 g, 0.6 mmol) in acetonitrile/water (10/1, v/v, 11 mL) was added ammonium cerium (IV) nitrate (1.3 g, 2.4 mmol). The mixture was allowed to warm to room temperature and was stirred for 30 min until TLC analysis (System C) showed removal of both *p*-methoxybenzyl protective groups. The reaction mixture was diluted with dichloromethane (25 mL) and washed with aq. $Na_2S_2O_3$ (20%, 10 mL). The layers were separated and the organic phase was washed with aq. $NaHCO_3$ (10%, 10 mL) and brine (10 mL), dried ($MgSO_4$), filtered, and concentrated *in vacuo*. The residue was applied onto a column of silica gel. Elution was effected with ethyl acetate/light petroleum (1/1 to 1/0, v/v). Concentration of the appropriate fractions yielded diol **18** as an oil (0.24 g, 0.52 mmol, 87%); Rf 0.08; ^{1}H NMR ($CDCl_3$, 300 MHz, HH-COSY): δ 7.39-7.27 (m, 5H, H arom), 5.43 (t, 1H, H-3', $J_{2,3}$, $J_{3,4}$ 9.7 Hz), 4.97 (t, 1H, H-4', $J_{4,5}$ 9.7 Hz), 4.79 (d, 1H, H-1', $J_{1,2}$ 3.6 Hz), 4.68-4.56 (AB, 2H, CH_2 Bn), 4.26 (dd, 1H, H-6a', $J_{5,6a}$ 5.0 Hz, $J_{6a,6b}$ 12.9 Hz), 4.29-4.00 (m, 2H, H-5', H-6b'), 3.85 (dddd, 1H, H-2), 3.82 (dd, 1H, H-3a, $J_{2,3a}$ 3.6 Hz, $J_{3a,3b}$ 10.1 Hz), 3.72 (dd, 1H, H-1a, $J_{1a,2}$ 4.0 Hz, $J_{1a,1b}$ 11.5 Hz), 3.61 (dd, 1H, H-1b, $J_{1b,2}$ 4.9 Hz), 3.59 (dd, 1H, H-2'), 3.41 (dd, 1H, H-3b, $J_{2,3b}$ 6.9 Hz), 3.15 (bs, 2H, 2x OH), 2.07, 2.02, 2.01 (3x s, 9H, 3x CH_3 Ac); $^{13}C\{^1H\}$ NMR ($CDCl_3$): δ 170.5, 170.1, 169.6 (3x C(O) Ac), 137.2 (Cq Bn), 128.4-127.8 (CH arom), 97.1 (C-1'), 76.6, 71.6, 70.4, 68.3, 67.1 (C-2, C-2', C-3', C-4', C-5'), 72.9, 70.3 (CH_2 Bn, C-3), 63.2, 61.7 (C-1, C-6'), 20.6, 20.5, 20.4 (3x CH_3 Ac); ESI-MS: $[M+NH_4]^+$ 488.

3-*O*-(3,4,6-Tri-*O*-acetyl-2-*O*-benzyl-α-D-glucopyranosyl)-1-*O*-*tert*-butyldiphenylsilyl-*sn*-glycerol (19)

Diol **18** (0.24 g, 0.52 mmol) was dissolved in pyridine (3 mL) and *tert*-butyldiphenylsilyl chloride (0.15 mL, 0.63 mmol) and a catalytic amount of 4-dimethylaminopyridine were added. The mixture was stirred at 60 °C for 48 h, after which methanol (1 mL) was added. The reaction mixture was concentrated, the residue was diluted with ethyl acetate (15 mL) and washed with aq. $NaHCO_3$ (10%, 5 mL). The layers were separated and the organic phase was washed with water (5 mL), dried ($MgSO_4$), filtered, and concentrated. Purification of the residual oil by silica gel column chromatography (eluent: ethyl acetate/light petroleum, 1/9 to 1/1, v/v) gave monosilylated dimer **19** as an oil (0.23 g, 0.32 mmol, 62%); Rf 0.67 (System C); ^{1}H NMR ($CDCl_3$): δ 7.68-7.26 (m, 15H, H arom), 5.43 (t, 1H, H-3', $J_{2,3}$, $J_{3,4}$ 9.6 Hz), 4.96 (t, 1H, H-4', $J_{4,5}$ 9.7 Hz), 4.85 (d, 1H, H-1', $J_{1,2}$ 3.6 Hz), 4.67-4.52 (AB, 2H, CH_2 Bn), 4.23 (dd, 1H, H-6a', $J_{5,6a}$ 7.7 Hz, $J_{6a,6b}$ 12.2 Hz), 4.08-3.93 (m, 3H, H-2, H-5', H-6b'), 3.83 (dd, 1H, H-3a, $J_{2,3a}$ 4.0 Hz, $J_{3a,3b}$ 10.3 Hz), 3.59 (dd, 1H, H-1a, $J_{1a,2}$ 3.6 Hz, $J_{1a,1b}$ 10.0 Hz), 3.74-3.44 (3x dd, 3H, H-1b, H-2', H-3b), 2.02, 2.01 (2x s, 9H, 3x CH_3 Ac), 1.07 (s, 9H, CH_3 *t*-Bu); ^{13}C{^{1}H} NMR ($CDCl_3$): δ 170.4, 169.9, 169.6 (3x C(O) Ac), 137.3 (Cq Bn), 135.3-127.6 (CH arom), 132.9 (2x Cq Ph), 97.7 (C-1'), 76.6, 71.7, 70.5, 68.4, 67.2 (C-2, C-2', C-3', C-4', C-5'), 72.9, 70.5 (CH_2 Bn, C-3), 64.4, 61.8 (C-1, C-6'), 26.7 (CH_3 *t*-Bu), 20.6, 20.5 (3x CH_3 Ac), 19.1 (Cq *t*-Bu); ESI-MS: $[M+Na]^+$ 731.

