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Alternative Synthesis of P-Chiral Phosphonite-Borane Complexes: Application to the Synthesis of Phostone−Phostone Dimers

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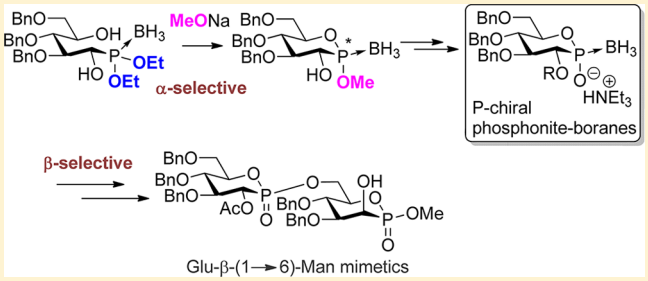
Supporting Information

ABSTRACT: An improved strategy for the synthesis of P-chiral gluco- and manno-phosphonite-borane complexes is described on the basis of the addition of diethyl phosphonite-borane to a glucal-derived aldehyde, followed by a cyclization coupled with an ethyl/methyl exchange. This direct P(III) strategy facilitates the obtention of various P-chiral phosphonite-boranes, of which further coupling reactions are described leading to the selective synthesis of two phostone dimers.



INTRODUCTION

The central role of glycans in many biological processes[1] is widely recognized, and raises the possibility of their use as therapeutics. Indeed the ability of glycans, and particularly the *β*-glucans, to boost biological responses by eliciting natural defenses such as the production of reactive oxygen species and phytoallexins, or by the stimulation of macrophages, confers strong immunostimulating[1b−d] and antitumoral[1a] effects on them. These activities are mediated by a wide range of pattern-recognition receptors, of which the lectin family is the most important. Exploitation of these natural polymers requires easy, reproducible access to well-defined samples on a large scale. The heterogeneous nature of biological extracts and the associated problems of purification favor the development of alternative sources, namely, efficient and stereoselective chemical synthesis.[2] The realization of this potential, however, is limited in part by the difficulties inherent in glycan synthesis and most pertinently by the need for the repeated formation of glycosidic bonds with very high and predictable stereoselectivity and yield.[3] Although enormous progress in glycosylation technology has been achieved in recent years,[3c,4] including the use of automated polymer-supported methods, glycan synthesis remains a highly challenging task for all but a few classes. As such we have been led to consider the synthesis of glycan mimetics as a possible alternative. Conceptually, this strategy is analogous to the frequent use of a complex biologically active natural product as the inspiration for the design of a less complex but equally potent surrogate.[5] The synthesis of glycan mimetics has been notably developed by Vasella and co-workers who described the preparation of oligomeric glycosyl acetylenes,[6] but in more recent years the field has been dominated by "Click" chemistry methods.[7] Another class of glycan-mimetics is based on the modification of the anomeric position and has been dominated by the iminosugars in which the anomeric carbon is replaced by a nitrogen atom.[8] Nevertheless, most glycan mimetics designed to date were intended as glycosidase inhibitors and not as novel surrogates for oligosaccharides, which is our current goal. Toward this end we have considered and have presented preliminary results for two mimetics of the glycosidic bond: (i) oligohydroxylamines[9] and (ii) oligophostones[10] (Figure 1).

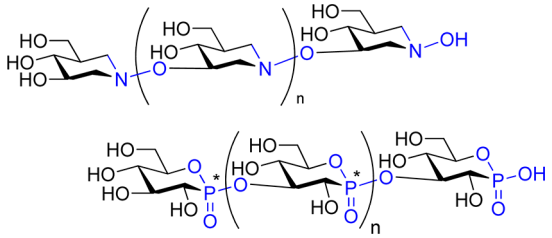


Figure 1. Oligohydroxylamines and oligophostones oligomers as glycan mimetics.

With regard to the synthesis of the oligophostones,[11,12] we have directed our attention to the use of coupling methods functioning at the P(III) oxidation level in view of their well-known superiority over P(V)-based methods in the nucleotide field.[13] In particular, we have focused our efforts on the use of the P-chiral phosphonite-boranes, air-stable analogues of the H-phosphinates,[14] as phostone donors and have described methods for their stereoselective synthesis and for the formation of mimetics of three of the four major classes of glycosidic bond (1,2-*trans*-equatorial, 1,2-*trans*-axial, and 1,2-*cis*-equatorial; Figure 2).[15] Continuing this theme, we present here

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an improved synthesis of the phosphonite-boranes and the synthesis of novel diphostones.

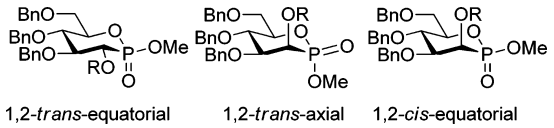
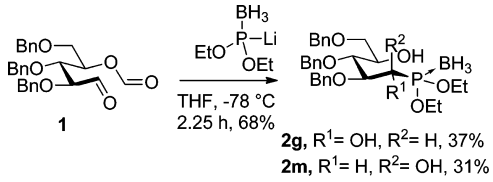


Figure 2. Three accessible classes of phostones.

RESULTS AND DISCUSSION

Gram scale reaction of the lithium salt of diethoxyphosphine-borane[16] with the glucal-derived aldehydo formate **1** in THF at −78 °C resulted in a 68% yield of the readily separable diols **2g** and **2m** with a dr of 45/55 favoring the glucoisomer (Scheme 1). Under the optimized conditions byproducts arising from the

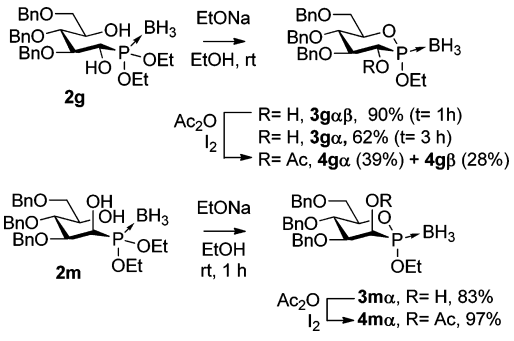
Scheme 1. Reaction of Lithio Diethoxyphosphine-Borane with a Glucal-Derived Aldehyde



retention of a formate group and/or premature cyclization were present in only trace amounts after work up of the initial reaction mixture.

Base-catalyzed cyclization was performed with the aid of catalytic sodium ethoxide in ethanol and provided the α- or β-manno- or glucophosphonites from linear **2g** or **2m**, respectively (Scheme 2). Depending on the reaction time and

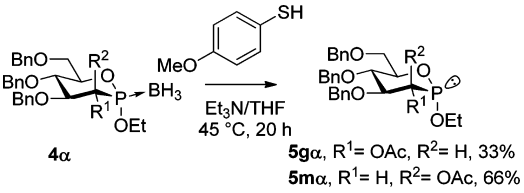
Scheme 2. Formation of Cyclic Phosphonite Boranes



base concentration, the product **3g** was obtained as a mixture of two diastereoisomers in 90% yield. However, upon standing (3 h), this mixture equilibrates to the more stable α-isomer **3g*α***, isolated as a single diastereoisomer in 62% yield.[17] In a similar manner, the manno- precursor **2m** furnished the desired cyclized compound **3m*α*** as a single diastereoisomer in 83% yield. X-ray crystallographic analysis of **3g*α*** provided the anomeric stereochemistry (see the Supporting Information), and acetylation furnished the corresponding esters **4g*α***, **4g*β*** and **4m*α*** in good yields.

