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Preparation and structure determination of two sugar amino acids via corresponding hydantoin derivatives

Miroslav Kóš [a,*], Bohumil Steiner [a], Vratislav Langer [b], Dalma Gyepesová [c], Marián Ďurík [c]

[a] *Institute of Chemistry, Slovak Academy of Sciences, SK-84238 Bratislava, Slovak Republic*
[b] *Department of Inorganic Environmental Chemistry, Chalmers University of Technology, SE-41296 Gothenburg, Sweden*
[c] *Institute of Inorganic Chemistry, Slovak Academy of Sciences, SK-84236 Bratislava, Slovak Republic*

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Abstract

(4*R*)-2,3-*O*-Isopropylidene-methylspiro[4,6-dideoxy-α-L-*lyxo*-hexopyranosid-4,5′-imidazolidin]-2′,4′-dione and (4*R*)-2,3-*O*-isopropylidene-methylspiro[4,6-dideoxy-β-D-*ribo*-hexopyranosid-4,5′-imidazolidin]-2′,4′-dione were prepared under various reaction conditions starting from methyl 6-deoxy-2,3-*O*-isopropylidene-α-L-*lyxo*-hexopyranosid-4-ulose. Corresponding α-amino acids methyl (4*R*)-4-amino-4-*C*-carboxy-4,6-dideoxy-α-L-*lyxo*-hexopyranoside and methyl (4*R*)-4-amino-4-*C*-carboxy-4,6-dideoxy-β-D-*ribo*-hexopyranoside were obtained from the above hydantoins by selective acid hydrolysis of the isopropylidene group, followed by basic hydrolysis of the hydantoin ring. The crystal structures of both hydantoin derivatives are also presented.

Keywords: Sugar amino acids; Hydantoins; Cyanohydrins; Methyl 2,3-*O*-isopropylidene-hexopyranosid-4-uloses; X-ray analysis

1. Introduction

The α-amino acids derived from carbohydrates represent a very significant group of organic compounds with respect to their biological activity. Some are naturally occurring [1–7] and many glycoprotein structures have been synthesized and studied intensively [8–22], especially in the past decade. Besides these mostly anomerically O- or N-linked glycopeptide derivatives and well-known 2-amino-2-deoxyaldonic acids [7], not many of such analogs have been prepared having the α-amino acid grouping as an integral part of saccharide backbone (optional position of the pyranose or furanose ring or open chain excluding C-2 position of aldonic acids) [1,3,23,24].

The importance of carbohydrate recognition in biological events has brought about growing interest in synthetically prepared suitable model compounds. Respecting the diversity of carbohydrate derivatives, we have started with the synthesis of different monosaccharide α-amino acids modifying the type of monosacharide and position of the α-amino acid grouping in the sugar backbone. Their transformation to more complex model compounds (oligosaccharides, peptides, etc.) is expected in the future.

* Corresponding author. Fax: +421-7-59410222.
E-mail address: chemmiro@savba.sk (M. Kóš).

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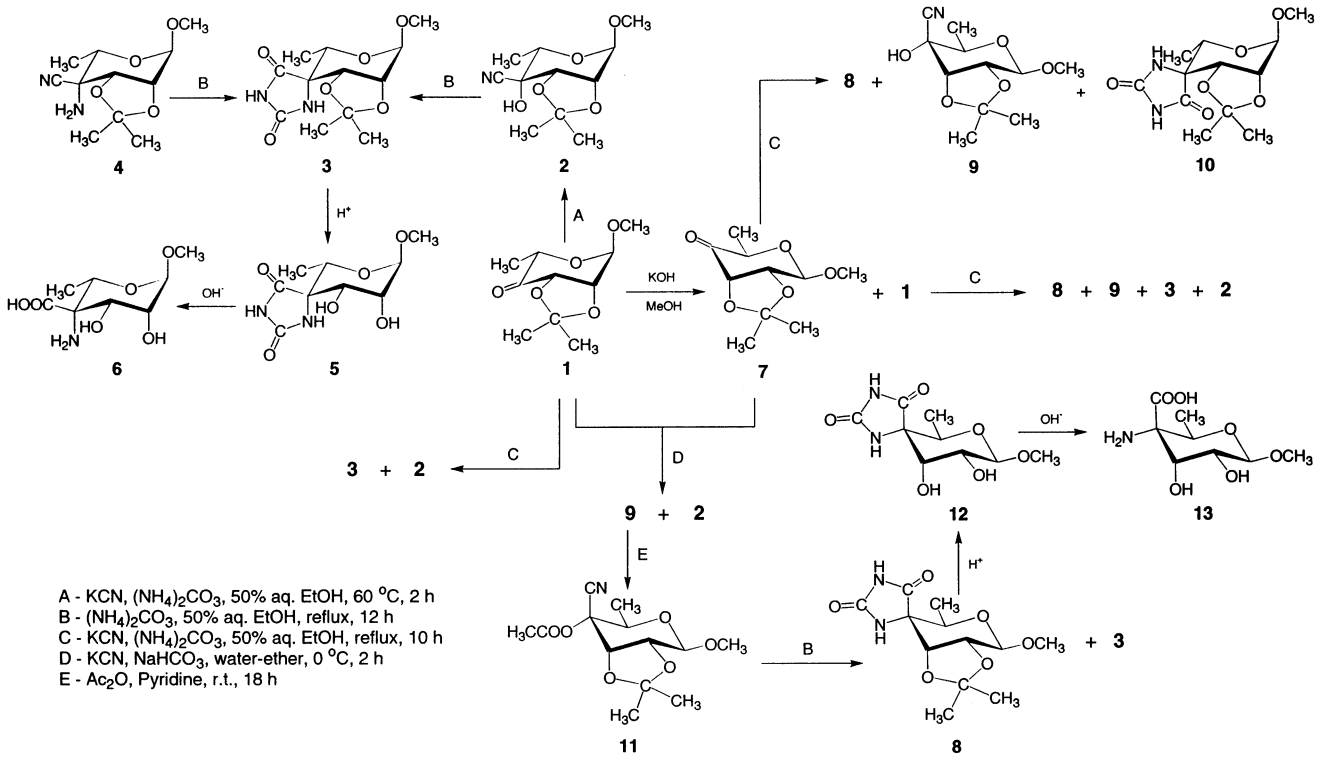

Scheme 1.

2. Results and discussion

In our previous paper [25] we described the preparation of methyl 4-amino-4-cyano-4,6-dideoxy-2,3-*O*-isopropylidene-α-L-talopyranoside and methyl 4-amino-4-cyano-4,6-dideoxy-2,3-*O*-isopropylidene-β-D-allopyranoside starting from methyl 6-deoxy-2,3-*O*-isopropylidene-α-L-*lyxo*-hexopyranosid-4-ulose. The conversion of these amino nitriles into corresponding amino acids using usual methods was unsuccessful. Acid hydrolysis led to the formation of decomposition products. On the other hand, base hydrolysis afforded only corresponding amino acid amides. The desired α-amino acids have now been made available by base hydrolysis of the corresponding hydantoin derivatives.