3-*O*-(3,4,6-Tri-*O*-acetyl-2-*O*-benzyl-α-D-glucopyranosyl)-2-*O*-methylthiomethyl-1-*O*-*tert*-butyldiphenylsilyl-*sn*-glycerol (20)

To a cooled (0 °C) mixture of 3-*O*-(3,4,6-tri-*O*-acetyl-2-*O*-benzyl-α-D-glucopyranosyl)-1-*O*-*tert*-butyldiphenylsilyl-*sn*-glycerol (**19**, 0.23 g, 0.32 mmol), dimethyl sulfide (0.23 mL, 3.2 mmol) and 2,6-lutidine (52 µL, 0.44 mmol) in acetonitrile (95 mL) was added benzoyl peroxide (0.31 g, 1.3 mmol) over a period of 30 min. After the last addition, the mixture was stirred for 30 min at room temperature, until TLC analysis (System A) confirmed disappearance of starting material. The mixture was concentrated, diluted with ethyl acetate (10 mL) and washed with water (5 mL). The organic layer was washed with aq. $NaHCO_3$ (10%, 5 mL), dried ($MgSO_4$), filtered, and concentrated under reduced pressure. Purification was accomplished by silica gel column chromatography (eluent: ethyl acetate/light petroleum, 2/98 to 1/3, v/v). Concentration of the appropriate fractions furnished **20** as an oil (0.15 g, 0.20 mmol, 63%); Rf 0.58; ^{1}H NMR ($CDCl_3$): δ 7.70-7.25 (m, 15H, H arom), 5.44 (t, 1H, H-3', $J_{2,3}$, $J_{3,4}$ 9.6 Hz), 4.98 (t, 1H, H-4', $J_{4,5}$ 9.7 Hz), 4.83 (d, 1H, H-1', $J_{1,2}$ 3.6 Hz), 4.75-4.55 (2x AB, 4H, CH_2 Bn, CH_2 MTM), 4.25 (dd, 1H, H-6a', $J_{5,6a}$ 3.9 Hz, $J_{6a,6b}$ 12.6 Hz), 4.06-3.96 (m, 3H, H-2, H-5', H-6b'), 3.84 (dd, 1H, H-3a, $J_{2,3a}$ 4.0 Hz, $J_{3a,3b}$ 11.4 Hz), 3.78-3.45 (m, 4H, H-1a, H-1b, H-3b, H-2'), 2.08 (s, 3H, CH_3 MTM), 2.04, 2.01 (2x s, 9H, 3x CH_3 Ac), 1.05 (s, 9H, CH_3 *t*-Bu); ^{13}C{^{1}H} NMR ($CDCl_3$): δ 170.1, 169.7, 169.4 (3x C(O) Ac), 137.5 (Cq Bn), 132.8, 132.7 (2x Cq Ph), 135.3-127.3 (CH arom), 97.0 (C-1'), 76.5, 74.9, 71.6, 68.3, 66.9 (C-2, C-2', C-3', C-4', C-5'), 74.0, 72.4, 68.2 (CH_2 MTM, CH_2 Bn, C-3), 62.6, 61.6 (C-1, C-6'), 26.5 (CH_3 *t*-Bu), 20.5, 20.3 (3x CH_3 Ac), 18.9 (Cq *t*-Bu), 13.3 (CH_3 MTM); ESI-MS: $[M+NH_4]^+$ 786.

