Synthesis of *gluco*-Configured Tetrahydroimidazopyridine-2-phosphonate-Derived Lipids, Potential Glucosyl Transferase Inhibitors

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The analogues **1** – **3** of dolichol monophosphatidyl β-D-glucose have been prepared as potential inhibitors of the glucosyl transferase Alg10p. $Pd(PPh_3)_4$-catalysed phosphonylation of the iodoimidazole **4** with diethyl, dimethyl, and diphenyl phosphite led to the corresponding phosphonic acid diesters, which were transformed into deprotected and silyl-protected diesters, deprotected monoesters, and protected and unprotected phosphonic acids (*Scheme*). A *N*-methyl imidazolium salt was obtained as a by-product of the dimethylphosphonylation of the iodoimidazole, and prepared in high yields by methylation of the imidazole **8** with MeI; the corresponding deprotected salt **11** inhibits sweet almond β-glucosidases ($IC_{50} = 308$ μM). Trichloroacetonitrile-promoted monoesterification of the acetylated mono-triethylammonium salt **19** with oleyl alcohol, phytanol, and dolichol-19, followed by deacetylation, gave the desired glycophospholipids.

Introduction. – Glycosyl transferases catalyse the regio- and stereoselective formation of a glycosidic bond between the reducing end of a mono- or oligosaccharide and a defined heteroatom (O or N) of their acceptor substrate[1]). The glycosyl donor is either a monosaccharide activated as a nucleoside diphosphate, a nucleoside monophosphate, or a dolichyl monophosphate, or then an oligosaccharide activated as a dolichyl monophosphate. Most glycosyl transferases transfer the glycosyl moiety with inversion of configuration at the anomeric centre of the transferred sugar residue [1]. There is a great amount of amino-acid sequence data, available on the internet[2]), that have been classified into sequence-related families [1]. However, crystal-structure details of glycosyl transferases are very scarce [2][3], and information about the active site and the amino-acid residues directly involved in the catalysis is limited [4–6]. Analysis of the isotope effects [7][8] and inhibition studies [9][10] strongly suggest that the reactive intermediate resembles a glycosyl cation similar to the reactive intermediate of the enzymic glycoside hydrolysis. It is, however, not clear whether the phosphate leaving group is protonated at one of its O-centres (by a functional equivalent of the catalytic acid in glycosidases) or activated by coordination to a metal ion (Mg^{2+}, Mn^{2+}), or whether a basic amino-acid residue, accepting a proton from the hydroxy or amido function of the acceptor is implied in catalysis. *fuco*-Configured 'azonia sugars', mimicking the positive charge of the putative cationic intermediate, inhibit fucosidases strongly, but fucosyl transferases only weakly. Addition of GDP

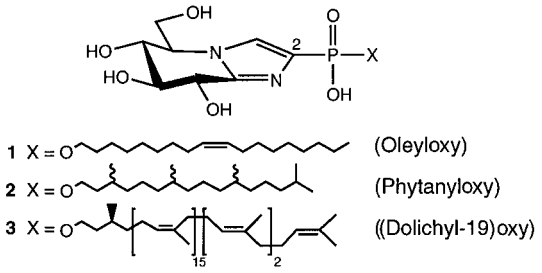
[1]) The acceptor of a monosaccharide is either a mono- or oligosaccharide or a phospholipid, and the acceptor of an oligosaccharide is either a peptide or a protein.

[2]) *B. Henrissat* and *P. Coutinho* at URL http://afmb.cnrs-mrs.fr/~pedro/CAZY/db.html.

(guanosine 5′-diphosphate) improves the inhibition of fucosyl transferases by 'azonia sugars'[3]) [9][11][12], and the nucleotide part of the fucosyl donor, *viz*. GDP, acts itself as inhibitor of fucosyl transferases. Analogues of UDP-Gal and GDP-Fuc with a nucleotide moiety bound to an unsaturated glycosyl or carba-glycosyl residue derived from glycosidase inhibitors mimic the shape of the hypothetical intermediate, and also inhibit galactosyl and fucosyl transferases, respectively [13][14]. Thus, potential inhibitors of glycosyl transferases may be obtained by appropriate modifications of glycosidase inhibitors [11–14], in spite of the obvious differences between glycosidases and glycosyl transferases.

We became interested in the inhibition of the glucosyl transferase Alg10p involved in the *N*-glycosylation process [15]. Alg10p is a transmembrane enzyme localized in the endoplasmic reticulum (ER). It uses β-D-Glc dolichyl-monophosphate [16][17] as glucosyl donor and catalyses the formation of a Glcα(1,2)Glc bond [18]. Neither the exact role of the dolichyl monophosphate moiety, nor the specificity of Alg10p are known. Inhibitors of Alg10p have not yet been reported.

The strong inhibition of retaining β-glycosidases by *gluco*-, *manno*-, and *galacto*-configured tetrahydroimidazopyridines [19–21] has been attributed mainly to the combined effect of a (partial) protonation of the imidazole moiety by the catalytic acid and an electrostatic interaction between the imidazolium cation and the catalytic base [22]. As Alg10p uses a β-D-configured glucosyl donor, it may interact similarly with a *gluco*-configured tetrahydroimidazopyridine. We planned to prepare the glucophospholipid analogues **1**–**3** from the known benzyl-protected imidazole **8** [19] *via* the phosphonates **5**–**7** (*Scheme*), introducing oleyl, phytanyl, and dolichyl substituents to evaluate the selectivity of Alg10p for the lipid moiety.

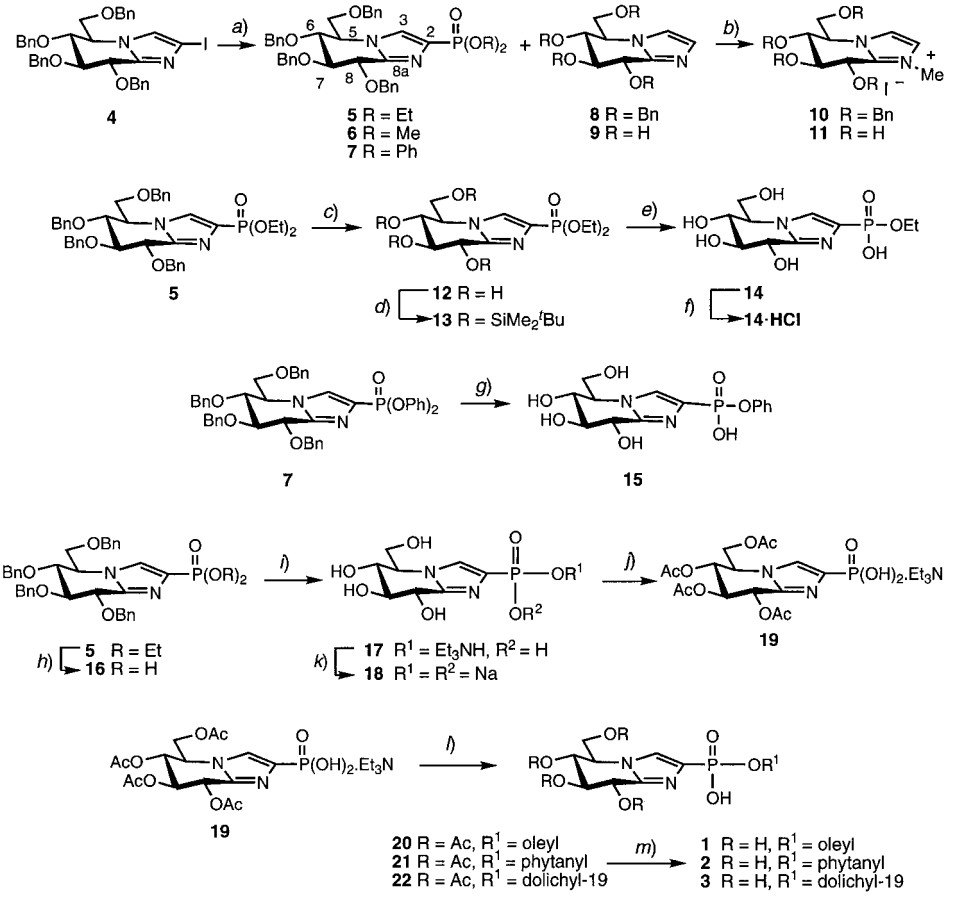


Synthesis. – The required imidazolylphosphonates **5**–**7** were obtained *via* the mono-iodoimidazole **4** that was prepared [23] similarly to the known bromo analogue [21][24] (*Scheme*). The phosphonate group was introduced by $Pd(PPh_3)_4$-catalysed cross-coupling with dialkyl or diphenyl hydrogen phosphites [25–29]. Treatment of **4** with diethyl hydrogen phosphite in the presence of Et_3N and $Pd(PPh_3)_4$ led to a mixture of the diethyl phosphonate **5** and the unsubstituted imidazole **8**. A **5**/**8** ratio of *ca*. 7:3 was determined from the integrals of the benzyl ^{1}H-NMR signals at 5.10 (**5**) and

[3]) The synergism of the inhibition of GDP and 'azonia sugars' is expressed by a 22–77-fold decrease of the IC_{50} for the piperidinium salts upon addition of GDP [11].

5.19 ppm (**8**); the phosphonate **5** was isolated in 62% yield[4]). The ratio **5**/**8** depends strongly on the concentration of the iodoimidazole **4** and the amount of the catalyst. In the presence of 0.3 equiv. of $[Pd(PPh_3)_4]$, the ratio **5**/**8** ranged from 1:1 (0.15M **4**) to 7:3 (0.3M **4**), and reached 9:1 in the presence of 1 equiv. $[Pd(PPh_3)_4]$ (0.3M **4**). To suppress the formation of **8**, we tested a range of amines and phosphites (*Table 1*). The bulkiest base, 1,2,2,6,6-pentamethylpiperidine (PMP), led to the highest **5**/**8** ratio and improved the yield of **5** to 71% (*Entry 3*).

Scheme



a) $[Pd(PPh_3)_4]$, Et_3N, toluene, $HPO(OR)_2$; **5** (62%); **6** (30%); **7** (84%). *b*) MeI, toluene, 95°; 98%. *c*) 20% $Pd(OH)_2$/C, AcOH, AcOEt/MeOH/H_2O, H_2; 89%. *d*) ^{t}BuMe$_2$SiCl, 1*H*-imidazole, 25°, 48 h. *e*) aq. NaOH soln., 70°, *Amberlite IRC 50* (H^+ form); 58%. *f*) 1M aq. HCl soln., *Bio-Rad AG 2-X8* resin (Cl^- form). *g*) 20% $Pd(OH)_2$/C, AcOH, MeOH/H_2O, H_2; 90%. *h*) Me_3SiBr, CH_2Cl_2. *i*) $Pd(OH)_2$, MeOH/AcOEt/H_2O 3:1:1, H_2; 81% (from **5**). *j*) Ac_2O, pyridine. *k*) *Dowex 50W8* (Na^+ form), *Dowex CCR-2* (Na^+ form). *l*) CCl_3CN, pyridine, oleyl alcohol for **20** (50% from oleyl alcohol), phytanol for **21** (61% from phytanol), or dolichol-19 for **22** (65% from dolichol-19). *m*) MeONa, MeOH, *Dowex IRC 50* (H^+ form); **1** (95%); **2** (66%); **3** (75%).

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4) Excess diethyl hydrogen phosphite led to increased amounts of triphenylphosphine oxide that had to be removed by repeated chromatography.