De-ethylation of **4g*α*** or **4m*α*** to give the requisite phosphonite-boranes was attempted under the conditions known for methyl removal (PhSH, Et_3N)[18] at the P(III) level, albeit with no success and degradation of the substrate. The more nucleophilic 4-methoxythiophenate anion resulted unexpectedly in the total deborylation of the phosphonite-borane, yielding the two gluco- and manno- configurated P-chiral phosphonites **5g*α*** and **5m*α*** as air-stable compounds (Scheme 3).[19] Classical conditions for the removal of a methyl

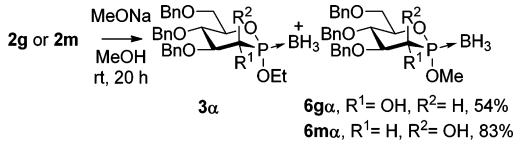
Scheme 3. Deborylation of an Ethyl Phosphonite Borane by Thiolate Anion



group at P(V) oxidation level involving the action of TMSBr[11c] left the starting material unchanged. The use of sodium iodide in refluxing acetonitrile[11d] was successful in partial de-ethylation, but was accompanied by deborylation and, more problematically, by the loss of the chiral information at the phosphorus atom.

The problematic de-ethylation step was circumvented by a transesterification to the corresponding methyl phosphonite-boranes (Table 1) and eventual known demethylation.[10] The

Table 1. Cyclization with Concomitant Ester Exchange



entry	dep	t (min)	3α/6α
1	**2g**	15	100/0
2	**2g**	55	59/41
3	**2g**	105	47/53
4	**2g**	225	39/61
5	**2m**	15	75/25
6	**2m**	40	57/43
7	**2m**	105	35/65
8	**2m**	20 h	0/100

more direct formation of the methyl phosphonite-boranes by reaction of the aldehydo formate **1** with the lithium salt of dimethoxyphosphine-borane followed by cyclization was not attempted because of the unstable and pyrophoric nature of the necessary phosphine.[20] Cyclization of ethyl phosphonite-boranes **2g** and **2m** in methanol in the presence of sodium methoxide afforded the desired cyclic methyl phosphonates **6** (Table 1). Monitoring of this reaction with LC−MS revealed the relative kinetics of cyclization and equilibration to methyl phosphonites. For the glucoisomer **2g**, the cyclization occurred very rapidly and was followed by slower transesterification of **3g*α*** to the methyl isomer **6g*α***. Consequently, under most conditions the product was obtained as a separable mixture of ethyl and methyl phosphonites, each in the form of a single α-diastereoisomer. However, with more concentrated reaction conditions, it was possible to fully exchange the ethyl group to the methyl group, enabling isolation of **6g*α*** in 54% yield. For the mannoisomer, the cyclization took place very rapidly, and equilibration to the methyl phosphonate **6m*α*** was complete

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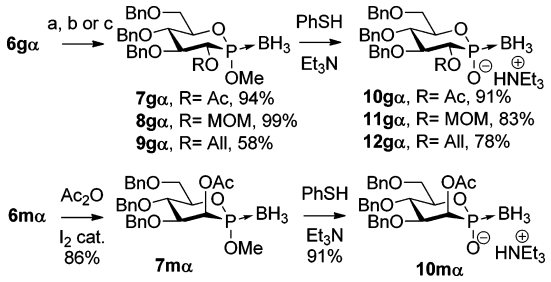
after 20 h,[21] providing the methyl phosphonite-borane **6mα** in 83% yield. Both compounds **6gα** and **6mα** were crystalline, and X-ray analysis confirmed the α-stereochemistry at phosphorus (see the Supporting Information).

The glucoconfigured methyl phosphonite-borane **6gα** was converted to the corresponding 2-*O*-acetyl, methoxymethyl, and allyl derivatives in 75, 99, and 58% yield, respectively, under standard conditions, and subsequent treatment with thiophenol and triethylamine[18] furnished the three corresponding ammonium phosphonite-boranes **10gα**, **11gα**, and **12gα** in good yields (Scheme 4). In a similar manner, the mannoisomer

Scheme 4. Formation and Isolation of Ammonium Phosphonite-Boranes[a]

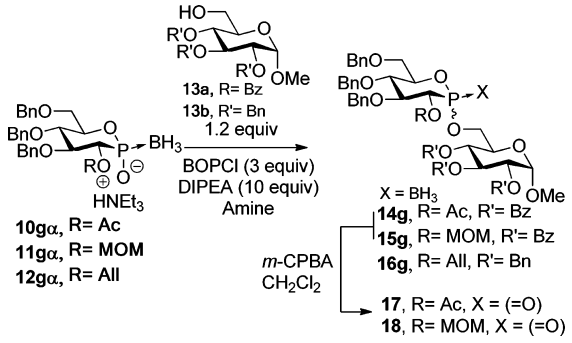


[a](a) Ac_2O, I_2 cat. (b) NaHMDS, MOMCl, THF, 0 °C. (c) NaHMDS, AllBr, THF, 0 °C.

6mα was converted to the ammonium phosphonite-borane **10mα** via acetylation and demethylation in 86 and 91% yield, respectively. Overall, the gluco- and manno-phosphonite-boranes **10gα** and **10mα**, whose spectral data agree fully with that of the samples prepared earlier by the original route,[10,22] are obtained by this approach in only four steps (global yield 17−20%) from the aldehyde **1**.

With an improved synthesis of the ammonium phosphonite-boranes **10**−**12** in hand, we briefly turned our attention to the influence of the 2-*O*-protecting group on coupling stereoselectivity and to the preparation of phostone dimers. The new strategy for the preparation of phosphonite-boranes presented here afforded the opportunity for the synthesis of 2-*O*-allyl and MOM-protected phosphonite-boranes and thus the chance to explore the influence of these protecting groups on coupling selectivity.[23] The reaction of the novel phosphonite-boranes **11gα** and **12gα** with alcohols **13** was investigated in the presence of BOPCl, 3-nitro-1,2,4-triazole (NT) or DMAP as the amine catalyst in various solvents (Table 2) and the α/β ratios of the coupled products were measured by ^{31}P or ^{1}H NMR of the crude reaction mixtures. In some cases, to circumvent problems of partial deborylation of the products, the crude coupling reaction mixtures were treated with *m*-CPBA before isolation so as to afford the more stable P(V) oxidation state.[24] The MOM-protected compound showed moderate β-diastereoselectivity and reactivity with NT in THF and PhMe (Table 2, entries 1 and 2) but did not furnish any coupling product in CH_2Cl_2 (Table 2, entry 3). With the DMAP as the nucleophilic partner in THF and PhMe (Table 2, entries 4 and 5), the equatorial product **15gβ** predominates, corresponding to a preponderance of inversion in accordance with our previous findings in the 2-*O*-acetyl series.[10] On the other hand, the DMAP/CH_2Cl_2 system furnished the axial compound as the major diastereoisomer (**15gβ**/**15gα**: 1/1.7), thereby providing the first entry to this configuration in the

Table 2. Influence of the 2-*O*-Protecting Group and Reaction Conditions on Coupling Stereoselectivity



entry	R	amine/solvent	α/β ratio	yield[a] (%)
1	**MOM**	NT/THF	0.4/1	15
2	**MOM**	NT/PhMe	0.2/1	28
3	**MOM**	NT/CH_2Cl_2	–	0
4	**MOM**	DMAP/THF	0.1/1	45[b]
5	**MOM**	DMAP/PhMe	0/1	66[b]
6	**MOM**	DMAP/CH_2Cl_2	1.7/1	62[b]
7	**Ac**	DMAP/CH_2Cl_2	0.2/1	68[b]
8	**All**	NT/THF	0.6/1	ND[c]
9	**All**	DMAP/PhMe	0.2/1	ND[c]
10	**All**	DMAP/CH_2Cl_2	2/1	ND[c]

[a]Isolated yields. [b]α/β ratio was measured after *m*-CPBA oxidation. [c]α/β ratio was measured by ^{31}P NMR on the crude reaction mixture.

glucose series. To confirm this tendency, **10gα** was reacted with **13a** in the DMAP/CH_2Cl_2 conditions, leading to the β adduct, and confirming the influence of the anchimeric assistance. With a 2-*O*-allyl ether **12gα**, the β isomer **16gβ** was obtained as the major component under both NT/THF and DMAP/PhMe conditions (Table 2, entries 8 and 9). Gratifingly, however, the DMAP/CH_2Cl_2 system favored again the α-diastereoisomer **16gα** (Table 2, entry 10).

