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Synthesis of 4-cyanophenyl and 4-nitrophenyl 1,5-dithio-D-ribopyranosides as well as their 2-deoxy and 2,3-dideoxy derivatives possessing antithrombotic activity☆

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Abstract

1,2,3,4-Tetra-*O*-acetyl-5-thio-D-ribopyranose as well as its 1-bromide were used as donors in the reaction with 4-cyano- and 4-nitrobenzenethiol, to give the corresponding thioglycosides in different anomeric ratios depending on the reaction conditions. Zemplén deacetylation afforded 4-cyanophenyl as well as 4-nitrophenyl 1,5-dithio-α- and β-D-ribopyranosides, respectively. 1,3,4-Tri-*O*-acetyl-2-deoxy-5-thio-D-*erythro*-pentopyranose was synthesized from methyl 2-deoxy-D-*erythro*-pentofuranoside and was coupled with 4-cyano- and 4-nitrobenzenethiol to give anomeric mixtures from which 4-cyanophenyl as well as 4-nitrophenyl 1,5-dithio-β-D-*erythro*-pentopyranosides were isolated after deacetylation. 1,4-Di-*O*-acetyl-2,3-dideoxy-5-thio-D-*glycero*-pentopyranose was obtained starting from 1,2;5,6-di-*O*-isopropylidene-D-mannitol and used as the donor in the glycosylation reaction with 4-cyano- and 4-nitrobenzenethiol. The resulting anomeric mixtures were separated to give, after deacetylation, 4-cyanophenyl as well as 4-nitrophenyl 2,3-dideoxy-1,5-dithio-β-D-*glycero*-pentopyranosides. All of these thioglycosides showed significant antithrombotic activity on rats after oral administration.

Keywords: 5-Thio-D-ribose, 5-thio-2-deoxy-D-*erythro*-pentose, and 5-thio-2,3-dideoxy-D-*glycero*-pentose derivatives; Glycosidation reactions; Thioglycosides; Oral antithrombotic activity

1. Introduction

In a previous paper [2], we have shown that in contrast to a statement in the literature [3] the oral antithrombotic effect of 4-cyanophenyl 1,5-dithio-pentopyranosides is not restricted to the β-D-*xylo* configuration, as both anomers of the corresponding D- and L-arabinopyranosides show a remarkably high biological activity. In order to check the influence of the configuration of the pentose unit, the synthesis of the corresponding 5-thio-D-ribopyranosides was decided upon. Furthermore, as the presence of the hydroxyl group at C-2 in the xylopyranosides is not essential for the antithrombotic activity either [4], the synthesis of the 2-deoxy and 2,3-dideoxy-ribopyranosides was also considered.

2. Results and discussion

*Synthesis of the 5-thio-*D*-ribopyranosides* **8** *and* **9**.—D-Ribose was converted, according to

☆ Orally active antithrombotic thioglycosides, Part VIII. For Part VII, see Ref. [1].

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the literature [5,6], via its 5-*O*-tosylate **1** into the *S*-acetate **2**, deacetylation of which was carried out with sodium methoxide in methanol at the boiling temperature in the presence of sodium borohydride to avoid the formation of disulfides. Hydrolysis of the resulting 5-thio-derivative **3** was carried out with 0.05 M sulfuric acid at 100 °C to give, after acetylation, an α,β anomeric mixture (ratio ~3:2) of tetraacetate **4** in high yield (81%). From this mixture, **4β** could be separated upon crystallization, and **4α** by column chromatography, but for further experiments the mixture was used. When this mixture was treated with hydrogen bromide in acetic acid, an α,β anomeric mixture (ratio ~1:3) of bromide **5** was formed. It is interesting to note that both anomers of **4** and **5** adopt the $^4C_1$ conformation ($J_{4,5ax} \sim 12$ Hz); this means that the anomeric effect, which forces the C-1 substituents into axial position, is operating only in the cases of the α anomers. However, in this configuration an energetically unfavored 1,3-diaxial interaction does exist.

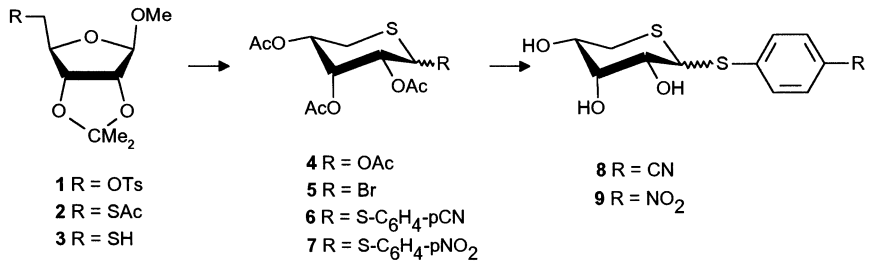
For the synthesis of the target thioglycosides, tetraacetate **4** was used as donor in 1,2-dichloroethane and trimethylsilyl triflate was used as promoter for the condensation with 4-cyanobenzenethiol. The reaction was carried out at 20 °C, **4** was consumed in 1 h and the corresponding thioglycosides **6** were formed in excellent yield (98%) containing the α,β anomers in a ratio of 17:3. When 4-nitrobenzenethiol was glycosylated with **4** in the presence of boron trifluoride etherate as promoter, the reaction was much slower (24 h), but the yield and the α:β ratio of the thioglycosides **7** were practically the same (see Table 1, entries 1 and 2). To get higher ratios of the β anomers, the acetobromo derivative **5** was used as donor in a mixture of acetonitrile and toluene, and zinc oxide as promoter for the condensation with 4-cyanobenzenethiol. The reaction was carried out at 50 °C, **5** was consumed in 1 h and the corresponding thioglycosides **6** were formed in 61% yield with an α:β ratio of 3:7. No significant change in the speed and outcome of the reaction was observed when potassium carbonate was used as promoter and acetone as solvent (see Table 1, entries 3 and 4). When 4-nitrobenzenethiol was used as acceptor in the zinc oxide-promoted reaction, the corresponding thioglycosides **7** were obtained in 74% yield (see Table 1, entry 5) with the same 3:7 α:β ratio as the 4-cyano-analogues **6**. From these mixtures, **6β**, **7α** and **7β** could be separated by crystallization. The crystalline glycosides **8α**, **8β**, **9α** and **9β**, obtained on deacetylation, were submitted to biological testing (Scheme 1).

Synthesis of the 2-deoxy-5-thio-D-erythro-*pentopyranosides* **25** *and* **27**.—For the synthesis of the corresponding thioglycosides, 1,3,4-tri-*O*-acetyl-2-deoxy-5-thio-D-*erythro*-pentopyranose (**11**) was needed as donor. This derivative had been obtained by Wong et al. [7] in 1995, in moderate yield (33%) using an enzyme-catalyzed aldol reaction of 3-thio-D-glyceraldehyde (**10**). As this method seemed to be unsuitable for the preparation of larger quantities, the classical approach of Ingles and Whistler [8], who converted 2-deoxy-D-ribose

Table 1
Influence of the reaction conditions on the glycosidation reactions

Entry	Donor	Acceptor [a]	Promoter	Solvent	Time	Temperature (°C)	Product	Yield (%)	α:β ratio
1	**4**	CN	TMSOTf	1,2-dichloroethane	1 h	20	**6**	98	17:3
2	**4**	NO_2	$BF_3{\cdot}Et_2O$	1,2-dichloroethane	24 h	20	**7**	99	9:1
3	**5**	CN	ZnO	MeCN, toluene	1 h	50	**6**	61	3:7
4	**5**	CN	K_2CO_3	acetone	1 h	60	**6**	52	1:9
5	**5**	NO_2	ZnO	MeCN, toluene	30 min	50	**7**	74	3:7
6	**11**	CN	TESOTf	1,2-dichloroethane	1 h	20	**24**	98	1:3
7	**11**	NO_2	TMSOTf	1,2-dichloroethane	1 h	20	**26**	99	1:2
8	**28**	CN	TESOTf	1,2-dichloroethane	30 min	−10	**46**	86	1:3
9	**28**	NO_2	TESOTf	1,2-dichloroethane	30 min	−10	**47**	99	3:7

[a] Substituent of the 4-substituted thiophenol.



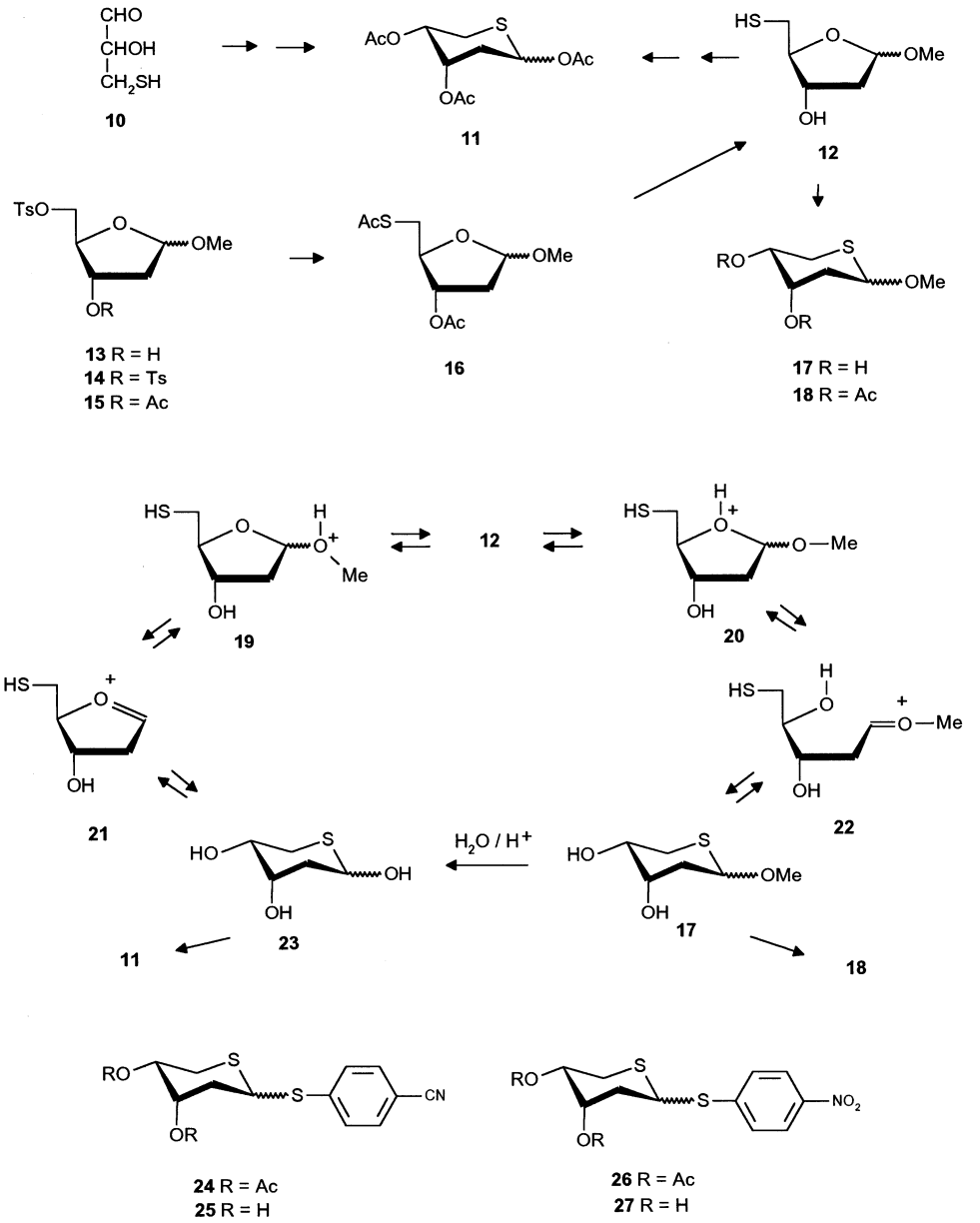
Scheme 1.