Table 1. *Phosphonylation of* **4** (0.4M **4** in toluene at 95° with 5 equiv. of $HPO(OR)_2$, 7 equiv. of base, and 0.3 equiv. of $[Pd(PPh_3)_4]$)

Entry	Phosphite	Base[a])	Time (h)	Ratio[b]) **5/8**	**6/8**	**7/8**	Yield [%] **5**	**6**	**7**
1	$HPO(OEt)_2$	Et_3N	26	70 : 30			62		
2	$HPO(OEt)_2$	$(^iPr)_2EtN$	18	83 : 17			60		
3	$HPO(OEt)_2$	PMP	19.5	95 : 05			71		
4[c])	$HPO(OEt)_2$	Et_3N	21	50 : 50			–		
5	$HPO(OMe)_2$	Et_3N	19		74 : 26			30	
6	$HPO(OMe)_2$	$(^iPr)_2EtN$	20		[d])			20	
7	$HPO(OMe)_2$	PMP	19.5		[d])			10	
8	$HPO(OPh)_2$	Et_3N	19			100 : 0			84
9	$HPO(OPh)_2$	$(^iPr)_2EtN$	18			100 : 0			83
10	$HPO(OPh)_2$	PMP	19.5			100 : 0			78
11[c])	$HPO(OPh)_2$	Et_3N	17			85 : 15			74

[a]) PMP: 1,2,2,6,6 pentamethylpiperidine. [b]) The ratio was determined on the basis of integrals of the benzyl ^{1}H-NMR signals. [c]) Reaction performed in the presence of CuI (0.36 equiv.). [d]) The ratio could not be determined, because of the insufficient amount of the expected products (**6**/**8**).

While the Pd^0-catalysed phosphonylation of a bromoimidazole with dimethyl hydrogen phosphite failed [29], dimethyl-phosphonylation of the iodoimidazole **4** in the presence of $[Pd(PPh_3)_4]$ and Et_3N yielded 30% of **6** (*Entry 5*). Using $(^iPr)_2EtN$ instead of Et_3N (*Entry 6*) proved detrimental. The major by-product of this coupling was an *N*-methylimidazolium salt that was isolated by flash chromatography (silica gel). Its NMR spectra are very similar to those of the iodide **10**, obtained by treating **8** with MeI in toluene (4 h at 95°). Presumably, **10** and the by-product differ only by the nature of the counterion. The unprotected *N*-methylimidazolium salt **11** was prepared in almost quantitative yields by methylation of **9**. With an IC_{50} value of 308 μM (37°, pH 6.8, phosphate buffer), **11** is a rather weak inhibitor of sweet-almond β-glucosidases [30].

Coupling of the iodide **4** with diphenyl hydrogen phosphite yielded 78–84% of **7** (*Entries 8–10*) without forming any of the dehalogenated imidazole **8**. To the best of our knowledge, this is the first example of a $[Pd(PPh_3)_4]$-catalysed coupling of diphenyl hydrogen phosphite with a halo(het)arene. Coupling **4** with either diethyl or diphenyl hydrogen phosphite in the presence of both $[Pd(PPh_3)_4]$ and CuI, as in the *Sonogashira* reaction [31][32], lowered the ratio **5**/**8** and **7**/**8** (*Entries 4* and *11*, resp.).

We briefly studied the deprotection of the phosphonates and the introduction of alternative protecting groups. Catalytic hydrogenolysis of the diethyl phosphonate **5** led cleanly to the tetrol **12**. Silylation of **12** yielded 87% of **13**. Saponification of **12** gave the monoester **14**, which was transformed into its hydrochloride, characterized by a pK_{HA} of 5.15. Hydrogenolysis of **7** provided the monophenyl ester **15** in excellent yields.

The synthesis of **1**–**3** was continued by dealkylating the diethyl phosphonate **5** with Me_3SiBr [33] to the phosphonic acid **16** which was subjected to hydrogenolytic debenzylation. The product was purified by chromatography on DEAE-cellulose (elution with aq. $HEt_3N^+HCO_3^-$) to afford a mixture of mostly the mono(triethylammonium) salt **17** and varying amounts of the corresponding acid (81%; 0.70–0.95 equiv.

of Et_3N by ^{1}H-NMR). Alternatively, **17** was obtained by treating the hydrogenolysis product with Et_3N, followed by lyophilization; this preparation also contained between 0.70 and 0.95 equiv. of Et_3N. Treatment of **17** with *Dowex 50W8* (Na^+ form) and then *Dowex CCR-2* (Na^+ form) led to the disodium salt **18**. The pK_{HA} values of **18** (7.69 and 4.84) were determined by titration of an aqueous solution with 0.1N HCl at 25°. The higher pK_{HA}, corresponding to the dissociation constant of the phosphonate group, is close to the pK_{HA} value of pyridin-2-ylphosphonic acid ($pK_a = 7.71$) [34]. The second pK_{HA} of **18** is slightly lower than that of the *gluco*-tetrahydroimidazopyridine **9** ($pK_{HA} = 6.10$). The third pK_{HA} value was not determined. Acetylation of **17** (Ac_2O, pyridine) gave the tetraacetate **19**. As chromatography of **19** (DEAE-cellulose) led to partial deacetylation, it was used without further purification and esterified with 0.87 equiv. of oleyl alcohol (=(*Z*)-octadec-9-en-1-ol) using trichloroacetonitrile in pyridine as coupling agent [35][36] to yield 50% of the oleyl phosphonate **20**. Other coupling agents, such as bromotris(dimethylamino) phosphonium hexafluorophosphate (BroP) [37][38], 2,4,6-triisopropylbenzensulfonyl chloride [39], oxalyl chloride, DMF (cat.) [40], and diethyl diazenedicarboxylate (DEAD)/PPh_3 [41][42] either led to incomplete transformation of the alcohol or to byproducts. Esterification of **19** with 0.80 equiv. of phytanol yielded 61% of the phytanyl phosphonate **21**. Similarly, esterification with dolichol-19 (= 3,7,11,15,19,23,27,31,35,39,43,47,51,55,59,63,67,71,75-nonadecamethylhexaheptaconta-6,10,14,18,22,26,30,34,38,42,46,50,54,58,62,66,70,74-octadecaen-1-ol), but using 5 equiv. of the phosphonate **19**[5]), provided 65% of the dolichyl phosphonate **22**. Deacetylation of **20**–**22** (NaOMe in MeOH followed by *Amberlite IRC 50* (H^+ form)) led to **1**, **2**, and **3** in 95%, 66%, and 75% yield, respectively.

This synthesis provides the *gluco*-configured tetrahydroimidazopyridine-2-phosphonates **1**–**3** in six steps from the iodoimidazole **4** and in overall yields of 24, 20 and 24%, respectively. The iodoimidazole **4** is available in five steps and 65% overall yield from the readily available 2,3,4,6-tetra-*O*-benzyl-D-gluconolactam [19][43]. The inhibitory effect of **1**–**3** on the ($\alpha 1 \rightarrow 2$) glucosyl transferase Alg10p is under investigation.

Formation of the C(2)–P bond in **5**–**7** is evidenced by ^1J(C(2),P) of 247.4 and 256.4 Hz in the ^{13}C-NMR spectra of **6** and **7**, respectively. Signal overlap did not allow the determination of ^1J(C(2),P) of **5**. However, the ^{13}C-NMR spectra of **17** and **18**, derived from **5** show a ^1J(C(2),P) of 190.4 and 202.6 Hz, respectively. The conformation of the phosphonate **17** in D_2O ($^7H_6$) is very similar to the one of the imidazole **9** [19] (*Table 2*). The FAB-MS of **20**–**22** evidence the formation of a monoester in each case. This is further corroborated by the shift of the ^{31}P-NMR signal from –1.12 ppm (CD_3OD) for **19** to 3.98 ppm (CD_3OD) for **20**, 3.78 ppm (CD_3OD) for **21**, and 3.87 ppm ($CD_3OD/CDCl_3$ 4 : 2) for **22**. The CH_2O signal of the alkoxy moiety of **20**–**22** is also shifted to characteristically lower field. The phosphonates **1** and **2**, but not **3**, are sufficiently well soluble in CD_3OD to lead to sharp ^{1}H-, ^{13}C-, and ^{31}P-NMR signals, while the spectra of **3** ($CDCl_3/CD_3OD/D_2O$ 10 : 7 : 1) showed only broad signals. The conformation of the saccharide moiety of **1**–**3** should be similar to that of **9** and **17** ($^7H_6$). This is fully evidenced only for **1** for which all coupling constants could be determined. The signals of H–C(5) or H–C(6) of **2** are hidden, but *J*(7,8) and *J*(6,7) are in agreement with the expected conformation (*Table 2*).

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5) The phosphonate **19** was used in excess, considering the price of dolichol-19.

Table 2. *Coupling Constants* J [Hz] *of Tetrahydroimidazopyridine* **9** *and Tetrahydroimidazopyridine-2-phosphonates* **1**, **2**, **17**, *and* **18**

	9	**17**	**18**	**1**	**2**
Solvent	D_2O	D_2O	D_2O	CD_3OD	CD_3OD
J(8,7)	8.7	9.7	9.0	8.0	8.1
J(7,8)	9.7	9.7	10.0	9.5	8.8
J(6,5)	9.7	8.8	10.0	8.0	[a])
J(5,CH−C(5))	2.5	3.1	2.5	4.0	4.1
J(5,CH′−C(5))	2.2	2.2	2.5	2.0	[a])
^2J(CH_2−C(5))	12.8	13.2	13.0	11.8	13.5

[a]) Coupling constant not determined due to overlap of the signals.

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Experimental Part

General. Solvents were distilled before use, toluene was degassed, and reactions were run under Ar. [Pd(PPh_3)$_4$] (*Aldrich*) and CuI (*Fluka*) were used without purification. Oleyl alcohol (tech. 85%, *Aldrich*) was purified by FC (hexane/AcOEt 9 :1) followed by FC (*RP-18* silica gel; MeOH/H_2O 9 :1 → 85 : 15). Phytanol was obtained in 64% yield (following the procedure of *Sakata et al.* [44]) by catalytic hydrogenation of phytol (*Fluka*) in the presence of Pd/C (10%) for 2 h. Dolichol-19 was purchased from the Polish Academy of Sciences (Institute of Biochemistry and Biophysics) and purified by FC (toluene) before use. TLC: *Merck* silica gel *60F$_{254}$* plates; detection by heating with 'mostain' (400 ml of 10% H_2SO_4 soln., 20 g of $(NH_4)_6Mo_7O_{24}\cdot 6\,H_2O$, 0.4 g of $Ce(SO_4)_2$). Flash chromatography (FC): silica gel *60* (*Fluka*; 0.04–0.063 mm), unless indicated otherwise. M.p.: uncorrected. ^{1}H-, ^{13}C-, and ^{31}P-NMR Spectra: chemical shifts δ in ppm rel. to TMS (^{1}H and ^{13}C) or H_3PO_4 (^{31}P) as external standard, and coupling constants J in Hz. FAB-MS: 3-nitrobenzyl alcohol as matrix, unless indicated otherwise.