Turning to the synthesis of diphostones, the glucophostone **19gα**[10] was selectively debenzylated at the 6-position with concomitant acetylation by the action of acetic anhydride in the presence of trifluoroacetic acid,[25] and exposure of the crude reaction mixture to molecular sieves[26] in methanol[27] furnished a separable mixture of mono- and di-deprotected compounds **21gα** and **22gα** in a 61% overall yield for both steps. In the same manner, the mannophostone **19mβ**[10] was selectively debenzylated and acetylated at the 6-position to furnish the diacetate **20mβ** in 90% yield. In this case, epimerization at phosphorus could not be avoided during the deprotection by sodium methoxide, and we obtained a separable mixture of diols **21mα** and **21mβ** in 93% yield (Scheme 5).[28]

The key coupling step was accomplished by reaction of the phosphonite-borane **10gα** with alcohol **22gα** under the conditions previously established, in the presence of BOPCl and DMAP in THF, affording the targeted dimer **23gβ** in 77% yield after *m*-CPBA oxidation. When diol **21gα** was employed as acceptor under the same conditions, the yield of diphostone **24gβ** dropped to a nevertheless respectable 58%. In both cases, coupling proceeded with complete β-stereoselectivity at phosphorus and, most notably, with total regioselectively for the 6-position of **21g**−**22g**. In the same manner, reaction of **10gα** with diol **21mβ** furnished stereoselectively and regioselectively the mixed β-(1→6)-gluco-mannophostone dimer **25gβ** in 63% yield (Scheme 6).

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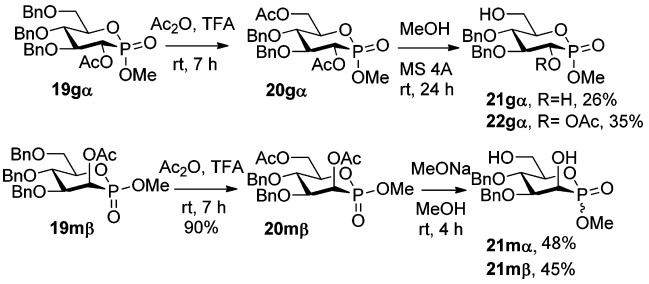
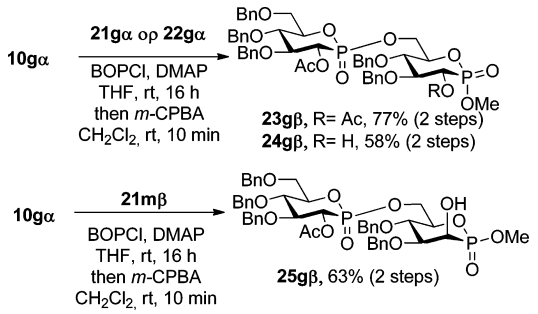
Scheme 5. Regioselective Monodebenzylation of Tri-*O*-benzylphostones



Scheme 6. Formation of Diphostones



CONCLUSION

In conclusion, we have established a novel strategy for the efficient synthesis of P-chiral phosphonite-boranes, which are key intermediates in the stereoselective synthesis of glycomimetics. This strategy is considerably shorter than our previous route and offers a la carte access to differently protected gluco- and manno-*H*-phosphinates. The gluco-configured phosphonite-borane **10gα** was successfully engaged in the synthesis of *β*-(1→6)-pseudodisaccharides **23**−**25** containing two phostone rings, potential mimetics of the Glu-*β*-(1→6)-Glu and Glu-*β*-(1→6)-Man disaccharides.

EXPERIMENTAL SECTION

General Information. Reactions were performed using oven-dried glassware under an atmosphere of argon. All separations were carried out under flash-chromatographic conditions on silica gel (prepacked column, 230−400 mesh) at medium pressure (20 psi). Reactions were monitored by thin-layer chromatography on silica gel plates (60 F_{254} aluminum sheets), which were rendered visible by ultraviolet and/or spraying with phosphomolybdic acid (10%) in EtOH or vanillin (15%) + sulfuric acid (2.5%) in EtOH followed by heating. THF, CH_2Cl_2, DMF, MeOH and MTBE (i.e., methyl *tert*-butyl ether) were purchased at the highest commercial quality and used without further purification. Reagent-grade chemicals were obtained from diverse commercial suppliers and were used as received. ^{1}H NMR (500 or 300 MHz) and ^{13}C NMR (125 or 75 MHz) spectra were recorded at 298 K. Chemical shifts are given in ppm (δ) and are referenced to the internal solvent signal or to TMS used as an internal standard. Multiplicities are declared as follows: s (singlet), brs (broad singlet), d (doublet), t (triplet), q (quadruplet), dd (doublet of doublet), ddd (doublet of doublet of doublet), dt (doublet of triplet), m (multiplet), AB = AB quartet, ABX = ABX system. Coupling constants *J* are given in Hz. Carbon multiplicities were determined by DEPT135 experiment. Diagnostic correlations were obtained by two-dimensional COSY, HSQC and HMBC experiments. Infrared spectra (IR) were recorded on a FT-IR system and the data are reported in reciprocal centimeters (cm^{-1}). $[\alpha]^{t\,(^oC)}_D$ is expressed in deg cm^3 g^{-1} dm^{-1}, and *c* is expressed in g/100 cm^3. Melting points were recorded in open capillary tubes and are uncorrected. High resolution mass spectra (HRMS) were determined by electrospray ionization (ESI).