As a starting compound we have used known methyl 6-deoxy-2,3-*O*-isopropylidene-α-L-*lyxo*-hexopyranosid-4-ulose (**1**) [25–31]. Reaction of **1** with KCN and $(NH_4)_2CO_3$ in aqueous ethanol at 60 °C (method A) afforded only methyl 4-cyano-6-deoxy-2,3-*O*-isopropylidene-α-L-talopyranoside (**2**) (Scheme 1). Heating of this cyanohydrin with $(NH_4)_2CO_3$ in aqueous ethanol under reflux (method B) gave the desired (4*R*)-2,3-*O*-isopropylidenemethylspiro[4,6-dideoxy-α-L-*lyxo*-hexopyranosid-4,5′-imidazolidin]-2′,4′-dione (**3**). Both these steps are high yielding (~80%) and therefore this two-step transformation of **1** to hydantoin **3** is more advantageous than direct transformation using heating of **1** with KCN and $(NH_4)_2CO_3$ in aqueous ethanol under reflux (method C), affording only about 35% of **3** and 20% of cyanohydrin **2**. Alternatively, hydantoin **3** can also be obtained in lower yield (~25%) from methyl 4-amino-4-cyano-4,6-dideoxy-2,3-*O*-isopropylidene-α-L-talopyranoside (**4**) [25] using method B and prolonged heating (20 h). Selective acid hydrolysis of 2,3-*O*-isopropylidene group in **3** afforded (4*R*)-methylspiro[4,6-dideoxy-α-L-*lyxo*-hexopyranosid-4,5′-imidazolidin]-2′,4′-dione (**5**), which upon basic hydrolysis of the hydantoin ring using barium hydroxide gave the desired methyl (4*R*)-4-amino-4-*C*-carboxy-4,6-dideoxy-α-L-*lyxo*-hexopyranoside (**6**) in about 40% yield.

In our previous paper [25] we also demonstrated that the starting 4-ulose **1** isomerizes under Strecker reaction conditions partially to methyl 6-deoxy-2,3-*O*-isopropylidene-β-D-

ribo-hexopyranosid-4-ulose (**7**) [31–33] and indeed, the amino nitriles corresponding to both **1** and **7** were isolated. It is important to note that under cyanohydrin or hydantoin reaction conditions no products corresponding to 4-ulose **7** were observed and only products corresponding to the starting 4-ulose **1** were isolated. On the other hand, starting from 4-ulose **7** itself using method C (Scheme 1), in addition to the expected (4*R*)-2,3-*O*-isopropylidene-methylspiro[4,6-dideoxy-β-D-*ribo*-hexopyranosid-4,5′-imidazolidin]-2′,4′-dione (**8**) and methyl 4-cyano-6-deoxy-2,3-*O*-isopropylidene-β-D-allopyranoside (**9**), a small amount of (4*S*)-2,3-*O*-isopropylidene-methylspiro[4,6-dideoxy-α-L-*lyxo*-hexopyranosid-4,5′-imidazolidin]-2′,4′-dione (**10**) was isolated as a result of base-catalyzed isomerization at the C-5 position of the pyranose ring. Because the described preparation of 4-ulose **7** [31–33] is suitable only for small scale preparation (difficult separation of a mixture of 4-uloses **1** and **7**) and another method [25] requires two more steps, for practical purposes it is more convenient to start from a crude mixture of **1** and **7** [31], followed by the high yielding preparation of a mixture of corresponding cyanohydrins **2** and **9** (Scheme 1). From this mixture, most of the cyanohydrin **2** can be separated by crystallization. Acetylation of the residual oily cyanohydrin **9** (slightly contaminated with **2**) afforded methyl 4-*O*-acetyl-4-cyano-6-deoxy-2,3-*O*-isopropylidene-β-D-allopyranoside (**11**), which is purified easily by crystallization (acetylation product of **2** is oily) thus avoiding column chromatography in both steps. From this acetylated cyanohydrin **11** directly, a high yield of the corresponding hydantoin **8** was obtained using method B. In this case, a small amount of hydantoin **3** was isolated as a result of base-catalyzed isomerization at C-5. (4*R*)-Methylspiro[4,6-dideoxy-β-D-*ribo*-hexopyranosid-4,5′-imidazolidin]-2′,4′-dione (**12**) and the final amino acid-methyl (4*R*)-4-amino-4-*C*-carboxy-4,6-dideoxy-β-D-*ribo*-hexopyranoside (**13**) were obtained applying the same reaction sequence and conditions as those used for the preparation of **6** (Scheme 1). Application of method C directly to a mixture of 4-uloses **1** and **7** led to the formation of hydantoins **3** and **8** (lower yields) together with a small amount of cyanohydrins **2** and **9**. Separation of individual compounds from this reaction mixture is, of course, more complicated.

As in the case of amino nitriles and cyanohydrins [25], the isolation of hydantoins only with *R* configuration (except small amounts of compound **10** with *S* configuration) indicates the high stereoselectivity of the reaction at C-4 ketone group.

The structure of the prepared compounds was determined on the basis of ^{1}H and ^{13}C NMR spectral data. These are summarized in Tables 1 and 2. The EI and CI (pyridine) mass spectra of the selected compounds were also confirmative.

The ^{1}H NMR spectra of **3** and **10** showed coupling constants for the anomeric proton ($J_{1,2}$) of ~ 0 Hz suggesting the $^{1}C_4$ conformation with an axial glycosidic methoxyl group, H-3 and H-5 [25,28]. Similarly, the very low value (~ 1.5 Hz) of coupling constant $J_{1,2}$ observed for compounds **5** and **6** also suggests the $^{1}C_4$ conformation. On the other hand, coupling constant $J_{1,2}$ of ~ 7 Hz in **8**, **11**, **12** and **13** indicates the inversion of a $^{1}C_4$ to a $^{4}C_1$ conformation with an equatorial glycosidic methoxy group and H-3, and an axial H-5. The same inversion was confirmed during the preparation of corresponding amino nitriles in our previous study [25].

The configuration at C-4 in **3** and **8** was unambiguously established by X-ray analysis. This confirmed the (4*R*)-α-L-*lyxo* configuration for **3** and (4*R*)-β-D-*ribo* configuration for **8**. The structure of compounds **3** and **8** and the numbering of the atoms is shown in Figs. 1 and 2, respectively. The H-positions have been put at calculated positions. The relevant crystallographic data for **3** and **8** are given in Table 3. The bond lengths and bond angles are listed in Table 4. A list of selected torsion angles is given in Table 5. The final positional parameters for compounds **3** and **8** are summarized in Tables 6 and 7[1]. As in the case of

[1] The refcodes of compounds **3** and **8** in the Cambridge Crystallographic Data Centre are CCDC nos. 138265 and 138266, respectively.

N-acetyl derivative of amino nitrile **4** [25] and related structures having an α-L-*talo* configuration [34–36], the X-ray and NMR data (e.g., torsion angles C-11–C-12–C-13–C-14 and C-11–O-15–C-15–C-14 about 30 and −70°, respectively; vicinal coupling constant $J_{2,3}$ about 6 Hz corresponding to the C-12–H-12A–C-13–H-13 angle of about 30°) indicate that the $^1C_4$ conformation for compound **3** is distorted into the direction of ^5E with considerable flattening at C-2 of the pyranose ring.

