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Note

Preparation, single-crystal X-ray diffraction and high-resolution NMR spectroscopic analyses of *N*-[(1,4-anhydro-5-deoxy-2,3-*O*-isopropylidene-D,L-ribitol)-5-yl]trimethylammonium iodide

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Abstract—The synthesis and isolation of 1,4-anhydro-5-deoxy-5-iodo-2,3-*O*-isopropylidene-D,L-ribitol and *N*-[(1,4-anhydro-5-deoxy-2,3-*O*-isopropylidene-D,L-ribitol)-5-yl]trimethylammonium iodide are described. The products were examined by ^{1}H, ^{13}C NMR spectroscopy, and *N*-[(1,4-anhydro-5-deoxy-2,3-*O*-isopropylidene-D,L-ribitol)-5-yl]trimethylammonium iodide was additionally analyzed by X-ray crystallography.

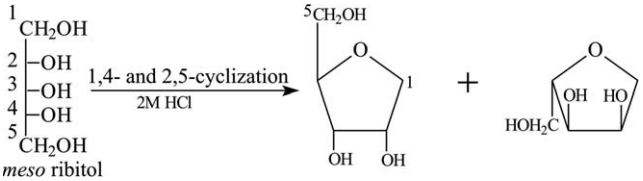
Keywords: Quaternary ammonium salt; 1,4-Anhydro-D,L-ribitol; ^{1}H, ^{13}C NMR spectroscopy; X-ray crystallography

Many alditols, in particular anhydroalditols and some of their derivatives, exhibit significant biological activity.[1–8] New activities of quaternary ammonium derivatives of alditols have been reported in the literature,[9–11] the best example being the paper on the synthesis of *N*-[(2*S*,3*S*,4*R*,5*S*)-2,5-anhydro-1,6-dideoxyhexitol-6-yl]-trimethylammonium tosylate,[9] a drug used in chemotherapy and for the treatment of Alzheimer's disease. In view of these developments, we decided to continue our synthetic and biological research on these compound types.

The conversion of hydroxyl groups has attracted considerable attention in carbohydrate chemistry. Iodide is a good leaving anion, and deoxyiodo sugars are amenable to further conversions, for example, by substitution or elimination reaction. The literature[12–15] reports various procedures for the direct replacement of primary hydroxyl groups by iodide anions.

We recently synthesized and isolated a number of quaternary *N*-[(1,4-anhydro-5-deoxy-2,3-*O*-isopropylidene-D,L-ribitol)-5-yl]ammonium salts from 1,4-anhydro-5-deoxy-2,3-*O*-isopropylidene-5-*O*-(*p*-toluenesulfonyl)-D,L-ribitol (the reactant containing the easily displaced 5-*O*-tosyl group) and determined their structures.[16] In order to compare the rapidity of quaternary ammonium salt formation from reactants with different leaving groups, we decided this time to synthesize analogous salts from 1,4-anhydro-5-deoxy-5-iodo-2,3-*O*-isopropylidene-D,L-ribitol (Scheme 2).

Commercially available D-ribitol (Scheme 1) was converted into 1,4-anhydro-2,3-*O*-isopropylidene-D,L-ribitol (**2**) by a known method.[16,17] The hydroxyl group at C-5 of compound **2** was then activated using iodine and triphenylphosphine to give 1,4-anhydro-5-deoxy-5-iodo-2,3-*O*-isopropylidene-D,L-ribitol (**3**) (yield 85%;



Scheme 1. 1,4- and 2,5-Cyclization of *meso*-ribitol.

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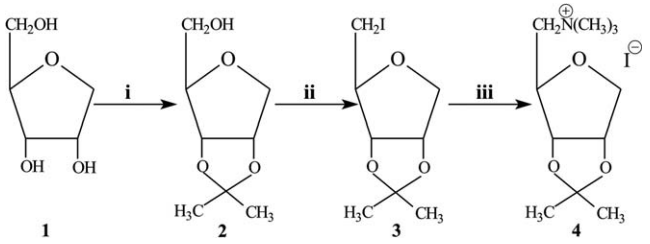