in a four-step process into an anomeric mixture of methyl 2-deoxy-5-thio-D-*erythro*-pentofuranosides (**12**), was considered. This could be transformed into a mixture of the corresponding methyl pyranosides **17** on treatment with methanolic hydrochloric acid. Hydrolysis of the latter at 75 °C with 0.25 M hydrochloric acid in 50% aqueous methanol was supposed to give the free thiosugar **23**. Only **17β** was characterized in the literature [8]. We repeated this reaction sequence with the following slight modifications. Tosylation of methyl 2-deoxy-D-ribofuranoside [8] gave, besides some unchanged starting material, the monotosylate **13** and ditosylate **14** in 72 and 21% yields, respectively, after separation by column chromatography. Both derivatives were unstable and decomposed on storage at room temperature. Acetylation of **13** gave **15**, which was converted immediately into the stable **16** by treatment with potassium thioacetate in *N*,*N*-dimethylformamide. The two anomers could be separated by column chromatography and their anomeric configuration was assigned according to the optical rotation. Deacetylation of **16** was carried out in boiling methanol with 1 equivalent of sodium methoxide and hydrolysis of the resulting crude thiol **12** was carried out by boiling its acidified (pH 4) aqueous solution. The products were isolated after acetylation by column chromatography, affording the triacetate **11** as an anomeric mixture (18.7%) as well as the methyl pyranoside **18β** (13.2%). Their structure was proved by ^{1}H NMR spectroscopy according to the following data. The $^1C_4$ conformation of the pyranose rings in **11β** and **18β** was evident from the presence of the large $J_{2ax,3ax}$ 12 Hz coupling, and the axial orientation of the anomeric substituent from the presence of the $J_{1eq,5eq}$ 1.7 Hz long-range coupling for the anomeric proton. The pyranose ring of **11α** was evident from the chemical shift of C-1 (being attached to a sulfur atom) but the conformation is uncertain as the coupling constants could not be determined due to the overlapping of the signals. Isolation of the methyl pyranoside **18β** means that, even in aqueous solution, besides the hydrolysis the furanoside **12** → pyranoside **17** isomerization also takes place, i.e. protonation of **12** can lead via the two isomeric oxonium ions **19** and **20** to the cyclic **21** or acyclic **22** oxocarbenium ions. However, while attack of the thiol group at C-1 of **21** led via a rearrangement to the hydrolyzed thiosugar **23**, the same attack at C-1 of **22** gave the methyl pyranoside **17**. Theoretically, protonation of the methoxy group of **17** could lead after hydrolysis directly to **23**, but because of the enhanced sensitivity of 2-deoxy-5-thio sugars towards acids [4] the yield of **23** decreased dramatically on prolonged hydrolysis or applying a more acidic pH. For the same reason, attempts to convert **18** by acetolysis into **11** were also unsuccessful (Scheme 2). Triacetate **11** is acid sensitive and can be stored only at temperatures below 5 °C, as at room temperature a slow decomposition takes place.

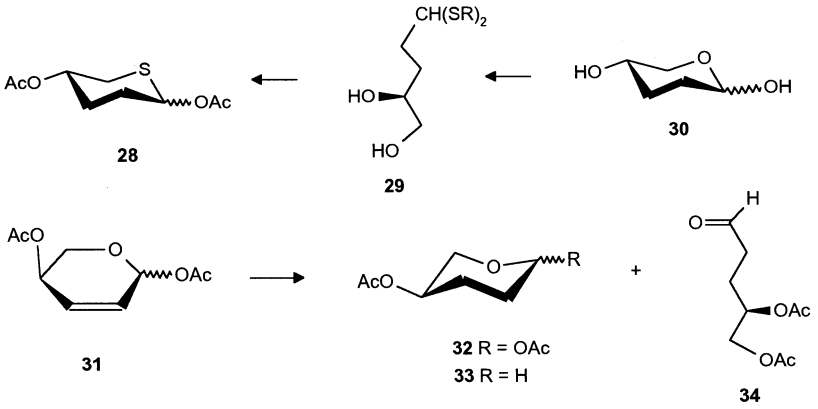
Condensation of triacetate **11** with 4-cyanobenzenethiol was carried out in 1,2-dichloroethane in the presence of triethylsilyl triflate as promoter at 20 °C, yielding a mixture of anomers **24α** and **24β** in excellent yield (98%) in a ratio of 1:3. A similar yield (99%) was achieved when 4-nitrobenzenethiol was used as aglycon and trimethylsilyl triflate as promoter, but the anomeric ratio of **26α** and **26β** obtained as a mixture was 1:2 (see Table 1, entries 6 and 7). The pure β anomers **25β** and **27β**, which crystallized after deacetylation

from the above anomeric mixtures, were submitted to biological testing.

Synthesis of the 2,3-dideoxy-5-thio-D-glycero-*pentopyranosides* **50** *and* **51**.—For the synthesis of the corresponding thioglycosides, 1,4-di-*O*-acetyl-2,3-dideoxy-5-thio-D-pentopyranose (**28**) was needed as donor; this could be prepared from 2,3-dideoxy-D-*glycero*-pentose (**30**) via its open-chain derivative **29**. The L-isomer of the latter was prepared by Allerton et al. in 1951 [9] by conversion of L-arabinose via hydrogenation of the 2-ene derivative **31** into **32**, which after hydrolysis and reaction with benzyl mercaptan yielded the antipode of **29** in an overall yield of ~7%. However, in our hands, hydrogenation of crude **31** [10] over Pd/C led to a complex mixture from which, after acetylation, besides the 1,5-anhydro-pentitol acetate **33** only the open-chain diacetate **34** could be isolated in 47 and 32% yields, respectively (Scheme 3). Analogous products were already described in the glucal



Scheme 2.

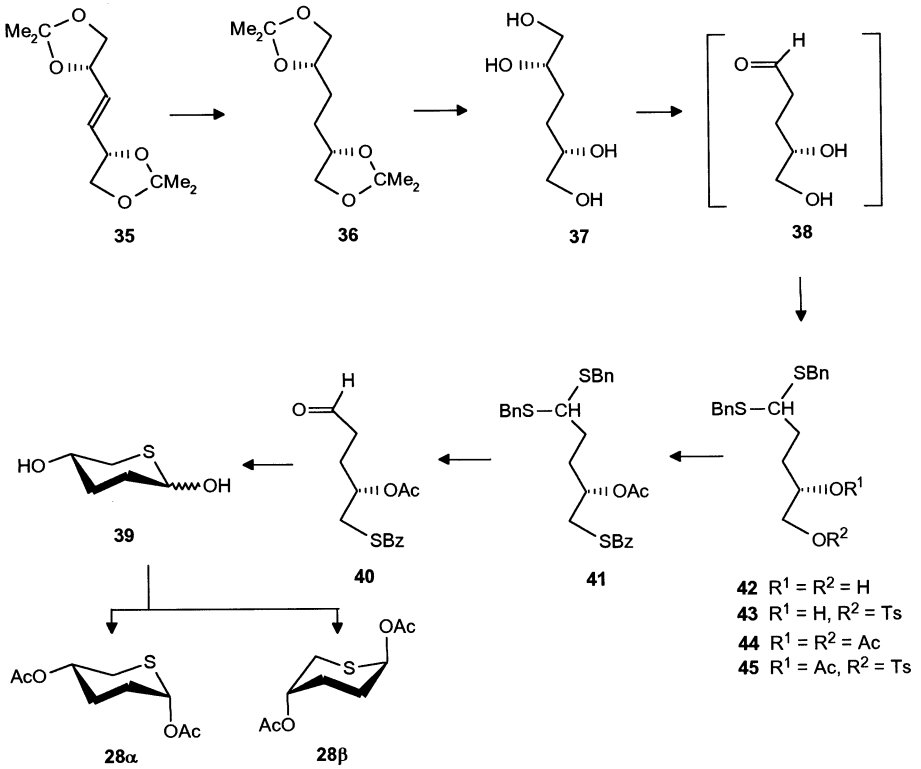


Scheme 3.

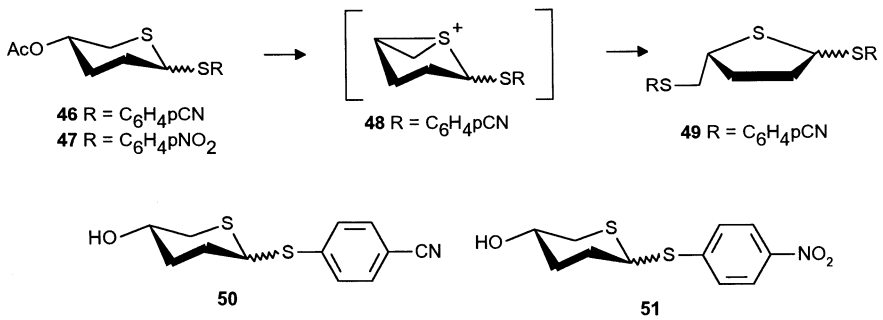
series depending on the quality of the applied Pd catalysts [10,11].

In 1968 Goodman published another 12-step synthesis of **29** starting from D-xylose [12], but because of the low overall yield of this approach we turned our attention to the intermediate **30**. This was prepared by Diekman et al. in 1989 [13] by conversion of 1,2:5,6-di-*O*-isopropylidene-D-mannitol into 2,3-*O*-isopropylidene-D-glyceraldehyde and Wittig-type chain elongation followed by hydrogenation and subsequent hydrolysis. We used 1,2:5,6-di-*O*-isopropylidene-D-*threo*-hex-3-enitol (**35**) [14–16] as starting material, which could be converted, in a yield of 71%, into 3,4-dideoxy-D-*threo*-hexitol (**37**) [17] by first saturating the double bond of **35** in the presence of triethylamine, and afterwards removing the isopropylidene groups from the resulting **36** by hydrochloric acid in methanol. Periodate oxidation of **37** afforded the 2,3-dideoxy-pentose **38** as a complex mixture of its anomeric furanose and pyranose forms [13] in nearly quantitative yield, but **38** could be converted without purification into the dibenzyl dithioacetal **42** in high yield. Tosylation and subsequent acetylation of **42** afforded diacetate **44** besides the mixed ester **45**, the primary tosyloxy group of which was exchanged by potassium thiobenzoate in *N*,*N*-dimethylformamide to give **41**. The mercapto groups of the latter were removed in aqueous tetrahydrofuran in the presence of mercuric oxide with boron trifluoride etherate [18]. The obtained aldehyde **40** gave, after Zemplén deacylation, the free 2,3-dideoxy-5-thiopentose **39**, which was obtained as a solid mixture containing the α- and β-pyranose isomers in a ratio of 2:1. The absence of any furanose structure is in accordance with the tendency of 5-thio sugars to form pyranosides exclusively [19]. After acetylation, the two crystalline anomers **28α** and **28β** could be separated by column chromatography, but they were not stable at room temperature and could be stored without decomposition only below 5 °C. According to their NMR spectra, in both anomers the 1-*O*-acetyl group is axially oriented, i.e. **28α** adopts the $^4C_1$, while **28β** the $^1C_4$ conformation. This means that the energy gained by the anomeric effect is enough to compensate the sterically unfavored diaxial arrangement of the two acetoxy groups in the latter conformer (Scheme 4).