*Diethyl (5*R,*6*R,*7*S,*8*S*)-6,7,8-Tris(benzyloxy)-5-[(benzyloxy)methyl]-5,6,7,8-tetrahydroimidazo[1,2-*a*]pyridine-2-phosphonate* (**5**). A mixture of **4** (1.0 g, 1.45 mmol) and [Pd(PPh_3)$_4$] (505 mg, 0.44 mmol) in toluene (3.6 ml) was treated with Et_3N (1.4 ml, 10 mmol) and HPO(OEt)$_2$ (0.94 ml, 7.28 mmol), warmed to 95°, and stirred for 19 h. After the addition of AcOEt (10 ml), the suspension was filtered through *Celite* and the residue washed with AcOEt (300 ml). The filtrate was concentrated to 150 ml, washed (H_2O), dried ($MgSO_4$), filtered, and evaporated. ^{1}H-NMR of the crude showed a mixture **5**/**8** *ca.* 70 :30, besides P(O)Ph_3 and HPO(OEt)$_2$. FC (hexane/AcOEt/Et_3N 7 :3 :0.03 → 0 :1 :1 :0.03) gave **8** [19] (242 mg, 30%) and a brown mixture containing principally **5** and P(O)Ph_3 (717 mg). FC of this mixture (CH_2Cl_2/i-PrOH 10 : 0.05 → 10 : 0.5) gave a colourless oil **5**/P(O)Ph_3 *ca.* 80 : 20. PO(Ph)$_3$ was removed by FC (*RP-C18* silica gel; MeOH/H_2O 8 : 2 → 9 : 1): **5** (624 mg, 62%) as a colourless oil. R_f (hexane/AcOEt/Et_3N 1 : 0.03) 0.2. UV ($CHCl_3$): 269 (2.81). IR (CCl_4): 3065*w*, 3032*w*, 2980*w*, 2929*w*, 2906*w*, 2867*w*, 1497*w*, 1454*m*, 1438*w*, 1362*w*, 1264*m*, 1235*m*, 1203*m*, 1117*s*, 1098*s*, 1062*s*, 1030*s*, 968*m*. ^{1}H-NMR ($CDCl_3$, 300 MHz): 1.35 (br. *q*, J = 6.4, 2 Me); 3.76 (*dd*, J = 5.2, 10.2, CH−C(5)); 3.81–3.90 (*m*, irrad. at 4.11 → change, CH′−C(5), H−C(6)); 4.12 (*dd*, J = 5.1, 6.7, irrad. at 3.84 → change, H−C(7)); 4.06–4.30 (*m*, 5 H, irrad. at 1.35 → change, 2 MeC*H*$_2$O, irrad. at 3.84 → change, H−C(5)); 4.46 (br. *s*, PhC*H*$_2$); 4.47 (*d*, J = 11.8, PhC*H*); 4.64 (*d*, J = 11.3, PhC*H*); 4.77 (*d*, J = 5.1, irrad. at 4.12 → change, H−C(8)); 4.78 (*d*, J = 11.8, PhC*H*); 4.80 (*d*, J = 11.7, PhC*H*); 4.82 (*d*, J 11.3, PhC*H*); 5.10 (*d*, J = 11.7, PhC*H*); 7.12–7.22 (*m*, 2 arom. H); 7.23–7.42 (*m*, 18 arom. H); 7.71 (*s*, H−C(3)). ^{13}C-NMR ($CDCl_3$, 75 MHz): 16.11 (*dq*, ^3J(C,P) = 5.9, Me); 16.15 (*dq*, ^3J(C,P) = 5.9, Me); 58.15 (*d*, C(5)); 62.23 (*t*, ^2J(C,P) = 4.9, 2 CH_2O); 67.71 (*t*, *C*H$_2$−C(5)); 72.23, 73.26, 73.57, 73.88 (4*t*, 4 Ph*C*H$_2$); 73.26, 75.88, 81.46 (3*d*, C(6), C(7), C(8)); 127.42 (*dd*, ^2J(C,P) = 40.3, C(3)); 127.68–128.54 (several *d*); *ca.* 131.87 (*d*, ^1J(C,P) ≈ 250, C(2)); 137.08, 137.41, 137.60, 137.97 (4*s*); 146.55 (*d*, ^3J(C,P) = 22.0, C(8a)). ^{31}P-NMR ($CDCl_3$, 121 MHz): 12.21. FAB-MS: 697 (100, [M + 1]$^+$), 1393 (20, [2M + 1]$^+$). Anal. calc. for $C_{40}H_{45}N_2O_7P$ (696.78): C 68.95, H 6.51, N 4.02; found: C 68.98, H 6.66, N 4.21.

*Dimethyl (5*R,*6*R,*7*S,*8*S*)-6,7,8-Tris(benzyloxy)-5-[(benzyloxy)methyl]-5,6,7,8-tetrahydroimidazo[1,2-*a*]pyridine-2-phosphonate* (**6**). A mixture of **4** (20 mg, 29.15 μmol) and $[Pd(PPh_3)_4]$ (10 mg, 8.74 μmol) in toluene (73 μl) was treated with Et_3N (28 μl, 0.2 mmol) and $HPO(OMe)_2$ (13 μl, 0.14 mmol), warmed to 95°, and stirred for 19 h. The mixture was concentrated and co-evaporated with toluene. The ^{1}H-NMR spectrum of the crude showed a mixture **6**/**8** *ca.* 70:30, besides $P(O)Ph_3$ and $HPO(OMe)_2$. FC (hexane/AcOEt 5:5 → 0:1) gave **8** (3 mg, 18%) and **6** as coloured oils. FC on *RP-C18* silica gel ($MeOH/H_2O$ 8:2) gave **6** (6 mg, 31%). Colourless oil. R_f (AcOEt) 0.26. IR (CCl_4) 3089*w*, 3065*w*, 3032*w*, 2950*w*, 2929*w*, 2854*w*, 1515*w*, 1497*w*, 1454*m*, 1361*w*, 1334*w*, 1268*m*, 1239*m*, 1207*w*, 1185*w*, 1098*s*, 1064*s*, 1039*s*. ^{1}H-NMR ($CDCl_3$, 300 MHz): 3.75 (*dd*, *J* = 5.3, 10.3, CH−C(5)); 3.78–3.89 (*m*, irrad. at 4.11 or 4.23 → change, CH′−C(5), H−C(6)); 3.80 (*d*, ^3J(H,P) = 7.0, Me); 3.84 (*d*, ^3J(H,P) = 7.0, Me); 4.11 (*dd*, *J* = 4.8, 6.9, irrad. at 4.76 → *d*, *J* ≈ 6.8, H−C(7)); 4.23 (*ddd*, *J* = 2.7, 4.8, 7.6, H−C(5)); 4.46 (*d*, *J* = 11.4, PhC*H*); 4.46 (*t*, *J* = 13.0, PhCH_2); 4.62 (*d*, *J* = 11.5, PhC*H*); 4.76 (*d*, *J* = 4.9, irrad. at 4.11 → *s*, H−C(8)); 4.77 (*d*, *J* = 11.4, PhC*H*); 4.78 (*d*, *J* = 11.5, PhC*H*); 4.80 (*d*, *J* = 11.8, PhC*H*); 5.08 (*d*, *J* = 11.5, PhC*H*); 7.12–7.20 (*m*, 2 arom. H); 7.22–7.42 (*m*, 18 arom. H); 7.72 (*s*, H−C(3)). ^{13}C-NMR ($CDCl_3$, 75 MHz): 52.87 (*dq*, ^2J(C,P) = 6.4, Me); 53.00 (*dq*, ^2J(C,P) = 6.4, Me); 58.33 (*d*, C(5)); 67.83 (*t*, CH_2−C(5)); 72.40, 73.35, 73.63, 73.92 (4*t*, PhCH_2); 73.35, 75.92, 81.38 (3*d*, C(6), C(7), C(8)); 127.79–128.64 (several *d*); 129.01 (*d*, ^1J(C,P) = 247.4, C(2)); 137.12, 137.44, 137.63, 138.01 (4*s*); 146.77 (*d*, ^3J(C,P) = 22.3, C(8a)). ^{31}P-NMR ($CDCl_3$, 121 MHz): 14.84. FAB-MS: 669 (100, $[M+1]^+$), 1338 (10, $[2(M+1)]^+$).

*Diphenyl (5*R,*6*R,*7*S,*8*S*)-6,7,8-Tris(benzyloxy)-5-[(benzyloxy)methyl]-5,6,7,8-tetrahydroimidazo[1,2-*a*]pyridine-2-phosphonate* (**7**). A mixture of **4** (20 mg, 29.15 μmol) and $[Pd(PPh_3)_4]$ (10 mg, 8.74 μmol) in toluene (73 μl) was treated with Et_3N (28 μl, 0.20 mmol) and $HPO(OPh)_2$ (28 μl, 0.14 mmol), warmed to 95°, and stirred for 19 h. The mixture was concentrated and co-evaporated with toluene. The ^{1}H-NMR spectrum of the crude showed **7**, besides $P(O)Ph_3$ and $HPO(OPh)_2$. FC (hexane/AcOEt 8:2 → 7:3 → 6:4) followed by FC (CH_2Cl_2/i-PrOH 10:0.05) gave **7** (19.4 mg, 84%). Colourless oil. R_f (hexane/AcOEt 4:6) 0.47. IR (CCl_4): 3066*w*, 3032*w*, 2923*w*, 2865*w*, 1593*m*, 1490*s*, 1454*m*, 1361*w*, 1280*m*, 1243*w*, 1216*m*, 1193*s*, 1162*m*, 1099*m*, 1070*m*, 1006*w*, 986*w*, 941*s*. ^{1}H-NMR ($CDCl_3$, 300 MHz): 3.71 (*dd*, *J* = 5.4, 10.7, irrad. at 4.19 → *d*, *J* ≈ 10.5, CH−C(5)); 3.81 (*dd*, *J* = 2.5, 10.7, irrad. at 4.19 → change, CH′−C(5)); 3.83 (*t*, *J* = 7.5, irrad. at 4.12 → change, H−C(6)); 4.12 (*dd*, *J* = 5.0, 7.2, irrad. at 3.83 → change, H−C(7)); 4.19 (*ddd*, *J* = 2.5, 5.4, 7.5, irrad. at 3.83 → change, H−C(5)); 4.39 (*d*, *J* = 11.7, PhC*H*); 4.44 (*d*, *J* = 11.7, PhC*H*); 4.46 (*d*, *J* = 11.2, PhC*H*); 4.64 (*d*, *J* = 11.2, PhC*H*); 4.78 (*d*, *J* = 10.7, PhC*H*); 4.79 (*d*, *J* = 11.3, 2 PhC*H*); 4.79 (*d*, *J* = 5.1, irrad. at 4.12 → change, H−C(8)); 5.06 (*d*, *J* = 11.7, PhC*H*); 7.06–7.44 (*m*, 30 arom. H); 7.76 (*s*, H−C(3)). ^{13}C-NMR ($CDCl_3$, 75 MHz): 58.31 (*d*, C(5)); 67.51 (*t*, CH_2−C(5)); 72.11, 73.27, 73.61, 73.95 (4*t*, 4 PhCH_2); 73.10, 75.96, 81.44 (3*d*, C(6), C(7), C(8)); 120.93–121.03, 124.91, 125.25 (several *d* of $P(OPh)_2$); 128.49 (*d*, ^1J(C,P) = 256.4, C(2)); 127.71–129.49 (several *d*); 136.88, 137.29, 137.50, 137.90 (4*s*); 146.85 (*d*, ^3J(C,P) = 22.0, C(8a)); 150.44 (*d*, ^2J(C,P) = 7.3); 150.49 (*d*, ^2J(C,P) = 7.3). ^{31}P-NMR ($CDCl_3$, 121 MHz): 5.24. FAB-MS: 793 (100, $[M+1]^+$).