Diethyl ((1*R*,2*S*,3*R*,4*R*)-2,3,5-tris(benzyloxy)-1,4-dihydroxypentyl)phosphonite-borane 2m and Diethyl ((1*S*,2*S*,3*R*,4*R*)-2,3,5-tris(benzyloxy)-1,4-dihydroxypentyl)phosphonite-borane 2g. To a solution of diethoxyphosphine-borane (4.08 g, 30 mmol) in THF (40 mL) at −78 °C under an argon atmosphere was added dropwise *n*-BuLi (17.5 mL, 25 mmol, 1.43 M solution in hexane) over 30 min. The resulting solution was stirred for 30 min, and the addition of the solution of aldehyde **1** (4.48 g, 10 mmol) in THF (30 mL) was performed dropwise over a 45 min period. The resulting solution was stirred for 1 h 30 min at −78 °C, quenched by addition of an aqueous solution of HCl (2 M), and extracted twice by methyl *tert*-butylether (MTBE). The combined organic layers were washed by brine, dried over $MgSO_4$, filtered and concentrated under a vacuum. The crude mixture was purified by chromatography on silica gel (eluent: EtOAc/heptane, 1/4), yielding the two diastereoisomers **2m** (1.70 g, 3.06 mmol, 31%) and **2g** (2.07 g, 3.72 mmol, 37%) as colorless oils. Data for **2m**: R_f = 0.15 (EtOAc/heptane, 1:4); $[\alpha]^{24}_D$ = +0.22 (*c* 1.4, $CHCl_3$); IR (neat) ν_{max} 3428, 3031, 2982, 2906, 2869, 2392, 1497, 1454, 1391, 1363, 1069, 1026 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.39−7.25 (m, 15H), 4.70 (d, *J* = 11.2 Hz, 1H), 4.65 (d, *J* = 10.8 Hz, 1H), 4.61 (d, *J* = 10.9 Hz, 1H), 4.55 (d, *J* = 11.2 Hz, 1H), 4.53 (d, *J* = 11.9 Hz, 1H), 4.48 (d, *J* = 11.8 Hz, 1H), 4.29 (t, *J* = 6.1 Hz, 1H), 4.20−4.01 (m, 7H), 3.64−3.55 (m, 2H), 1.30 (t, *J* = 7.1 Hz, 3H), 1.22 (t, *J* = 7.1 Hz, 3H), 1.16−0.00 (br s, 3H); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 138.0 (C_q), 137.6 (C_q), 137.5 (C_q), 128.7 (2× CH), 128.6 (2× CH), 128.6 (2× CH), 128.5 (2× CH), 128.4 (CH), 128.2 (3× CH), 128.0 (CH), 79.4 (d, *J* = 4.4 Hz, CH), 76.4 (d, *J* = 11.0 Hz, CH), 73.7 (CH_2), 73.2 (CH_2), 72.6 (CH_2), 71.4 (d, *J* = 63.1 Hz, CH), 71.2 (CH_2), 70.3 (CH), 64.3 (CH_2), 64.2 (CH_2), 16.7 (d, *J* = 5.5 Hz, CH_3), 16.6 (d, *J* = 5.5 Hz, CH_3). ^{31}P NMR (122 MHz, $CDCl_3$) δ 140.0−139.0 (m); HRMS (ESI-TOF) calcd for $C_{30}H_{42}BO_7PNa$ $[M + Na]^+$ 579.2659, found 579.2665. Data for **2g**: R_f = 0.13 (EtOAc/heptane, 1:4); $[\alpha]^{24}_D$ = +1.63 (*c* 1.0, $CHCl_3$); IR (neat) ν_{max} 3507, 3031, 2982, 2906, 2868, 2384, 1454, 1391, 1363, 1071, 1022 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.36−7.25 (m, 13H), 7.23−7.17 (m, 2H), 4.70 (s, 2H), 4.57 (d, *J* = 11.2 Hz, 1H), 4.56 (d, *J* = 12.0 Hz, 1H), 4.48 (d, *J* = 11.9 Hz, 1H), 4.43 (d, *J* = 11.2 Hz, 1H), 4.24 (dd, *J* = 1.1 and 4.0 Hz, 1H), 4.22−4.01 (m, 6H), 3.75 (ddd, *J* = 2.1 and 5.0 and 7.3 Hz, 1H) 3.70−3.58 (m, 2H), 1.30 (t, *J* = 7.1 Hz, 3H), 1.26 (t, *J* = 7.1 Hz, 3H), 1.20−(−0.15) (br s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 138.2 (C_q), 137.8 (C_q), 137.6 (C_q), 128.6 (6× CH), 128.4 (3× CH), 128.2 (CH), 128.1 (CH), 128.0 (3× CH), 127.9 (CH), 77.0 (d, *J* = 11.5 Hz, CH), 76.2 (d, *J* = 6.6 Hz, CH), 74.1 (CH_2), 73.6 (2× CH_2), 71.7 (CH), 71.1 (CH_2), 70.1 (d, *J* = 62.6 Hz, CH), 64.3 (d, *J* = 4.9 Hz, CH_2), 64.2 (d, *J* = 5.5 Hz, CH_2), 16.7 (d, *J* = 5.5 Hz, CH_3), 16.6 (d, *J* = 5.5 Hz, CH_3). ^{31}P NMR (122 MHz, $CDCl_3$) δ 140.5−138.5 (m); HRMS (ESI-TOF) calcd for $C_{30}H_{42}BO_7PNa$ $[M + Na]^+$ 579.2659, found 579.2683.

(2*S*,3*S*,4*S*,5*S*,6*R*)-2-Boranyl-4,5-bis(benzyloxy)-6-((benzyloxy)methyl)-2-ethoxy-1,2-oxaphosphinan-3-ol 3g*α*. To a solution of phosphonate **2g** (380 mg, 0.68 mmol) in dry EtOH (3 mL) was added EtONa (10 wt % solution in EtOH, 3 drops). The resulting solution was stirred at room temperature for 1 h. Dowex H^+ was then added, and the mixture was further stirred for 10 min, filtered, and evaporated under a vacuum. The crude mixture was purified by column chromatography on silica gel (eluent: EtOAc/heptane, 1:4), yielding the product as an unseparable mixture of two diastereoisomers **3g*αβ*** (313 mg, 0.61 mmol, 90%). Pure **3g*α*** was obtained when the reaction was performed in similar manner from **2g** (60 mg, 0.108 mmol) during 3 h, furnishing **3g*α*** (34 mg, 0.067 mmol, 62%): R_f = 0.32 (EtOAc/heptane, 1:2); mp 85.7−86.5 °C; $[\alpha]^{23}_D$ = +68.2 (*c* 1.0, $CHCl_3$); IR (neat) ν_{max} 3479, 3031, 2983, 2908, 2869, 2397, 1454, 1361, 1106, 1057, 1026, 962, 734, 696 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.37−7.26 (m, 13H), 7.20−7.13 (m, 2H), 4.92 (d, *J* = 11.2 Hz, 1H), 4.84 (d, *J* = 10.6 Hz, 1H), 4.84 (d, *J* = 11.2 Hz, 1H), 4.62 (d, *J* = 12.0 Hz, 1H), 4.60 (d, *J* = 10.6 Hz, 1H), 4.54 (d, *J* = 12.0 Hz, 1H), 4.26−4.16 (m, 3H), 3.98−3.89 (m, 2H), 3.84 (dd, *J* = 3.5 and 11.2 Hz, 1H), 3.76 (t, *J* = 9.6 Hz, 1H), 3.73 (dd, *J* = 1.9 and 11.3 Hz, 1H), 1.34

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(t, J = 7.1 Hz, 3H), 0.98−0.13 (br s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 138.3 (C_q), 137.9 (C_q), 137.8 (C_q), 128.8 (2× CH), 128.7 (2× CH), 128.6 (2× CH), 128.2 (2× CH), 128.2 (2× CH), 128.1 (2× CH), 128.0 (2× CH), 128.0 (CH), 82.9 (d, J = 1.1 Hz, CH), 77.5 (CH), 76.7 (d, J = 11.0 Hz, CH), 76.4 (CH_2), 75.8 (CH_2), 73.9 (CH_2), 71.7 (d, J = 58.7 Hz, CH), 68.9 (d, J = 7.3 Hz, CH_2), 65.4 (d, J = 2.7 Hz, CH_2), 16.8 (d, J = 4.6 Hz, CH_3). ^{31}P NMR (122 MHz, $CDCl_3$) δ 132.0 (br s); HRMS (ESI-TOF) calcd for $C_{28}H_{36}BNaO_6P$ $[M + Na]^+$ 533.2240, found 533.2221.