3. Experimental

General methods.—^{1}H and ^{13}C NMR spectra (in $CDCl_3$ unless specified other, internal standard Me_4Si) were recorded on a Bruker Avance DPX 300 instrument operating at 300.13 and 75.46 MHz working frequencies, respectively. For the assignments of signals, 1D NOESY and C–H heterocorrelated experiments were used. The quaternary carbon atoms were identified on the basis of a semiselective INEPT experiment and a 1D INADEQUATE pulse sequence technique. The EI

Table 1
^{1}H chemical shifts and coupling constants of the prepared compounds (in $CDCl_3$)

Compound	Chemical shifts (δ, ppm)								Coupling constants (J, Hz)		
	H-1	H-2	H-3	H-5	H-6	OMe	CMe_2		$J_{1,2}$	$J_{2,3}$	$J_{5,6}$
3 [a]	4.95(s)	4.16(d)	4.57(d)	4.02(q)	1.19(d)	3.39(s)	1.56(s)	1.37(s)	0	5.6	6.3
5 [b]	4.81(d)	3.90(dd)	4.17(d)	4.15(q)	1.16(d)	3.41(s)			1.6	3.1	6.4
6 [b]	4.82(d)	3.93(dd)	4.37(d)	4.32(q)	1.21(d)	3.42(s)			1.6	3.4	6.7
8 [c]	4.43(d)	4.20(dd)	4.35(d)	3.96(q)	1.35(d)	3.54(s)	1.55(s)	1.38(s)	7.0	5.2	6.5
10 [d]	4.71(s)	4.32(d)	3.95(dd) [e]	3.62(q)	1.30(d)	3.49(s)	1.50(s)	1.34(s)	0	4.8	6.2
11 [f]	4.45(d)	3.91(dd)	4.70(d)	4.18(q)	1.50(d)	3.54(s)	1.58(s)	1.41(s)	6.7	5.4	6.4
12 [d]	4.62(d)	4.00(dd)	3.98(d)	4.10(q)	1.25(d)	3.55(s)			7.5	3.8	6.5
13 [b]	4.60(d)	4.23(dd)	4.04(d)	3.89(q)	1.24(d)	3.51(s)			7.7	3.2	6.4

[a] 9.34 and 6.18 ppm (both broad singlets) for NH protons in hydantoin.
[b] Measured in D_2O.
[c] 8.92 and 6.07 ppm (both broad singlets) for NH protons in hydantoin.
[d] Measured in CD_3OD.
[e] Coupling constant $J_{3,NH}$ 9.0 Hz.
[f] 2.21 ppm (singlet) for protons of CH_3 group in acetyl.

Table 2
^{13}C chemical shifts of the prepared compounds (in $CDCl_3$)

Compound	Chemical shifts (δ, ppm)											
	C-1	C-2	C-3	C-4	C-5	C-6	OMe	CMe_2	$C(CH_3)_2$		C=O	
3	97.8	73.2	73.4	67.1	64.0	14.1	55.0	110.1	25.6	25.4	174.0	157.3
5 [a]	102.1	68.9	67.7	71.2	67.3	14.2	56.0				177.4	160.0
6 [a]	103.9	70.8	68.5	[b]	68.7	16.8	57.9				174.7	
8	102.9	75.5	74.4	65.1	70.0	14.5	57.1	110.4	27.8	26.2	171.7	156.5
10 [c]	102.3	77.2	78.6	64.0	73.1	18.2	57.9	111.3	28.5	26.4	173.9	160.0
11 [d]	102.7	73.6	72.5	71.3	70.8	14.4	57.0	111.0	27.6	25.9	168.7	
12 [c]	103.1	70.4	72.3	[b]	70.0	14.9	57.1				175.0	159.1
13 [a]	102.8	70.3	71.8	65.3	72.7	15.8	57.6				175.4	

[a] Measured in D_2O.
[b] The corresponding signal was not observed.
[c] Measured in CD_3OD.
[d] 114.4 ppm for CN in cyanohydrin.

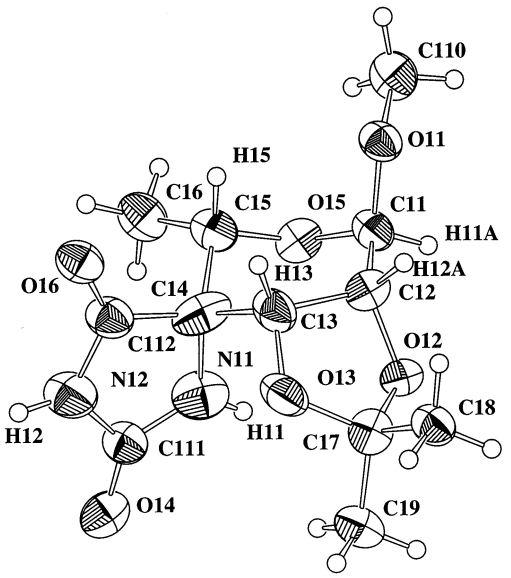

Fig. 1. ZORTEP plot and atomic numbering of (4*R*)-2,3-*O*-isopropylidene-methylspiro[4,6-dideoxy-α-L-*lyxo*-hexopyranosid-4,5′-imidazolidin]-2′,4′-dione (**3**).

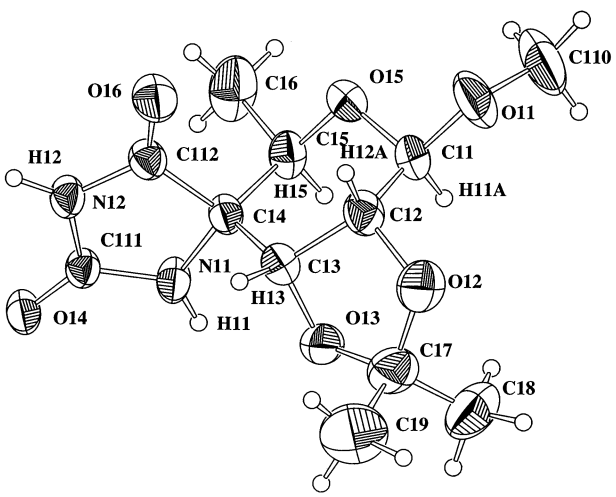

Fig. 2. ZORTEP plot and atomic numbering of (4*R*)-2,3-*O*-isopropylidene-methylspiro[4,6-dideoxy-β-D-*ribo*-hexopyranosid-4,5′-imidazolidin]-2′,4′-dione (**8**).

and CI (using pyridine as a reactive gas) mass spectra (70 eV) were obtained on a Finnigan MAT SSQ 710 instrument. Specific rotations were determined on a Perkin–Elmer 241 polarimeter (10 cm cell). Microanalyses were performed on a Fisons EA 1108 analyzer. Melting points were determined with a Boetius PHMK 05 microscope. All reactions were monitored by thin-layer chromatography (TLC) on Silica Gel plates (E. Merck) using the following solvents: 3:2 EtOAc–hexane (eluent A) and 3:1 MeOH–$CHCl_3$ (eluent B). Visualization was affected with iodine vapour or H_2SO_4. Column chromatography was performed as flash chromatography on Silica Gel 60 (E. Merck, 230–400 mesh) with the same eluents.

X-ray techniques.—Crystal and experimental data for compounds **3** and **8** are listed in Table 3. The structure was solved by direct methods and refined by a full-matrix least-squares technique. The crystallographic computations were performed with SHELX [37] and SHELX93 [38]. The ZORTEP program [39] was used for the illustration.

*Methyl 6-deoxy-2,3-*O*-isopropylidene-α-*L-lyxo-*hexopyranosid-4-ulose* (**1**), *methyl 4-amino-4-cyano-4,6-dideoxy-2,3-*O*-isopropylidene-α-*L-*talopyranoside* (**4**) *and methyl 6-deoxy-2,3-*O*-isopropylidene-β-*D-ribo-*hexopyranosid-4-ulose* (**7**).—These starting compounds were prepared according to the described procedures [25,31].