*(5*R,*6*R,*7*S,*8*S*)-6,7,8-Tris(benzyloxy)-5-[(benzyloxy)methyl]-5,6,7,8-tetrahydro-5-methylimidazo[1,2-*a*]pyridinium Iodide* (**10**). A soln. of **8** [19] (50 mg, 89.3 μmol) in toluene (0.5 ml) was treated with MeI (30 μl, 0.45 mmol) and kept at 95° for 4 h. Evaporation of the mixture followed by co-evaporation with toluene gave 64 mg of **10** (quant.). Coloured gel. R_f (AcOEt/iPrOH/H_2O 10:3:0.5) 0.57. UV ($CHCl_3$) 259 (3.6). IR ($CHCl_3$): 3405*w*, 3155*w*, 3089*w*, 3067*w*, 3010*w*, 2946*s*, 2871*m*, 1602*m*, 1536*m*, 1497*m*, 1455*s*, 1364*m*, 1088*s*, 1001*m*, 909*m*. ^{1}H-NMR (CD_3Cl, 300 MHz): 3.78 (*dd*, *J* = 2.9, 10.6, irrad. at 4.50 → *d*, *J* ≈ 10.6, CH−C(5)); 3.97 (*dd*, *J* = 8.8, 10.6, irrad. at 4.50 → *d*, *J* = 10.3, CH′−C(5)); 4.10 (*s*, Me); 4.14 (*dd*, *J* = 4.1, 5.3, irrad. at 4.50 → *d*, *J* ≈ 5, H−C(6)); 4.20 (*dd*, *J* = 3.5, 5.3, irrad. at 5.94 → *d*, *J* ≈ 5.6, H−C(7)); 4.41 (*d*, *J* = 11.8, PhC*H*); 4.46 (*d*, *J* = 11.8, PhC*H*); 4.48–4.52 (*m*, H−C(5)); 4.57 (*d*, *J* = 11.8, PhC*H*); 4.64 (*d*, *J* = 11.1, PhC*H*); 4.82 (*d*, *J* = 11.8, PhC*H*); 4.94 (2*d*, *J* = 11.8, *J* = 11.1, 2 PhC*H*); 5.08 (*d*, *J* = 11.1, PhC*H*); 5.94 (*d*, *J* = 3.3, H−C(8)); 7.08–7.41 (*m*, 20 arom. H); 7.44 (*d*, *J* = 2.1, H−C(3)); 7.49 (*d*, *J* = 2.1, H−C(2)). ^{13}C-NMR ($CDCl_3$, 75 MHz): 37.40 (*q*, Me); 61.94 (*d*, C(5)); 69.80 (*t*, CH_2−C(5)); 70.37, 72.75, 74.33 (3*d*, C(6), C(7), C(8)); 73.20, 73.56, 73.65, 73.70 (4*t*); 121.35 (*d*, C(3)); 124.42 (*d*, C(2)); 128.10–128.78 (several *d*, arom. C); 136.31, 136.36, 136.69, 136.88 (4*s*); 141.12 (*s*, C(8a)). FAB-MS: 575 (100, M^+), 1277 (8, $[2M+I]^+$.

*(5*R,*6*R,*7*S,*8*S*)-5,6,7,8-Tetrahydro-6,7,6-trihydroxy-5-(hydroxymethyl)-5-methylimidazo[1,2-*a*]pyridinium Iodide* (**11**). A soln. of **9** (10 mg, 0.05 mmol) and MeI (4 μl, 0.064 mmol) in DMSO (0.25 ml) was kept at 23° for 5 h. Evaporation gave **11** (17 mg, quant.). Colourless resin. R_f (AcOEt/MeOH 5:1) 0.04. ^{1}H-NMR (300 MHz, (D_6)DMSO): 3.69–3.79 (*m*, irrad at 4.79 → change, H−C(6), H−C(7)); 3.87 (*s*, Me); 3.82 (*dd*, *J* = 12.0, 4.2, CH−C(5)); 4.04–4.08 (*m*, H−C(5)); 4.79 (*d*, *J* = 6.0, H−C(8)); 7.75, 7.77 (2*d*, *J* = 3.0, H−C(2), H−C(3)). ^{1}H-NMR (300 MHz, D_2O): 3.96 (*s*, Me); 3.99–4.02 (*m*, irrad. at 4.99 → change, H−C(6), H−C(7)); 4.12 (*dd*, *J* = 12.8, 3.1, CH−C(5)); 4.24–4.27 (*m*, H−C(5)); 4.30 (*dd*, *J* = 12.8, 2.5, CH−C(5)); 4.98 (*m*, H−C(8)); 7.49, 7.65 (2*d*, *J* = 2.1, H−C(2), H−C(3)). ^{13}C-NMR (75 MHz, (D_6)DMSO)

35.56 (*q*, Me); 58.29 (*t*, $CH_2C(5)$); 62.79 (*d*, C(5)); 66.19, 66.40 (2*d*, C(6), C(7)); 74.10 (*d*, C(8)); 119.51 (*d*, C(2)); 124.52 (*d*, C(3)); 143.97 (*s*, C(8a)). FAB-MS: 215 (100, M^+).

*Diethyl (5*R*,6*R*,7*S*,8*S*)-5,6,7,8-Tetrahydro-6,7,8-trihydroxy-5-(hydroxymethyl)imidazo[1,2-*a*]pyridine-2-phosphonate* (**12**). A mixture of **5** (250 mg; 0.36 mmol), AcOEt/MeOH/H_2O 0.5:3:0.5 (1 ml), AcOH (0.5 ml), and 20% $Pd(OH)_2$ was hydrogenated at atmospheric pressure for 20 h. The suspension was filtered through *Celite*, washed with MeOH (20 ml) and chromatographed (AcOEt/^{i}PrOH/H_2O 8:4:1) to give **12** as white powder after lyophilization (107 mg, 89%). R_f (AcOEt/^{i}PrOH/H_2O 8:4:1) 0.3. IR (KBr): 3386*s* (br.), 3000*s*, 2985*s*, 1644*m*, 1528*s*, 1394*s*, 1221*s*, 1024*s* (br.), 860*m*, 797*s*, 697*m*, 662*s*, 603*s*. ^{1}H-NMR (D_2O, 300 MHz): 1.30 (*t*, $J=7.2$, 2 Me); 3.81 (*dd*, $J=9.2$, 9.9, irrad. at 4.63 → *d*, irrad. at 3.94 → change, H–C(7)); 3.94 (*t*, $J=9.2$, H–C(6)); 4.04–4.13 (*m*, irrad. at 3.94 → change, irrad. at 4.26 → change, H–C(5)); CH–C(5)); 4.14 (*q*, $J=7.2$, irrad. at 1.30 → change, 2 MeCH_2); 4.26 (*dd*, $J=3.3$, 13.8, CH′–C(5)); 4.63 (*d*, $J=9.9$, H–C(8)); 7.93 (*s*, H–C(3)). ^{13}C-NMR (D_2O, 75 MHz): 15.49 (*dq*, ^3J(C,P) = 6.4, 2 *Me*CH_2); 58.85 (*t*, *C*H_2–C(5)); 64.19 (*dt*, ^2J(C,P) = 4.8, 2 Me*C*H_2); 60.97 (*d*, C(5)); 67.23, 67.96, 74.53 (3*d*, C(6), C(7), C(8)); 127.52 (*d*, ^1J(C,P) = 247.4, C(2)); 128.47 (*dd*, ^2J(C,P) = 36.7, C(3)); 150.32 (*d*, ^3J(C,P) = 22.3, C(8a)). ^{31}P-NMR (D_2O, 121 MHz): 14.62. FAB-MS: 337 (100, $[M+1]^+$), 359 (61, $[M+Na]^+$), 695 (13, $[2M+Na]^+$).

*Diethyl (5*R*,6*R*,7*S*,8*S*)-6,7,8-Tris[[(*tert*-Butyl)dimethylsilyl]oxy]-5-([[(*tert*-Butyl)dimethylsilyl]oxy]methyl)-5,6,7,8-tetrahydroimidazo[1,2-*a*]pyridine-2-phosphonate* (**13**). A soln. of **12** (30 mg, 89.3 μmol) in DMF (0.15 ml) was treated with ^{t}BuMe$_2$SiCl (188 mg, 1.25 mmol) and 1*H*-imidazole (170 mg, 2.5 mmol) and stirred at 25° for 48 h. The mixture was diluted with Et_2O, washed by H_2O. Combined org. phase was dried ($MgSO_4$), filtered, and evaporated. FC (hexane/AcOEt 7:3) gave **13** (61 mg, 87%). White solid. R_f (hexane/AcOEt 3:7) 0.75. IR (CCl_4): 2955*s*, 2930*s*, 2897*m*, 2858*s*, 1515*w*, 1472*m*, 1463*w*, 1442*w*, 1390*w*, 1362*w*, 1259*s*, 1236*m*, 1188*w*, 1099*s*, 1034*m*, 1006*w*, 970*w*, 940*m*, 838*s*, 668*w*, 594*w*. ^{1}H-NMR (C_6D_6, 500 MHz): 0.01, 0.03, 0.08, 0.10, 0.13, 0.15, 0.25, 0.40 (8*s*, 8 Me); 0.85, 0.92, 0.93; 1.03 (4*s*, *Me*$_3$CSi); 1.16 (*dt*, $J=0.5$, 7.0, Me); 1.18 (*dt*, $J=0.5$, 7.0, 2 Me); 3.82 (*dd*, $J=7.0$, 11.0, CH–C(5)); 3.87 (*dd*, $J=4.5$, 11.0, CH′–C(5)); 4.10–4.28 (*m*, 2 MeCH_2, H–C(5), H–C(6)); 4.29 (*t*, $J=2.2$, irrad. at 5.0 → *d*, H–C(7)); 5.00 (*dd*, $J=0.7$, 2.2, H–C(8)); 7.87 (*s*, H–C(3)). ^{13}C-NMR (C_6D_6, 125 MHz): −5.53, −5.33, −4.88, −4.84, −4.55, −4.51, −4.22, −4.03, −3.99 (8*t*, 8 Me); 16.53 (*dq*, ^3J(C,P) = 5.2, Me); 16.56 (*dq*, ^3J(C,P) = 5.0, Me); 18.1, 18.19, 18.35, 18.54 (4*s*, 4 Me$_3$*C*Si); 25.85, 25.95, 26.01, 26.29 (4*q*, 4 *Me*$_3$CSi); 61.83 (*t*, ^2J(C,P) = 5.1, Me*C*H_2); 61.93 (*t*, ^2J(C,P) = 5.3, Me*C*H_2); 63.43 (*t*, *C*H_2–C(5)); 63.73 (*d*, C(5)); 69.64, 71.63, 77.54 (3*d*, C(6), C(7), C(8)); 129.12 (*dd*, ^2J(C,P) = 36.9, C(3)); 130.99 (*d*, ^1J(C,P) = 241.2, C(2)); 146.92 (*d*, ^3J(C,P) = 22.0, C(8a)). ^{31}P-NMR (C_6D_6, 202 MHz): 11.56. FAB-MS: 735 (84, $[M+1-{}^t\text{Bu}]^+$), 793 (100, $[M+1]^+$). Anal. calc. for $C_{36}H_{77}N_2O_7Si_4P$ (793.34): C 54.50, H 9.78, N 3.53, P 3.90; found: C 54.54, H 9.66, N 3.54, P 3.84.