Scheme 2. Formation of *N*-[(1,4-anhydro-5-deoxy-2,3-*O*-isopropylidene-D,L-ribitol)-5-yl]trimethylammonium iodide (**4**). Reagents: (i) acetone, concd H_2SO_4; (ii) I_2, Ph_3P, imidazole, toluene; (iii) 33% ethanolic solution of Me_3N.

mp 35.0–36.6 °C). The structure of **3** was determined by 2D ^1H NMR (500 MHz). The reaction of **3** with a 33% ethanolic solution of trimethylamine (70 °C, 1.5 h) yielded *N*-[(1,4-anhydro-5-deoxy-2,3-*O*-isopropylidene-D,L-ribitol)-5-yl]trimethylammonium iodide (**4**). Crystallization of the crude product from ethanol produced compound **4** in the form of colorless crystals (yield 72%; mp 196.0–198.0 °C). Its identity was confirmed by ^1H and ^{13}C NMR spectroscopy and additionally by single-crystal X-ray diffractometry (Tables 1–5; Figs. 1 and 2a).

As we have mentioned, we have successfully developed an efficient three-step process for the synthesis of the new compound, 1,4-anhydro-5-deoxy-5-iodo-2,3-*O*-isopropylidene-D,L-ribitol (**3**), which, on being heated with a 33% ethanolic solution of trimethylamine, yields the expected salt, *N*-[(1,4-anhydro-5-deoxy-2,3-*O*-isopropylidene-D,L-ribitol)-5-yl]trimethylammonium iodide (**4**). Unfortunately, although *N*-[(1,4-anhydro-5-deoxy-2,3-*O*-isopropylidene-D,L-ribitol)-5-yl]ammonium tosylates are biodegradable, none of them display any antibacterial or antifungal activity. The next step in our research will be to study the biological activities of quaternary ammonium salts with the iodide anion. We shall describe further results in this area in our next report.

Table 1. Crystal data and structure refinement for *N*-[(1,4-anhydro-5-deoxy-2,3-*O*-isopropylidene-D,L-ribitol)-5-yl]trimethylammonium iodide

Empirical formula	$C_{11}H_{22}INO_3$
Formula weight	343.20
Temperature (K)	298(2)
Wavelength (Å)	0.71073
Crystal system, space group	Monoclinic, $P2_1/n$
Unit cell dimensions	
a (Å)	7.667(2)
b (Å)	14.324(2)
c (Å)	12.882(3)
B	93.48(3)
Volume (Å^3)	1412.1(6)
Z	4
Calculated density (mg m^{-3})	1.614
Absorption coefficient (mm^{-1})	2.263
Absorption correction methods	Empirical
Max. and min. transmission	0.800 and 0.760
F(000)	688
Crystal size (mm)	$0.5 \times 0.1 \times 0.1$
Theta range for data collection (°)	$2.13 < \theta < 25.04$
Index ranges, *h*, *k*, *l*	$-9 \rightarrow 9$, $0 \rightarrow 17$, $-15 \rightarrow 0$
Reflections collected/unique	2522/2413 [$R_{int} = 0.0500$]
Reflections [$I > 2\sigma(I)$]	2413
Completeness $2\theta = 50.08$ (%)	0.965
Refinement method	Full-matrix least-squares on F^2
Data/restraints/parameters	2413/0/150
Goodness-of-fit on F^2	1.041
Final *R* indices [$I > 2\sigma(I)$]	$R_1 = 0.0589$, $wR_2 = 0.1160$
R Indices (all data)	$R_1 = 0.1849$, $wR_2 = 0.1641$
Largest difference peak and hole (e Å^{-3})	0.946/−1.099

Table 2. Atomic coordinates ($\times 10^4$) and equivalent isotropic displacement parameters (Å$^2 \times 10^3$) for *N*-[(1,4-anhydro-5-deoxy-2,3-*O*-isopropylidene-D,L-ribitol)-5-yl]trimethylammonium iodide[a]