2-*O*-Acetoxymethyl-3-*O*-(3,4,6-tri-*O*-acetyl-2-*O*-benzyl-α-D-glucopyranosyl)-1-*O*-*tert*-butyldiphenylsilyl-*sn*-glycerol (21)

Synthesis of **21** from **20** (0.15 g, 0.20 mmol) was accomplished as described for the preparation of **11**. Purification by silica gel column chromatography (eluent: ethyl acetate/light petroleum, 1/9 to 1/3, v/v) afforded pure **21** (0.13 g, 0.17 mmol, 85%); Rf 0.36 (System A); ^{1}H NMR ($CDCl_3$): δ 7.69-7.24 (m, 15H, H arom), 5.43 (t, 1H, H-3', $J_{2,3}$, $J_{3,4}$ 9.6 Hz), 5.29 (s, 2H, OCH_2O), 4.97 (t, 1H, H-4', $J_{4,5}$ 9.9 Hz), 4.82 (d, 1H, H-1', $J_{1,2}$ 3.4 Hz), 4.59 (s, 2H, CH_2 Bn), 4.23 (dd, 1H, H-6a', $J_{5,6a}$ 3.9 Hz, $J_{6a,6b}$ 11.3 Hz), 4.01-3.93 (m, 3H, H-2, H-5', H-6b'), 3.89 (dd, 1H, H-3a, $J_{2,3a}$ 3.8 Hz, $J_{3a,3b}$ 13.6 Hz), 3.75-3.68 (m, 2H, H-1a, H-1b), 3.59 (dd, 1H, H-2'), 3.48 (dd, 1H, H-3b, $J_{2,3b}$ 6.8 Hz), 2.04, 2.01, 2.00 (3x s, 12H, 4x CH_3 Ac), 1.05 (s, 9H, CH_3 *t*-Bu); ^{13}C{^{1}H} NMR ($CDCl_3$): δ 170.1, 169.7, 169.6, 169.4 (4x C(O) Ac), 137.5 (Cq Bn), 132.8, 132.7 (2x Cq Ph), 135.5-127.4 (CH arom), 97.1 (C-1'), 88.2 (OCH_2O), 78.6, 76.4, 71.5, 68.3, 67.0 (C-2, C-2', C-3', C-4', C-5'), 72.6, 68.4 (CH_2 Bn, C-3), 63.3, 61.8 (C-1, C-6'), 26.5 (CH_3 *t*-Bu), 20.7, 20.5, 20.3 (3x CH_3 Ac), 18.9 (Cq *t*-Bu); ESI-MS: $[M+NH_4]^+$ 798; Anal. Calcd. for $C_{41}H_{52}O_{13}Si$ (780.32): C, 63.06; H, 6.71; Si, 3.60. Found: C, 63.01; H, 6.68, Si, 3.65.

9-{2-(3,4,6-Tri-*O*-acetyl-2-*O*-benzyl-α-D-glucopyranosyloxy)ethoxymethyl}-6-*N*-benzoyl-adenine (23)

Commercially available 6-*N*-benzoyladenine (**22**, 0.48 g, 2.0 mmol) was silylated by refluxing for 6 h in a mixture of 1,1,1,3,3,3-hexamethyldisilazane (5 mL) and pyridine (2 mL). The reaction mixture was concentrated and excess HMDS was removed by repeated evaporation with toluene (5x 5 mL). Silylated 6-*N*-benzoyladenine was dissolved in 1,2-dichloroethane (5 mL) and 1-*O*-acetoxymethyl-(2-*O*-(3,4,6-tri-*O*-acetyl-2-*O*-benzyl-α-D-glucopyranosyl)glycol (**11**, 0.60 g, 1.2 mmol) and a catalytic amount of TMSOTf (26 µL, 0.12 mmol) were subsequently added. The mixture was stirred at reflux temperature for 16 h. The reaction mixture was quenched with triethylamine (0.5 mL), diluted with dichloromethane and washed with aq. $NaHCO_3$ (10%, 5 mL) and water (5 mL). The organic phase was dried ($MgSO_4$), filtered, and concentrated. The residue was extensively purified by silica gel column chromatography (eluent: dichloromethane/light petroleum, 3/1 to 1/0, v/v) to yield solely 9-*N* linked dimer **23** (0.41 g, 0.60 mmol, 50%) as a yellowish foam; Rf: 0.53 (System D); ^{1}H NMR ($CDCl_3$): δ 9.13 (bs, 1H, NH), 8.85, 8.19 (2x s, 2H, H-2, H-8), 8.04-7.19 (m, 10H, H arom), 5.78-5.66 (AB, 2H, H-1a', H-1b'), 5.44 (t, 1H, H-3", $J_{2,3,}$, $J_{3,4}$ 9.8 Hz), 4.97 (t, 1H, H-4", $J_{4,5}$ 9.8 Hz), 4.83 (d, 1H, H-1", $J_{1,2}$ 3.6 Hz), 4.69-4.53 (AB, 2H, CH_2 Bn), 4.23 (dd, 1H, H-6a", $J_{5,6a}$ 4.6 Hz, $J_{6a,6b}$ 12.3 Hz), 4.10 (dd, 1H, H-6b", $J_{5,6b}$ 7.2 Hz), 4.10-4.01 (m, 2H, H-3a', H-5"), 3.82-3.70 (m, 3H, H-3b', H-4a', H-4b'), 3.59 (dd, 1H, H-2"), 2.06, 2.03, 2.01 (3x s, 9H, 3x CH_3 Ac): ^{13}C{^{1}H} NMR ($CDCl_3$): δ 169.8, 169.4, 169.0 (3x C(O) Ac), 151.9, 143.1 (C-2, C-8), 151.7, 149.2 (C-4, C-6), 165.1 (C(O) Bz), 136.9 (Cq Bn), 132.9 (Cq Bz), 131.8-127.0 (CH arom), 122.6 (C-5), 96.2 (C-1"), 76.2, 71.0, 68.0, 66.6 (C-2", C-3", C-4", C-5"), 72.2 (CH_2 Bn, C-1'), 67.6, 66.8 (C-3', C-4'), 61.3 (C-6"), 20.1, 20.0 (3x CH_3 Ac); ESI-MS: $[M+H]^+$ 692; Anal. Calcd. for $C_{34}H_{37}N_5O_{11}$ (691.25): C, 59.04; H, 5.39; N, 10.12. Found: C, 59.05; H, 5.43, N, 10.16.