Condensation of a mixture of the anomeric peracetates (**28α** and **28β**) with 4-cyano- and 4-nitrobenzenethiol was performed in 1,2-dichloroethane at −10 °C in the presence of triethylsilyl triflate as promoter affording the corresponding glycosides **46** and **47** in 1:3 and 3:7 α:β ratios, respectively (see Table 1, entries 8 and 9). From these mixtures, the pure β isomers **46β** and **47β** could be obtained by crystallization and gave, on deacetylation, **50β** and **51β**, respectively, which were both submitted to biological testing. When the coupling reaction with the cyanobenzenethiol was carried out at 20 °C, a rearrangement took place and instead of the thiopyranosides only a 5-substituted-1,4,5-trithiofuranoside **49** could be isolated (see Scheme 5). Despite the fact that the absolute configuration of this



Scheme 4.



Scheme 5.

derivative could not be determined (only the furanoid structure by selective INEPT NMR measurements, proving the location of one of the thiophenol moieties at C-5), it is probable that, according to the depicted reaction mechanism, an inversion at C-4 took place. A further indirect proof of this mechanism was obtained when the isolated mixture of the thiopyranosides **46** was treated under the same reaction conditions as used for the glycosidation at 20 °C, affording the aforementioned rearranged product **49**.

Biological results.—The oral antithrombotic activity of **8α**, **8β**, **9α**, **9β**, **25β**, **27β**, **49**, **50β** and **51β** was determined in rats, using Pescador's model [20]. All compounds were administered orally 3 h before ligation. From the data listed in Table 2, it can be seen that all compounds apart from the 4-nitrophenyl thioglycoside **27β** were more active than beciparcil [2], used as the reference compound. This means that the antithrombotic activity is not restricted to the D-*xylo* configuration and that the presence of the hydroxyl groups at C-2 and C-3 is not essential for the biological effect either.

Table 2
Oral antithrombotic activity of **8α**, **8β**, **9α**, **9β**, **25β**, **27β**, **49β** and **50β** in rats using Pescador's model [20] compared with beciparcil

Compound	Ref [a]	**8α**	**8β**	**9α**	**9β**	**25β**	**27β**	**49**	**50β**	**51β**
ED_{50} (mg/kg)	25	3	10	10	2	3	25	3	3	1

[a] Ref, reference compound (beciparcil = 4-cyanophenyl 1,5-dithio-β-D-xylopyranoside) [2].

3. Experimental

General methods.—Organic solutions were dried over $MgSO_4$ and concentrated under diminished pressure at or below 40 °C. TLC: E. Merck precoated Silica Gel 60 F_{254} plates, with hexane–EtOAc mixtures (*A*, 1:1; *B*, 2:1; *C*, 3:1; *D*, 4:1), EtOAc–EtOH mixture (*E* 3:1), EtOAc (*F*) and toluene–MeOH mixture (*G*, 9:1); detection by spraying the plates with a 0.02 M solution of I_2 and a 0.3 M solution of KI in 10% aq H_2SO_4 solution followed by heating at ca. 200 °C. For column chromatography, Kieselgel 60 was used. The mp are uncorrected. Optical rotations were determined on 1.0% solutions in $CHCl_3$ at 20 °C unless stated otherwise. NMR spectra were recorded with a Bruker AC 250 spectrometer at 250 MHz (^{1}H) and 62.9 MHz (^{13}C) for solutions in $CDCl_3$ (internal Me_4Si) unless stated otherwise. Multiplicities of the ^{13}C NMR spectra were obtained from DEPT experiments. The assignment of the protons was based on homonuclear decoupling experiments. The ratio of α:β anomeric mixtures was determined by ^{1}H NMR.

1,2,3,4-Tetra-O-*acetyl-5-thio*-D-*ribopyranose* (**4**).—To a stirred solution of **2** [6] (16 g, 0.1 mol) in MeOH (100 mL), 4 M NaOMe (2 mL) and $NaBH_4$ (0.05 g) were added and the mixture was boiled for 10 min; (R_f 0.55 → 0.65, solvent *D*). The solution was concentrated and hot 0.05 M H_2SO_4 was added to the residue. The mixture was stirred on a steam bath for 1 h whereupon a clear solution was obtained. This was cooled, neutralized with $NaHCO_3$, filtered with charcoal and concentrated. Toluene (3 × 100 mL) was added and evaporated from the residue, which was then treated with Ac_2O (150 mL) in pyridine (200 mL). After the usual processing, a semisolid residue (27 g, 81%) was obtained, which according to NMR spectroscopy contained **4α** and **4β** in a ratio of 3:2. Crystallization from ether–hexane afforded crystalline **4β** (9.5 g, 28.5%) mp 121–123 °C; lit. 123–124 °C [6]; R_f 0.55 (solvent *B*); ^{1}H NMR: δ 5.97 (d, 1 H, $J_{1,2}$ 8.5 Hz, H-1), 5.45 (dd, 1 H, $J_{3,4} \sim 2.5$ Hz, H-3), 5.12 (dd, 1 H, $J_{2,3} \sim 2$ Hz, H-2), 5.10 (ddd, 1 H, $J_{4,5ax}$ 9.8, $J_{4,5eq}$ 3.6 Hz, H-4), 3.04 (dd, 1 H, $J_{5ax,5eq}$ 13.4 Hz, H-5ax), 2.71 (dd, 1 H, H-5eq), 1.90–2.10 (4s, 12 H, 4 OAc); ^{13}C NMR: δ 170.0–169.0 (4 C=O), 71.0, 69.8, 69.3, 68.9 (C-1,2,3,4), 26.6 (C-5), 20.8–20.2 (4 OAc).

Column chromatography (solvent *A*) of the mother liquor gave, besides a further crop of **4β** (0.7 g, 2.1%), the α anomer **4α** (16.7 g, 50%); $[\alpha]_D + 217°$; lit. $[\alpha]_D + 221°$ (*c* 0.77, MeOH) [6]; R_f 0.45 (solvent *B*); ^{1}H NMR: δ 5.90 (d, 1 H, $J_{1,2}$ 4.7 Hz, H-1), 5.52 (dd, 1 H, $J_{3,4} \sim 2.5$ Hz, H-3), 5.12 (dd, 1 H, $J_{2,3} \sim 2$ Hz, H-2), 5.10 (ddd, 1 H, $J_{4,5ax}$ 11.9, $J_{4,5eq}$ 3.4 Hz, H-4), 3.16 (dd, 1 H, $J_{5ax,5eq}$ 12.9 Hz, H-5ax), 2.44 (dd, 1 H, H-5eq), 1.90–2.10 (4s, 12 H, 4 OAc); ^{13}C NMR: δ 170.0–169.0 (4 C=O), 70.1, 70.0, 68.8, 68.4 (C-1,2,3,4), 21.8 (C-5), 20.8–20.2 (4 OAc).

2,3,4-Tri-O-*acetyl*-*5*-*thio*-D-*ribopyranosyl bromide* (**5**).—To a stirred solution of a 3:2 anomeric mixture of tetraacetates **4α** and **4β** (3.3 g, 10 mmol) in CH_2Cl_2 (30 mL), HBr in AcOH (33%, 15 mL) was added and stirring was continued for 1 h at rt. Then the mixture was poured into ice-water, extracted with CH_2Cl_2, washed with 6% aq $NaHCO_3$, water and concentrated to yield, according to NMR spectroscopy, a 1:3 anomeric mixture of **5α** and **5β** (3.3 g, 95%): R_f 0.65 (solvent *B*); ^{1}H NMR: α anomer, δ 5.61 (dd, 1 H, H-3), 5.4–5.0 (m, 3 H, $J_{4,5ax}$ 12.0 Hz, H-1,2,4), 3.31 (dd, 1 H, $J_{5ax,5eq}$ 12.7 Hz, H-5ax), 2.62 (dd, 1

H, H-5eq), 2.20, 2.08, 2.04 (3s, 9 H, 3 OAc); ^{13}C NMR: δ 169.5–169.0 (3 C=O), 70.4, 69.9, 68.2 (C-2,3,4), 47.6 (C-1), 23.1 (C-5), 20.9–20.4 (3 OAc). ^{1}H NMR: β anomer, δ 5.55 (dd, 1 H, $J_{3,4} \sim 2.5$ Hz, H-3), 5.2 (m, 2 H, $J_{2,3} \sim 2$, $J_{4,5ax}$ 10.5, $J_{4,5eq}$ 4.2 Hz, H-2,4), 4.96 (d, 1 H, $J_{1,2}$ 9.8 Hz, H-1), 3.10 (dd, 1 H, $J_{5ax,5eq}$ 13.2 Hz, H-5ax), 2.65 (dd, 1 H, H-5eq), 2.14, 2.07, 2.03 (3s, 9 H, 3 Oac); ^{13}C NMR: δ 169.5–169.0 (3 C=O), 74.2, 69.4, 69.3 (C-2,3,4), 43.4 (C-1), 29.4 (C-5), 20.9–20.4 (3 OAc). Anal. Calcd for $C_{11}H_{15}BrO_6S$: C, 37.20; H, 4.26; Br, 22.50; S, 9.03. Found: C, 37.10; H, 4.38; Br, 22.32; S, 8.91.

4-Cyanophenyl 2,3,4-tri-O-*acetyl-1,5-dithio*-D-*ribopyranoside* (**6**).—(i) To a stirred solution of **4** (0.73 g, 2.2 mmol) and 4-cyanobenzenethiol (0.6 g, 4.4 mmol) in dry 1,2-dichloroethane (20 mL), under argon Me_3SiOTf (0.4 mL, 2.2 mmol) was added at −10°C. After stirring at rt for 1 h, the reaction was quenched with Et_3N, concentrated and submitted to column chromatography (solvent *B*) to yield **6** (0.88 g, 98%) as a 17:3 mixture of α and β anomers: R_f 0.4 (solvent *B*); ^{1}H NMR: α anomer, δ 7.58–7.46 (m, 4 H, aromatic), 5.60 (dd, 1 H, $J_{3,4}$ 2.4 Hz, H-3), 5.33 (dd, 1 H, $J_{2,3}$ 2.4 Hz, H-2), 5.14 (ddd, 1 H, $J_{4,5ax}$ 11.5, $J_{4,5eq}$ 3.9 Hz, H-4), 4.68 (d, 1 H, $J_{1,2}$ 5.1 Hz, H-1), 3.32 (dd, 1 H, $J_{5ax,5eq}$ 13.2 Hz, H-5ax), 2.58 (dd, 1 H, H-5eq), 2.25, 2.08, 2.02 (3s, 9 H, 3 OAc); β anomer, δ 7.65–7.50 (m, 4 H, aromatic), 5.60 (dd, 1 H, $J_{3,4} \sim 2.5$ Hz, H-3), 5.14 (m, 2 H, $J_{2,3} \sim 2$, $J_{4,5ax}$ 11.3, $J_{4,5eq}$ 3.9 Hz, H-2,4), 4.41 (d, 1 H, $J_{1,2}$ 10.7 Hz, H-1), 3.10 (dd, 1 H, $J_{5ax,5eq}$ 13.0 Hz, H-5ax), 2.56 (dd, 1 H, H-5eq), 2.16, 2.04, 2.00 (3s, 9 H, 3 OAc); ^{13}C NMR: δ 170.0–169.0 (3 C=O), 139.5, 132.4, 130.9, 111.0 (aromatic) 118.1 (CN), 71.8, 70.1, 69.8 (C-2,3,4), 46.1 (C-1), 28.0 (C-5), 21.0–20.4 (3 OAc). Anal. Calcd for $C_{18}H_{19}NO_6S_2$: C, 52.80; H, 4.68; N, 3.42; S, 15.66. Found: C, 52.69; H, 4.58; N, 3.50; S, 15.71.

(ii) To a suspension of **5** (1.0 g, 2.8 mmol) and ZnO (0.3 g, 3.7 mmol) in MeCN (10 mL) and toluene (10 mL), 4-cyanobenzenethiol (0.45 g, 3.3 mmol) was added and the mixture was stirred at 50 °C for 1 h. The reaction mixture was filtered through Celite, washed with CH_2Cl_2, concentrated and submitted to column chromatography (solvent *B*) to yield **6** (0.7 g, 61%) as a 3:7 mixture of α and β anomers.