(2*S*,3*R*,4*S*,5*S*,6*R*)-2-Boranyl-4,5-bis(benzyloxy)-6-((benzyloxy)methyl)-2-ethoxy-1,2-oxaphosphinan-3-ol 3g*α*. To a solution of phosphonate **2m** (330 mg, 0.59 mmol) in dry EtOH (2.5 mL) was added EtONa (10 wt % solution in EtOH, 3 drops). The resulting solution was stirred at room temperature for 1 h. Dowex H^+ was then added, and the mixture was further stirred for 10 min, filtered, and evaporated under a vacuum. The crude mixture was purified by column chromatography on silica gel (eluent: EtOAc/heptane, 1:4), yielding the product **3g*α*** as a colorless solid (250 mg, 0.49 mmol, 83%): R_f = 0.32 (EtOAc/heptane, 1:2); $[\alpha]^{23}_D$ = +38.8 (c 1.0, $CHCl_3$); IR (neat) ν_{max} 3345, 3064, 3031, 2906, 2869, 2396, 1454, 1364, 1094, 1025, 967 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.37−7.26 (m, 13H), 7.20−7.15 (m, 2H), 4.86 (d, J = 10.6 Hz, 1H), 4.71 (s, 2H), 4.64 (d, J = 12.1 Hz, 1H), 4.56 (d, J = 12.1 Hz, 1H), 4.55 (d, J = 10.6 Hz, 1H), 4.20−4.10 (m, 4H), 4.04 (t, J = 9.5 Hz, 1H), 4.02 (dd, J = 2.8 and 9.3 Hz, 1H), 3.82 (dd, J = 4.3 and 11.2 Hz, 1H), 3.82 (dd, J = 1.6 and 11.2 Hz, 1H), 2.84−2.19 (br s, 1H), 1.29 (t, J = 6.9 Hz, 3H), 0.98−0.13 (br s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 138.1 (C_q), 137.9 (C_q), 137.5 (C_q), 128.8 (2× CH), 128.6 (2× CH), 128.6 (2× CH), 128.3 (CH), 128.3 (2× CH), 128.2 (2× CH), 128.1 (CH), 128.0 (2× CH), 127.9 (CH), 80.0 (d, J = 1.8 Hz, CH), 77.7 (d, J = 11.0 Hz, CH), 76.0 (CH_2), 73.8 (CH_2), 73.5 (d, J = 3.7 Hz, CH), 72.6 (CH_2), 69.3 (d, J = 7.3 Hz, CH_2), 67.2 (d, J = 62.3 Hz, CH), 64.7 (d, J = 3.7 Hz, CH_2), 16.7 (d, J = 4.6 Hz, CH_3). ^{31}P NMR (122 MHz, $CDCl_3$) δ 133.4 (br s); HRMS (ESI-TOF) calcd for $C_{28}H_{40}BNO_6P$ $[M + NH_4]^+$ 528.2686, found 528.2664.

(2*S*,3*S*,4*S*,5*S*,6*R*)-2-Boranyl-4,5-bis(benzyloxy)-6-((benzyloxy)methyl)-2-ethoxy-1,2-oxaphosphinan-3-yl acetate 4g*α* and (2*R*,3*S*,4*S*,5*S*,6*R*)-2-Borane-4,5-bis(benzyloxy)-6-((benzyloxy)methyl)-2-ethoxy-1,2-oxaphosphinan-3-yl acetate 4g*β*. To a mixture of both diastereoisomers **3g*α*** and **3g*β*** (300 mg, 0.588 mmol) in Ac_2O (2 mL) was added a catalytic amount of I_2 (10 mg). The resulting mixture was stirred at room temperature for 6 h. It was then quenched by careful addition of saturated aqueous $NaHCO_3$ and stirred for 30 min. The mixture was then extracted twice by EtOAc. Combined organic layers were washed by brine, dried over $MgSO_4$, filtered and concentrated under a vacuum. The crude mixture was purified by chromatography on silica gel (eluent: EtOAc/heptane, 1/3), yielding the two diastereoisomers **4g*β*** (89 mg, 0.165 mmol, 28%) and **4g*α*** (122 mg, 0.23 mmol, 39%) as colorless oils. Data for **4g*β***: R_f = 0.44 (EtOAc/heptane, 1:2); $[\alpha]^{24}_D$ = +51.6 (c 1.0, $CHCl_3$); IR (neat) ν_{max} 3064, 3031, 2925, 2870, 2398, 1750, 1454, 1368, 1219, 1054, 1025, 971 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.40−7.25 (m, 13H), 7.20−7.15 (m, 2H), 5.35 (dd, J = 8.5 and 8.9 Hz, 1H), 4.85 (d, J = 11.7 Hz, 1H), 4.84 (d, J = 11.5 Hz, 1H), 4.74 (d, J = 11.5 Hz, 1H), 4.61 (d, J = 12.0 Hz, 1H), 4.61 (d, J = 10.7 Hz, 1H), 4.53 (d, J = 12.0 Hz, 1H), 4.29−4.11 (m, 3H), 4.05 (dt, J = 2.6 and 9.2 Hz, 1H), 4.00 (t, J = 9.4 Hz, 1H), 3.86 (dt, J = 2.7 and 11.0 Hz, 1H), 3.75 (dd, J = 2.1 and 11.1 Hz, 1H), 2.05 (s, 3H), 1.31 (t, J = 7.2 Hz, 3H), 1.00−(−0.13) (br s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 169.8 (d, J = 2.7 Hz, C_q), 138.0 (C_q), 137.9 (C_q), 137.8 (C_q), 128.7 (6× CH), 128.2 (CH), 128.1 (2× CH), 128.1 (2× CH), 127.9 (2× CH), 127.8 (2× CH), 82.2 (d, J = 11.0 Hz, CH), 76.9 (d, J = 5.5 Hz, CH), 76.9 (d, J = 1.6 Hz, CH), 75.7 (CH_2), 75.7 (CH_2), 73.8 (CH_2), 71.8 (d, J = 50.0 Hz, CH), 68.8 (d, J = 7.1 Hz, CH_2), 65.0 (d, J = 5.5 Hz, CH_2), 20.8 (CH_3), 16.5 (d, J = 5.5 Hz, CH_3). ^{31}P NMR (122 MHz, $CDCl_3$) δ 140.1−137.3 (m); HRMS (ESI-TOF) calcd for $C_{30}H_{42}BNO_7P$ $[M + NH_4]^+$ 570.2792, found 570.2784. Data for **4g*α***: R_f = 0.26 (EtOAc/heptane, 1:3); $[\alpha]^{24}_D$ = +94.2 (c 1.2, $CHCl_3$); IR (neat) ν_{max} 3064, 3031, 2936, 2870, 2400, 1760, 1454, 1368, 1215, 1054, 1025, 977 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.40−7.22 (m, 13H), 7.20−7.10 (m, 2H), 5.46 (dd, J = 9.1 and 10.5 Hz, 1H), 4.87 (d, J = 11.2 Hz, 1H), 4.83 (d, J = 10.6 Hz, 1H), 4.70 (d, J = 11.4 Hz, 1H), 4.65 (d, J = 12.1 Hz, 1H), 4.61 (d, J = 10.6 Hz, 1H), 4.57 (d, J = 12.1 Hz, 1H), 4.32−4.16 (m, 3H), 4.09 (dt, J = 2.4 and 10.4 Hz, 1H), 3.89 (t, J = 9.7 Hz, 1H), 3.87 (dd, J = 5.2 and 11.5 Hz, 1H), 3.76 (dd, J = 1.9 and 12.2 Hz, 1H), 2.00 (s, 3H), 1.34 (t, J = 7.1 Hz, 3H), 1.00−(−0.13) (br s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 169.1 (d, J = 3.3 Hz, C_q), 138.1 (C_q), 137.9 (C_q), 137.6 (C_q), 128.7 (2× CH), 128.6 (5× CH), 128.2 (2× CH), 128.0 (2× CH), 128.0 (2× CH), 127.7 (2× CH), 80.9 (CH), 77.8 (CH), 76.9 (d, J = 11.0 Hz, CH), 76.1 (CH_2), 75.9 (CH_2), 73.8 (CH_2), 70.1 (d, J = 57.1 Hz, CH), 68.7 (d, J = 7.7 Hz, CH_2), 65.3 (d, J = 2.2 Hz, CH_2), 20.6 (CH_3), 16.7 (d, J = 4.4 Hz, CH_3). ^{31}P NMR (122 MHz, $CDCl_3$) δ 131.7−129.8 (m); HRMS (ESI-TOF) calcd for $C_{30}H_{42}BNO_7P$ $[M + NH_4]^+$ 570.2792, found 570.2784.