9-{2-(2-*O*-Benzyl-α-D-glucopyranosyloxy)ethoxymethyl}-6-*N*-benzoyladenine (24)

To a stirred solution of 9-{2-(3,4,6-tri-*O*-acetyl-2-*O*-benzyl-α-D-glucopyranosyloxy)ethoxymethyl}-6-*N*-benzoyladenine (**23**, 0.41 g, 0.60 mmol) in 1,4-dioxane (15 mL) was added potassium *tert*-butoxide (1 M in

methanol, 35 mL). The mixture was stirred for 1 min, after which acetic acid (2.0 mL) was added. The reaction mixture was diluted with dichloromethane (15 mL), and poured into aq. $NaHCO_3$ (10%, 5 mL). The layers were separated and the organic phase was washed with water (5 mL), dried ($MgSO_4$), filtered, and concentrated under reduced pressure. The residual foam was applied onto a column of silica gel. Elution with methanol/dichloromethane (1/9, v/v) and concentration of the appropriate fractions afforded triol **24** (0.24 g, 0.42 mmol, 70%); Rf 0.26 (System E); ^{1}H NMR ($CDCl_3$): δ 9.61 (bs, 1H, NH), 8.81, 8.31 (2x s, 2H, H-2, H-8), 8.06-7.26 (m, 10H, H arom), 5.69 (s, 2H, H-1a', H-1b'), 4.73-4.52 (AB, 2H, CH_2 Bn, d, 1H, H-1", $J_{1,2}$ 3.9 Hz), 4.12 (m, 1H, H-6a"), 3.84-3.42 (m, 8H, H-3a, H-3b', H-4a', H-4b', H-3", H-5", H-6b"), 3.28 (dd, 1H, H-2", $J_{2,3}$ 9.5 Hz), 2.01 (bs, 1H, OH), 1.35 (bs, 2H, 2x OH): ^{13}C{^{1}H} NMR ($CDCl_3$): δ 165.5 (C(O) Bz), 152.3, 143.7 (C-2, C-8), 151.6, 149.3 (C-4, C-6), 137.7 (Cq Bn), 133.0 (Cq Bz), 132.3-127.4 (CH arom), 122.1 (C-5), 96.8 (C-1"), 78.9, 72.4, 71.3, 70.6 (C-2", C-3", C-4", C-5"), 72.8, 72.3 (C-1', CH_2 Bn), 68.1, 66.7 (C-3', C-4'), 61.1 (C-6"); ESI-MS: $[M+H]^+$ 566.