*Ethyl Hydrogen (5*R*,6*R*,7*S*,8*S*)-5,6,7,8-Tetrahydro-6,7,8-trihydroxy-5-(hydroxymethyl)imidazo[1,2-*a*]pyridine-2-phosphonate* (**14**). A soln. of **12** (14 mg, 41.6 μmol) in 1M aq. NaOH (200 μl) was stirred at 70° for 14 h, neutralized with *Amberlite IRC 50* (H^+ form), filtered, and evaporated. A soln. of the residue in MeOH (5 ml) was adsorbed on silica gel. FC (^{i}PrOH/H_2O 8:2) gave **14** as white powder after lyophilization (7.5 mg, 58%). R_f (iPrOH/H_2O 7:3) 0.5. ^{1}H-NMR (D_2O, 300 MHz): 1.96 (*t*, $J=7.3$, irrad. at 3.85 → *s*, Me); 3.80 (*t*, $J=9.6$, irrad. at 4.26 → change, irrad. at 3.94 → change, H–C(7)); 3.85 (*q*, $J=7.3$, MeCH_2); 3.94 (*t*, $J=9.6$, H–C(6)); 4.00–4.08 (*m*, irrad. at 4.26 → change, irrad. at 3.94 → change, H–C(5)); 4.07 (*dd*, $J=2.8$, 13.0, irrad. at 4.26 → change, CH–C(5)); 4.26 (*dd*, $J=2.3$, 13.0, CH′–C(5)); 4.62 (*d*, $J=9.6$, H–C(8)); 7.57 (*s*, H–C(3)). ^{13}C-NMR (D_2O, 75 MHz): 15.77 (*dq*, ^3J(C,P) = 6.4, Me); 58.75 (*t*, *C*H_2–(5)); 64.37 (*dt*, ^2J(C,P) = 4.8, Me*C*H_2); 60.56 (*d*, *C*(5)); 67.32, 68.11, 74.78 (3*d*, C(6), C(7), C(8)); 124.55 (*dd*, ^2J(C,P) = 31.9, C(3)); 134.77 (*d*, ^1J(C,P) = 226.7, C(2)); 148.64 (*d*, ^3J(C,P) = 19.1, C(8a)). ^{31}P-NMR (D_2O, 121 MHz): 8.30. FAB-MS (glycerol): 309 (9.40, $[M+1]^+$), 331 (5.72, $[M+Na]^+$).

*Ethyl Hydrogen (5*R*,6*R*,7*S*,8*S*)-5,6,7,8-Tetrahydro-6,7,8-trihydroxy-5-(hydroxymethyl)imidazo[1,2-*a*]pyridine-2-phosphonate Hydrochloride* (**14**·HCl). A soln. of **14** (10 mg, 32 μmol) in D_2O (0.7 ml) was treated with 1M aq. HCl (20 μl), evaporated, co-evaporated with H_2O, and lyophilized. The residue was taken up in H_2O (1 ml), treated with *Bio-Rad AG 2-X8* resin (Cl^- form), filtered, and lyophilized to give 8 mg of **14**·HCl. ^{1}H-NMR (D_2O, 300 MHz): 1.23 (*t*, $J=7.0$, *Me*CH_2); 3.92 (*q*, $J=7.2$, Me*C*H_2); 3.93 (br. *t*, $J=9.6$, irrad. at 4.89 → *d*, $J\approx10$, H–C(7)); 4.03 (*t*, $J=9.2$, irrad. at 4.26 → *d*, $J\approx10$, H–C(6)); 4.11 (*dd*, $J=3.2$, 12.8, irrad. at 4.26 → *d*, $J\approx10$, CH–C(5)); 4.22–4.29 (*m*, H–C(5)); 4.32 (*dd*, $J=2.4$, 12.8, irrad. at 4.26 → change, CH′–C(5)); 4.89 (*d*, $J=8.4$, H–C(8)); 7.84 (*s*, H–C(3)). ^{13}C-NMR (D_2O, 75 MHz): 18.45 (*dq*, ^3J(C,P) = 6.1, Me); 61.15 (*t*, *C*H_2–C(5)); 65.19 (*dt*, ^2J(C,P) = 6.1, Me*C*H_2); 65.28 (*d*, C(5)); 69.31, 69.68, 75.99 (3*d*, C(6), C(7), C(8)); 127.89 (*dd*, ^2J(C,P) = 20.7, C(3)); 131.59 (*d*, ^1J(C,P) = 202.6, C(2)); 150.99 (*d*, ^3J(C,P) = 7.3, C(8a)). ^{31}P-NMR (D_2O, 121 MHz): −1.78.

*Phenyl Hydrogen (5*R,*6*R,*7*S,*8*S*)-5,6,7,8-Tetrahydro-6,7,8-trihydroxy-5-(hydroxymethyl)imidazo[1,2-*a*]pyridine-2-phosphonate* (**15**). A soln. of **7** (17 mg, 21.4 μmol) in MeOH/H_2O/AcOH 2 : 0.5 : 1 (1.75 ml) was treated with 20% $Pd(OH)_2$/C (17 mg) and hydrogenated at atmospheric pressure for 34 h. The suspension was filtered through *Celite*, and the residue washed with MeOH/H_2O 9 : 1. Evaporation of the filtrate gave 10 mg of crude which was taken up in H_2O (1 ml) treated with *Dowex 50W8* (H^+ form), filtered, and lyophilized. The residue was taken up in MeOH/H_2O 1 : 1 (1.5 ml), treated with activated charcoal, filtered, and lyophilized to give 10 mg of white solid **15**. R_f (^{i}PrOH/H_2O 8 : 2) 0.32. ^{1}H-NMR (D_2O, 300 MHz): 3.81 (*t*, *J* = 8.8, irrad. at 4.65 → *d*, *J* ≈ 9.3, H–C(7)); 3.94 (*t*, *J* = 8.8, H–C(6)); 3.98–4.11 (*m*, H–C(5), CH–C(5)); 4.21 (br. *d*, *J* = 12.8, CH′–C(5)); 4.65 (*d*, *J* = 8.8, H–C(8)); 7.03 (br. *d*, *J* = 7.8, 2 arom. H); 7.16 (br. *t*, *J* = 7.8, arom. CH); 7.32 (br. *t*, *J* = 7.8, 2 arom. H); 7.52 (*s*, H–C(3)). ^{13}C-NMR (D_2O, 75 MHz): 61.53 (*t*, CH_2–C(5)); 63.32 (*d*, C(5)); 70.12, 70.89, 77.52 (3*d*, C(6), C(7), C(8)); 124.18, 124.23, 127.34 (3*d*, arom. CH); 128.03 (*dd*, ^2J(C,P) = 34.2, C(3)); 132.58 (*d*, arom. CH); 137.18 (*d*, ^1J(C,P) = 233.17, C(2)); 151.66 (*d*, ^3J(C,P) = 20.7, C(8a)); 154.5 (*d*, ^2J(C,P) = 7.3). ^{31}P-NMR (D_2O, 121 MHz): 6.05, ESI-MS (negative mode): 355 (100, $[M-1]^-$).

*Triethylammonium Hydrogen (5*R,*6*R,*7*S,*8*S*)-6,7,8-Trihydroxy-5-(hydroxymethyl)imidazo[1,2-*a*]pyridine-2-phosphonate* (**17**). A soln. of **5** (260 mg, 0.373 mmol) in CH_2Cl_2 (3.5 ml) at 0° was treated with Me_3SiBr (0.29 ml, 2.24 mmol), warmed to 25°, and stirred for 16 h. The mixture was concentrated and co-evaporated with toluene (4 × 5 ml). The residue was taken up in MeOH/H_2O 9 : 1 (2 ml), evaporated, and co-evaporated with toluene until crude **16** became a foam (241 mg). A soln. of crude **16** in MeOH/AcOEt/H_2O 3 : 1 : 1 (4 ml) was treated with 20% $Pd(OH)_2$/C (180 mg) and hydrogenated at atmospheric pressure for 19 h. The suspension was filtered through *Celite*, and the residue washed with MeOH/H_2O 95 : 5 (75 ml). Evaporation of the filtrate gave 116.5 mg of crude **17**, which was taken up in 1 ml of H_2O and applied to a DEAE-cellulose column (*Cellex-D*, *Bio-rad*, 18 × 1.5 cm; UV detection). The column was washed with H_2O (30 ml), and **17** was eluted with a triethylammonium hydrogen carbonate buffer (pH ≈ 7; 5 mM, 30 ml; 10 mM, 40 ml; 20 mM, 40 ml). The fractions containing **17** were combined and lyophilized (3 ×) to give **17** (110 mg, 81%, 0.83 equiv. of Et_3NH^+).

Triethylammonium salt **17** was also obtained after treatment of an aq. soln. of crude deproteced free acid with Et_3N (3 equiv.). The soln. was evaporated, concentrated, and co-evaporated with toluene. The residue was taken up in H_2O/MeOH *ca.* 1 : 1, treated with activated charcoal, and filtered. Evaporation and lyophilization (3 ×) gave **17** (0.87 equiv. of Et_3NH^+).

*Data of (5*R,*6*R,*7*S,*8*S*)-6,7,8-Tris(benzyloxy)-5-[(benzyloxy)methyl]-5,6,7,8-tetrahydroimidazo[1,2-*a*]pyridine-2-phosphonic Acid* (**16**): R_f (*RP C18*, MeOH/H_2O 9 : 1) 0.6. IR ($CHCl_3$): 3500–2233*w* (br.), 3028*m*, 2971*m*, 1602*w*, 1496*m*, 1454*m*, 1363*m*, 1230*m*, 1094*s*, 996*s*. ^{1}H-NMR (CD_3OD, 300 MHz): 3.78 (*dd*, *J* = 6.5, 10.6, CH–C(5)); 3.90 (*dd*, *J* = 3.2, 10.6, CH′–C(5)); 4.20 (*dd*, *J* = 5.7, 9.7, H–C(6)); 4.22 (br. *t*, *J* = 4.9, irrad. at 5.01 → *d*, *J* ≈ 5.4, H–C(7)); 4.42 (*d*, *J* = 11.8, PhC*H*); 4.50 (*d*, *J* = 11.8, PhC*H*); 4.52 (*d*, *J* = 11.4, PhC*H*); 4.60–4.72 (*m*, irrad. at 3.90 → change, H–C(5), 3 PhC*H*); 4.80 (*d*, *J* = 11.4, PhC*H*); 4.91 (*d*, *J* = 11.4, PhC*H*); 5.01 (*d*, *J* = 4.1, irrad. at 4.22 → *s*, H–C(8)); 7.12–7.39 (*m*, 20 arom. H); 7.70 (*d*, *J* = 2.5, H–C(3)). ^{13}C-NMR (CD_3OD, 75 MHz): 62.18 (*d*, C(5)); 69.06 (*t*, CH_2–C(5)); 72.86, 74.77, 78.43 (3*d*, C(6), C(7), C(8)); 74.20, 74.28, 74.64, 75.03 (4*t*, 4 PhCH_2); 127.86 (*dd*, ^2J(C,P) = 22.0, C(3)); 130.03 (*d*, ^1J(C,P) = 214.0, C(2)); 129.21–129.73 (several *d*)); 138.43–138.71 (4*s*); 146.52 (*d*, ^3J(C,P) = 8.5, C(8a)). ^{31}P-NMR (CD_3OD, 121 MHz): −1.63. FAB-MS: 663 (32, $[M+Na]^+$); 685 (100, $[M-1+2\,Na]^+$); 707 (43, $[M-2+3\,Na]^+$; 1347 (16, $[2(M-1)+3\,Na]^+$).