Atom	*x*	*Y*	*z*	U_{eq}
I-1	2389(1)	1926(1)	5758(1)	62(1)
C-1	11512(13)	−358(8)	8707(9)	48(3)
C-2	9568(12)	−327(8)	8680(9)	47(3)
C-3	9000(12)	−555(8)	7568(8)	47(3)
C-4	10659(12)	−496(7)	6990(8)	37(2)
O-5	11933(9)	−80(5)	7675(6)	54(2)
O-6	9024(9)	594(5)	8825(6)	52(2)
C-7	7556(12)	741(9)	8095(10)	56(3)
O-8	7755(9)	129(6)	7281(6)	56(2)
C-9	5893(15)	536(10)	8627(10)	70(4)
C-10	7583(19)	1743(9)	7744(12)	78(4)
C-11	11170(12)	−1484(7)	6641(8)	43(2)
N-12	12751(11)	−1528(6)	6007(8)	52(3)
C-13	12562(16)	−957(9)	5068(9)	63(3)
C-14	13003(17)	−2539(9)	5751(10)	65(4)
C-15	14396(15)	−1236(11)	6634(10)	72(4)
H-1A	11938	−983	8864	57
H-1B	12019	71	9224	57
H-2	9085	−761	9176	56
H-3	8490	−1181	7512	57
H-4	10454	−98	6376	45
H-9A	4913	789	8221	105
H-9B	5753	−127	8693	105
H-9C	5957	816	9305	105
H-10A	6569	1866	7290	117
H-10B	7579	2146	8339	117
H-10C	8617	1854	7379	117
H-11A	10186	−1752	6236	52
H-11B	11383	−1869	7255	52
H-13A	13552	−1053	4659	94
H-13B	11514	−1133	4670	94
H-13C	12497	−311	5258	94
H-14A	13272	−2883	6380	98
H-14B	11951	−2781	5410	98
H-14C	13948	−2600	5299	98
H-15A	14482	−1572	7279	108
H-15B	15397	−1371	6247	108
H-15C	14353	−578	6772	108

[a] U_{eq} is defined as one third of the trace of the orthogonalized U_{ij} tensor.

Table 3. Selected bond lengths (Å) for *N*-[(1,4-anhydro-5-deoxy-2,3-*O*-isopropylidene-D,L-ribitol)-5-yl]trimethylammonium iodide

	Bond length
C-1–O-5	1.442(12)
C-1–C-2	1.489(13)
C-2–O-6	1.399(13)
C-2–C-3	1.508(15)
C-3–O-8	1.401(13)
C-3–C-4	1.514(14)
C-4–O-5	1.408(12)
C-4–C-11	1.542(13)
O-6–C-7	1.438(12)
C-7–O-8	1.382(14)
C-7–C-10	1.505(18)
C-7–C-9	1.513(16)
C-11–N-12	1.504(12)
N-12–C-13	1.459(14)
N-12–C-14	1.501(15)
N-12–C-15	1.515(14)

Table 4. Selected valence angles (°) for *N*-[(1,4-anhydro-5-deoxy-2,3-*O*-isopropylidene-D,L-ribitol)-5-yl]trimethylammonium iodide

Valence angles	[°]
O-5–C-1–C-2	104.5(8)
O-6–C-2–C-1	109.3(9)
O-6–C-2–C-3	105.0(8)
C-1–C-2–C-3	104.2(8)
O-8–C-3–C-2	104.6(8)
O-8–C-3–C-4	114.3(9)
C-2–C-3–C-4	104.6(8)
O-5–C-4–C-3	106.7(8)
O-5–C-4–C-11	113.1(8)
C-3–C-4–C-11	109.2(8)
C-4–O-5–C-1	106.0(7)
C-2–O-6–C-7	106.2(8)
O-8–C-7–O-6	106.6(8)
O-8–C-7–C-10	111.9(11)
O-6–C-7–C-10	108.1(10)
O-8–C-7–C-9	110.8(10)
O-6–C-7–C-9	108.9(10)
C-10–C-7–C-9	110.4(11)
C-7–O-8–C-3	110.4(9)
N-12–C-11–C-4	115.1(8)
C-13–N-12–C-14	111.5(10)
C-13–N-12–C-11	112.6(9)
C-14–N-12–C-11	106.2(9)
C-13–N-12–C-15	108.9(10)
C-14–N-12–C-15	105.6(9)
C-11–N-12–C-15	111.8(9)

Table 5. Selected torsion angles (°) for *N*-[(1,4-anhydro-5-deoxy-2,3-*O*-isopropylidene-D,L-ribitol)-5-yl]trimethylammonium iodide