9-{2-(2-*O*-Benzyl-6-*O*-[4,4'-dimethoxytrityl]-α-D-glucopyranosyloxy)ethoxymethyl}-6-*N*-benzoyladenine (25)

Dimethoxytrityl chloride (0.11 g, 0.33 mmol) was added to a solution of triol **24** (0.14 g, 0.25 mmol) in pyridine (2 mL). After stirring for 3 h complete conversion of starting material had occurred, as was visualized by TLC analysis (System E). Excess dimethoxytrityl chloride was destroyed with methanol (1 mL). The reaction mixture was concentrated and the residue was diluted with dichloromethane (10 mL), and washed with aq. $NaHCO_3$ (10%, 5 mL) and water (5 mL). The organic phase was dried ($MgSO_4$), filtered, and concentrated *in vacuo*. Purification by silica gel column chromatography (eluent: methanol/dichloromethane/triethylamine, 0/98/2 to 2/96/2, v/v/v) gave diol **25** as a foam (0.21 g, 0.24 mmol, 96%); Rf 0.68; ^{1}H NMR ($CDCl_3$): δ 9.69 (bs, 1H, NH), 8.78, 8.20 (2x s, 2H, H-2, H-8), 8.02-7.20 (m, 23H, H arom), 5.67 (s, 2H, H-1a', H-1b'), 4.70-4.56 (AB, 2H, CH_2 Bn, d, 1H, H-1", $J_{1,2}$ 3.7 Hz), 4.15 (m, 1H, H-6a"), 3.80-3.35 (m, 8H, H-3a', H-3b', H-4a', H-4b', H-3", H-4", H-5", H-6b"), 3.69 (2x s, 6H, 2x OCH_3), 3.24 (dd, 1H, H-2", $J_{2,3}$ 9.7 Hz), 2.11 (bs, 1H, OH), 1.20 (bs, 1H, OH); ^{13}C{^{1}H} NMR ($CDCl_3$): δ 165.1 (C(O) Bz), 158.2 (2x $COCH_3$), 152.0, 149.4 (C-4, C-6), 144.8 (2x Cq DMT), 137.9 (Cq Bn), 135.9 (Cq DMT), 133.4 (Cq Bz), 132.5-126.6 (CH arom), 122.4 (C-5), 96.7 (C-1"), 85.9 (Cq DMT), 79.2, 72.9, 71.2, 70.5 (C-2", C-3", C-4", C-5"), 72.8 (C-1', CH_2 Bn), 68.2, 66.7 (C-3', C-4'), 63.4 (C-6"), 55.0 (2x OCH_3); ESI-MS: $[M+H]^+$ 869.

9-{2-(α-D-Glucopyranosyloxy 3,4-bisphosphate)ethoxymethyl}-adenine (4)

To a stirred mixture of 9-{2-(2-*O*-benzyl-6-*O*-[4,4'-dimethoxytrityl]-α-D-glucopyranosyloxy)ethoxymethyl}-6-*N*-benzoyladenine (**25**, 0.21 g, 0.24 mmol) and phosphoramidite **26** (0.36 g, 1.0 mmol) in dichloromethane (3 mL) was added a solution of 1*H*-tetrazole (87 mg, 1.2 mmol) in acetonitrile (3 mL). After stirring for 5 min, TLC analysis (System D) revealed conversion of **25** into a higher-running product (Rf 0.42). ^{31}P NMR (CH_2Cl_2) showed two major resonances at δ 142.2 and 141.1. The mixture was cooled (0 °C) and the intermediate phosphite triesters were oxidized (*t*-BuOOH, 1 mL) to the corresponding phosphate triesters. TLC analysis (System D) after 15 min showed complete conversion to a product with Rf 0.22. ^{31}P NMR (CH_2Cl_2) showed two major resonances (δ -2.6, -2.7). The mixture was diluted with dichloromethane (10 mL) and poured into water (5 mL). The layers were separated and the organic phase was dried ($MgSO_4$), filtered and concentrated. Crude **27** was dissolved in a mixture of 1,4-dioxane/methanol/NaOH (4 M) (14/5/1, v/v/v, 24