(iii) To a stirred suspension of **5** (1.0 g, 2.8 mmol) and potassium carbonate (0.6 g, 4.3 mmol) in acetone (50 mL), 4-cyanobenzenethiol (0.45 g, 3.3 mmol) was added and the mixture was refluxed for 1 h. After cooling to rt, the precipitated salts were filtered off and washed with acetone. The filtrate was concentrated and submitted to column chromatography (solvent *B*) to yield **6** (0.6 g, 52%) as a 1:9 mixture of α and β anomers. Recrystallization from diethyl ether yielded **6β** (0.34 g, 29%): mp 112–115 °C (diethyl ether); $[\alpha]_D + 70°$ (*c* 0.5, $CHCl_3$).

4-Nitrophenyl 2,3,4-tri-O-*acetyl-1,5-dithio*-D-*ribopyranoside* (**7**).—(i) To a stirred solution of **4** (0.73 g, 2.2 mmol) and 4-nitrobenzenethiol (0.45 g, 2.9 mmol) in dry 1,2-dichloroethane (20 mL), $BF_3{\cdot}EtO_2$ (0.27 mL, 2.2 mmol) was added. The mixture was kept at rt for 24 h, then poured into ice-cold 6% aq $NaHCO_3$ solution (25 mL). The separated organic layer was washed with water, 6% aq $NaHCO_3$ and concentrated to yield **7** (0.93 g, 99%) as a 9:1 mixture of α and β anomers. Recrystallization from diethyl ether yielded **7α** (0.42 g, 45%): mp 112–115 °C (diethyl ether); $[\alpha]_D + 407°$ (*c* 0.5, $CHCl_3$); R_f 0.4 (solvent *B*); ^{1}H NMR: δ 8.16–7.60 (m, 4 H, aromatic), 5.62 (dd, 1 H, $J_{3,4}$ 2.7 Hz, H-3), 5.35 (dd, 1 H, $J_{2,3}$ 2.7 Hz, H-2), 5.15 (ddd, 1 H, $J_{4,5ax}$ 11.5, $J_{4,5eq}$ 4.2 Hz H-4), 4.74 (d, 1 H, $J_{1,2}$ 4.9 Hz, H-1), 3.32 (dd, 1 H, $J_{5ax,5eq}$ 13.2 Hz, H-5ax), 2.60 (dd, 1 H, H-5eq), 2.25, 2.08, 2.02 (3s, 9 H, 3 OAc); ^{13}C NMR: δ 169.5 (3 C=O), 145.2, 144.0 129.4, 124.0 (aromatic), 71.8, 70.2, 69.1 (C-2,3,4), 50.4 (C-1), 22.8 (C-5), 20.9–20.7 (3 OAc). Anal. Calcd for $C_{17}H_{19}NO_8S_2$: C, 47.55; H, 4.46; N, 3.26; S, 14.93. Found: C, 47.63; H, 4.48; N, 3.30; S, 14.87.

(ii) To a suspension of **5** (1.0 g, 2.8 mmol) and ZnO (0.3 g, 3.7 mmol) in MeCN (10 mL) and toluene (10 mL), 4-nitrobenzenethiol (0.5 g, 3.2 mmol) was added and the mixture was stirred at 50 °C for 30 min. The reaction mixture was filtered through Celite, washed with CH_2Cl_2, concentrated and submitted to column chromatography (solvent *B*) to yield **7**

(0.9 g, 74%) as a 3:7 mixture of α and β anomers. Recrystallization from diethyl ether yielded **7β** (0.45 g, 37%): mp 143–146 °C (diethyl ether); $[\alpha]_D + 83°$ (*c* 0.5, $CHCl_3$); R_f 0.4 (solvent *B*); ^{1}H NMR: δ 8.16–7.60 (m, 4 H, aromatic), 5.62 (dd, 1 H, $J_{3,4} \sim 2.5$ Hz, H-3), 5.16 (dd, 1 H, $J_{2,3} \sim 2$ Hz, H-2), 5.15 (ddd, 1 H, $J_{4,5ax}$ 11.5, $J_{4,5eq}$ 4.1 Hz, H-4), 4.46 (d, 1 H, $J_{1,2}$ 10.7 Hz, H-1), 3.12 (dd, 1 H, $J_{5ax,5eq}$ 12.7 Hz, H-5ax), 2.58 (dd, 1 H, H-5eq), 2.18, 2.02, 2.00 (3s, 9 H, 3 OAc). Anal. Calcd for $C_{17}H_{19}NO_8S_2$: C, 47.55; H, 4.46; N, 3.26; S, 14.93. Found: C, 47.47; H, 4.51; N, 3.32; S, 14.97.

*4-Cyanophenyl 1,5-dithio-α-*D*-ribopyranoside* (**8α**).—Deacetylation of **6** (α:β = 17:3; 0.88 g, 2.1 mmol) with 1 M NaOMe (0.1 mL) in MeOH (20 mL) yielded, after neutralization with solid CO_2, **8α** (0.29 g, 48%) which crystallized from the solution: mp 195–197 °C (ether); $[\alpha]_D + 446°$ (*c* 0.5, MeOH); R_f 0.3 (solvent *G*); ^{1}H NMR (Me_2SO-d_6): δ 7.72–7.46 (m, 4 H, aromatic), 5.24, 5.08, 5.05 (3brs, 3 H, OH), 4.66 (d, 1 H, $J_{1,2}$ 3.7 Hz, H-1), 4.00 (m, 1 H, $J_{2,3}$ 2.2 Hz, H-2), 3.72 (m, 1 H, $J_{4,5ax}$ 9.0, $J_{4,5eq} \sim 3.5$ Hz, H-4), 3.68 (m, 1 H, $J_{3,4} \sim 2.5$ Hz, H-3), 2.82 (dd, 1 H, $J_{5ax,5eq}$ 13.1 Hz, H-5ax), 2.48 (dd, 1 H, H-5eq). Anal. Calcd for $C_{12}H_{13}NO_3S_2$: C, 50.87; H, 4.62; N, 4.94; S, 22.63. Found: C, 50.81; H, 4.58; N, 4.88; S, 22.72.

*4-Cyanophenyl 1,5-dithio-β-*D*-ribopyranoside* (**8β**).—Deacetylation of **6β** (0.34 g, 0.8 mmol) with 1 M NaOMe (0.1 mL) in MeOH (10 mL) yielded, after neutralization with solid CO_2 and column chromatography (solvent *F*), **8β** (0.17 g, 72%): mp 154–157 °C (ether); $[\alpha]_D - 11°$ (*c* 0.5, MeOH); R_f 0.6 (solvent *F*); ^{1}H NMR (Me_2SO-d_6): δ 7.78–7.60 (m, 4 H, aromatic), 5.47, 5.07, 5.00 (3d, 3 H, OH), 4.46 (d, 1 H, $J_{1,2}$ 10.0 Hz, H-1), 3.88 (m, 1 H, $J_{3,4} \sim 2.5$ Hz, H-3), 3.70 (m, 1 H, $J_{4,5ax}$ 10.7, $J_{4,5eq} \sim 3.9$ Hz, H-4), 3.55 (m, 1 H, $J_{2,3}$ 2.0 Hz, H-2), 2.91 (dd, 1 H, $J_{5ax,5eq}$ 12.5 Hz, H-5ax), 2.28 (dd, 1 H, H-5eq). Anal. Calcd for $C_{12}H_{13}NO_3S_2$: C, 50.87; H, 4.62; N, 4.94; S, 22.63. Found: C, 50.92; H, 4.56; N, 4.98; S, 22.68.

*4-Nitrophenyl 1,5-dithio-α-*D*-ribopyranoside* (**9α**).—Deacetylation of **7α** (0.4 g, 0.9 mmol) with M NaOMe (0.1 mL) in MeOH (20 mL) yielded, after neutralization with solid CO_2 and column chromatography (solvent *G*), **9α** (0.2 g, 71%): mp 76–80 °C (ether); $[\alpha]_D + 440°$ (*c* 0.5, MeOH); R_f 0.2 (solvent *G*); ^{1}H NMR (Me_2SO-d_6): δ 8.12–7.55 (m, 4 H, aromatic), 5.34, 5.15, 5.05 (3d, 3 H, OH), 4.73 (d, 1 H, $J_{1,2}$ 3.6 Hz, H-1), 4.02 (m, 1 H, $J_{2,3}$ 2.0 Hz, H-2), 3.80–3.65 (m, 2 H, $J_{4,5ax}$ 10.0, $J_{4,5eq} \sim 3.5$ Hz, H-3,4), 2.85 (dd, 1 H, $J_{5ax,5eq}$ 12.9 Hz, H-5ax), 2.48 (dd, 1 H, H-5eq). Anal. Calcd for $C_{11}H_{13}NO_5S_2$: C, 43.55; H, 4.32; N, 4.62; S, 21.14. Found: C, 43.61; H, 4.38; N, 4.68; S, 21.22.

*4-Nitrophenyl 1,5-dithio-β-*D*-ribopyranoside* (**9β**).—Deacetylation of **7β** (0.45 g, 1.0 mmol) with 1 M NaOMe (0.1 mL) in MeOH (25 mL) yielded, after neutralization with solid CO_2 and column chromatography (solvent *G*), **9β** (0.22 g, 71%): mp 155–160 °C (ether); $[\alpha]_D + 8°$ (*c* 0.5, MeOH); R_f 0.2 (solvent *G*); ^{1}H NMR (Me_2SO-d_6): δ 8.15–7.65 (m, 4 H, aromatic), 5.50, 5.08, 5.05 (3d, 3 H, OH), 4.52 (d, 1 H, $J_{1,2}$ 10.3 Hz, H-1), 3.88 (m, 1 H, $J_{3,4} \sim 2.5$ Hz, H-3), 3.72 (m, 1 H, $J_{4,5ax}$ 10.0, $J_{4,5eq}$ 3.7 Hz, H-4), 3.58 (m, 1 H, $J_{2,3}$ 1.9 Hz, H-2), 2.93 (dd, 1 H, $J_{5ax,5eq}$ 12.5 Hz, H-5ax), 2.28 (dd, 1 H, H-5eq). Anal. Calcd for $C_{11}H_{13}NO_5S_2$: C, 43.55; H, 4.32; N, 4.62; S, 21.14. Found: C, 43.59; H, 4.28; N, 4.59; S, 21.11.

*Methyl 2-deoxy-5-*O*-p-tolylsulfonyl-*D*-erythro-pentofuranoside* (**13**) *and methyl 2-deoxy-3,5-di-*O*-p-tolylsulfonyl-*D*-erythro-pentofuranoside* (**14**).—Crude methyl 2-deoxy-D-*erythro*-pentofuranoside, obtained from 2-deoxy-D-*erythro*-pentopyranose (10 g) according to Ref. [7] was dissolved with stirring in pyridine (100 mL) and tosyl chloride (21.2 g, 1.5 equiv) was added at 0 °C. After 1 h the temperature was raised to 20 °C and after 1 h the mixture was worked up in the usual way to give after column chromatography (solvent *A*) and concentration of the first fraction **14** (6.5 g, 21%) as an unstable syrup: R_f 0.8 (solvent *A*). Anal. Calcd for $C_{20}H_{24}O_8S_2$: C, 52.62; H, 5.30; S, 14.05. Found: C, 52.50; H, 5.44; S, 13.88.

Concentration of the second fraction gave **13** (14.7 g, 72%) as an unstable syrup: R_f 0.4 (solvent *A*). Anal. Calcd for $C_{13}H_{18}O_6S$: C, 51.64; H, 6.00; S, 10.60. Found: C, 51.56; H, 6.12; S, 10.42.