O-5–C-1–C-2–O-6	−81.5(10)
O-5–C-1–C-2–C-3	30.4(11)
O-6–C-2–C-3–O-8	−17.2(10)
C-1–C-2–C-3–O-8	−132.2(9)
O-6–C-2–C-3–C-4	103.2(9)
C-1–C-2–C-3–C-4	−11.7(11)
O-8–C-3–C-4–O-5	102.4(9)
C-2–C-3–C-4–O-5	−11.4(11)
O-8–C-3–C-4–C-11	−135.1(9)
C-2–C-3–C-4–C-11	111.1(9)
C-3–C-4–O-5–C-1	31.1(10)
C-11–C-4–O-5–C-1	−88.9(9)
C-1–C-1–O-5–C-4	−38.8(10)
C-1–C-2–O-6–C-7	137.7(9)
C-3–C-2–O-6–C-7	26.3(10)
C-2–O-6–C-7–O-8	−26.2(12)
C-2–O-6–C-7–C-10	−146.6(10)
C-2–O-6–C-7–C-9	93.4(11)
O-6–C-7–O-8–C-3	15.1(12)
C-10–C-7–O-8–C-3	133.1(10)
C-9–C-7–O-8–C-3	−103.3(11)
C-2–C-3–O-8–C-7	1.1(11)
C-4–C-3–O-8–C-7	−112.7(10)
O-5–C-4–C-11–N-12	−64.4(11)
C-3–C-4–C-11–N-12	177.0(8)
C-4–C-11–N-12–C-13	−57.5(12)
C-4–C-11–N-12–C-14	−179.8(9)
C-4–C-11–N-12–C-15	65.5(12)

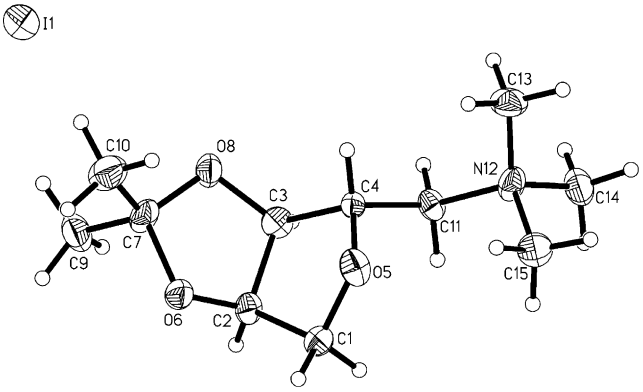

Figure 1. The molecular structure of *N*-[(1,4-anhydro-5-deoxy-2,3-*O*-isopropylidene-D,L-ribitol)-5-yl]trimethylammonium iodide showing the atom-labeling scheme and 25% probability displacement ellipsoids. H atoms are shown as small spheres of arbitrary radii.

1. Experimental

1.1. General methods

Commercial ribitol (Fluka) was used. All reactions were monitored by thin-layer chromatography (TLC) on Kieselgel 60 F_{254} Silica Gel plates (E. Merck, 0.20 mm thickness). The spots were detected by spraying with 5% ethanolic H_2SO_4 and charring. ^1H NMR and ^{13}C NMR spectra were recorded at 25 °C on a Varian Unity Plus spectrometer at 500 and 100 MHz, respectively, with Me_4Si as the internal standard. Assignments were based on homonuclear decoupling experiments, together with homo- and heteronuclear correlation. Elementary analyses were carried out on a Carlo Erba apparatus. MALDI-TOF mass spectra in the positive-ion mode were obtained using a Bruker Biflex III spectrometer with α-cyano-4-hydroxycinnamic acid as the matrix.

1.2. Single-crystal X-ray crystallography

Diffraction data were collected at room temperature (293 K) on a KUMA KM-4 four-circle diffractometer[18]