General procedures for the preparation of cyanohydrins and hydantoins.—Method A. To a solution of 4-ulose **1** (6.49 g, 30 mmol) in 50% aq EtOH (50 mL) was added KCN (3.9 g, 60 mmol) and $(NH_4)_2CO_3$ (11.53 g, 120 mmol), and the mixture was stirred at 60 °C for 2 h. Ethanol was then evaporated and after cooling a white solid separated from the aqueous solution.

Method B. A mixture of cyanohydrin **2** (4.87 g, 20 mmol) (or an equimolar amount of amino nitrile **4** or acetylated cyanohydrin **11**) and $(NH_4)_2CO_3$ (7.69 g, 80 mmol) in 50% aq EtOH (35 mL) was stirred and heated under reflux for 12 h. Ethanol was evaporated to give an aqueous solution of the product.

Method C. A mixture of 4-ulose **1** (4.32 g, 20 mmol) (or an equimolar amount of 4-ulose **7** or a mixture of **1** and **7**), KCN (2.6 g, 40 mmol), and $(NH_4)_2CO_3$ (7.69 g, 80 mmol) in 50% aq EtOH (35 mL) was stirred and heated under reflux for 10 h. Ethanol was evaporated under reduced pressure and the product was extracted from an aqueous solution with $CHCl_3$ (3×30 mL). The combined extracts were dried (Na_2SO_4) and the solvent was evaporated to give the crude reaction product, which was chromatographed on a silica gel column (4.5×55 cm, eluent A).

Method D. KCN (3.91 g, 60 mmol), water (18 mL) and $NaHCO_3$ (5.04 g, 60 mmol) were sequentially added to a stirred solution of a mixture of 4-uloses **1** and **7** (6.49 g, 30 mmol) in ether (150 mL) under cooling at 0 °C, and the stirring at this temperature continued for 2 h. The ethereal layer was then separated and the water layer was extracted with ether (3 × 30 mL). The combined ethereal solutions were dried (Na_2SO_4) and the solvent was evaporated to afford the crude oily product.

*Methyl 4-cyano-6-deoxy-2,3-*O*-isopropylidene-α-*L*-talopyranoside* (**2**).—The crude white solid obtained from method A was crystallized from 4:1 EtOAc–hexane to afford white needles of cyanohydrin **2** (6.42 g, 88%),

Tabl;e 3
Crystallographic and experimental data for compounds **3** and **8** [a]

	3	**8**
Formula	$C_{12}H_{18}N_2O_6$	$C_{12}H_{18}N_2O_6$
Formula weight	286.28	286.28
Crystal system	tetragonal	monoclinic
Space group	$P4_3$	$P2_1$
Unit cell dimensions		
a (Å)	18.54690(10)	14.4151(3)
b (Å)	18.54690(10)	6.91240(10)
c (Å)	9.53950(10)	15.3274(2)
α (°)	90	
β (°)	90	104.9740(10)
γ (°)	90	
Unit cell volume V (Å^3)	3281.47(4)	1475.41(4)
Formula units per unit cell, Z	8	4
$F(000)$	1216	608
D_{calcd} (g cm^{-3})	1.151	1.289
Radiation	Mo K_α	Mo K_α
Wavelength, λ (Å)	0.71073	0.71073
Absorption coefficient μ (mm^{-1})	0.093	0.104
Temperature, T (K)	297(2)	297(2)
Crystal description	colourless needle	colourless needle
Crystal size (mm)	0.80 (max)	1.20 (max)
	0.08 (min)	0.40 (min)
Diffractometer	Siemens SMART CCD	Siemens SMART CCD
Intensity data collection		
θ Range (°)	1.10–25.47	1.38–33.07
Range of h	$-22 \rightarrow 22$	$-21 \rightarrow 22$
Range of k	$-22 \rightarrow 22$	$-10 \rightarrow 10$
Range of l	$-11 \rightarrow 11$	$-23 \rightarrow 23$
Scan mode	ω	ω
Total number of reflections	6070	10318
No. of independent reflections $[I>2\sigma(I)]$	5076	7551
Structure refinement		
Minimization of	$\Sigma w(\lvert F_o\rvert-\lvert F_c\rvert)^2$	$\Sigma w(\lvert F_o\rvert-\lvert F_c\rvert)^2$
Anisotropic thermal parameters	all non-hydrogen atoms	all non-hydrogen atoms
Isotropic thermal parameters	hydrogen atoms	hydrogen atoms
No. of refined parameters	406	405
Weighting scheme	$[\sigma^2(F_o^2)+(0.0973P)^2+0.5075P]^{-1}$ where $P=(\lvert F_o\rvert^2+2\lvert F_c\rvert^2)/3$	$[\sigma^2(F_o^2)+(0.1000P)^2+0.0000P]^{-1}$ where $P=(\lvert F_o\rvert^2+2\lvert F_c\rvert^2)/3$
$R=\Sigma\lVert F_o\rvert-\lvert F_c\rVert/\Sigma\lvert F_o\rvert$	0.0591	0.0496
$R_w=[\Sigma w(\lvert F_o\rvert-\lvert F_c\rvert)^2/\Sigma w\lvert F_o\rvert^2]^{1/2}$	0.1749	0.1570
$S=[\Sigma w(\lvert F_o\rvert-\lvert F_c\rvert)^2/(N_{obs}-N_{var})]^{1/2}$	1.237	1.013
Final $(\Delta/\sigma)_{max}$	0.001	0.001

[a] Standard deviations in parentheses.

Table 4
Bond lengths (Å) and bond angles (°) for compounds **3** and **8** [a]