Data of **17**: R_f (MeOH/NH_3/H_2O 4 : 3 : 1) 0.57. UV (H_2O): 232 (2.78). IR (KBr): 3386*s* (br.), 2361*m*, 1654*w*, 1476*m*, 1398*m*, 1109*s* (br.), 903*m*, 667*m*, 592*s*, 492*m*. ^{1}H-NMR (D_2O, 300 MHz): 1.27 (*t*, *J* = 7.6, 3 *Me*CH_2); 3.19 (*q*, *J* = 7.6, 3 MeC*H*$_2$); 3.90 (*t*, *J* = 9.7, irrad. at 4.83 → change, H–C(7)); 4.02 (*dd*, *J* = 8.8, 9.7, irrad. at 3.90 → change, H–C(6)); 4.09 (*dd*, *J* = 3.1, 13.2, CH–C(5)); 4.19 (br. *d*, *J* = 8.8, H–C(5)); 4.30 (*dd*, *J* = 2.2, 13.2, CH′–C(5); 4.83 (*d*, *J* = 9.7, irrad. at 3.90 → change, H–C(8)); 7.60 (*s*, H–C(3)). ^{13}C-NMR (D_2O, 75 MHz): 10.99 (*q*, 3 Me); 49.46 (*t*, 3 MeCH_2); 61.01 (*t*, CH_2–C(5)); 64.66 (*d*, C(5)); 69.52, 69.69, 76.29 (3*d*, C(6), C(7), C(8)); 125.02 (*dd*, ^2J(C,P) = 22.0, C(3)); 137.40 (*d*, ^1J(C,P) = 190.4, C(2)); 149.59 (*d*, ^3J(C,P) = 8.8, C(8a)). ^{31}P-NMR (D_2O, 121 MHz): −1.97. ESI-MS (MeOH/H_2O 1 : 1, 1% AcOH, negative mode): 279 ($[M-1]^-$), 339 ($[M+AcO]^-$), 559 ($[2M-1]^-$), 839 ($[3\,M-1]^-$).

*Disodium (5*R,*6*R,*7*S,*8*S*)-6,7,8-Trihydroxy-5-(hydroxymethyl)imidazo[1,2-*a*]pyridine-2-phosphonate* (**18**). A soln. of **17** (60 mg, 0.164 mmol, 0.75 equiv. of Et_3NH^+) in H_2O (5 ml) was treated with *Dowex 50W8* (Na^+ form) then with *Dowex CCR-2* (Na^+ form), filtered, and lyophilized to give **18** (38 mg) as a white solid, of which 25 mg were taken up in a minimum of H_2O (*ca.* 0.2 ml) and treated with MeOH (1.5 ml) until a white precipitate was formed. The mixture was kept for 12 h at 4°. The precipitate was isolated by centrifugation to give, after washing with MeOH and drying under vacuum, 20 mg of **18**. White powder. UV (H_2O): 230 (3.10). IR (KBr): 3384*s* (br.), 1648*m*, 1523*m*, 1438*m*, 1334*m*, 1069*s* (br.), 996*s*, 952*s*, 906*m*, 667*s*, 602*s*, 498*s*. ^{1}H-NMR (D_2O,

500 MHz): 3.76 (*dd*, *J* = 9.0, 10.0, irrad. at 4.61 → change, H–C(7)); 3.90 (*t*, *J* = 10.0, H–C(6)); 3.96–4.01 (*m*, H–C(5)); 4.01 (*dd*, *J* = 2.5, 13.0, CH–C(5)); 4.21 (*dd*, *J* = 2.5, 13.0, CH′–C(5)); 4.61 (*d*, *J* = 9.0, H–C(8)); 7.31 (*s*, H–C(3)). ^{13}C-NMR (D_2O, 125 MHz): 61.08 (*t*, *C*H$_2$–C(5)); 63.26 (*d*, C(5)); 69.82, 70.38, 77.13 (3*d*, C(6), C(7), C(8)); 123.69 (*dd*, ^2J(C,P) = 26.8, C(3)); 142.41 (*d*, ^1J(C,P) = 202.6, C(2)); 149.29 (*d*, ^3J(C,P) = 14.6, C(8a)). ^{31}P-NMR (D_2O, 202 MHz): 2.64. FAB-MS (glycerine, negative mode): 279 (100, [*M* – 2 Na]$^-$), 301 (59, [*M* – Na]$^-$). Anal. calc. for $C_8H_{11}N_2Na_2O_7P \cdot 0.75\ H_2O$ (337.64): C 28.46, H 3.73, N 8.29; found: C 28.64, H 3.67, N 8.14.

*Triethylammonium Hydrogen (5*R,*6*R,*7*S,*8*S*)-6,7,8-Triacetoxy-5-[(acetoxy)methyl]-5,6,7,8-tetrahydroimidazo[1,2-*a*]pyridine-2-phophonate* (**19**). A soln. of **17** (0.70 equiv. of Et_3NH^+; 15 mg, 40 μmol) in pyridine (0.5 ml) was treated with Ac_2O (195 μl) and stirred at 25° overnight. The soln. was evaporated and co-evaporated with toluene. The phosphonate **19** (23 mg, 0.72 equiv. of Et_3NH^+) was used for the next step without further purification. R_f (AcOEt/MeOH/H_2O 8 : 4 : 1) 0.5. UV (H_2O): 289 (2.28), 234 (2.89). IR (KBr): 3444*m*, 2677*w*, 2360*w*, 1748*s*, 1652*w*, 1435*w*, 1373*m*, 1229*s*, 1036*s*, 920*w*, 838*w*. ^{1}H-NMR (CD_3OD, 300 MHz): 1.29 (*t*, *J* = 7.9, 3 *Me*CH$_2$); 2.06, 2.08, 2.09, 2.11 (4*s*, 4 AcO); 3.19 (*q*, *J* = 7.9, 3 MeC*H*$_2$); 4.42 (*dd*, *J* = 5.4, 12.6, CH–C(5)); 4.59 (*dd*, *J* = 3.8, 12.6, CH′–C(5)); 4.67–4.76 (*m*, H–C(5)); 5.54 (br. *t*, *J* ≈ 6.5, irrad. at 4.7 → *d*, *J* ≈ 9.0, H–C(6)); 5.56 (br. *t*, *J* ≈ 6.0, irrad. at 6.16 → *d*, *J* ≈ 7.5, H–C(7)); 6.16 (*dd*, *J* = 5.1, 0.7, H–C(8)); 7.74 (*d*, *J* = 1.2, H–C(3)). ^{13}C-NMR (D_2O, 75 MHz): 8.25 (*q*, 3 *Me*CH$_2$); 20.29, 20.28, 21.96, 22.06 (4*q*, 4 Me); 46.75 (*t*, 3 MeCH$_2$); 56.53 (*d*, C(5)); 62.15 (*t*, *C*H$_2$–C(5)); 66.11, 66.69, 70.43 (3*d*, C(6), C(7), C(8)); 126.60 (*dd*, ^2J(C,P) = 36.7, C(3)); 135.12 (*d*, ^1J(C,P) = 236.2, C(2)); 142.62 (*d*, ^3J(C,P) = 20.6, C(8a)); 172.51–173.66 (several *s*, 4 C=O). ^{31}P-NMR (CD_3OD, 121 MHz): – 1.12. FAB-MS: 102 (72, Et_3NH^+), 449 (29, [*M* + 1]$^+$), 550 (15, [(*M* + Et_3NH]$^+$), 592 (100, [*M* – 3 + Et_3N + 2 Na]$^+$), 693 (12, [*M* – 3 + 2 Et_3N + 2 Na]$^+$).

Oleyl[6]) *Hydrogen (5*R,*6*R,*7*S,*8*S*)-6,7,8-Triacetoxy-5-[(acetoxy)methyl]-5,6,7,8-tetrahydroimidazo[1,2-*a*]pyridine-2-phosphonate* (**20**). A soln. of **19** (39 mg, 0.068 mmol) and oleyl alcohol (16 mg, 0.059 mmol) in pyridine (1 ml) was treated at 25° with CCl_3CN (0.1 ml, 1 mmol) and warmed to 70°. After 13 h, the resulting brown soln. was evaporated and co-evaporated with toluene, dissolved in AcOEt (10 ml), and washed (H_2O). The aq. phase was extracted with AcOEt (4 × 10 ml). The combined org. phases were dried ($MgSO_4$), filtered, and evaporated. FC (silica gel 60; AcOEt/^{i}PrOH/H_2O 10 : 1 : 0.1 → 10 : 4 : 1) followed by *RP 18* (MeOH/H_2O 8 : 2 → 95 : 5) gave **20** (27 mg) as a brown gel. A soln. of **20** in MeOH (2 ml) was treated with activated charcoal and gave, after filtration and evaporation, **20** (20 mg, 50% from oleyl alcohol). Solid. R_f (AcOEt/MeOH/H_2O 8 : 4 : 1) 0.6. UV ($CHCl_3$): 273 (2.24), 245 (2.64). IR (CCl_4): 3341*w*, 3135*w*, 2927*s*, 2855*m*, 1763*s*, 1512*w*, 1466*w*, 1433*w*, 1369*w*, 1260*m*, 1222*s*, 1065*s*, 946*w*, 904*w*. ^{1}H-NMR (CD_3OD, 300 MHz): 0.89 (*t*, *J* = 6.4, Me); 1.29–1.40 (*m*, 22 H); 1.46–1.58 (*m*, C*H*$_2$CH$_2$O); 1.92–2.25 (*m*, C*H*$_2$CH=CHC*H*$_2$); 2.06, 2.07, 2.09, 2.10 (4*s*, 4 AcO); 3.76 (*q*, *J* = 6.4, irrad. at 1.53 → *d*, CH$_2$C*H*$_2$O); 4.43 (*dd*, *J* = 5.4, 12.7, CH–C(5)); 4.57 (*dd*, *J* = 3.6, 12.7, CH′–C(5)); 4.54 (br. *q*, *J* ≈ 4.5, H–C(5)); 5.28–5.42 (*m*, irrad. at 2.20 → change, CH$_2$C*H*=C*H*CH$_2$); 5.51 (*t*, *J* = 7.0, H–C(6)); 5.55 (*dd*, *J* = 5.5, 7.5, irrad. at 6.09 → *d*, *J* ≈ 8.0, H–C(7)); 6.09 (*d*, *J* = 5.5, H–C(8)); 7.59 (*d*, *J* = 0.9, H–C(3)). ^{13}C-NMR (CD_3OD, 75 MHz): 14.38 (*q*, Me); 20.49–20.82 (several *q*); 23.68–30.86 (several *t*); 31.87 (*t*, ^3J(C,P) = 7.3, *C*H$_2$CH$_2$O); 30.03 (*t*, CH$_2$) 58.14 (*d*, C(5)); 63.17 (*t*, *C*H$_2$–C(5)); 67.52, 67.76, 71.76 (C(6), C(7), C(8)); 65.88 (*dt*, ^2J(C,P) = 6.1, CH$_2$*C*H$_2$O); 125.99 (*dd*, ^2J(C,P) = 30.5, C(3)); 131.00 (*d*, CH=CH); 139.00 (*d*, ^1J(C,P) = 225.8, C(2)); 143.47 (*d*, ^3J(C,P) = 18.0, C(8a)); 171.01, 171.22, 171.61, 172.00 (4*s*, 4 C=O). ^{31}P-NMR (CD_3OD): 3.98. FAB-MS: 721 (100, [*M* + Na]$^+$).