Methyl 3-O-acetyl-2-deoxy-5-O-p-tolylsulfonyl-D-erythro-pentofuranoside (**15**).—Acetylation of **13** (12.1 g, 40 mmol) in pyridine (30 mL) with Ac_2O (10 mL) gave, after the usual processing, **15** (13.1 g, 95%): R_f 0.6 (solvent *A*); ^{13}C NMR: δ 170.8 and 170.3 (C=O), 144.9, 132.7 129.8 and 127.8 (aromatic), 105.5 and 105.0 (C-1) 81.1, 80.7, 74.3 and 73.8 (C-3,4), 70.3 and 69.5 (C-5), 54.9 (OMe), 38.7 and 38.6 (C-2), 21.5 (Ts–Me), 20.8 and 20.7 (OAc). Anal. Calcd for $C_{15}H_{20}O_7S$: C, 52.32; H, 5.85; S, 9.31. Found: C, 52.28; H, 5.98; S, 9.24.

Methyl 3-O-acetyl-5-S-acetyl-2-deoxy-D-erythro-pentofuranoside (**16**).—To a stirred solution of **15** (17.2 g, 50 mmol) in DMF (50 mL), KSAc (7.4 g, 65 mmol) was added and stirring was continued at 100 °C for 1 h. The mixture was concentrated, the residue was dissolved in CH_2Cl_2, and washed with water. The residue obtained on concentration was submitted to column chromatography (solvent *B*), to give **16** (12 g, 97%). From this mixture, the two anomers could be separated by repeated column chromatography (solvent *C*), to give **16α** $[\alpha]_D + 99°$; R_f 0.55 (solvent *B*); ^1H NMR: δ 5.04 (dd, 1 H, $J_{1,2a}$ 5.4, $J_{1,2b}$ 1.0 Hz, H-1), 4.86 (ddd, 1 H, $J_{3,4}$ 5.4 Hz, H-3), 4.22 (ddd, 1 H, $J_{4,5a}$ 5.2, $J_{4,5b}$ 5.6 Hz, H-4), 3.36 (s, 3 H, OMe), 3.24 (dd, 1 H, $J_{5a,5b}$ 13.8 Hz, H-5a), 3.18 (dd, 1 H, H-5b), 2.38 (ddd, 1 H, $J_{2a,2b}$ 14.6, $J_{2a,3}$ 8.3, $J_{2b,3}$ 2.4 Hz, H-2a), 2.35 (s, 3 H, SAc), 2.05, (s, 3 H, OAc), 1.94 (ddd, 1 H, H-2b); ^{13}C NMR: δ 194.5 (S–C=O), 170.6 (C=O), 104.4 (C-1), 80.5, 75.5 (C-3,4), 54.9 (OMe), 39.0 (C-2), 31.2 (C-5), 30.3 (SAc), 20.8 (OAc) and **16β** $[\alpha]_D - 53°$; R_f 0.55 (solvent *B*); ^1H NMR: δ 5.2–5.05 (m, 2 H, $J_{1,2a}$ 2.4, $J_{1,2b}$ 4.4, $J_{3,4}$ ~5 Hz, H-1,3), 4.10 (ddd, 1 H, $J_{4,5a}$ 6.3, $J_{4,5b}$ 7.8 Hz, H-4), 3.25 (dd, 1 H, $J_{5a,5b}$ 13.7 Hz, H-5a), 3.24 (s, 3 H, OMe), 3.03 (dd, 1 H, H-5b), 2.40 (ddd, 1 H, $J_{2a,2b}$ 14.4, $J_{2a,3}$ 7.1 Hz, H-2a), 2.33 (s, 3 H, SAc), 2.03, (s, 3 H, OAc), 1.93 (ddd, 1 H, $J_{2b,3}$ 4.4 Hz, H-2b); ^{13}C NMR: δ 194.5 (S–C=O), 170.0 (C=O), 105.3 (C-1), 82.4, 76.4 (C-3,4), 54.9 (OMe), 38.8 (C-2), 32.5 (C-5), 30.1 (SAc), 20.6 (OAc). Anal. Calcd for $C_{10}H_{16}O_5S$: C, 48.37; H, 6.50; S, 12.91. Found for **16α**: C, 48.28; H, 6.57; S, 12.83; Found for **16β**: C, 48.30; H, 6.62; S, 12.79.

1,3,4-Tri-O-acetyl-2-deoxy-5-thio-D-erythro-pentopyranose (**11**) *and methyl 3,4-di-O-acetyl-2-deoxy-5-thio-β-D-erythro-pentopyranoside* (**18β**).—To a stirred solution of **16** (14.5 g, 58 mmol) in MeOH (150 mL), 4 M NaOMe (14.5 mL) and $NaBH_4$ (0.05 g) were added and the mixture was boiled for 10 min (R_f 0.55 → 0.30, solvent *B*). The mixture was concentrated after neutralization with solid CO_2. The residue was dissolved in water (100 mL) and the pH was adjusted to 4 by addition of 5 M HCl (~11 mL). The solution was boiled for 90 min (R_f 0.80 → 0.2–0.3, solvent *F*), filtered with charcoal, and concentrated. The residue was coevaporated with toluene (3 × 50 mL), then pyridine (50 mL) and Ac_2O (30 mL) were added. After 20 h, the mixture was processed in the usual way and the residue obtained on concentration was separated by column chromatography (solvent *B*). Concentration of the first fraction gave **18β** (1.9 g, 13.2%): $[\alpha]_D -330°$; R_f 0.75 (solvent *A*); ^1H NMR: δ 5.28 (ddd, 1 H, $J_{4,5ax}$ 1.7, $J_{4,5eq}$ 4.9 Hz, H-4), 5.20 (ddd, 1 H, $J_{3,4}$ 2.7 H-3), 4.59 (dd, 1 H, $J_{1,2ax}$ 2.7, $J_{1,2eq}$ 3.9, $J_{1,5eq}$ 1.7 Hz, H-1), 3.38 (s, 3 H, OMe), 3.12 (dd, 1 H, $J_{5ax,5eq}$ 14.4 Hz, H-5ax), 2.72 (dd, 1 H, H-5eq), 2.40 (ddd, 1 H, $J_{2ax,2eq}$ 12.9, $J_{2ax,3}$ 12.0, $J_{2eq,3}$ 2.8, Hz, H-2ax), 2.15 (ddd, 1 H, H-2eq), 2.12, 2.00 (2s, 2 × 3 H, OAc); ^{13}C NMR: δ 170.1, 169.5 (C=O), 81.3 (C-1), 67.2, 66.4 (C-3,4), 56.0 (OMe), 4.0 (C-2), 26.8 (C-5), 20.8, 20.7 (OAc). Anal. Calcd for $C_{10}H_{16}O_5S$: C, 48.37; H, 6.50; S, 12.91. Found: C, 48.31; H, 6.52; S, 12.85.

Concentration of the second fraction gave **11** (3.0 g, 18.7%), which according to NMR spectroscopy contained the α,β anomers in a 2:3 ratio; R_f 0.6 (solvent *A*); ^1H NMR: α anomer, δ 5.78 (dd, 1 H, $J_{1,2ax}$ 3.5, $J_{1,2eq}$ 3.5 Hz, H-1), 5.30–5.15 (m, 2 H, H-3,4), 3.45–3.20 (m, 2 H, H-5ax,5eq), 2.70–2.20 (m, 2 H, H-2ax,2eq), 2.11, 2.09, 2.02 (3s, 9 H, OAc); ^{13}C NMR: δ 170.0–168.8 (C=O), 69.9, 68.5, 67.1 (C-1,3,4), 35.5 (C-2), 22.4 (C-5), 20.8–20.4 (OAc); ^1H NMR: β anomer, δ 6.01 (dd, 1 H, $J_{1,2ax}$ ~2.5, $J_{1,2eq}$ ~3.5, $J_{1,5eq}$ 1.7 Hz, H-1), 5.35 (ddd, 1 H, $J_{4,5ax}$ 1.8, $J_{4,5eq}$ 4.9 Hz, H-4), 5.10 (ddd, 1 H, $J_{3,4}$ ~2.5 Hz, H-3), 3.26 (dd, 1 H, $J_{5ax,5eq}$ 14.7 Hz, H-5ax), 2.85 (dd, 1 H, H-5eq), 2.70–2.20 (m, 2 H, $J_{2ax,3}$ ~12.0, $J_{2eq,3}$ ~2.5 Hz, H-2ax,2eq), 2.12, 2.10, 2.01

(3s, 9 H, OAc); ^{13}C NMR: δ 170.0–168.8 (C=O), 72.0, 67.0, 65.6 (C-1,3,4), 32.1 (C-2), 27.9 (C-5), 20.8–20.4 (OAc). Anal. Calcd for $C_{11}H_{16}O_6S$: C, 47.82; H, 5.84; S, 11.60. Found: C, 47.80; H, 5.89; S, 11.51.

4-Cyanophenyl 3,4-di-O-*acetyl-2-deoxy-1,5-dithio*-D-erythro-*pentopyranoside* (**24**).—To a stirred solution of **11** (0.4 g, 1.4 mmol) and 4-cyanobenzenethiol (0.4 g, 2.9 mmol) in dry 1,2-dichloroethane (15 mL) under argon, Et_3SiOTf (0.35 mL, 1.4 mmol) was added at −10 °C. After stirring at rt for 1 h, the reaction was quenched with Et_3N. The mixture was concentrated and submitted to column chromatography (solvent *B*) to yield **24** (0.5 g, 98%) as a 1:3 mixture of α and β anomers: R_f 0.4 (solvent *B*); ^{1}H NMR: α anomer, δ 7.65–7.50 (m, 4 H, aromatic), 5.25–5.05 (m, 2 H, $J_{4,5ax}$ 7.6, $J_{4,5eq}$ 3.0 Hz, H-3,4), 4.40 (dd, 1 H, $J_{1,2eq}$ 5.7, $J_{1,2ax}$ 5.7 Hz, H-1), 3.20 (dd, 1 H, $J_{5ax,5eq}$ 13.9 Hz, H-5ax), 2,79 (dd, 1 H, H-5eq), 2.57 (ddd, 1 H, $J_{2ax,2eq} \sim 14$ Hz, H-2eq), 2.18 (ddd, 1 H, H-2ax), 2.13, 2.03 (2s, 6 H, OAc); ^{1}H NMR: β anomer, δ 7.65–7.50 (m, 4 H, aromatic), 5.38 (ddd, 1 H, H-3), ~5.15 (m, 1 H, $J_{4,5ax}$ 9.5, $J_{4,5eq}$ 3.0 Hz, H-4), 4.54 (dd, 1 H, $J_{1,2ax}$ 9.5, $J_{1,2eq}$ 2.8 Hz, H-1), 3.12 (dd, 1 H, $J_{5ax,5eq}$ 13.7 Hz, H-5ax), 2,79 (dd, 1 H, H-5eq), 2.49 (ddd, 1 H, $J_{2ax,2eq} \sim 14$ Hz, H-2eq), ~2.20 (m, 1 H, H-2ax), 2.11, 2.05 (2s, 6 H, OAc). Anal. Calcd for $C_{16}H_{17}NO_4S_2$: C, 54.68; H, 4.88; N, 3.99; S, 18.25. Found: C, 54.73; H, 4.91; N, 3.90; S, 18.33.