	3	**8**
Bond lengths		
O-26–C-212	1.202(5)	1.202(2)
N-11–C-111	1.333(4)	1.331(2)
N-11–C-14	1.449(4)	1.451(2)
C-14–C-15	1.525(5)	1.541(2)
C-14–C-112	1.526(5)	1.540(2)
C-14–C-13	1.545(5)	1.534(2)
O-16–C-112	1.206(4)	1.198(2)
N-21–C-211	1.342(4)	1.336(2)
N-21–C-24	1.441(4)	1.459(2)
C-24–C-212	1.514(5)	1.537(2)
C-24–C-25	1.530(5)	1.547(2)
C-24–C-23	1.540(5)	1.533(2)
O-14–C-111	1.219(4)	1.228(2)
N-12–C-112	1.352(5)	1.374(2)
N-12–C-111	1.395(5)	1.378(2)
O-24–C-211	1.218(4)	1.229(2)
N-22–C-212	1.363(5)	1.379(2)
N-22–C-211	1.390(5)	1.382(2)
O-23–C-23	1.410(4)	1.424(2)
O-23–C-27	1.433(5)	1.447(2)
O-13–C-13	1.408(4)	1.423(2)
O-13–C-17	1.437(5)	1.430(3)
O-22–C-27	1.426(4)	1.440(2)
O-22–C-22	1.420(4)	1.423(2)
O-12–C-17	1.427(4)	1.437(3)
O-12–C-12	1.418(5)	1.424(3)
C-25–O-25	1.443(4)	1.416(2)
C-25–C-26	1.496(5)	1.510(2)
C-15–O-15	1.439(4)	1.413(2)
C-15–C-16	1.514(6)	1.524(3)
O-25–C-21	1.419(4)	1.430(2)
C-21–O-21	1.404(4)	1.384(2)
C-21–C-22	1.518(5)	1.520(3)
O-15–C-11	1.399(4)	1.426(2)
C-11–O-11	1.405(5)	1.380(2)
C-11–C-12	1.529(5)	1.513(3)
O-21–C-210	1.414(5)	1.429(3)
O-11–C-110	1.414(6)	1.434(4)
C-22–C-23	1.515(5)	1.532(2)
C-12–C-13	1.509(5)	1.518(2)
C-27–C-29	1.500(6)	1.501(3)
C-27–C-28	1.529(6)	1.499(4)
C-17–C-19	1.500(7)	1.513(4)
C-17–C-18	1.525(6)	1.504(4)
Bond angles		
C-111–N-11–C-14	112.7(3)	113.20(14)
N-11–C-14–C-15	111.8(3)	110.46(14)
N-11–C-14–C-112	101.6(3)	100.96(12)
C-15–C-14–C-112	113.1(3)	113.37(15)
N-11–C-14–C-13	114.8(3)	110.37(14)
C-15–C-14–C-13	107.2(3)	112.46(13)
C-112–C-14–C-13	108.3(3)	108.65(14)
C-211–N-21–C-24	112.3(3)	111.96(13)
N-21–C-24–C-212	101.7(3)	101.34(12)
N-21–C-24–C-25	112.2(3)	110.81(13)
C-212–C-24–C-25	115.1(3)	113.03(13)
N-21–C-24–C-23	113.7(3)	111.26(12)
C-212–C-24–C-23	107.2(3)	109.67(13)
C-25–C-24–C-23	107.0(3)	110.45(12)
C-112–N-12–C-111	111.9(3)	112.41(14)
C-212–N-22–C-211	111.7(3)	111.67(14)
O-16–C-112–N-12	127.5(4)	126.9(2)
O-16–C-112–C-14	126.1(3)	127.4(2)
N-12–C-112–C-14	106.4(3)	105.64(13)
O-24–C-211–N-21	127.5(3)	127.4(2)
O-24–C-211–N-22	125.2(3)	124.08(15)
N-21–C-211–N-22	107.2(3)	108.57(12)
C-23–O-23–C-27	108.8(2)	107.29(13)
C-13–O-13–C-17	108.8(3)	105.9(2)
O-26–C-212–N-22	127.3(3)	126.1(2)
O-26–C-212–C-24	126.1(3)	128.1(2)
N-22–C-212–C-24	106.4(3)	105.82(13)
O-14–C-111–N-11	127.8(3)	126.8(2)
O-14–C-111–N-12	124.7(3)	125.5(2)
N-11–C-111–N-12	107.5(3)	107.75(13)
C-27–O-22–C-22	105.3(3)	109.85(12)
C-17–O-12–C-12	104.8(3)	109.11(14)
O-25–C-25–C-26	108.5(3)	108.13(15)
O-25–C-25–C-24	105.8(3)	108.23(13)
C-26–C-25–C-24	114.5(3)	113.58(15)
O-15–C-15–C-16	107.7(3)	107.5(2)
O-15–C-15–C-14	106.6(3)	109.21(14)
C-16–C-15–C-14	114.9(3)	112.9(2)
C-25–O-25–C-21	113.4(3)	111.30(13)
O-21–C-21–O-25	111.9(3)	107.4(2)
O-21–C-21–C-22	105.0(3)	107.54(14)
O-25–C-21–C-22	113.4(3)	111.57(14)
C-11–O-15–C-15	113.0(3)	111.15(14)
O-15–C-11–O-11	111.9(3)	107.8(2)
O-15–C-11–C-12	113.3(3)	109.25(15)
O-11–C-11–C-12	105.5(3)	108.0(2)
C-21–O-21–C-210	114.8(3)	114.4(2)
C-11–O-11–C-110	113.8(4)	112.9(2)
O-22–C-22–C-21	110.3(3)	109.8(2)
O-22–C-22–C-23	101.8(3)	102.27(13)
C-21–C-22–C-23	116.9(3)	114.13(13)
O-12–C-12–C-13	102.2(3)	102.42(15)
O-12–C-12–C-11	110.7(3)	110.8(2)
C-13–C-12–C-11	116.9(3)	112.13(14)
O-23–C-23–C-22	103.8(3)	101.97(13)
O-23–C-23–C-24	111.0(3)	108.04(12)
C-22–C-23–C-24	113.2(3)	115.06(13)
O-13–C-13–C-12	104.0(3)	101.41(15)
O-13–C-13–C-14	111.2(3)	109.23(14)
C-12–C-13–C-14	113.3(3)	116.12(14)
O-22–C-27–O-23	105.4(3)	104.94(14)
O-22–C-27–C-29	109.1(3)	108.2(2)
O-23–C-27–C-29	109.7(3)	111.1(2)
O-22–C-27–C-28	111.1(3)	112.3(2)
O-23–C-27–C-28	108.2(3)	107.7(2)
C-29–C-27–C-28	112.9(3)	112.4(2)
O-13–C-17–O-12	104.9(3)	105.1(2)
O-13–C-17–C-19	109.9(4)	110.4(2)
O-12–C-17–C-19	108.8(3)	108.0(3)
O-13–C-17–C-18	108.7(4)	108.6(2)
O-12–C-17–C-18	111.7(3)	110.2(2)
C-19–C-17–C-18	112.6(4)	114.2(3)

[a] Standard deviations in parentheses.

having the same physical and spectral constants as described previously [25].

Alternatively, the cyanohydrin **2** can be prepared starting from a mixture of 4-uloses **1** and **7**. Addition of EtOAc to the crude oily product from method D resulted in the crystallization of **2** (3.5 g, 48%). Moreover, a small amount of **2** (about 8% yield) can be obtained from column chromatography of the reaction product from method C starting from a mixture of 4-uloses **1** and **7**.

*(4*R*) - 2,3 -* O *- Isopropylidene - methylspiro-[4,6-dideoxy-*α*-*L*-*lyxo*-hexopyranosid-4,5′-imidazolidin]-2′,4′-dione* (**3**).—The aqueous solution from method B (starting from cyanohydrin **2**) was left overnight in a refrigerator. The separated solid was recrystallized from water to give **3** as white needles (4.47 g, 78%); mp 216–217 °C; $[\alpha]_D$ −28° (*c* 1, MeOH); EIMS *m*/*z* (I_r/%) 271 (41, $[M-Me]^+$), 255 (18, $[M-OMe]^+$), 242 (44), 169 (65), 167 (20), 129 (24), 126 (100), 115 (56), 100 (32), 85 (44), 73 (64), 59 (20), 43 (50); CIMS *m*/*z* 366 (100%, $[M+C_5H_5NH]^+$). Anal. Calcd for $C_{12}H_{18}N_2O_6$: C, 50.35; H, 6.34; N, 9.79. Found: C, 50.12; H, 6.40; N, 9.86.

Alternativelly, the hydantoin **3** was prepared (27% yield) from amino nitrile **4** applying method B, followed by the same work-up as above. In addition, compound **3** together with compound **2** can be obtained from 4-ulose **1** applying method C. The fractions with R_f 0.38 (eluent A) from column chromatography were collected and evaporated to afford pure **3** (37% yield). The fractions with R_f 0.76 gave **2** (18% yield). Moreover, a small amount of **3** (6% yield) was isolated by column chromatography (eluent A) of the crude reaction mixture from method B (after extraction of the product with chloroform) starting from acetylated cyanohydrin **11**. Finally, column chromatography of the reaction products from method C (starting from a mixture of 4-uloses **1** and **7**) afforded **3** in 28% yield.