Phytanyl[6]) *Hydrogen (5*R,*6*R,*7*S,*8*S*)-6,7,8-Triacetoxy-5-[(acetoxy)methyl]-5,6,7,8-tetrahydroimidazo[1,2-*a*]pyridine-2-phosphonate* (**21**). A soln. of **19** (22 mg, 42.7 μmol) in pyridine (0.5 ml) was treated with phytanol (10.2 mg, 34 μmol) and CCl_3CN (8.6 μl, 85.4 μmol), and stirred at 60° for 18 h. After workup as described for **20**, FC ($CHCl_3$ → $CHCl_3$/MeOH/H_2O 10 : 1.2 : 0.1 → 10 : 1.5 : 0.1 → 10 : 2 : 0.2) gave **21** containing *ca*. 15% of the deacetylated product at C(8) (determined by ^{1}H-NMR). Acetylation of the mixture (1.2 ml of pyridine/Ac_2O 5 : 1, 25°, overnight) gave **21** (15 mg, 61% from phytanol). Solid. R_f ($CHCl_3$/MeOH/H_2O 10 : 2 : 0.25) 0.24. IR (CCl_4): 3353*w*, 3138*w*, 2956*s*, 2927*s*, 2868*m*, 1763*s*, 1512*w*, 1463*m*, 1432*w*, 1369*m*, 1222*s*, 1065*s*, 946*s*, 903*w*. UV ($CDCl_3$): 274 (1.96), 243 (2.49). ^{1}H-NMR (CD_3OD, 300 MHz): 0.80 (*d*, *J* = 6.4, irrad. at 1.54 → change, Me); 0.82 (*d*, *J* = 6.4, irrad. at 1.54 → change, Me); 0.86, 0.87, 0.88 (3*d*, *J* = 6.4, 3 Me); 1.00–1.45 (*m*, 21 H); 1.53 (*sept.*, *J* = 6.5, 1 H); 1.47–1.66 (*m*, 2 H); 2.06, 2.07, 2.09, 2.10 (4*s*, 4 AcO); 3.72–3.90 (*m*, CH$_2$OP); 4.43 (*dd*, *J* = 5.1, 12.1, irrad. at 4.90 → *d*, *J* ≈ 12.5, CH–C(5)); 4.58 (*dd*, *J* = 3.3, 12.1, irrad. at 4.90 → *d*, *J* ≈ 12.5,

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[6]) Oleyl = *(Z)-octadec-9-enyl*; phytanyl = *3,7,11,15-tetramethylhexadecyl*; dolichyl-19 = *3,7,11,15,19,23,27,31,35,39,43,47,51,55,59,63,67,71,75-nonadecamethylhexaheptaconta-6,10,14,18,22,26,30,34,38,42,46,50,54,58,62,66,70,74-octadecaenyl.*

CH′–C(5)); 4.90 (br. *q*, *J* ≈ 4.6, H–C(5)); 5.51 (*t*, *J* = 6.5, irrad. at 4.90 → *d*, *J* ≈ 8.0, H–C(6)); 5.56 (*dd*, *J* = 4.7, 6.5, irrad. at 6.09 → *d*, *J* ≈ 8, H–C(7)); 6.09 (*dd*, *J* = 0.9, 4.7, H–C(8)); 7.60 (*s*, H–C(3)). ^{13}C-NMR (CD_3OD, 75 MHz): 19.69–23.07 (several *q*, 9 Me); 25.47, 25.85 (2*t*); 29.10–33.95 (several *d*); 38.37–40.52 (several *t*); 63.17 (*t*, CH_2–C(5)); 64.19 (*m*, CH_2OP); 58.20 (*d*, C(5)); 67.46, 67.65, 71.57 (3*d*, C(6), C(7), C(8)); 126.09 (*dd*, ^2J(C,P) = 30.5, C(3)); 138.68 (*d*, ^1J(C,P) = 225.8, C(2)); 143.48 (*d*, ^3J(C,P) = 19.5, C(8a)); 170.93, 171.16, 171.58, 171.92 (4*s*, 4 C=O). ^{31}P-NMR (CD_3OD, 121 MHz): 3.78. FAB-MS: 751 (100, $[M+Na]^+$). Anal. calc. for $C_{36}H_{61}N_2O_{11}P \cdot 2\,H_2O$ (764.12): C 56.53, H 8.56, N 3.66; found: C 56.36, H 8.44, N 3.65.

Dolichyl-19[6]) *Hydrogen (5*R,*6*R,*7*S,*8*S*)-6,7,8-Triacetoxy-5-[(acetoxy)methyl]-5,6,7,8-tetrahydroimidazo[1,2-*a*]pyridine-2-phosphonate* (**22**). A soln. of **19** (22 mg, 42.7 μmol) in pyridine (0.4 ml) was treated with dolichol-19 (10 mg, 7.6 μmol) and CCl_3CN (9 μl, 90 μmol) and stirred at 60° for 18 h. The mixture was evaporated and co-evaporated with toluene, diluted with $CHCl_3$, washed with H_2O, dried ($MgSO_4$), and filtered. Evaporation and FC ($CHCl_3 \rightarrow CHCl_3$/MeOH/$H_2O$ 10 : 0.6 : 0.05 → 10 : 0.8 : 0.05 → 10 : 1.0 : 0.05) followed by acetylation (0.6 ml pyridine/Ac_2O 5 : 1, 25°, overnight) gave **22** (10 mg, 65% from dolichol-19). Coloured gel. R_f ($CHCl_3$/MeOH/H_2O 10 : 2 : 0.25) 0.31. IR (CCl_4): 3317*w*, 2962*s*, 2928*s*, 2955*m*, 1762*s*, 1664*w*, 1449*m*, 1376*m*, 1261*s*, 1222*s*, 1088*s*, 1031*s*. ^{1}H-NMR (CD_3OD/$CDCl_3$ 4 : 2, 500 MHz): 0.84 (*d*, *J* = 6.5, Me); 1.10–1.45 (*m*, 15 H instead of the expected 5 H); 1.62, 1.60 (2*s*, 4 Me); 1.68 (*s*, 15 Me); 1.93–2.08 (*m*, 70 H); 2.09, 2.10, 2.11, 2.12 (4*s*, 4 AcO); 3.66–3.84 (*m*, CH_2OP); 4.43 (*dd*, *J* = 5.5, 12.5, irrad. at 4.63 → *d*, *J* ≈ 12.8, CH–C(5)); 4.56 (*dd*, *J* = 3.5, 12.5, irrad. at 4.63 → *d*, *J* ≈ 12.8, CH′–C(5)); 4.63 (br. *q*, *J* ≈ 5.0, H–C(5)); 5.46 (*dd*, *J* = 6.5, 7.5, irrad. at 4.63 → *d*, *J* ≈ 7.8, H–C(6)); 5.54 (*dd*, *J* = 5.7, 7.5, irrad. at 6.07 → *d*, *J* ≈ 7.5, H–C(7)); 6.07 (*d*, *J* = 5.5, H–C(8)); 7.57 (*s*, H–C(3)). ^{13}C-NMR (CD_3OD/$CDCl_3$ 4 : 2, 125 MHz): 16.26–20.86 (several *q*); 23.74, 23.85 (2*q*); 25.93–27.44 (several *t*); 29.89 (*d*); 32.59–40.43 (several *t*); 57.56 (*d*, C(5)); 62.64 (*t*, CH_2–C(5)); 63.71 (*t*, CH_2OP); 66.85, 67.12, 71.12 (3*d*, C(6), C(7), C(8)); 124.97–126.55 (several *d*); 131.65–135.87 (several *s*); 138.29 (*d*, ^1J(C,P) = 224.0, C(2)); 142.50 (*d*, ^3J(C,P) = 18.7, C(8a)); 170.23, 170.42, 170.79, 171.29 (4*s*, *4* C=O). ^{31}P-NMR (CD_3OD/$CDCl_3$ 4 : 2, 202 MHz): 3.87. FAB-MS: 1766 (19, $[M+Na]^+$).

Oleyl[6]) *Hydrogen (5*R,*6*R,*7*S,*8*S*)-5,6,7,8-Tetrahydro-6,7,8-trihydroxy-5-(hydroxymethyl)imidazo[1,2-*a*]pyridine-2-phosphonate* (**1**). A soln. of **20** (12 mg, 17.5 μmol) in MeOH (1 ml) was treated at 25° with a 0.5M soln. of MeONa in MeOH (41 ml), and stirred for 45 min. MeOH (3 ml) was added, and the mixture was neutralized with *Amberlite IRC50* (H^+ form). The resin was filtered and the filtrate evaporated. The residue (10 mg) was taken up in hot MeOH (*ca.* 0.25 ml), and **1** was precipitated at 0° by the addition of cold MeCN, separated by filtration, and dried under vacuum, affording **1** (8.5 mg, 95%). White solid. R_f (AcOEt/MeOH/H_2O 10 : 4 : 1) 0.2. IR (KBr): 3356*s* (br.), 2924*s*, 2853*s*, 1522*m*, 1466*m*, 1184*m*, 1066*s*, 828*w*. ^{1}H-NMR (CD_3OD, 500 MHz): 0.89 (*t*, *J* = 6.9, Me); 1.20–1.40 (*m*, 22 H); 1.53–1.61 (*m*, CH_2CH_2O); 1.98–2.07 (*m*, CH_2CH=$CHCH_2$); 3.70 (*dd*, *J* = 8.1, 9.5, irrad. at 4.54 → change, H–C(7)); 3.79 (*q*, *J* = 6.5, CH_2CH_2O); 3.84 (*dd*, *J* = 8.0, 9.5, irrad. at 3.70 → change, H–C(6)); 3.89–3.94 (*m*, H–C(5)); 3.96 (*dd*, *J* = 4.0, 11.8, CH–C(5)); 4.18 (*dd*, *J* = 2.0, 11.8, CH′–C(5)); 4.54 (*d*, *J* = 8.0, H–C(8)); 5.29–5.37 (*m*, CH_2CH=$CHCH_2$); 7.60 (*d*, *J* = 0.9, H–C(3)). ^{13}C-NMR (CD_3OD, 125 MHz): 14.47 (*q*, Me); 23.77–30.94 (several *d*); 32.04 (*dt*, ^3J(C,P) = 7.3, CH_2CH_2O); 33.09 (*t*, CH_2); 61.19 (*t*, CH_2–C(5)); 63.24 (*dt*, ^2J(C,P) = 5.5, CH_2CH_2O); 65.88 (*d*, C(5)); 69.27, 69.59, 71.28 (3*d*, C(6), C(7), C(8)); 125.10 (*dd*, ^2J(C,P) = 29.1, C(3)); 130.86, 130.92 (2*d*, CH=CH); 136.78 (*d*, ^1J(C,P) = 197.5, C(2)); 149.44 (*d*, ^3J(C,P) = 16.8, C(8a)). ^{31}P-NMR (CD_3OD, 121 MHz): 5.89. FAB-MS: 553 (69, $[M+Na]^+$), 575 (100, $[M-1+Na]^+$).