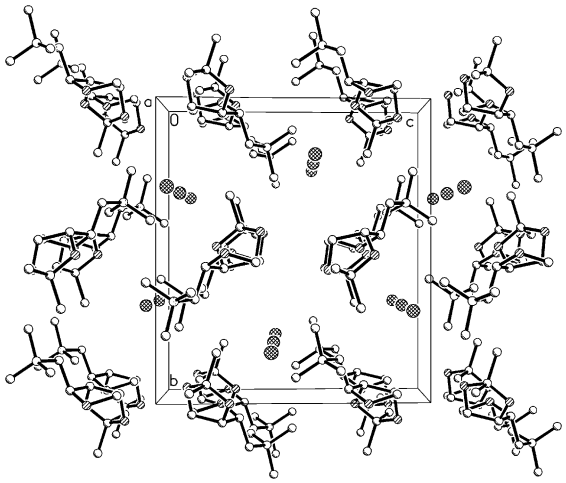

Figure 2a. The arrangement of the molecules of *N*-[(1,4-anhydro-5-deoxy-2,3-*O*-isopropylidene-D,L-ribitol)-5-yl]trimethylammonium iodide in the unit cell, viewed along the *a* axis. H atoms have been omitted.

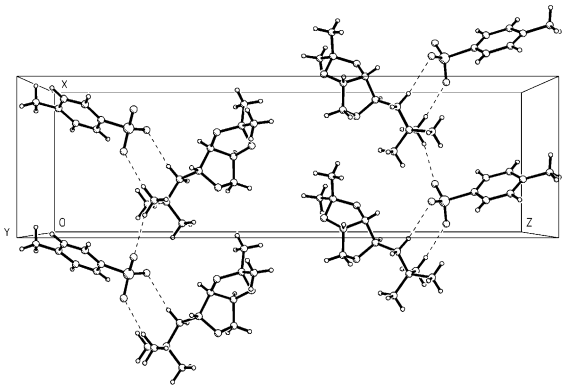

Figure 2b. View of cell packing along the *b*-direction of *N*-[(1,4-anhydro-5-deoxy-2,3-*O*-isopropylidene-D,L-ribitol)-5-yl]trimethylammonium tosylate.[16]

with MoKα radiation ($\lambda = 0.71073$ Å) using the $2\Theta/\omega$ scan mode. All H atoms were placed geometrically and refined using a riding model with C–H = 0.97–0.98 Å and $U_{iso}(H) = 1.2U_{eq}(C)$ (C–H = 0.96 Å and $U_{iso}(H) = 1.5U_{eq}(C)$ in the case of the methyl H atoms). The crystallographic data, data collection and structure refinement are summarized in Table 1. The compound structure with the numbering of the C, O, N atoms and the molecular packing in the crystal are shown in Figures 1 and 2a, respectively.[19,20] The coordinates of the atoms and their isotropic temperature factors are presented in Table 2, and a selection of important geometric parameters for the crystal are given in Tables 3 and 4.

The crystal structure was solved by the SHELXS program[21] and refined to $R_1 = 0.1849$ (2413 reflections—all unique), and $R_1 = 0.0589$ (1023 reflections with $F_0 > 2\sigma(F_0)$) by the full-matrix least-squares method using the SHELX-97 program[22] based on 150 parameters. The empirical absorption correction was prepared with the DIFABS program,[23] and the computing publication material with the PLATON program.[24]

We had hypothesized that the quaternary ammonium salts with the same cation but another counterion could have a different crystallographic structure. Now we have an opportunity to test this hypothesis: two crystallographic structures of quaternary ammonium salts are presented in Figure 3a (iodide) and b (tosylate).

Conformational analysis[25] of *N*-[(1,4-anhydro-5-deoxy-2,3-*O*-isopropylidene-D,L-ribitol)-5-yl]trimethylammonium iodide (**4**) shows that the five-membered tetrahydrofuran O-5–C-1–C-2–C-3–C-4 ring in the title compound is very similar to a *T* conformation (twisted around the O-5–C-1 bond) with ring-puckering parameters[26] $\theta = 0.35(1)$ Å