*(4*R*) - methylspiro[4,6 - dideoxy -* α *-* L *-* lyxo*-hexopyranosid - 4,5′ - imidazolidin] - 2′,4′ - dione* (**5**).—A suspension of hydantoin **3** (2.86 g, 10 mmol) in diluted AcOH (50%, 50 mL) was heated at 90 °C for 45 min. The reaction mixture became clear during the first 10 min. The solvent was evaporated to dryness under diminished pressure and the residual white solid was recrystallized from 9:1 acetone–hexane to afford pure **5** (1.65 g, 67%); mp 192–193 °C; $[\alpha]_D$ −93° (*c* 1, MeOH); EIMS *m*/*z* (I_r/%) 247 (8, $[M+1]^+$), 215 (5), 202 (26), 129 (14), 74 (100). Anal. Calcd for $C_9H_{14}N_2O_6$: C, 43.90; H, 5.73; N, 11.38. Found: 43.79; H, 5.77; N, 11.42.

*Methyl (4*R*)-4-amino-4-*C*-carboxy-4,6-dideoxy-*α*-*L*-*lyxo*-hexopyranoside* (**6**).—A mixture of hydantoin **5** (1.23 g, 5 mmol), barium hydroxide octahydrate (4.73 g, 15 mmol) and water (50 mL) was heated under reflux for 5 h. Carbon dioxide gas was then passed through the hot reaction mixture. The separated barium carbonate was removed by filtration and washed with hot water. After cooling to room temperature (rt), another portion of barium carbonate separated. Filtration and decolourizing with charcoal gave a clear solution. Water was evaporated under diminished pressure and the residual solid was purified on a column of silica gel (eluent B). Fractions with R_f 0.51 (eluent B) were collected and evaporated to afford **6** (0.44 g, 40%). An analytical sample (white needles) was obtained by recrystallization from MeOH; mp 223–226 °C (decomposition); $[\alpha]_D$ −58° (*c* 1, H_2O); EIMS *m*/*z* (I_r/%) 190 (10, $[M-OMe]^+$), 177 (10), 104 (59), 103 (100), 102 (23), 85 (37), 74 (73), 56 (18), 55 (18), 45 (12). Anal. Calcd for $C_8H_{15}NO_6$: C, 43.44; H, 6.83; N, 6.33. Found: C, 43.30; H, 6.90; N, 6.39.

Table 5
Selected torsion angles (°) for compounds **3** and **8**

	3	**8**
C-110–O-11–C-11–O-15	−61.38	−75.82
C-110–O-11–C-11–C-12	175.05	163.97
N-11–C-14–C-13–O-13	−39.29	50.05
C-12–O-12–C-17–O-13	33.31	−1.84
C-112–N-12–C-111–N-11	−0.38	3.14
C-11–C-12–C-13–C-14	31.02	−33.26
C-11–O-15–C-15–C-14	−71.46	70.50
O-12–C-12–C-13–O-13	30.80	−35.11
C-11–O-15–C-15–C-16	164.76	−166.06
O-14–C-111–N-11–C-14	−179.58	172.53
O-13–C-13–C-14–C-112	73.38	161.36
O-16–C-112–C-14–C-15	−59.36	−67.97

Table 6
Atomic coordinates and equivalent isotropic displacement parameters (Å^2) for compound **3** [a]

Atom	*x*	*y*	*z*	U_{eq}
N-11	0.41200(14)	0.85991(16)	−0.4844(3)	0.0397(6)
H-11	0.3869	0.8710	−0.5572	0.042(10)
C-11	0.23264(18)	0.8973(2)	−0.3813(4)	0.0481(9)
H-11A	0.2008	0.9152	−0.4555	0.059(12)
O-11	0.19160(13)	0.88668(17)	−0.2591(3)	0.0598(7)
N-12	0.50341(15)	0.82628(17)	−0.3528(3)	0.0476(7)
H-12	0.5464	0.8132	−0.3304	0.038(9)
O-12	0.30743(13)	0.99538(14)	−0.4659(3)	0.0509(6)
C-12	0.28694(19)	0.9564(2)	−0.3444(4)	0.0476(8)
H-12A	0.2646	0.9897	−0.2775	0.038(9)
O-13	0.40670(13)	0.98730(14)	−0.3274(3)	0.0516(6)
C-13	0.35881(18)	0.9322(2)	−0.2869(4)	0.0458(8)
H-13	0.3563	0.9301	−0.1844	0.041(9)
O-14	0.52060(12)	0.83942(16)	−0.5920(3)	0.0542(7)
C-14	0.38330(17)	0.85829(18)	−0.3443(4)	0.0402(7)
C-15	0.31928(19)	0.8071(2)	−0.3321(4)	0.0468(8)
H-15	0.3005	0.8088	−0.2361	0.052(10)
O-15	0.26508(12)	0.83342(14)	−0.4270(3)	0.0464(6)
O-16	0.45071(15)	0.82367(17)	−0.1352(3)	0.0596(7)
C-16	0.3352(2)	0.7296(2)	−0.3709(5)	0.0593(10)
H-16A	0.2912	0.7024	−0.3711	0.064(13)
H-16B	0.3679	0.7093	−0.3037	0.094(17)
H-16C	0.3566	0.7279	−0.4624	0.077(14)
C-17	0.3708(2)	1.0338(2)	−0.4257(5)	0.0534(9)
C-18	0.3525(3)	1.1046(3)	−0.3523(7)	0.0780(14)
H-18A	0.3223	1.0950	−0.2727	0.076(15)
H-18B	0.3276	1.1357	−0.4164	0.12(2)
H-18C	0.3962	1.1275	−0.3217	0.18(4)
C-19	0.4172(3)	1.0446(3)	−0.5527(5)	0.0716(13)
H-19A	0.4608	1.0690	−0.5263	0.13(2)
H-19B	0.3916	1.0731	−0.6204	0.10(2)
H-19C	0.4289	0.9985	−0.5928	0.061(12)
C110	0.1340(3)	0.8376(3)	−0.2764(6)	0.0835(16)
H-11B	0.0960	0.8602	−0.3288	0.16(3)
H-11C	0.1161	0.8234	−0.1860	0.095(17)
H-11D	0.1507	0.7957	−0.3259	0.083(17)
C-111	0.48167(17)	0.84241(19)	−0.4893(4)	0.0423(8)
C-112	0.44879(18)	0.8336(2)	−0.2601(4)	0.0452(8)
N-21	0.25314(15)	0.75105(14)	0.2946(3)	0.0385(6)
H-21	0.2570	0.7801	0.3646	0.034(9)
O-21	0.32594(13)	0.95521(13)	0.0549(3)	0.0464(6)
C-21	0.29693(18)	0.92440(18)	0.1770(4)	0.0405(7)
H-21A	0.2918	0.9621	0.2482	0.043(9)
N-22	0.23757(18)	0.65095(15)	0.1747(3)	0.0487(7)
H-22	0.2266	0.6069	0.1565	0.074(15)
O-22	0.17586(12)	0.89739(13)	0.2530(3)	0.0473(6)
C-22	0.22243(18)	0.89828(17)	0.1348(4)	0.0406(8)
H-22A	0.2026	0.9308	0.0637	0.054(11)
O-23	0.14532(13)	0.80147(13)	0.1169(3)	0.0468(6)
C-23	0.21661(17)	0.82129(17)	0.0831(4)	0.0385(7)
H-23	0.2230	0.8202	−0.0189	0.060(12)
O-24	0.20519(16)	0.65327(13)	0.4093(3)	0.0569(7)
C-24	0.27132(17)	0.77007(17)	0.1525(4)	0.0381(7)
O-25	0.34163(12)	0.86891(12)	0.2312(2)	0.0403(5)
C-25	0.34528(18)	0.80618(18)	0.1421(4)	0.0420(8)
H-25	0.3537	0.8215	0.0451	0.042(9)
O-26	0.27775(16)	0.68644(15)	−0.0427(3)	0.0583(7)
C-26	0.4068(2)	0.7601(2)	0.1896(5)	0.0555(10)
H-26A	0.4507	0.7874	0.1852	0.077(14)
H-26B	0.4106	0.7187	0.1297	0.049(11)
H-26C	0.3985	0.7447	0.2843	0.049(11)
C-27	0.11632(19)	0.8534(2)	0.2126(4)	0.0476(9)
C-28	0.0592(2)	0.8976(2)	0.1353(6)	0.0629(11)
H-28A	0.0425	0.9358	0.1950	0.085(16)
H-28B	0.0195	0.8670	0.1106	0.052(11)
H-28C	0.0799	0.9178	0.0518	0.081(16)
C-29	0.0872(2)	0.8158(3)	0.3398(5)	0.0610(11)
H-29A	0.1263	0.7958	0.3929	0.069(14)
H-29B	0.0553	0.7778	0.3111	0.096(18)
H-29C	0.0612	0.8497	0.3967	0.11(2)
C-210	0.3898(3)	0.9955(3)	0.0757(5)	0.0734(14)
H-21B	0.3797	1.0360	0.1353	0.14(3)
H-21C	0.4073	1.0124	−0.0131	0.072(14)
H-21D	0.4256	0.9656	0.1190	0.067(14)
C-211	0.22942(19)	0.68292(18)	0.3056(4)	0.0440(8)
C-212	0.26509(19)	0.69800(18)	0.0789(4)	0.0435(8)