Phytanyl[6]) *Hydrogen (5*R,*6*R,*7*S,*8*S*)-5,6,7,8-Tetrahydro-6,7,8-trihydroxy-5-(hydroxymethyl)imidazo[1,2-*a*]pyridine-2-phosphonate* (**2**). A soln. of **21** (15 mg, 20.6 μmol) in MeOH (1.2 ml) was treated with 0.5M MeONa in MeOH (49 μl) and stirred for 90 min. After dilution with MeOH (4 ml), the mixture was neutralized with *Amberlite IRC50* (H^+ form). The resin was filtered and the filtrate evaporated. The residue (13 mg) was taken up in hot MeOH (*ca.* 0.2 ml), and **2** was precipitated at 0° by the addition of cold MeCN. Filtration and drying under vacuum gave **2** (7 mg, 61%). White solid. R_f ($CHCl_3$/MeOH/H_2O 3 : 1 : 0.1) 0.16. IR (KBr): 3382*s* (br), 2953*s*, 2912*s*, 2839*s*, 1522*w*, 1460*m*, 1375*w*, 1262*w*, 1189*m*, 1138*m*, 1065*s*, 901*w*, 856*w*, 805*w*. ^{1}H-NMR (CD_3OD, 300 MHz): 0.85 (*m*, Me); 0.89 (br. *d*, *J* = 7.2, irrad. at 1.53 → change, 4 Me); 1.0–1.44 (*m*, 21 H); 1.53 (*sept.*, *J* = 8.8, irrad. at 0.87 → change, 1 H); 1.50–1.70 (*m*, 3 H); 3.72 (*t*, *J* = 8.8, irrad. at 4.19 → *d*, *J* ≈ 9.3, H–C(7)); 3.84 (*m*, irrad. at 3.96 → change, H–C(6), CH_2O); 3.96 (*m*, CH–C(5), H–C(5)); 4.19 (*dd*, *J* = 4.1, 13.5, irrad. at 3.96 → br. *s*, CH′–C(5)); 4.58 (*d*, *J* = 8.1, H–C(8)); 7.66 (*d*, *J* = 1.2, H–C(3)). ^{13}C-NMR (CD_3OD, 75 MHz): 19.73–23.05 (several *q*); 25.46, 25.85 (2*t*); 29.12–33.95 (several *d*); 38.37–40.52 (several *t*); 61.04 (*t*, CH_2–C(5)); 64.30 (*dt*, ^3J(C,P) = 6.1, CH_2O); 61.04 (*d*, C(5)); 69.15, 69.25, 76.05 (3*d*, C(6), C(7), C(8)); 125.47 (*dd*, ^2J(C,P) = 26.8, C(3)); 135.54 (*d*, ^1J(C,P) = 216.1, C(2)); 149.6 (*d*, ^3J(C,P) = 13.4, C(8a)). ^{31}P-NMR (CD_3OD): 4.30. FAB-MS: 281 (43, $[(M-\text{phytanyloxy}+1]^+$), (561 (43, $[(M+1]^+$), 583

(100, [M + Na]$^+$), 605 (60, [M − 1 + 2 Na]$^+$), 1188 (4, [2 M − 1 + 3 Na]$^+$). HR-FAB-MS: 561.3676, (MH$^+$; calc. 561.3668).

Dolichyl^6) *Hydrogen (5*R,*6*R,*7*S,*8*S*)-5,6,7,8-Tetrahydro-6,7,8-trihydroxy-5-(hydroxymethyl)imidazo[1,2-a]pyridine-2-phosphonate* (**3**). A soln. of **22** (14 mg, 8.02 μmol) in THF/MeOH 1:2 (0.75 ml) was treated with 0.4M of MeONa in MeOH (24 μl) at 25° and stirred for 105 min. The soln. was diluted with THF (*ca.* 2 ml), neutralized with *Amberlite IRC50* (H$^+$ form). The resin was filtered off and the filtrate evaporated. FC ($CHCl_3$/MeOH/H_2O 10:1:0.15 → 10:2:0.25 → 10:3.5:0.5), evaporation, washing with MeOH, and drying *in vacuo* gave **3** (9.3 mg, 75%). R_f ($CHCl_3$/MeOH/H_2O 10:2:0.25) 0.28. IR (CCl_4): 3286*m* (br.), 2960*s*, 2926*s*, 2855*s*, 1736*w*, 1598*w*, 1451*m*, 1376*m*, 1260*w*, 1194*w*, 1072*m*. ^{1}H-NMR ($CDCl_3$/CD_3OD/D_2O 10:7:1, 500 MHz): 0.59 (*d*, *J* = 6.5, Me); 0.75–1.20 (*m*, 15 H instead of the expected 5 H); 1.40, 1.36, 1.34 (3*s*, 4 Me); 1.42 (*s*, 15 Me); 1.86–1.69 (*m*, 70 H); 3.48 (br. *t*, *J* ≈ 8.5, 1 H); 3.51–3.68 (*m*, 4 H); 3.74 (br. *d*, *J* ≈ 12, CH−C(5)); 3.91 (br. *d*, *J* ≈ 12, CH′−C(5)); 4.80–4.95 (*m*, 18 H); 7.23 (br. *s*, H−C(3)). ^{13}C-NMR ($CDCl_3$/CD_3OD/D_2O 10:7:1, 125 MHz): some signals are hidden by the noise; 15.36–18.36 (several *q*); 22.74, 22.86 (2*q*, 2 Me) 24.64–26.26 (several *t*); 28.82 (*d*, CH); 29.11–39.58 (several *t*); 60.78 (*t*, C(5)); 63.0 (*t*, CH_2−C(5)); 64.5 (*t*, CH_2O); 67.06, 67.5, 74.21 (3*d*, C(6), C(7), C(8)); 123.75–125.34 (several *d*); 130.71–134.84 (several *s*). ^{31}P-NMR ($CDCl_3$/CD_3OD/D_2O 10:7:1, 202 MHz) 7.4. FAB-MS: 1577 (100, [M + 1]$^+$). MALDI-MS (THA (1,2,3,4-tetrahydroacridin-9-amine hydrochloride)/citrate 2:1): 1576.7 (M^+), 1599.0 ([M + Na]$^+$). ESI-FT/MS/MS: 281 (100, [M − dolichyloxy + 2]$^+$), 1577 (84, [M + 1]$^+$). HR-ESI-FT/MS: 1576.2602 (MH$^+$; calc. 1576.2588).

REFERENCES

[1] J. A. Campbell, G. J. Davies, V. Bulone, B. Henrissat, *Biochem. J.* **1997**, *326*, 929.
[2] S. Charnok, G. J. Davies, *Biochemistry* **1999**, *38*, 6369.
[3] A. Vrielink, W. Rüger, H. P. C. Driessen, P. S. Freemont, *EMBO* **1994**, *13*, 3413.
[4] E. H. Holmes, Z. Xu, A. L. Sherwood, B. A. Macher, *J. Biol. Chem.* **1995**, *270*, 8145.
[5] B. W. Murray, S. Takayama, J. Schultz, C.-W. Wong, *Biochemistry* **1996**, *35*, 11183.
[6] C. J. Britten, M. Bird, *Biochim. Biophys. Acta* **1997**, *1334*, 57.
[7] S. C. Kim, A. N. Singh, F. M. Raushel, *Arch. Biochem. Biophys.* **1988**, *267*, 54.
[8] B. W. Murray, V. Wittmann, M. D. Burkart, S.-C. Hung, C.-H. Wong, *Biochemistry* **1997**, *36*, 823.
[9] Y. Ichikawa, Y.-C. Lin, D. Dumas, G.-J. Shen, E. Garcia-Juncade, M. A. Williams, R. Bayer, C. Ketcham, L. E. Walker, J. C. Paulson, C.-H. Wong, *J. Am. Chem. Soc.* **1992**, *114*, 9283.
[10] T. Hayashi, B. W. Murray, R. Wang, C.-H. Wong, *Bioorg. Med. Chem.* **1997**, *5*, 497.
[11] L. Qiao, B. W. Murray, M. Shimazaki, J. Schultz, C. H. Wong, *J. Am. Chem. Soc.* **1996**, *118*, 7653.
[12] I. Jefferies, B. R. Bowen, *Bioorg. Med. Chem. Lett.* **1997**, *7*, 1171.
[13] S. Cai, M. R. Stroud, S. Hakomori, T. Toyokuni, *J. Org. Chem.* **1992**, *57*, 6693.
[14] R. R. Schmidt, K. Frische, *Bioorg. Med. Chem. Lett.* **1993**, *3*, 1747.
[15] R. D. Cumming, in 'Glycoconjugates, Composition, Structure, and Function', Eds. H. J. Allen and E. C. Kisailus, Marcel Dekker, New York, 1992, p. 333.
[16] N. H. Behrens, L. F. Leloir, *Proc. Natl. Acad. Sci. U.S.A.* **1970**, *66*, 153.
[17] C. J. Waechter, *Ann. Rev. Biochem.* **1976**, *45*, 95.
[18] P. Burda, M. Aebi, *Glycobiology* **1998**, *8*, 455.
[19] T. Granier, N. Panday, A. Vasella, *Helv. Chim. Acta* **1997**, *80*, 979.
[20] K. Tatsuta, S. Miura, S. Ohta, H. Gunji, *Tetrahedron Lett.* **1995**, *36*, 1085.
[21] K. Tatsuta, S. Miura, H. Gunji, *Bull. Chem. Soc. Jpn.* **1997**, *70*, 427.
[22] T. D. Heightman, M. Locatelli, A. Vasella, *Helv. Chim. Acta* **1996**, *79*, 2190.
[23] N. Panday, A. Vasella, in preparation.
[24] K. Tatsuta, S. Miura, *Tetrahedron Lett.* **1995**, *36*, 6721.
[25] T. Hirao, T. Masunaga, Y. Ohshiro, T. Agawa, *Synthesis* **1981**, 56.
[26] T. Hirao, T. Masunaga, N. Yamada, Y. Ohshiro, T. Agawa, *Bull. Chem. Soc. Jpn.* **1982**, *55*, 909.
[27] Y. Xu, J. Zhang, *Synthesis* **1984**, 778.
[28] H. Lei, M. S. Stoakes, A. W. Schwabacher, *Synthesis* **1992**, 1255.
[29] J. Lin, C. M. Thompson, *J. Heterocycl. Chem.* **1994**, *31*, 1701.
[30] N. Panday, Ph. D. Thesis, in preparation.
[31] K. Sonogashira, Y. Tohda, N. Hagihara, *Tetrahedron Lett.* **1975**, *50*, 4467.
[32] C. Cai, A. Vasella, *Helv. Chim. Acta* **1995**, *78*, 2053.

[33] T. Morita, Y. Okamoto, H. Sakurai, *Bull. Chem. Soc. Jpn.* **1978**, *51*, 2169.
[34] D. Redmore, *J. Org. Chem.* **1973**, *38*, 1306.
[35] L. A. Vargas, L. X. Miao, A. F. Rosenthal, *Biochim. Biophys. Acta* **1984**, *796*, 123.
[36] L. Qiao, J. C. Vederas, *J. Org. Chem.* **1993**, *58*, 3480.
[37] J. Coste, M.-N. Dufour, A. Pantaloni, B. Castro, *Tetrahedron Lett.* **1990**, *31*, 669.
[38] N. Galeotti, J. Coste, P. Bedos, P. Jouin, *Tetrahedron Lett.* **1996**, *37*, 3997.
[39] K. Yamauchi, F. Une, S. Tabata, M. Kinoshita, *J. Chem. Soc., Perkin Trans. 1* **1986**, 765.
[40] D. V. Patel, K. Rielly-Gauvin, D. E. Ryono, *Tetrahedron Lett.* **1990**, *31*, 5591.
[41] O. Mitsunobu, M. Eguchi, *Bull. Chem. Soc. Jpn.* **1971**, *44*, 3427.
[42] O. Mitsunobu, *Synthesis* **1981**, 1.
[43] R. Hoos, A. B. Naughton, A. Vasella, *Helv. Chim. Acta* **1992**, *75*, 1802.
[44] Y. Sakata, Y. Hirano, H. Tatemitsu, S. Misumi, H. Ochiai, H. Shibata, *Tetrahedron* **1989**, *45*, 4717.

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