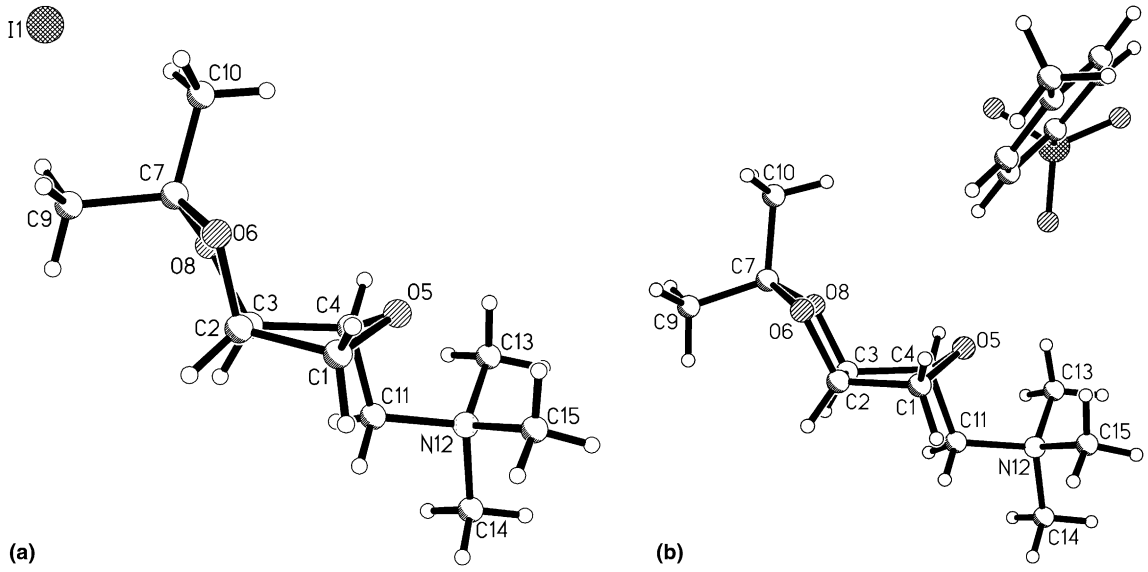

Figure 3. Comparison of conformations of *N*-[(1,4-anhydro-5-deoxy-2,3-*O*-isopropylidene-D,L-ribitol)-5-yl]trimethylammonium iodide (a) and *N*-[(1,4-anhydro-5-deoxy-2,3-*O*-isopropylidene-D,L-ribitol)-5-yl]trimethylammonium tosylate[16] (b).

and $\varphi = 19(2)°$ (Fig. 3a), pseudorotation parameters[27] $P = 108(1)°$ and $\tau_m = 38.3(7)°$ for the C-2–C-3 bond, and delta parameter[28] $\Delta = 216°$, whereas the five-membered dioxolane O-6–C-2–C-3–O-8–C-7 ring of this salt adopts an envelope conformation on the O-6 atom (Fig. 3a) with $\theta = 0.25(1)$ Å and $\varphi = 184(3)°$, pseudorotation parameters $P = 272(1)°$ and $\tau_m = 27.6(7)°$ for the C-3–O-8 bond, and $\Delta = 544.7°$.

Conformational analysis of *N*-[(1,4-anhydro-5-deoxy-2,3-*O*-isopropylidene-D,L-ribitol)-5-yl]trimethylammonium tosylate[16] shows that the tetrahydrofuran O-5–C-1–C-2–C-3–C-4 ring adopts an envelope conformation on O-5 (Fig. 3b) with $\theta = 0.347(5)$ Å and $\varphi = 178.5(9)°$, pseudorotation parameters $P = 268.3(5)°$ and $\tau_m = 38.6(3)°$ for the C-2–C-3 bond, and delta parameter $\Delta = 216°$, but that the five-membered dioxolane O-6–C-2–C-3–O-8–C-7 ring of this salt adopts an envelope conformation on the C-7 atom (Fig. 3b) with $\theta = 0.275(5)°$ and $\varphi = 223(1)°$, $P = 313.0(6)°$, and $\tau_m = 31.5(3)°$ for the C-3–O-8 bond, and $\Delta = 625.9°$.

The packing in the crystal lattice shows that the title compound **4** has a layered structure and forms columns along the *a*-axis (Fig. 2a). Furthermore, unlike the structure of *N*-[(1,4-anhydro-5-deoxy-2,3-*O*-isopropylidene-D,L-ribitol)-5-yl]trimethylammonium tosylate (Fig. 2b), compound **4** does not form hydrogen bonds (Fig. 2a).