[a] Standard deviations in parentheses.

*(4*R*) - 2,3* - O - *Isopropylidene - methylspiro-[4,6-dideoxy-β*-D-ribo-*hexopyranosid-4,5′-imidazolidin]-2′,4′-dione* (**8**).—An aqueous solution from method B (starting from acetylated cyanohydrin **11**; 5.7 g, 20 mmol) was extracted with $CHCl_3$ (3 × 40 mL). The combined extracts were dried (Na_2SO_4), filtered and the solvent was evaporated. The residue was chromatographed on a column of silica gel (eluent A, fractions with R_f 0.24 were collected) to give **8** (4.64 g, 81%). Recrystallization from 1:1 EtOAc–hexane afforded white needles of **8**; mp 226–228 °C; $[\alpha]_D$ −5° (*c* 1, MeOH); EIMS *m*/*z* (I_r/%) 271 (13, $[M - Me]^+$), 255 (8, $[M - OMe]^+$), 242 (44), 211 (12), 197 (10), 169 (27), 139 (22), 126 (58), 115 (66), 100 (100), 85 (70), 73 (19), 55 (21), 43 (30); CIMS *m*/*z* 366 (100%, $[M + C_5H_5NH]^+$). Anal. Calcd for $C_{12}H_{18}N_2O_6$: C, 50.35; H, 6.34; N, 9.79. Found: C, 50.17; H, 6.42; N, 9.71.

Alternativelly, the hydantoin **8** can be prepared from 4-ulose **7** (4.32 g, 20 mmol) applying the reaction conditions of method C. The fractions with R_f 0.24 from column chromatography (eluent A) were collected and evaporated to afford compound **8** (2.41 g, 42%). Application of reaction conditions of method C to a mixture of 4-uloses **1** and **7**

Table 7
Atomic coordinates and equivalent isotropic displacement parameters (Å^2) for compound **8** [a]

Atom	x	y	z	U_{eq}
N-11	0.19324(11)	−0.1759(2)	0.89973(10)	0.0491(3)
H-11	0.19975(11)	−0.0636(2)	0.92469(10)	0.039(5)
O-15	0.08384(11)	−0.1145(2)	0.65645(8)	0.0565(3)
C-14	0.12798(11)	−0.2152(2)	0.81219(10)	0.0400(3)
O-13	0.01900(9)	−0.0046(2)	0.86270(9)	0.0555(3)
N-12	0.21103(11)	−0.4862(2)	0.88084(10)	0.0463(3)
H-12	0.23197(11)	−0.6024(2)	0.89244(10)	0.066(7)
C-15	0.15612(12)	−0.0957(3)	0.73813(13)	0.0504(4)
H-15	0.16167(12)	0.0408(3)	0.75615(13)	0.060(6)
O-12	−0.11955(9)	−0.0297(3)	0.75114(11)	0.0677(4)
C-11	−0.00307(14)	−0.0234(3)	0.66246(12)	0.0530(4)
H-11A	0.00933(14)	0.1098(3)	0.68421(12)	0.052(6)
O-11	−0.06588(14)	−0.0261(3)	0.57756(10)	0.0825(5)
C-12	−0.04743(12)	−0.1392(3)	0.72515(12)	0.0508(4)
H-12A	−0.07434(12)	−0.2605(3)	0.69630(12)	0.054(6)
O-14	0.30358(9)	−0.3377(2)	1.00967(8)	0.0484(3)
C-13	0.02383(12)	−0.1796(3)	0.81517(11)	0.0450(3)
H-13	0.00116(12)	−0.2879(3)	0.84542(11)	0.045(5)
C-112	0.14296(12)	−0.4343(3)	0.80378(11)	0.0441(3)
O-16	0.10198(12)	−0.5392(2)	0.74395(10)	0.0622(4)
C-111	0.24197(11)	−0.3313(2)	0.93746(10)	0.0397(3)
C-16	0.2504(2)	−0.1615(5)	0.7202(2)	0.0870(9)
H-16A	0.3023(3)	−0.1351(31)	0.7723(7)	0.106(12)
H-16B	0.2607(9)	−0.0931(26)	0.6690(10)	0.139(16)
H-16C	0.2476(6)	−0.2980(9)	0.7081(16)	0.090(10)
C-110	−0.0447(3)	0.1193(7)	0.5188(2)	0.1134(14)
H-11B	−0.0879(14)	0.1063(28)	0.4599(6)	0.182(22)
H-11C	0.0202(8)	0.1039(26)	0.5147(15)	0.103(12)
H-11D	−0.0522(20)	0.2451(7)	0.5426(11)	0.210(30)
C-17	−0.0801(2)	0.0495(4)	0.8397(2)	0.0672(6)
C-18	−0.0866(2)	0.2667(5)	0.8368(3)	0.0906(9)
H-18A	−0.0613(17)	0.3177(5)	0.8965(4)	0.162(19)
H-18B	−0.1526(3)	0.3048(5)	0.8147(16)	0.110(11)
H-18C	−0.0502(15)	0.3161(5)	0.7974(14)	0.117(13)
C-19	−0.1310(3)	−0.0444(8)	0.9036(3)	0.1154(14)
H-19A	−0.0961(15)	−0.0182(47)	0.9648(3)	0.164(22)
H-19B	−0.1342(24)	−0.1816(11)	0.8937(18)	0.205(30)
H-19C	−0.1948(10)	0.0071(42)	0.8929(18)	0.164(19)
O-25	0.58395(8)	−0.0445(2)	1.26157(8)	0.0482(3)
N-21	0.33869(9)	0.0154(2)	1.11453(8)	0.0404(3)
H-21	0.30497(9)	−0.0888(2)	1.10719(8)	0.070(7)
O-24	0.42154(10)	0.0498(2)	1.19084(10)	0.0376(3)
N-22	0.38133(11)	0.3158(2)	1.09530(10)	0.0463(3)
H-22	0.38034(11)	0.4282(2)	1.07107(10)	0.064(7)
O-22	0.44029(11)	−0.1106(3)	1.42266(8)	0.0616(4)
C-25	0.50557(11)	−0.0860(3)	1.18669(10)	0.0424(3)
H-25	0.48551(11)	−0.2204(3)	1.19104(10)	0.038(5)
O-23	0.34656(9)	−0.1543(2)	1.27878(7)	0.0477(3)
C-21	0.56522(13)	−0.1072(3)	1.34432(11)	0.0476(4)
H-21A	0.55306(13)	−0.2468(3)	1.34228(11)	0.043(5)
O-21	0.64563(10)	−0.0642(3)	1.41328(9)	0.0660(4)
C-22	0.48074(12)	0.0007(3)	1.36356(10)	0.0457(3)
H-22A	0.50170(12)	0.1269(3)	1.39063(10)	0.057(6)
O-24	0.26312(10)	0.1725(2)	0.98319(8)	0.0530(3)
C-23	0.39523(11)	0.0256(3)	1.28094(10)	0.0413(3)
H-23	0.35425(11)	0.1325(3)	1.29039(10)	0.049(6)
C-212	0.44286(12)	0.2638(2)	1.17677(11)	0.0420(3)
O-26	0.50015(10)	0.3678(2)	1.22598(10)	0.0578(3)
C-211	0.32147(11)	0.1649(2)	1.05742(10)	0.0410(3)
C-26	0.5391(2)	−0.0629(4)	1.10175(13)	0.0658(6)
H-26A	0.4859(3)	−0.0815(29)	1.04993(13)	0.075(8)
H-26B	0.5879(10)	−0.1572(19)	1.1013(7)	0.099(11)
H-26C	0.5650(13)	0.0646(11)	1.1001(7)	0.083(9)
C-210	0.7249(2)	−0.1921(6)	1.4190(2)	0.0943(10)
H-21B	0.7771(6)	−0.1550(21)	1.4690(10)	0.097(10)
H-21C	0.7451(10)	−0.1849(25)	1.3641(7)	0.097(11)
H-21D	0.7058(5)	−0.3221(8)	1.4277(15)	0.142(17)
C-27	0.3570(2)	−0.2131(4)	1.37138(11)	0.0567(5)
C-28	0.3710(2)	−0.4281(4)	1.3760(2)	0.0764(7)
H-28A	0.3135(6)	−0.4906(4)	1.3421(13)	0.098(11)
H-28B	0.3851(16)	−0.4694(6)	1.4379(2)	0.110(12)
H-28C	0.4234(10)	−0.4620(5)	1.3511(14)	0.127(15)
C-29	0.2722(2)	−0.1505(6)	1.4042(2)	0.0844(9)
H-29A	0.2839(6)	−0.1790(22)	1.4674(3)	0.089(9)
H-29B	0.2160(3)	−0.2187(19)	1.3713(8)	0.072(8)
H-29C	0.2625(7)	−0.0139(7)	1.3948(10)	0.062(7)