(2*S*,3*R*,4*S*,5*S*,6*R*)-2-Boranyl-4,5-bis(benzyloxy)-6-((benzyloxy)methyl)-2-ethoxy-1,2-oxaphosphinan-3-yl acetate 4m*α*. To a solution of alcohol **3m*α*** (23 mg, 0.045 mmol) in Ac_2O (1 mL) was added a catalytic amount of I_2 (1 mg). The resulting mixture was stirred at room temperature for 24 h. It was then quenched by careful addition of saturated aqueous $NaHCO_3$ and stirred for 30 min. The mixture was then extracted twice by EtOAc. Combined organic layers were washed by brine, dried over $MgSO_4$, filtered and concentrated under a vacuum, yielding the acetate **4m*α*** (24 mg, 0.0435 mmol, 97%): R_f = 0.29 (EtOAc/heptane, 1:3); $[\alpha]^{24}_D$ = +4.7 (c 1.9, $CHCl_3$); IR (neat) ν_{max} 3064, 3031, 2934, 2405, 1753, 1497, 1454, 1368, 1216, 1095, 1052, 1021, 967 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.39−7.28 (m, 13H), 7.23−7.16 (m, 2H), 5.79 (t, J = 2.9 Hz, 1H), 4.90 (d, J = 10.5 Hz, 1H), 4.77 (d, J = 10.9 Hz, 1H), 4.70 (d, J = 12.1 Hz, 1H), 4.60 (d, J = 12.1 Hz, 1H), 4.56 (d, J = 10.8 Hz, 1H), 4.55 (d, J = 11.0 Hz, 1H), 4.28−4.15 (m, 3H), 4.12 (dd, J = 3.1 and 9.6 Hz, 1H), 4.00 (t, J = 9.8 Hz, 1H), 3.91 (dd, J = 3.8 and 10.9 Hz, 1H), 3.79 (dd, J = 1.7 and 11.3 Hz, 1H), 2.21 (s, 3H), 1.34 (t, J = 7.1 Hz, 3H), 1.09−(−0.10) (br s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 169.9 (d, J = 3.7 Hz, C_q), 138.2 (C_q), 137.9 (C_q), 137.4 (C_q), 128.7 (2× CH), 128.6 (2× CH), 128.6 (2× CH), 128.5 (2× CH), 128.3 (CH), 128.2 (CH), 128.0 (2× CH), 127.9 (CH), 78.4 (CH), 77.9 (d, J = 11.9 Hz, CH), 76.0 (CH_2), 73.9 (d, J = 3.7 Hz, CH), 73.8 (CH_2), 72.0 (CH_2), 69.3 (d, J = 7.3 Hz, CH_2), 66.2 (d, J = 63.2 Hz, CH), 65.1 (d, J = 2.7 Hz, CH_2), 21.0 (CH_3), 16.7 (d, J = 4.6 Hz, CH_3). ^{31}P NMR (122 MHz, $CDCl_3$) δ 133.8−130.0 (m); HRMS (ESI-TOF) calcd for $C_{30}H_{42}BNO_7P$ $[M + NH_4]^+$ 570.2792, found 570.2787.

(2*S*,3*S*,4*S*,5*S*,6*R*)-4,5-Bis(benzyloxy)-6-((benzyloxy)methyl)-2-ethoxy-1,2-oxaphosphinan-3-yl acetate 5g*α*. To a solution of phosphonite-borane **4g*α*** (120 mg, 0.21 mmol) in THF (2 mL) was added Et_3N (603 μL, 4.35 mmol) and thiophenol (609 mg, 4.35 mmol). The resulting solution was stirred at 45 °C for 20 h. It was then concentrated under a vacuum and purified by column chromatography on silica gel (eluent: EtOAc/heptane, 1:7), yielding the phosphonite **5g*α*** as a colorless oil (68 mg, 0.07 mmol, 33%): R_f = 0.30 (EtOAc/heptane, 1:3); $[\alpha]^{24}_D$ = +184.0 (c 0.3, $CHCl_3$); IR (neat) ν_{max} 3032, 2929, 1744, 1454, 1369, 1230, 1089, 1043 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.39−7.20 (m, 13H), 7.20−7.10 (m, 2H), 4.99 (dd, J = 10.4 and 25.6 Hz, 1H), 4.83 (d, J = 11.3 Hz, 1H), 4.82 (d, J = 10.5 Hz, 1H), 4.72 (d, J = 11.3 Hz, 1H), 4.64 (d, J = 12.2 Hz, 1H), 4.54 (d, J = 11.8 Hz, 2H), 4.28−4.19 (m, 1H), 4.15 (t, J = 10.3 Hz, 1H), 4.04−3.91 (m, 2H), 3.84 (dd, J = 3.7 and 10.8 Hz, 1H), 3.75 (t, J = 9.6 Hz, 1H), 3.68 (dd, J = 2.0 and 10.5 Hz, 1H), 2.00 (s, 3H), 1.28 (t, J = 6.9 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 170.3 (d, J = 3.7 Hz, C_q), 138.8 (C_q), 138.2 (2× C_q), 128.6 (2× CH), 128.6 (3× CH), 128.5 (2× CH), 128.2 (2× CH), 128.0 (2× CH), 127.8 (CH), 127.7 (CH), 127.7 (2× CH), 81.0 (CH), 78.4 (CH), 75,9 (CH_2), 75.7 (CH_2), 74.8 (d, J = 114.2 Hz, CH), 73.9 (CH), 73.7 (CH), 65.9 (d, J = 22 Hz, CH_2), 20.9 (CH_3), 17.6 (d, J = 5.5 Hz, CH_3). ^{31}P NMR (122 MHz, $CDCl_3$) δ 145.5; HRMS (ESI-TOF) calcd for $C_{30}H_{36}PO_7$ $[M + H]^+$ 539.2199, found 539.2141.