mL). After stirring for 16 h, the mixture was neutralized with acetic acid (0.28 mL) and concentrated. Subsequent removal of the acid-labile dimethoxytrityl group with aq. acetic acid (80%, 10 mL, 1 h) afforded, after repeated evaporation with water (3x 10 mL) to remove traces of acid, crude **28**. Compound **28** was dissolved in water (15 mL) and washed with ethyl acetate (5 mL) and dichloromethane (5 mL). Concentration of the aqueous phase and purification by gel-filtration (HW-40, S Omnilabo, eluent: 0.15 M TEAB in water/methanol, 9/1, v/v) furnished pure **28**. Finally, hydrogenolysis of **28** over Pd-black (spatula) in water (10 mL) with two drops of acetic acid gave crude target adenophostin A analog **4**. Purification by HW-40 gel-filtration (0.15 M TEAB in water/methanol, 9/1, v/v), ion-exchange (Dowex® 50Wx4 (Na^+-form) and lyophilization yielded totally deprotected 9-{2-(α-D-glucopyranosyloxy 3,4-bisphosphate)ethoxymethyl}-adenine (**4**) as a white fluffy solid (47 mg, 91 μmol, 38%); ^1H NMR (D_2O, 300 MHz, HH-COSY): δ 8.27, 8.21 (2x s, 2H, H-2, H-8), 5.68 (s, 2H, H-1a', H-1b'), 4.90 (d, 1H, H-1", $J_{1,2}$ 3.9 Hz), 3.95 (q, 1H, H-3", $J_{2,3}$, $J_{3,4}$ 9.0 Hz, $^3J_{HP}$ 9.0 Hz), 3.95 (q, 1H, H-4", $J_{4,5}$ 9.9 Hz, $^3J_{HP}$ 9.9 Hz), 3.82 (dd, 1H, H-6a", $J_{5,6a}$ 3.5 Hz, $J_{6a,6b}$ 12.9 Hz), 3.78-3.61 (m, 5H, H-3a', H-3b', H-4a', H-4b', H-5"), 3.66 (dd, 1H, H-2"), 3.57 (dd, 1H, H-6b", $J_{5,6b}$ 2.9 Hz); $^{13}C\{^1H\}$ NMR (D_2O, 75 MHz, CH-COSY): δ 153.6, 143.3 (C-2, C-8), 99.1 (C-1"), 78.1 (C-3", $^2J_{CP}$ 2.7 Hz, $^3J_{CP}$ 6.3 Hz), 73.9 (C-1'), 72.7 (C-4", $^2J_{CP}$ 2.3 Hz, $^3J_{CP}$ 7.1 Hz), 72.0 (C-5", $^3J_{CP}$ 3.6 Hz), 71.9 (C-2", $^3J_{CP}$ 3.3 Hz), 69.1, 67.6 (C-3', C-4'), 60.9 (C-6"); ^{31}P NMR (D_2O, 121 MHz, PH-COSY): δ 2.6 (C-4"-P), 2.1 (C-3"-P); ESI-MS: $[M-H]^-$ 531; Anal. Calcd. for $C_{14}H_{23}N_5O_{13}P_2$ (531.08): C, 31.65; H, 4.36; N, 13.18; P, 11.66. Found: C, 31.60; H, 4.39, N, 13.19; P, 11.70.

(2*S*)-9-[(1-{3,4,6-Tri-*O*-acetyl-2-*O*-benzyl-α-D-glucopyranosyloxy}-3-*tert*-butyldiphenylsilyloxy-2-propoxy)-methyl]-6-*N*-benzoyladenine (29)

Vorbrüggen-type condensation of 2-*O*-acetoxymethyl-3-*O*-(3,4,6-tri-*O*-acetyl-2-*O*-benzyl-α-D-glucopyranosyl)-1-*O*-*tert*-butyldiphenylsilyl-*sn*-glycerol (**21**, 0.13 g, 0.17 mmol) with commercially available 6-*N*-benzoyladenine (**22**) was performed as described for **11** (→ **23**). The crude product was extensively purified by silica gel column chromatography (eluent: methanol/dichloromethane/light petroleum, 0/1/2 to 2/98/0, v/v/v). Concentration of the appropriate fractions furnished 9-*N* linked **29** as a yellowish foam (86 mg, 90 μmol, 52%); Rf 0.60 (System D); ^1H NMR ($CDCl_3$, 300 MHz, HH-COSY): δ 9.35 (bs, 1H, NH), 8.83, 8.01 (2x s, 2H, H-2, H-8), 8.10-7.25 (m, 20H, H arom), 5.77-5.67 (AB, 2H, H-1a', H-1b'), 5.39 (t, 1H, H-3", $J_{2,3}$, $J_{3,4}$ 9.6 Hz), 4.96 (t, 1H, H-4", $J_{4,5}$ 9.8 Hz), 4.81 (d, 1H, H-1", $J_{1,2}$ 3.6 Hz), 4.68-4.54 (AB, 2H, CH_2 Bn), 4.22 (dd, 1H, H-6a", $J_{5,6a}$ 4.1 Hz, $J_{6a,6b}$ 12.4 Hz), 3.94 (dd, 1H, H-6b", $J_{5,6b}$ 2.4 Hz), 3.91-3.84 (m, 2H, H-3a', H-4'), 3.80 (ddd, 1H, H-5"), 3.66 (dd, 1H, H-5a', $J_{4,5a}$ 5.2 Hz, $J_{5a,5b}$ 7.6 Hz), 3.62-3.60 (m, 1H, H-5b'), 3.59 (dd, 1H, H-2"), 3.41 (dd, 1H, H-3b', $J_{2,3b}$ 8.8 Hz, $J_{3a,3b}$ 11.0 Hz), 2.03, 2.02, 1.98 (3x s, 9H, 3x CH_3 Ac), 10.2 (s, 9H, CH_3 *t*-Bu); $^{13}C\{^1H\}$ NMR ($CDCl_3$): δ 170.5, 170.2, 169.7 (3x C(O) Ac), 164.7 (C(O) Bz), 153.0, 143.6 (C-2, C-8), 152.0, 149.6 (C-4, C-6), 135.5 (Cq Bn), 133.8, 132.8 (2x Cq Ph, Bz), 135.5-127.2 (CH arom), 122.6 (C-5), 97.5 (C-1"), 77.4, 76.8, 72.0, 68.4, 67.3 (C-4', C-2", C-3", C-4", C-5"), 73.3, 72.4, 69.8 (CH_2 Bn, C-1', C-3'), 63.3, 61.7 (C-5', C-6"), 26.7 (CH_3 *t*-Bu), 20.8, 20.6 (3x CH_3 Ac), 19.1 (Cq *t*-Bu); ESI-MS: $[M+H]^+$ 961; Anal. Calcd. for $C_{51}H_{57}N_5O_{12}Si$ (959.38): C, 63.80; H, 5.98; N, 7.29; Si, 2.93. Found: C, 63.77; H, 5.99, N, 7.34; Si, 2.99