1.3. 1,4-Anhydro-5-deoxy-5-iodo-2,3-*O*-isopropylidene-D,L-ribitol (3)

1,4-Anhydro-2,3-*O*-isopropylidene-D,L-ribitol (**2**) (0.61 g, 3.50 mmol), iodine (1.25 g, 4.94 mmol), imidazole (0.72 g, 10.72 mmol) and triphenylphosphine (1.38 g, 5.27 mmol) were dissolved in toluene (70.0 mL), and the mixture was stirred at 70 °C for 3 h. The pH was adjusted to pH 2 with $NaHCO_3$. The toluene phase was washed with water and dried with $MgSO_4$. The solvent was removed in vacuo to give the title compound as an oil. After crystallization from EtOH, **3** (0.84 g, 85%) was obtained: mp 35.0–36.6 °C; R_f 0.68 (2:3 acetone–hexane). ^{1}H NMR ($CDCl_3$): δ 1.36 and 1.53 (2s, each 3H, CMe_2), 3.14 (dd, 1H, $J_{4,5'}$ 8.1, $J_{5,5'}$ 10.3, H-5′), 3.19 (dd, 1H, $J_{4,5}$ 5.9, H-5), 4.02 (br d, 2H, $J_{1,1'}$ 2.92, H-1, H-1′), 4.22 (td, 1H, $J_{3,4}$ 2.0, H-4), 4.66 (dd, 1H, $J_{2,3}$ 5.9, H-3), 4.85 (m, 1H, H-2); ^{13}C NMR ($CDCl_3$): δ 113.24 (C, CMe_2), 84.82 (C-3), 84.60 (C-4), 81.31 (C-2), 72.91 (C-1), 4.81 (C-5), 26.91–25.32 (Me_2, CMe_2). Anal. Calcd for $C_8H_{13}IO_3$ (284.09): C, 33.82; H, 4.61. Found: C, 33.57; H, 4.79.

1.4. *N*-[(1,4-Anhydro-5-deoxy-2,3-*O*-isopropylidene-D,L-ribitol)-5-yl]trimethylammonium iodide (4)

Compound **3** (0.07 g, 0.25 mmol) and a 33% ethanolic solution of Me_3N (1.5 mL) were heated in a glass ampoule for 90 min at 70 °C until compound **3** was dissolved. The solution was then cooled, and EtOH, together with the excess of Me_3N, were removed in vacuo to give colorless crystals of compound **4** (0.06 g, 72%): mp 196.0–198.0 °C; R_f 0.0 (2:3 acetone–hexane). A single crystal of the compound suitable for X-ray diffractometry was obtained by very slow crystallization from ethanol. ^{1}H NMR (D_2O): δ 1.25 and 1.41 (2s, each 3H, CMe_2), 3.10 (s, 9H, NMe_3), 3.34 (br d, 1H, $J_{5,5'}$ 14.0, H-5′), 3.49 (dd, 1H, $J_{4,5'}$ 11.7, H-5), 3.89 (dd, 1H, $J_{1',2}$ 3.4, H-1′), 4.00 (d, 1H, $J_{1,1'}$ 11.7, H-1), 4.55 (d, 1H, $J_{4,5'}$ 11.2, H-4), 4.62 (d, 1H, $J_{2,3}$ 5.9, H-3), 4.88 (dd, 1H, $J_{1,2}$ 3.4, H-2); ^{13}C NMR (D_2O): δ 113.75 (C, CMe_2), 83.47 (C-3), 80.36 (C-2), 79.52 (C-4), 71.32 (C-1), 63.33 (C-5), 54.09 (C, NMe_3), 25.39 and 23.66 (Me_2, CMe_2). MALDI-TOF MS (CHCA): *m*/*z* 216.3 ($[M-I]^+$). Anal. Calcd for $C_{11}H_{22}INO_3$ (343.20): C, 38.50; H, 6.64; N, 4.08. Found: C, 38.22; H, 6.41; N, 4.28.

Supplementary data

Full crystallographic details, excluding structure features, have been deposited (Deposition No. CCDC 293040) with the Cambridge Crystallographic Data Centre. These data may be obtained, on request, from the CCDC, 12 Union Road, Cambridge CB2 1EZ, UK. Tel.: +44 1223 336408; fax: +44 1223 336033; e-mail: deposit@ccdc.cam.ac.uk.