(2*S*,3*R*,4*S*,5*S*,6*R*)-4,5-Bis(benzyloxy)-6-((benzyloxy)methyl)-2-ethoxy-1,2-oxaphosphinan-3-yl acetate 5m*α*. To a solution of phosphonite-borane **4m*α*** (143 mg, 0.26 mmol) in THF (2.5 mL) was added Et_3N (720 μL, 5.18 mmol) and thiophenol (725 mg, 5.18 mmol). The resulting solution was stirred at 45 °C for 20 h. It was

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then concentrated under a vacuum and purified by column chromatography on silica gel (eluent: EtOAc/heptane, 1:7), yielding the phosphonite **5mα** as a colorless oil (93 mg, 0.173 mmol, 66%): R_f = 0.33 (EtOAc/heptane, 1:3); $[\alpha]^{24}_D$ = +24.3 (*c* 0.8, $CHCl_3$); IR (neat) ν_{max} 3031, 2929, 2893, 1743, 1454, 1368, 1228, 1093, 1040 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.41−7.23 (m, 13H), 7.19−7.10 (m, 2H), 5.42 (dd, *J* = 3.3 and 15.2 Hz, 1H), 4.86 (d, *J* = 10.5 Hz, 1H), 4.71 (d, *J* = 11.0 Hz, 1H), 4.68 (d, *J* = 12.2 Hz, 1H), 4.56 (d, *J* = 12.2 Hz, 1H), 4.51 (d, *J* = 11.0 Hz, 1H), 4.49 (d, *J* = 10.5 Hz, 1H), 4.25−4.16 (m, 1H), 4.12 (dd, *J* = 3.4 and 9.6 Hz, 1H), 4.01−4.82 (m, 4H), 3.71 (dd, *J* = 1.9 and 10.9 Hz, 1H), 2.19 (s, 3H), 1.26 (t, *J* = 7.0 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 170.7 (d, *J* = 2.2 Hz, C_q), 138.5 (C_q), 138.4 (C_q), 138.2 (C_q), 128.5 (6× CH), 128.3 (2× CH), 128.2 (2× CH), 128.0 (2× CH), 127.9 (CH), 127.8 (CH), 127.7 (CH), 79.0 (CH), 75.8 (CH_2), 75.0 (d, *J* = 7.7 Hz, CH), 74.7 (d, *J* = 4.9 Hz, CH), 73.7 (CH_2), 71.9 (CH), 71.8 (CH_2), 70.1 (d, *J* = 3.3 Hz, CH_2), 65.6 (d, *J* = 20.9 Hz, CH_2), 21.3 (CH_3), 17.4 (d, *J* = 6.0 Hz, CH_3). ^{31}P NMR (122 MHz, $CDCl_3$) δ 146.5; HRMS (ESI-TOF) calcd for $C_{30}H_{36}PO_7$ $[M + H]^+$ 539.2199, found 539.2189.

(2*S*,3*S*,4*S*,5*S*,6*R*)-2-Boranyl-4,5-bis(benzyloxy)-6-((benzyloxy)methyl)-2-methoxy-1,2-oxaphosphinan-3-ol 6gα. To a solution of phosphonate **2g** (542 mg, 0.9759 mmol) in dry MeOH (7 mL) was added MeONa (25 wt % solution in MeOH, 30 drops). The resulting solution was stirred at room temperature overnight. Dowex H^+ was then added, and the mixture was further stirred for 10 min, filtered, and evaporated under a vacuum. The crude mixture was purified on silica gel (eluent: EtOAc/heptane 1:2), yielding the product **6gα** as a colorless oil (260 mg, 0.52 mmol, 54%): mp 85.2−87.0 °C; $[\alpha]^{23}_D$ = +74.6 (*c* 1.5, $CHCl_3$); IR (neat) ν_{max} 3490, 3064, 3031, 2921, 2869, 2398, 1454, 1361, 1106, 1056, 1026, 973, 736, 697 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.38−7.25 (m, 13H), 7.20−7.11 (m, 2H), 4.91 (d, *J* = 11.1 Hz, 1H), 4.84 (d, *J* = 10.5 Hz, 1H), 4.82 (d, *J* = 11.1 Hz, 1H), 4.62 (d, *J* = 11.9 Hz, 1H), 4.60 (d, *J* = 10.5 Hz, 1H), 4.54 (d, *J* = 12.1 Hz, 1H), 4.22−4.13 (m, 1H), 3.99−3.89 (m, 2H), 3.87−3.79 (m, 1H), 3.83 (d, *J* = 10.9 Hz, 3H), 3.79−3.69 (m, 2H), 2.49−2.05 (br s, 1H), 1.22−(−0.08) (m, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 138.2 (C_q), 137.9 (C_q), 137.8 (C_q), 128.8 (2× CH), 128.7 (2× CH), 128.7 (2× CH), 128.2 (CH), 128.2 (CH), 128.1 (3× CH), 128.0 (2× CH), 128.0 (2× CH), 82.9 (d, *J* = 1.6 Hz, CH), 77.4 (CH), 76.7 (CH), 76.4 (CH_2), 75.8 (CH_2), 73.8 (CH_2), 71.7 (d, *J* = 58.7 Hz, CH), 68.8 (d, *J* = 7.1 Hz, CH_2), 55.3 (d, *J* = 3.3 Hz, CH_3); ^{31}P NMR (122 MHz, $CDCl_3$) δ 136.6−133.3 (m); HRMS (ESI-TOF) calcd for $C_{27}H_{38}BNO_6P$ $[M + NH_4]^+$ 514.2530, found 514.2532. In some cases, the β isomer was isolated and characterized. Data for **6gβ**: R_f = 0,17 (EtOAc/heptane, 1:3); $[\alpha]^{26}_D$ = +42.0 (*c* 0.7, $CHCl_3$); IR (neat) ν_{max} 3502, 3030, 2868, 2376, 1454, 1062, 1029, 969, 738, 698 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 7.34−7.29 (m, 13H), 7.18−7.16 (m, 2H), 4.86 (d, *J* = 11.2 Hz, 1H), 4.83 (d, *J* = 10.7 Hz, 1H), 4.81 (d, *J* = 11.2 Hz, 1H), 4.61−4.58 (m, 2H), 4.51 (d, *J* = 11.8 Hz, 1H), 4.23−4.19 (m, 1H), 3.93−3.87 (m, 3H), 3.86−3.83 (m, 1H), 3.82 (d, *J* = 11.3 Hz, 3H), 3.74 (dd, *J* = 11.0 and 2.4 Hz, 1H), 2.29 (br s, 1H), 0.86−0.22 (m, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 138.0 (C_q), 137.9 (C_q), 137.8 (C_q), 128.9 (2× CH), 128.7 (2× CH), 128.7 (2× CH), 128.3 (CH), 128.2 (3× CH), 128.1 (CH), 128.1 (2× CH), 128.0 (2× CH), 83.9 (d, *J* = 11.9 Hz, CH), 76.9 (CH), 76.7 (CH), 75.8 (CH_2), 75.4 (CH_2), 73.7 (CH_2), 71.1 (d, *J* = 52.2 Hz, CH), 68.9 (d, *J* = 7.3 Hz, CH_2), 55.0 (d, *J* = 4.6 Hz, CH_3); ^{31}P NMR (122 MHz, $CDCl_3$) δ 145.8−144.4 (m); HRMS (ESI-TOF) calcd for $C_{27}H_{38}BNO_6P$ $[M + NH_4]^+$ 514.2530, found 514.2500.