(2*S*)-9-[(1-{2-*O*-Benzyl-α-D-glucopyranosyloxy}-3-*tert*-butyldiphenylsilyloxy-2-propoxy)-methyl]-6-*N*-benzoyladenine (30)

Deacetylation of **29** (50 mg, 50 μmol) was executed as described previously for the deacetylation of compound **23**. Purification was achieved by silica gel column chromatography (eluent: methanol/dichloromethane, 0/1 to 5/95, v/v). Concentration of the appropriate fractions gave **30** as a foam (40 mg, 48 μmol, 96%); Rf 0.71 (System E); $^{13}C\{^1H\}$ NMR ($CDCl_3$): δ 165.7 (C(O) Bz), 152.7, 144.2 (C-2, C-8), 152.1, 149.3 (C-4, C-6), 138.1 (Cq Bn), 133.4, 132.8, 132.7 (2x Cq Ph, Cq Bz), 135.5-127.3 (CH arom), 122.6 (C-5), 97.5 (C-1"), 79.3, 78.1, 72.5, 71.4, 70.4 (C-4', C-2", C-3", C-4", C-5"), 73.0, 72.6 (CH_2 Bn, C-3'), 68.7 (C-1'), 63.5, 61.9 (C-5', C-6"), 26.7 (CH_3 *t*-Bu), 19.1 (Cq *t*-Bu); ESI-MS: $[M+H]^+$ 835.

(2*R*)-9-[(1-{2-*O*-Benzyl-6-*O*-[4,4'-dimethoxytrityl]-α-D-glucopyranosyloxy}-3-[4,4'-dimethoxytrityloxy]-2-propoxy)methyl]-6-*N*-benzoyladenine (31)

A mixture of **30** (40 mg, 48 μmol) and TBAF (1 M in THF, 72 μL) in 1,4-dioxane (0.5 mL) was stirred at 50 °C for 2 h, after which removal of the TBDPS-group had taken place as visualized by TLC analysis. Pyridine (2 mL) was added and the mixture was concentrated to a smaller volume. The residue was repeatedly diluted with pyridine (5x 5 mL) and concentrated. Subsequent protection of both primary hydroxyl functions was executed as described earlier for the synthesis of compound **25**. Crude **31** was applied onto a column of silica gel. Elution was effected with methanol/dichloromethane/light petroleum (0/1/3 to 2/98/0, v/v/v, containing 2% of triethylamine). Concentration of the appropriate fractions furnished diol **31** as a foam (55 mg, 46 μmol, 96%); Rf 0.35 (System D); ^1H NMR ($CDCl_3$, 300 MHz, HH-COSY): δ 8.76, 8.28 (2x s, 2H, H-2, H-8), 7.96-6.70 (m, 36H, H arom), 5.88-5.72 (AB, 2H, H-1a', H-1b'), 4.72 (d, 1H, H-1", $J_{1,2}$ 3.5 Hz), 4.53-4.17 (AB, 2H, CH_2 Bn), 3.89-3.71 (m, 3H, H-3", H-4", H-5"), 3.70, 3.69, 3.68, 3.67 (4x s, 12H, 4x OCH_3), 3.44-3.15 (m, 7H, H-3a', H-3b', H-4', H-5a', H-5b', H-6a", H-6b"), 3,33 (d, 1H, H-2", $J_{2,3}$ 9.6 Hz); $^{13}C\{^1H\}$ NMR ($CDCl_3$, 75 MHz): δ 165.1 (C(O) Bz), 158.5, 158.3 ($COCH_3$), 152.8, 143.7 (C-2, C-8), 152.3, 149.3 (C-4, C-6), 144.9, 144.5 (2x Cq DMT), 138.2 (Cq Bn), 135.8, 133.6 (Cq DMT, Bz), 132.6-126.6 (CH arom), 122.7 (C-5), 113.1, 113.0 (CH arom DMT), 97.4 (C-1"), 86.4, 86.0 (Cq DMT), 79.4, 77.1, 72.8, 71.4, 70.5 (C-4', C-2", C-3", C-4", C-5"), 73.0, 72.7 (CH_2 Bn, C-1'), 68.9 (C-3'), 63.5, 63.4 (C-5', C-6"), 55.1 (OCH_3); ESI-MS: $[M+H]^+$ 1201.