4-Cyanophenyl 2-deoxy-1,5-dithio-β-D-erythro-*pentopyranoside* (**25β**).—Deacetylation of **24** (α:β 1:3, 0.45 g, 1.3 mmol) with 1 M NaOMe (0.1 mL) in MeOH (10 mL) yielded, after neutralization with solid CO_2, **25β** (0.1 g, 26%), which crystallized from the solution: mp 188–190 °C (MeOH); $[\alpha]_D$ −134° (*c* 0.5, MeOH); R_f 0.3 (solvent *G*); ^{1}H NMR (Me_2SO-d_6): δ 7.78–7.55 (m, 4 H, aromatic), 4.90 and 4.85 (2d, 2 H, OH), 4.78 (dd, 1 H, $J_{1,2ax}$ 10.0, $J_{1,2eq}$ 2.7 Hz, H-1), 3.85 (m, 1 H, $J_{3,4}$ 3.4 Hz, H-3), 3.71 (m, 1 H, $J_{4,5ax}$ 9.3, $J_{4,5eq}$ 3.4 Hz, H-4), 2.93 (dd, 1 H, $J_{5ax,5eq}$ 13.0 Hz, H-5ax), 2,49 (dd, 1 H, H-5eq), 2.32 (ddd, 1 H, $J_{2ax,2eq}$ 13.3, $J_{2eq,3}$ 6.3, $J_{2ax,3}$ 2.4 Hz, H-2eq), 1.98 (ddd, 1 H, H-2ax). Anal. Calcd for $C_{12}H_{13}NO_2S_2$: C, 53.91; H, 4.90; N, 5.24; S, 23.98. Found: C, 53.87; H, 4.86; N, 5.16; S, 23.85.

4-Nitrophenyl 3,4-di-O-*acetyl-2-deoxy-1,5-dithio*-D-erythro-*pentopyranoside* (**26**).—To a stirred solution of **11** (0.4 g, 1.4 mmol) and 4-nitrobenzenethiol (0.48 g, 3 mmol) in dry 1,2-dichloroethane (15 mL) under argon, Me_3SiOTf (0.3 mL, 1.4 mmol) was added at −10 °C. After stirring at rt for 1 h, the reaction was quenched with Et_3N, concentrated and the residue was submitted to column chromatography (solvent *B*) to yield **26** (0.53 g, 99%) as a 1:2 mixture of α and β anomers: R_f 0.4 (solvent *B*); ^{1}H NMR: α anomer, δ 8.15–7.55 (m, 4 H, aromatic), 5.25–5.05 (m, 2 H, $J_{3,4} \sim 3$, $J_{4,5ax}$ 7.8, $J_{4,5eq}$ 3.4 Hz, H-3,4), 4.46 (t, 1 H, $J_{1,2ax}$ 5.8, $J_{1,2eq}$ 5.8 Hz, H-1), 3.23 (dd, 1 H, $J_{5ax,5eq}$ 13.9 Hz, H-5ax), 2,80 (dd, 1 H, H-5eq), ~2.60 (m, 1 H, $J_{2ax,2eq} \sim 14$, $J_{2ax,3} \sim 3$ Hz, H-2eq), ~2.20 (m, 1 H, H-2ax), 2.13, 2.05 (2s, 6 H, OAc); ^{1}H NMR: β anomer, δ 8.15–7.55 (m, 4 H, aromatic), 5.40 (ddd, 1 H, $J_{3,4} \sim 3$ Hz, H-3), ~5.15 (m, 1 H, $J_{4,5ax}$ 9.3, $J_{4,5eq}$ 3.4 Hz, H-4), 4.58 (dd, 1 H, $J_{1,2ax}$ 9.8, $J_{1,2eq}$ 3.2 Hz, H-1), 3.11 (dd, 1 H, $J_{5ax,5eq}$ 13.5 Hz, H-5ax), 2,80 (dd, 1 H, H-5eq), 2.52 (ddd, 1 H, $J_{2ax,2eq} \sim 14$, $J_{2ax,3} \sim 3$, $J_{2eq,3} \sim 5$ Hz, H-2eq), ~2.20 (m, 1 H, H-2ax), 2.11, 2.06 (2s, 6 H, OAc). Anal. Calcd for $C_{15}H_{17}NO_6S_2$: C, 48.51; H, 4.61; N, 3.77; S, 17.26. Found: C, 48.57; H, 4.66; N, 3.80; S, 17.33.

4-Nitrophenyl 2-deoxy-1,5-dithio-β-D-erythro-*pentopyranoside* (**27β**).—Deacetylation of **26** (α:β 1:2, 0.53 g, 1.4 mmol) with 1 M NaOMe (0.1 mL) in MeOH (20 mL) yielded, after neutralization with solid CO_2, **27β** (0.12 g, 29%), which crystallized from the solution: mp 132–134 °C (MeOH); $[\alpha]_D$ −77° (*c* 0.5, MeOH); R_f 0.7 (solvent *F*); ^{1}H NMR (Me_2SO-d_6): δ 8.16–7.60 (m, 4 H, aromatic), 4.94 and 4.88 (2d, 2 H, OH), 4.85 (dd, 1 H, $J_{1,2ax}$ 10.0, $J_{1,2eq}$ 2.7 Hz, H-1), 3.87 (m, 1 H, $J_{3,4} \sim 3$ Hz, H-3), 3.72 (m, 1 H, $J_{4,5ax}$ 9.5, $J_{4,5eq}$ 3.4 Hz, H-4), 2.95 (dd, 1 H, $J_{5ax,5eq}$ 12.9 Hz, H-5ax), 2,51 (dd, 1 H, H-5eq), 2.35 (ddd, 1 H, $J_{2ax,2eq}$ 13.4, $J_{2ax,3}$ 2.2 $J_{2eq,3}$ 6.6 Hz, H-2eq), 2.01 (ddd, 1 H, H-2ax). Anal. Calcd for $C_{11}H_{13}NO_4S_2$: C, 45.98; H, 4.56; N, 4.87; S, 22.31. Found: C, 45.89; H, 4.63; N, 4.91; S, 22.40.

4-O-*Acetyl-1,5-anhydro-2,3-dideoxy*-L-glycero-*pentitol* (**33**) *and 4,5-di*-O-*acetyl-2,3-dideoxy*-L-glycero-*pentose* (**34**).—A solution of the crude diacetate **31** (5 g, 25 mmol) [9] in

MeOH (50 mL) was hydrogenated in the presence of 10% Pd/C (250 mg) for 3 h. The filtered solution was concentrated and the residue separated by column chromatography (solvent *B*). The fraction having R_f 0.6 (solvent *A*) contained **33** (1.7 g, 47%): $[\alpha]_D - 17°$; ^{1}H NMR: δ 4.80 (m, 1 H, $J_{4,5a}$ 3.1, $J_{4,5b}$ 5.9 Hz, H-4), 3.76 (dd, 1 H, $J_{5a,5b}$ 11.7 Hz, H-5a), 3.65 (m, 2 H, H-1a,b), 3.58 (dd, 1 H, H-5b), 2.10–1.50 (m, 4 H, H-2a,b,3a,b); ^{13}C NMR: δ 170.2 (C=O), 69.4, 67.6 (C-1,5), 67.8 (C-4), 27.9, 22.7 (C-2,3), 20.9 (OAc). Anal. Calcd for $C_7H_{12}O_3$: C, 58.32; H, 8.39. Found: C, 58.28; H, 8.31.

Concentration of the fraction having R_f 0.4 (solvent *A*) gave **34** (1.6 g, 32%): $[\alpha]_D + 27°$; ^{1}H NMR: δ 9.77 (dd, 1 H, $J_{1,2a}$ 1.1, $J_{1,2b}$ 1.1 Hz, H-1), 5.10 (m, 1 H, $J_{4,5a}$ 3.8, $J_{4,5b}$ 6.0 Hz, H-4), 4.25 (dd, 1 H, $J_{5a,5b}$ 11.9 Hz, H-5a), 4.05 (dd, 1 H, H-5b), 2.55 (m, 2 H, H-2a,b), ~2.0 (m, 2 H, H-3a,b), 2.05, 2.04 (2s, 6 H, OAc); ^{13}C NMR: δ 200.6 (C-1), 170.6, 170.4 (C=O), 70.5 (C-4), 64.6 (C-5), 39.4 (C-2), 23.0 (C-3), 20.8, 20.6 (OAc). Anal. Calcd for $C_9H_{14}O_5$: C, 53.46; H, 6.98. Found: C, 56.28; H, 7.11.

3,4-Dideoxy-1,2:5,6-di-O-*isopropylidene*-D-threo-*hexitol* (**36**).—A solution of **35** [14–16] (22.8 g, 0.1 mol) in MeOH (250 mL) and Et_3N (5 mL) was hydrogenated in the presence of 10% Pd/C (1 g) for 2 h. Concentration of the filtered solution gave **36** (23 g, 100%). An aliquot part (1 g) was purified by column chromatography: R_f 0.55 (solvent *C*); $[\alpha]_D + 22°$; ^{1}H NMR: δ 4.22 (m, 2 H, H-2,5), 4.12 (dd, 2 H, $J_{1a,2}$ 6.0, $J_{1b,2}$ 7.0, $J_{1a,1b}$ 7.5 Hz, H-1a,6a), 3.55 (dd, 2 H, H-1b,6b), 1.80–1.50 (m, 4 H, H-3a,b,4a,b), 1.40, 1.32 (2s, 12 H, CMe_2); ^{13}C NMR: δ 108.7 (CMe_2), 75.4 (C-2,5), 69.1 (C-1,6), 29.4 (C-3,4), 26.8, 25.6 (CMe_2). Anal. Calcd for $C_{12}H_{22}O_4$: C, 62.58; H, 9.63. Found: C, 62.68; H, 9.70.

3,4-Dideoxy-D-threo-*hexitol* (**37**).—A solution of crude **36** (22 g) in MeOH (250 mL) and 1 M HCl (50 mL) was kept at 20 °C for 1 h. After neutralization with solid $NaHCO_3$, the mixture was concentrated and the residue coevaporated with EtOH (2 × 100 mL). The residue was extracted with hot EtOH (2 × 50 mL), the filtrate was concentrated to 30 mL and was diluted with EtOAc (100 mL) to give **37** (10.2 g, 71%): mp 91–93 °C; lit. mp 92–94 °C [18].

2,3-Dideoxy-D-glycero-*pentose dibenzyl dithioacetal* (**42**).—To a stirred solution of **37** (15 g, 0.1 mol) in water (160 mL), a solution of $NaIO_4$ (22.5 g, 0.105 mol) in water (250 mL) was added at 0 °C over a period of 15 min. The starting material was gradually converted into **38** (R_f 0.35 → 0.65, solvent *E*) while $NaIO_3$ precipitated. The mixture was filtered after 30 min, the filtrate was concentrated and the residue was coevaporated with EtOH (2 × 200 mL). The residue was passed through a short column (solvent *E*) to give upon concentration a syrup (11.8 g, 100%) containing an anomeric mixture of the corresponding furanose and pyranose structures. This was dissolved in concd HCl (35 mL) and benzyl mercaptan (31 mL, 0.25 mol) was added with stirring. The mixture turned dark blue. After 1 h, it was poured into a mixture of water (300 mL) and CH_2Cl_2 (200 mL), the aq solution was extracted with CH_2Cl_2 (200 mL) and the combined extracts were washed with 5% aq $NaHCO_3$ and water. Upon concentration, the residue was purified by column chromatography (solvent *A*) to yield **42** (25.1 g 72%) as syrup: $[\alpha]_D - 23°$; lit. $[\alpha]_D - 23°$ [11]; R_f 0.3 (solvent *A*); ^{1}H NMR: δ 7.30–7.10 (m, 10 H, aromatic), 3.78 (d, 2 H, CH_2Ph), 3.70 (d, 1 H, CH_2Ph), 3.68 (d, 1 H, CH_2Ph), 3.48 (m, 1 H, H-1), 3.42 (m, 2 H, $J_{4,5b}$ 8.1, $J_{5a,5b}$ 11.6 Hz, H-4,5a), 3.26 (dd, 1 H, H-5b), 2.00–1.35 (m, 4 H, H-2a,b,3a,b); ^{13}C NMR: δ 138.8, 137.8, 128.7, 128.2, 126.7 (aromatic), 71.4 (C-4), 66.2 (C-5), 50.2 (C-1), 34.5, 34.4 (CH_2Ph), 31.2, 30.2 (C-2,3).