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References

1. Wiśniewski, A. *Wiad. Chem.* **1992**, *46*, 847–861.
2. Gagnon, O.; Gertman, P. M.; Iber, F. L. *Am. J. Med. Sci.* **1967**, *254*, 284.
3. McAleer, W. J.; Marcus, H. Z. Jpn Kokai Tokkyo Koho, JP 6332, 767 [8832, 767].
4. Kondo, M.; Inoue, K. Jpn Kokai Tokkyo Koho, JP 6388, 197 [8888, 197].
5. Gaenshirt, K.; Handel, K. D.; Walker, W. H.; von Eisenhart-Rothe B. Ger. Offen. DE 3, 722, 984.
6. Institöris, E.; Szikla, K.; Ötvös, L.; Gál, F. *Cancer Chemother. Pharmacol.* **1989**, *24*, 311–313.
7. Kozlov, I. A.; Politis, P. K.; Aerschot, A. V.; Busson, R.; Herdewijn, P.; Orgel, L. E. *J. Am. Chem. Soc.* **1999**, *121*, 2653–2656.
8. Lescrinier, E.; Esnouf, R. M.; Schraml, J.; Busson, R.; Herdewijn, P. *Helv. Chim. Acta* **2000**, *83*, 1291–1310.
9. Mantell, S. J.; Ford, P. S.; Watkin, D. J.; Fleet, G. W. J.; Brown, D. *Tetrahedron* **1993**, *49*, 3343–3358.
10. Felli, C.; Carrea, G.; Chiari, M.; De Amici, M.; De Micheli, C. *J. Chromatogr. A* **1996**, *741*, 287–294.

11. De Amici, M.; Dallanoce, C.; Angeli, P.; Marucci, G.; Cantalamessa, F.; De Micheli, C. *Il Farmaco* **2000**, *55*, 535–543.
12. Hanessian, S.; Ponpipom, M. M.; Lavallee, P. *Carbohydr. Res.* **1972**, *24*, 45.
13. Binkley, R. W.; Hehemann, D. G. *J. Org. Chem.* **1978**, *43*, 3244.
14. Harrison, I. T.; Harrison, S. *Compendium of Organic Synthetic Methods*; Wiley Interscience: New York, 1971; Vol. 1, p 331; Harrison, I. T.; Harrison, S. *Compendium of Organic Synthetic Methods*; Wiley Interscience: New York, 1974; Vol. 2, p 137.
15. Garegg, P. J.; Samuelsson, B. *J. Chem. Soc., Perkin Trans. 1* **1980**, 2866–2869.
16. Skorupa, E.; Dmochowska, B.; Pellowska-Januszek, L.; Wojnowski, W.; Chojnacki, J.; Wiśniewski, A. *Carbohydr. Res.* **2004**, *339*, 2355–2362.
17. Kurszewska, M.; Skorupowa, E.; Madaj, J.; Wiśniewski, A. *J. Carbohydr. Chem.* **2003**, *23*, 169–177.
18. *Kuma KM-4 Software User's Guide*, v. 3.1, Kuma Diffraction: Wrocław, Poland, 1989.
19. Mortherwell, S.; Clegg, S. PLUTO-78*; Program for Drawing and Molecular Structure*; University of Cambridge: UK, 1978.
20. Johnson C. K. *ORTEP II*; *Report ORNL*-5138, Oak Ridge National Laboratory: Oak Ridge, TN, USA, 1976.
21. Sheldrick, G. M. *Acta Crystallogr., Sect. A* **1990**, *46*, 467–473.
22. Sheldrick, G. M. SHELXL-97. *Program for Crystal Structure Refinement*; University of Göttingen: Göttingen, 1997.
23. Walker, N.; Stuart, D. *Acta Crystallogr., Sect. A* **1983**, *39*, 158–166.
24. Spek, A. L. *J. Appl. Crystallogr.* **2003**, *36*, 7–13.
25. Evans, G. G.; Boeyens, J. A. *Acta Crystallogr., Sect. B* **1989**, *45*, 581–590.
26. Cremer, D.; Pople, J. A. *J. Am. Chem. Soc.* **1975**, *97*, 1354–1358.
27. Rao, S. T.; Westhof, E.; Sundaralingam, M. *Acta Crystallogr., Sect. A* **1981**, *37*, 421–425.
28. Altona, C.; Geise, H. J.; Romers, C. *Tetrahedron* **1968**, *24*, 13–32.