(2*R*)-9-[(1-{α-D-Glucopyranosyloxy 3,4-bisphosphate}-3-hydroxy-2-propoxy)methyl]-adenine (5)

Phosphitylation of diol **34** (55 mg, 46 μmol) with phosphoramidite **26** was executed as described for **25**. ^{31}P NMR (CH_2Cl_2) showed two major resonances at δ 141.2, 141.1. TLC analysis revealed conversion of starting material into a somewhat lower-running product (Rf 0.53, System D). Oxidation with *t*-BuOOH (0.5 mL) of the intermediate phosphite triesters to the corresponding phosphate triesters (→ **32**) was complete in 15 min as visualized by TLC analysis (Rf 0.41, System D) and ^{31}P NMR (CH_2Cl_2, major resonances at δ -2.6 and -2.7). Removal of the base-labile and acid-labile protective groups as described earlier for **27** gave crude **33**. Purification was accomplished by HW-40 gel-filtration (S, Omnilabo, 0.15 M TEAB in water/methanol, 9/1, v/v) to give pure **33**. Finally, hydrogenolysis of compound **33** over Pd-black (spatula) and purification by HW-40 gel-filtration (S, Omnilabo, 0.15 M TEAB in water/methanol, 9/1, v/v), ion-exchange (Dowex® 50Wx4, Na^+-form), and lyophilization afforded (2*R*)-9-*N*-[(1-{α-D-glucopyranosyloxy 3,4-bisphosphate}-3-hydroxy-

2-propoxy)methyl]-adenine (**5**) as a white fluffy solid (15 mg, 27 μmol, 59%); ^{1}H NMR (D_2O, 600 MHz, HH-COSY): δ 8.31, 8.25 (2x s, H-2, H-8), 5.80-5.75 (AB, 2H, H-1a', H-1b'), 4.83 (d, 1H, H-1", $J_{1,2}$ 3.8 Hz), 4.29 (q, 1H, H-3", $J_{2,3}$, $J_{3,4}$, $^3J_{HP}$ 9.0 Hz), 3.93 (m, 1H, H-4'), 3.91 (q, 1H, H-4", $J_{4,5}$, $^3J_{HP}$ 9.8 Hz), 3.84 (dd, 1H, H-6a", $J_{5,6}$ 3.4 Hz, $J_{6a,6b}$ 13.1 Hz), 3.33 (dd, 1H, H-5a', $J_{4,5a}$ 3.9 Hz), 3.64-3.61 (m, 2H, H-3a', H-2"), 3.58 (dd, 1H, H-5b', $J_{4,5b}$ 4.6 Hz, $J_{5a,5b}$ 12.3 Hz), 3.52 (dd, 1H, H-6b", $J_{5,6b}$ 1.5 Hz), 3.48 (ddd, 1H, H-5"), 3.45 (dd, 1H, H-3b', $J_{3b,4}$ 5.5 Hz, $J_{3a,3b}$ 11.0 Hz); ^{13}C NMR (D_2O, 150 MHz, CH-COSY): δ 151.6, 145.2 (C-4, C-6), 121.2 (C-5), 101.2 (C-1"), 81.1 (C-4'), 79.6 (C-3", $^2J_{CP}$ 1.9 Hz, $^3J_{CP}$ 7.1 Hz), 75.5 (C-1'), 74.3 (C-4", $^2J_{CP}$ 4.1 Hz, $^3J_{CP}$ 6.5 Hz), 74.0 (C-2", $^3J_{CP}$ 3.7 Hz), 73.9 (C-5", $^3J_{CP}$ 2.3 Hz), 63.5 (C-5'), 62.7 (C-6"); ^{31}P NMR (D_2O, 242 MHz, PH-COSY): δ 3.2 (C-3"-P), 2.7 (C-4"-P); ESI-MS: $[M-H]^-$: 560; Anal. Calcd. for $C_{15}H_{25}N_5O_{14}P_2$ (561.09): C, 32.10; H, 4.49; N, 12.48; P, 11.04. Found: C, 32.14; H, 4.50, N, 12.52; P, 11.02

References and notes

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(*Received in UK* 21 *February* 1997; *revised* 19 *March* 1997; *accepted* 20 *March* 1997)