4,5-Di-O-*acetyl-2,3-dideoxy*-D-glycero-*pentose dibenzyl dithioacetal* (**44**) *and 4*-O-*acetyl-2,3-dideoxy-5*-O-p-*toluenesulfonyl*-D-glycero-*pentose dibenzyl dithioacetal* (**45**).—To a stirred solution of **42** (3.5 g, 10 mmol) in pyridine (20 mL), a solution of tosyl chloride (2.8 g, 15 mmol) in pyridine (15 mL) was added at 0 °C during 10 min. Stirring was continued at 20 °C for 1 h when the starting material was converted into **43** (R_f 0.3 → 0.7, solvent *A*). Then Ac_2O (4 mL) was added and after 1 h the mixture was processed the usual way to give, after column chromatography (solvent *D*) and concentration of the fraction having R_f 0.3 (solvent *D*), **44** (0.5 g, 11.6%): $[\alpha]_D - 7°$; ^{1}H NMR: δ 7.35–7.15 (m, 10 H, aromatic), 4.90

(m, 1 H, $J_{4,5a}$ 3.3, $J_{4,5b}$ 6.4 Hz, H-4), 4.11 (dd, 1 H, $J_{5a,5b}$ 11.9 Hz, H-5a), 3.91 (dd, 1 H, H-5b), 3.82 (d, 2 H, CH_2Ph), 3.73 (d, 1 H, CH_2Ph), 3.72 (d, 1 H, CH_2Ph), 3.48 (m, 1 H, H-1), 2.08, 2.04 (2s, 6 H, OAc), 1.85–1.60 (m, 4 H, H-2a,b,3a,b); ^{13}C NMR: δ 169.9, 169.7 (C=O), 137.7, 137.6, 128.5, 128.1, 126.6 (aromatic), 70.4 (C-4), 64.3 (C-5), 49.6 (C-1), 34.3, 34.2 (CH_2Ph), 30.5, 27.8 (C-2,3), 20.5, 20.2 (OAc). Anal. Calcd for $C_{23}H_{28}O_4S_2$: C, 63.86; H, 6.52; S, 14.82. Found: C, 63.70; H, 6.57; S, 14.73.

Concentration of the fraction having R_f 0.6 (solvent *B*) gave **45** (3.7 g, 68%): $[\alpha]_D - 17°$; ^1H NMR: δ 7.75–7.15 (m, 14 H, aromatic), 4.76 (m, 1 H, $J_{4,5a}$ 3.5, $J_{4,5b}$ 5.2 Hz, H-4), 4.07 (dd, 1 H, $J_{5a,5b}$ 10.9 Hz, H-5a), 3.89 (dd, 1 H, H-5b), 3.79 (d, 2 H, CH_2Ph), 3.72 (d, 1 H, CH_2Ph), 3.70 (d, 1 H, CH_2Ph), 3.43 (m, 1 H, H-1), 2.42 (s, 3 H, Me), 1.92 (s, 3 H, OAc), 1.75–1.55 (m, 4 H, H-2a,b,3a,b); ^{13}C NMR: δ 170.1 (C=O), 144.9, 137.9, 137.8, 132.6, 129.8, 128.9, 128.5, 127.8, 127.0 (aromatic), 70.2 (C-4), 69.6 (C-5), 50.0 (C-1), 34.3, 34.2 (CH_2Ph), 30.8, 27.8 (C-2,3), 21.6 (Me), 20.7 (OAc). Anal. Calcd for $C_{28}H_{32}O_5S_3$: C, 61.74; H, 5.92; S, 17.66. Found: C, 61.68; H, 5.99; S, 17.55.

4-O-*Acetyl-5*-S-*benzoyl-2,3-dideoxy*-D-glycero-*pentose dibenzyl dithioacetal* (**41**).—A solution of **45** (4.9 g, 9 mmol) and KSBz (2.5 g, 14.2 mmol) in DMF (25 mL) was stirred at 50 °C for 2 h. The residue obtained upon concentration was purified by column chromatography (solvent *C*) to give **41** (4 g, 88%): $[\alpha]_D - 6°$; R_f 0.55 (solvent *C*); ^1H NMR: δ 7.95–7.10 (m, 14 H, aromatic), 4.92 (m, 1 H, $J_{4,5a}$ 4.6, $J_{4,5b}$ 6.6 Hz, H-4), 3.83 (d, 2 H, CH_2Ph), 3.76 (d, 1 H, CH_2Ph), 3.74 (d, 1 H, CH_2Ph), 3.48 (m, 1 H, H-1), 3.33 (dd, 1 H, $J_{5a,5b}$ 13.9 Hz, H-5a), 3.10 (dd, 1 H, H-5b), 2.00 (s, 3 H, OAc), 1.85–165 (m, 4 H, H-2a,b,3a,b); ^{13}C NMR: δ 190.2 (S–C=O), 169.8 (C=O), 137.6, 137.5, 136.2, 133.2, 128.6, 128.2, 128.1, 126.8, 126.6 (aromatic), 71.3 (C-4), 49.8 (C-1), 34.3, 34.3 (CH_2Ph), 31.8, 30.7, 30.4 (C-2,3,5), 20.6 (OAc). Anal. Calcd for $C_{23}H_{30}O_3S_3$: C, 65.85; H, 5.92; S, 18.83. Found: C, 65.77; H, 5.90; S, 18.58.

4-O-*Acetyl-5*-S-*benzoyl-2,3-dideoxy*-D-glycero-*pentose* (**40**).—To a stirred slurry of yellow HgO (2.5 g) in THF (50 mL) and water (7.5 mL), $BF_3{\cdot}Et_2O$ (48%, 1.6 mL) and subsequently a solution of **41** (5.1 g, 10 mmol) in THF (10 mL) were added at 10 °C. Stirring was continued at 20 °C for 2 h, then the mixture was poured onto a stirred slurry of Na_2CO_3 (5 g) in Et_2O (200 mL). The separated organic solution was washed with 10% aq K_2CO_3, 10% aq KI and water. The residue obtained upon concentration gave, after column chromatography (solvent *C*), **40** (1.85 g, 66%): $[\alpha]_D - 2°$; R_f 0.5 (solvent *B*); ^1H NMR: δ 7.95–7.45 (m, 5 H, aromatic), 9.76 (t, 1 H, $J_{1,2a}$ 1.0, $J_{1,2b}$ 1.0 Hz, H-1), 5.08 (m, 1 H, $J_{4,5a}$ 4.5, $J_{4,5b}$ 6.1 Hz, H-4), 3.42 (dd, 1 H, $J_{5a,5b}$ 14.2 Hz, H-5a), 3.22 (d, 1 H, H-5b), 2.55 (m, 2 H, $J_{2,3}$.7.3 Hz, H-2a,b), 2.05 (s, 3 H, OAc), 2.04 (m, 2 H, H-3a,b); ^{13}C NMR: δ 200.8 (C-1), 190.6 (S–C=O), 170.3 (C=O), 136.4, 133.5, 128.6, 127.2 (aromatic), 71.6 (C-4), 39.6, 32.0, 25.4 (C-2,3,5), 20.8 (OAc). Anal. Calcd for $C_{14}H_{16}O_4S$: C, 59.98; H, 5.76; S, 11.42. Found: C, 59.93; H, 5.67; S, 11.22.

2,3-Dideoxy-5-thio-D-glycero-*pentopyranose* (**39**).—To a solution of **40** (2.8 g, 10 mmol) in MeOH (20 mL), 4 M NaOMe (0.2 mL), and after 24 h an additional 4 M NaOMe (0.2 mL) were added. The mixture was neutralized with solid CO_2 after 48 h and the residue obtained on concentration was partitioned between water and CH_2Cl_2. The aq solution was concentrated and the residue filtered through a short column with EtOAc to give, on concentration, **39** (1.03 g, 77%) containing the α,β anomers in a 2:1 ratio: mp 68–71 °C; $[\alpha]_D + 71°$; R_f 0.5 (solvent *F*); ^1H NMR (Me_2SO-d_6): α anomer, δ 5.70, 4.90 (2d, 2 H, OH), 4.72 (dd, 1 H, $J_{1,2ax}$ 2.7, $J_{1,2eq}$ 2.7, $J_{1,5eq} \sim 1$ Hz, H-1), 3.58 (m, 1 H, $J_{4,5ax}$ 10.5, $J_{4,5eq}$ 3.9 Hz, H-4), 2.70 (dd, 1 H, $J_{5ax,5eq}$ 12.4 Hz, H-5ax), 2,40 (dd, 1 H, H-5_{eq}), 2.10–1.75 (m, 4 H, H-2a,b,3a,b); ^{13}C NMR: δ 68.6, 68.3 (C-1,4), 35.6, 30.4, 29.2 (C-2,3,5). 10.9. ^1H NMR (Me_2SO-d_6): β anomer, δ 5.70, 4.80 (2d, 2 H, OH), 4.68 (dd, 1 H, $J_{1,2ax}$ 9.0, $J_{1,2eq}$ 2.7 Hz, H-1), 3.60 (m, 1 H, $J_{4,5ax}$ 9.0, $J_{4,5eq}$ 3.2 Hz, H-4), 2.64 (dd, 1 H, $J_{5ax,5eq}$ 13.5 Hz, H-5eq), 2,44 (dd, 1 H, H-5ax), 2.15–1.25 (m, 4 H, H-2a,b,3a,b); ^{13}C NMR: δ 72.7, 66.7 (C-1,4), 39.0, 34.1, 32.3 (C-2,3,5). Anal. Calcd for $C_5H_{10}O_2S$: C, 44.75; H, 7.51; S, 23.89. Found: C, 44.77; H, 7.48; S, 23.84.

*1,4-Di-*O*-acetyl-2,3-dideoxy-5-thio-*D*-glycero-pentopyranose* (**28**).—Acetylation of **39** (1.8 g, 13.4 mmol) with Ac_2O (8 mL) in pyridine (10 mL) gave, after the usual processing, **28** (2.43 g, 83%) containing the α,β anomers in a ~1:1 ratio: mp 72–74 °C (ether–hexane). They could be partly separated by column chromatography (solvent *D*) to give **28α**: mp 64–66 °C; $[\alpha]_D$ + 207°; R_f 0.4 (solvent *D*); ^{1}H NMR: δ 5.75 (t, 1 H, $J_{1,2ax}$ 3.2, $J_{1,2eq}$ 3.2, $J_{1,5eq}$ ~ 1 Hz, H-1), 4.97 (dddd, 1 H, $J_{4,5ax}$ 10.7, $J_{4,5eq}$ 4.0 Hz, H-4), 2.92 (dd, 1 H, $J_{5ax,5eq}$ 12.4 Hz, H-5ax), 2.65 (dd, 1 H, H-5eq), 2.35–1.75 (m, 4 H, $J_{3ax,4}$ 11.0, $J_{3eq,4}$ 4.2 Hz, H-2a,b,3a,b), 2.12, 2.06 (2s, 6 H, OAc); ^{13}C NMR: δ 169.5, 169.4 (C=O), 70.8, 69.8 (C-1,4), 32.9, 27.4, 26.1 (C-2,3,5). 21.2, 21.1 (OAc); and **28β**: mp 123–125 °C; $[\alpha]_D$ − 315°; R_f 0.3 (solvent *D*); ^{1}H NMR: δ 5.84 (t, 1 H, $J_{1,2ax}$ ~ 2.5, $J_{1,2eq}$ ~ 2.5, $J_{1,5eq}$ ~ 1 Hz, H-1), 5.08 (ddd, 1 H, $J_{4,5ax}$ 2.2, $J_{4,5eq}$ 4.6 Hz, H-4), 3.17 (dd, 1 H, $J_{5ax,5eq}$ 14.4 Hz, H-5ax), 2.74 (dd, 1 H, H-5eq), 2.40–1.75 (m, 4 H, $J_{3ax,4}$ ~ 3, $J_{3eq,4}$ ~ 3 Hz, H-2a,b,3a,b), 2.13, 2.11 (2s, 6 H, OAc); ^{13}C NMR: δ 170.3, 169.3 (C=O), 70.6, 65.1 (C-1,4), 27.9, 26.8, 24.1 (C-2,3,5). 21.0, 20.9 (OAc). Anal. Calcd for $C_9H_{14}O_4S$: C, 49.53; H, 6.47; S, 14.69. Found for **28α**: C, 49.47; H, 6.48; S, 14,58. Found for **28β**: C, 49.51; H, 6.49; S, 14,63.