[a] Standard deviations in parentheses.

afforded **8** in 25% yield (after column chromatography separation).

(4S) - 2,3 - O - Isopropylidene - methylspiro-[4,6-dideoxy-α-L-lyxo-hexopyranosid-4,5′-imidazolidin]-2′,4′-dione (**10**).—The fractions with R_f 0.35 (eluent A) from column chromatography of the reaction product (method C, starting from 4-ulose **7**) were collected and evaporated to give white small needles of **10** (0.29 g, 5%); mp 278–279 °C; $[\alpha]_D$ −65° (*c* 1, MeOH); EIMS *m/z* (I_r/%) 271 (6, $[M - Me]^+$), 226 (36), 168 (11), 140 (16), 139 (51), 100 (10), 99 (100), 85 (9), 59 (24), 43 (17); CIMS *m/z* 366 (100%, $[M + C_5H_5NH]^+$). Anal. Calcd for $C_{12}H_{18}N_2O_6$: C, 50.35; H, 6.34; N, 9.79. Found: C, 50.46; H, 6.40; N, 9.86.

Methyl 4-O-acetyl-4-cyano-6-deoxy-2,3-O-isopropylidene-β-D-allopyranoside (**11**).—Ethyl acetate (25 mL) was added to the crude oily product from method D and the solution was left overnight in a refrigerator. The separated crystals of cyanohydrin **2** were filtered off and the residual solution was concentrated under diminished pressure to give the crude oily cyanohydrin **9** (3.2 g). This was acetylated with Ac_2O (5 mL) and pyridine (10 mL) for 18 h at rt, followed by concentration and coevaporation with toluene to give, after recrys-

tallization from ether, **11** (3.38 g, 80%) as white needles; mp 171–172 °C; $[\alpha]_D$ −42° (*c* 1, MeOH); EIMS *m*/*z* (I_r/%) 202 (18), 177 (8), 127 (28), 109 (18), 104 (33), 86 (16), 85 (24), 83 (22), 74 (100), 59 (15), 55 (25), 44 (82), 43 (19). Anal. Calcd for $C_{13}H_{19}NO_6$: C, 54.73; H, 6.71; N, 4.91. Found: C, 54.56; H, 6.79; N, 4.97.

*(4R) - Methylspiro[4,6 - dideoxy -β-*D-ribo-*hexopyranosid - 4,5′ - imidazolidin] - 2′4′dione* (**12**).—Starting from (4*R*)-2,3-*O*-isopropylidene-methylspiro[4,6-dideoxy-β-D-*ribo*-hexopyranosid-4,5′-imidazolidin]-2′,4′-dione (**8**; 2.86 g, 10 mmol) and application of the same reaction procedure as described for the preparation of **5** afforded white crystals of **12** (1.48 g, 60%). The analytical sample was obtained by recrystallization from 10:1 $CHCl_3$–MeOH); mp 248–250 °C; $[\alpha]_D$ +29° (*c* 1, MeOH); EIMS *m*/*z* (I_r/%) 202 (8), 129 (9), 127 (16), 74 (100), 60 (10). Anal. Calcd for $C_9H_{14}N_2O_6$: C, 43.90; H, 5.73; N, 11.38. Found: 43.82; H, 5.78; N, 11.31.

*Methyl (4*R*)-4-amino-4-*C*-carboxy-4,6-dideoxy-β-*D-ribo-*hexopyranoside* (**13**).—Starting from (4*R*)-methylspiro[4,6-dideoxy-β-D-*ribo*-hexopyranosid-4,5′-imidazolidin]-2′,4′-dione (**12**; 0.98 g, 4 mmol), the same reaction procedure was used as described for the preparation of **6**. The fractions with R_f 0.42 from column chromatography (eluent B) were collected and evaporated under reduced pressure. The crude product was recrystallized from 5:1 acetone–water to give white crystals of **13** (0.33 g, 37%); mp 225–228 °C (dec); $[\alpha]_D$ +1.3° (*c* 1, H_2O); EIMS *m*/*z* (I_r/%) 177 (14), 104 (42), 103 (100), 102 (13), 86 (15), 85 (30), 74 (35), 56 (8), 55 (10). Anal. Calcd for $C_8H_{15}NO_6$: C, 43.44; H, 6.83; N, 6.33. Found: C, 43.51; H, 6.87; N, 6.38.

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