*4-Cyanophenyl 4-*O*-acetyl-2,3-dideoxy-1,5-dithio-*D*-glycero-pentopyranoside* (**46**).—To a stirred solution of **28** (1.0 g, 4.6 mmol) and 4-cyanobenzenethiol (1.25 g, 9.2 mmol) in dry 1,2-dichloroethane (30 mL) under argon, Et_3SiOTf (1.15 mL, 4.6 mmol) was added at − 10 °C. After stirring at − 10 °C for 30 min, the reaction was quenched with Et_3N, concentrated and submitted to column chromatography (solvent *D*) to yield **46** (1.15 g, 86%) as a 1:3 mixture of α and β anomers. R_f 0.4 (solvent *D*). Recrystallization from ether gave **46β** (0.44 g, 33%); mp 108–110 °C (ether); $[\alpha]_D$ − 275° (*c* 0.5, $CHCl_3$); ^{1}H NMR: α anomer, δ 7.60–7.40 (m, 4 H, aromatic), 4.97 (m, 1 H, $J_{4,5ax}$ 9.8, $J_{4,5eq}$ ~ 2.5 Hz, H-4), 4.47 (t, 1 H, $J_{1,2ax}$ 3.2, $J_{1,2eq}$ 3.2 Hz, H-1), 3.06 (dd, 1 H, $J_{5ax,5eq}$ ~ 13 Hz, H-5ax), 2.72 (dd, 1 H, H-5eq), 2.40–1.80 (m, 4 H, H-2a,b,3a,b), 2.0.5 (s, 3 H, OAc); ^{13}C NMR: δ 170.0 (C=O), 69.9 (C-4), 47.0 (C-1), 32.5, 28.4, 27.1 (C-2,3,5). 21.0 (OAc); ^{1}H NMR: β anomer, δ 7.60–7.50 (m, 4 H, aromatic), 4.98 (m, 1 H, $J_{4,5ax}$ 8.6, $J_{4,5eq}$ ~ 2.5 Hz, H-4), 4.28 (dd, 1 H, $J_{1,2ax}$ 8.8, $J_{1,2eq}$ 2.7 Hz, H-1), 2.96 (dd, 1 H, $J_{5ax,5eq}$ 13.4 Hz, H-5eq), 2.74 (dd, 1 H, H-5ax), 2.48 (m, 1 H, H-2a), 2.10 (m, 1 H, H-2b), 2.07 (s, 3 H, OAc), 2.05 (m, 1 H, H-3a), 1.65 (m, 1 H, H-3b); ^{13}C NMR: δ 170.0 (C=O), 140.5, 132.2, 129.6, 109.8 (aromatic), 118.4 (CN), 68.5 (C-4), 47.0 (C-1), 32.2, 31.7, 29.7 (C-2,3,5). 21.0 (OAc). Anal. Calcd for $C_{14}H_{15}NO_2S_2$: C, 57.31; H, 5.15; N, 4.77; S, 21.85. Found: C, 57.39; H, 5.22; N, 4.83; S, 21.91.

When the same reaction was carried out at 20 °C, a mixture was formed containing **46** only in traces and after column chromatography (solvent *D*) and subsequent crystallization from MeOH, 4-cyanophenyl 2,3-dideoxy-1,4,5-trithio-5-(4-cyanophenyl)-L-*glycero*-pentofuranoside (**49**, 0.39 g, 23%) could be isolated: mp 123–125 °C (MeOH); $[\alpha]_D$ − 369° (*c* 0.5, $CHCl_3$); ^{1}H NMR: δ 7.60–7.50 (m, 4 H, aromatic), 7.40–7.30 (m, 4 H, aromatic), 5.01 (t, 1 H, $J_{1,2a}$ 4.9, $J_{1,2b}$ 4.9 Hz, H-1), 3.80 (m, 1 H, $J_{4,5a}$ 6.6, $J_{4,5b}$ 7.8 Hz, H-4), 3.18 (dd, 1 H, $J_{5a,5b}$ 13.2 Hz, H-5a), 3.13 (dd, 1 H, H-5b), 2.45 (m, 2 H, H-2a,3a), 2.18 (m, 1 H, H-2b), 2.05 (m, 1 H, H-3b); ^{13}C NMR: δ 143.6, 143.1, 132.4, 132.4, 128.6, 127.7, 109.5, 109.1 (aromatic), 118.6, 118.5 (CN), 54.1 (C-1), 48.4 (C-4), 38.6, 36.6 (C-2,5). 33.9 (C-3). Anal. Calcd for $C_{19}H_{16}N_2S_3$: C, 61.92; H, 4.38; N, 7.60; S, 26.10. Found: C, 61.88; H, 4.35; N, 4.30; S, 25.92.

*4-Nitrophenyl 4-*O*-acetyl-2,3-dideoxy-1,5-dithio-*D*-glycero-pentopyranoside* (**47**).—To a stirred solution of **28** (1.0 g, 4.6 mmol) and 4-nitrobenzenethiol (1.4 g, 9.2 mmol) in dry 1,2-dichloroethane (30 mL) under argon, Et_3SiOTf (1.15 mL, 4.6 mmol) was added at − 10 °C. After stirring at − 10 °C for 30 min, the reaction was quenched with Et_3N, concentrated and submitted to column chromatography (solvent *D*) to yield **47** (1.42 g, 99%) as a 3:7 mixture of α and β anomers: R_f 0.4 (solvent *D*). Recrystallization from ether gave **47β** (0.88 g, 61%): mp 127–130 °C (ether); $[\alpha]_D$ − 192° (*c* 0.5, $CHCl_3$); ^{1}H NMR: α anomer, δ 8.14–7.48 (m, 4 H, aromatic), 4.98 (m, 1 H, $J_{4,5ax}$ 9.8, $J_{4,5eq}$ 3.9 Hz, H-4), 4.52 (t, 1 H, $J_{1,2ax}$

3.9, $J_{1,2eq}$ 3.9 Hz, H-1), 3.06 (dd, 1 H, $J_{5a,5eq}$ 13.2 Hz, H-5ax), 2.74 (dd, 1 H, H-5eq), 2.38 (m, 2 H, H-2a,b), 2.05 (s, 3 H, OAc), 1.92 (m, 2 H, H-3a,b); ^{13}C NMR: δ 170.1 (C=O),146.6, 144.7, 129.2, 124.0 (aromatic), 70.0 (C-4), 47.0 (C-1), 32.7, 28.6, 27.3 (C-2,3,5). 21.2 (OAc); ^{1}H NMR: β anomer, δ 8.15–7.50 (m, 4 H, aromatic), 4.98 (m, 1 H, $J_{4,5ax}$ 8.6, $J_{4,5eq} \sim 3$ Hz, H-4), 4.35 (dd, 1 H, $J_{1,2ax}$ 9.0, $J_{1,2eq}$ 2.9 Hz, H-1), 2.98 (dd, 1 H, $J_{5ax,5eq}$ 13.4 Hz, H-5eq), 2.76 (dd, 1 H, H-5ax), 2.72 (m, 1 H, H-3a), 2.52 (m, 1 H, H-2a), 2.15 (m, 1 H, H-2b), 2.08 (m, 1 H, H-3b), 2.08 (s, 3 H, OAc); ^{13}C NMR: δ 170.1 (C=O), 145.9, 144.2, 128.8 123.8 (aromatic), 68.5 (C-4), 46.9 (C-1), 32.2, 31.7, 29.7 (C-2,3,5). 21.1 (OAc). Anal. Calcd for $C_{13}H_{15}NO_4S_2$: C, 49.82; H, 4.82; N, 4.47; S, 20.46. Found: C, 49.90; H, 4.86; N, 4.51; S, 20.43.

4-Cyanophenyl 2,3-dideoxy-1,5-dithio-β-D-glycero-*pentopyranoside* (**50β**).—Deacetylation of **46β** (0.42 g, 1.4 mmol) with 1 M NaOMe (0.1 mL) in MeOH (15 mL) yielded, after neutralization with solid CO_2 and column chromatography (solvent *G*), **50β** (0.27 g, 75%): mp 133–135 °C (ether); $[\alpha]_D$ −164° (*c* 0.4, MeOH); R_f 0.3 (solvent *G*); $[\alpha]_D$ −275° (*c* 0.5, $CHCl_3$); ^{1}H NMR (Me_2SO-d_6): δ 7.76–7.56 (m, 4 H, aromatic), 5.03 (d, 1 H, OH), 4.64 (dd, 1 H, $J_{1,2ax}$ 10.6, $J_{1,2eq}$ 2.9 Hz, H-1), 3.67 (m, 1 H, $J_{4,5ax}$ 8.3, $J_{4,5eq} \sim 2.5$ Hz, H-4), 2.66 (dd, 1 H, $J_{5ax,5eq}$ 12.9 Hz, H-5eq), 2.63 (dd, 1 H, H-5ax), 2.34 (m, 1 H, H-2a), 1.95 (m, 1 H, $J_{3ax,4} \sim 8.2$, $J_{3eq,4} \sim 3.8$ Hz, H-3a), 1.83 (m, 1 H, H-2b), 1.48 (m, 1 H, H-3b). Anal. Calcd for $C_{12}H_{13}NOS_2$: C, 57.34; H, 5.21; N, 5.57; S, 25.51. Found: C, 57.43; H, 5.16; N, 5.50; S, 25.59.

4-Nitrophenyl 2,3-dideoxy-1,5-dithio-β-D-glycero-*pentopyranoside* (**51β**).—Deacetylation of **47β** (0.86 g, 2.7 mmol) with 1 M NaOMe (0.1 mL) in MeOH (30 mL) yielded, after neutralization with solid CO_2 and column chromatography (solvent *G*), **51β** (0.52 g, 70%): mp 142–145 °C (ether); $[\alpha]_D$ −119° (*c* 0.5, MeOH); R_f 0.3 (solvent *G*); ^{1}H NMR (Me_2SO-d_6): δ 8.18–7.65 (m, 4 H, aromatic), 5.05 (d, 1 H, OH), 4.69 (dd, 1 H, $J_{1,2ax}$ 10.2, $J_{1,2eq}$ 2.9 Hz, H-1), 3.68 (m, 1 H, $J_{4,5ax}$ 8.3, $J_{4,5eq} \sim 2.5$ Hz, H-4), 2.68 (dd, 1 H, $J_{5ax,5eq}$ 12.9 Hz, H-5eq), 2.64 (dd, 1 H, H-5ax), 2.45 (m, 1 H, $J_{3ax,4} \sim 8.2$, $J_{3eq,4} \sim 3.8$ Hz, H-3a), 2.35 (m, 1 H, H-2a), 1.85 (m, 1 H, H-2b), 1.50 (m, 1 H, H-3b). Anal. Calcd for $C_{11}H_{13}NO_3S_2$: C, 48.69; H, 4.83; N, 5.16; S, 23.63. Found: C, 48.75; H, 4.79; N, 5.11; S, 23.57.

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