(2*S*,3*R*,4*S*,5*S*,6*R*)-2-Boranyl-4,5-bis(benzyloxy)-6-((benzyloxy)methyl)-2-methoxy-1,2-oxaphosphinan-3-ol 6mα. To a solution of phosphonate **2m** (1.11 g, 1.98 mmol) in dry MeOH (14 mL) was added MeONa (10 wt % solution in EtOH, 30 drops). The resulting solution was stirred at room temperature overnight. Dowex H^+ was then added, and the mixture was further stirred for 10 min, filtered, and evaporated under a vacuum. The crude mixture was purified by column chromatography on silica gel (eluent: EtOAc/heptane, 1:2), yielding the product **6mα** as a colorless solid (816 mg, 1.64 mmol, 83%): mp 71.1−72.7 °C; $[\alpha]^{23}_D$ = +52.0 (*c* 0.5, $CHCl_3$); IR (neat) ν_{max} 3474, 3064, 3031, 2869, 2396, 1454, 1364, 1096, 1070, 1050, 1026, 974, 735, 698 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 7.35−7.25 (m, 13H), 7.19−7.13 (m, 2H), 4.84 (d, *J* = 10.7 Hz, 1H), 4.69 (s, 2H), 4.62 (d, *J* = 11.9 Hz, 1H), 4.54 (d, *J* = 12.2 Hz, 1H), 4.53 (d, *J* = 10.7 Hz, 1H), 4.21−4.17 (m, 1H), 4.14−4.09 (m, 1H), 4.05 (t, *J* = 9.2 Hz, 1H), 3.99 (dd, *J* = 9.2 and 2.7 Hz, 1H), 3.80 (dd, *J* = 11.3 and 4.0 Hz, 1H), 3.74 (d, *J* = 11.0 Hz, 3H), 3.77−3.69 (m, 1H), 2.54 (d, *J* = 17.7 Hz, 1H), 0.96−0.18 (m, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 138.0 (C_q), 137.9 (C_q), 137.5 (C_q), 128.8 (2× CH), 128.6 (2× CH), 128.6 (2× CH), 128.3 (CH), 128.2 (2× CH), 128.2 (2× CH), 128.1 (CH), 128.1 (2× CH), 127.9 (CH), 80.0 (d, *J* = 2.2 Hz, CH), 77.8 (d, *J* = 11.5 Hz, CH), 75.9 (CH_2), 73.8 (CH_2), 73.3 (d, *J* = 3.8 Hz, CH), 72.5 (CH_2), 69.2 (d, *J* = 7.1 Hz, CH_2), 66.9 (d, *J* = 63.1 Hz, CH), 54.5 (d, *J* = 3.3 Hz, CH_3); ^{31}P NMR (122 MHz, $CDCl_3$) δ 137.7−134.7 (m); HRMS (ESI-TOF) calcd for $C_{27}H_{38}BNO_6P$ $[M + NH_4]^+$ 514.2530, found 514.2551. Anal. Calcd for $C_{27}H_{34}BO_6P$: C, 65.34; H, 6.90. Found: C, 65.35; H, 6.86. In some cases, the β isomer was isolated and characterized. Data for **6mβ**: R_f = 0.17 (EtOAc/heptane 1:3); $[\alpha]^{26}_D$ = +7.2 (*c* 0.5, $CHCl_3$); IR (neat) ν_{max} 3435, 3032, 2924, 2379, 1454, 1072, 1029, 970, 737, 699 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) 7.36−7.24 (m, 13H), 7.23−7.18 (m, 2H), 4.72 (d, *J* = 11.2 Hz, 1H), 4.67 (d, *J* = 11.5 Hz, 1H), 4.62 (d, *J* = 11.3 Hz, 1H), 4.59−4.54 (m, 2H), 4.49 (d, *J* = 12.0 Hz, 1H), 4.33 (dd, *J* = 8.0 and 3.2 Hz, 1H), 4.31−4.25 (m, 1H), 4.12−4.07 (m, 1H), 4.04 (t, *J* = 7.4 Hz, 1H), 3.88 (d, *J* = 11.0 Hz, 3H), 3.85 (ddd, *J* = 10.9, 4.6, and 1.1 Hz, 1H), 3.77 (dd, *J* = 10.7 and 3.9 Hz, 1H), 2.61 (br s, 1H), 0.92−0.09 (m, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) 138.0 (C_q), 137.8 (C_q), 137.4 (C_q), 128.9 (2× CH), 128.7 (2× CH), 128.7 (2× CH), 128.5 (CH), 128.2 (3× CH), 128.1 (2× CH), 128,0 (CH), 128.0 (2× CH), 79.9 (d, *J* = 4.6 Hz, CH), 76.9 (d, *J* = 6.4 Hz, CH), 74.5 (CH_2), 73.6 (CH_2), 73.2 (d, *J* = 4.6 Hz, CH), 73.2 (CH_2), 69.3 (d, *J* = 5.5 Hz, CH_2), 67.0 (d, *J* = 44.9 Hz, CH), 55.5 (d, *J* = 4.6 Hz, CH_3); ^{31}P NMR (122 MHz, $CDCl_3$) 138.0−136.1 ppm; HRMS (ESI-TOF) calcd for $C_{27}H_{34}BO_6P$ $[M + NH_4]^+$ 514.2530, found 514.2528.

(2*S*,3*S*,4*S*,5*S*,6*R*)-2-Boranyl-4,5-bis(benzyloxy)-6-((benzyloxy)methyl)-2-methoxy-1,2-oxaphosphinan-3-yl acetate 7gα. To a solution of phosphonate **6gα** (148.5 mg, 0.30 mmol) in acetic anhydride (2.4 mL) was added I_2 (1.5 mg, 0.006 mmol, 2 mol %) and dry pyridine (3 drops, cat). The resulting solution was stirred at room temperature for 4 h. The reaction was quenched by a saturated aqueous solution of $Na_2S_2O_3$. A saturated solution of $NaHCO_3$ and EtOAc were added to the reaction mixture and stirred for 30 min. The two layers were separated, and the aqueous layer was extracted twice with EtOAc. Combined organic layers were dried over $MgSO_4$, filtered and evaporated. The crude mixture was purified on silica gel (eluent: EtOAc/heptane 1:3), yielding the product **7gα** as a colorless oil (151 mg, 0.28 mmol, 94%), which data correspond to those previously reported.[10]

(2*S*,3*R*,4*S*,5*S*,6*R*)-2-Boranyl-4,5-bis(benzyloxy)-6-((benzyloxy)methyl)-2-methoxy-1,2-oxaphosphinan-3-yl acetate 7mα. To a solution of phosphonate **6mα** (467 mg, 0.94 mmol) in acetic anhydride (7.3 mL) was added I_2 (5.3 mg, 0.019 mmol, 2 mol %) and dry pyridine (5 drops, cat). The resulting solution was stirred at room temperature for 4.5 h. The reaction was quenched by a saturated aqueous solution of $Na_2S_2O_3$. A saturated solution of $NaHCO_3$ and EtOAc were added to the reaction mixture and stirred for 30 min. The two layers were separated, and the aqueous layer was extracted twice with EtOAc. Combined organic layers were dried over $MgSO_4$, filtered and evaporated. The crude mixture was purified on silica gel (eluent: EtOAc/heptane 15:85), yielding the product **7mα** as a colorless oil (436 mg, 0.81 mmol, 86%), which data correspond to those previously reported.[10]

(2*S*,3*S*,4*S*,5*S*,6*R*)-4,5-Bis(benzyloxy)-6-((benzyloxy)methyl)-2-boranyl-2-methoxy-3-(methoxymethoxy)-1,2-oxaphosphinane 8gα. To a solution of **6gα** (30 mg, 0.06 mmol) at −78 °C in THF (0.6 mL) were added a solution of NaHMDS in THF (1M) (72 μL, 0.072 mmol, 1.2 equiv) and MOMCl (9.1 μL, 0,12 mmol, 2 equiv). The resulting mixture was stirred at −10 °C overnight. A saturated solution of NH_4Cl was added to the reaction, and the two layers were separated. Aqueous layer was extracted three times with EtOAc. Combined organic layers were washed by brine, dried over

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$MgSO_4$, filtered and concentrated yielding **8gα** as a colorless oil (32 mg, 0.06 mmol, 99%): R_f = 0.54 (EtOAc/heptane 3:7); $[\alpha]^{24}_D$ = +45.3 (*c* 0.5, $CHCl_3$); IR (neat) ν_{max} 3064, 3031, 2925, 2867, 2398, 1454, 1110, 1050, 1021, 993, 970, 749, 736, 697 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) 7.37−7.23 (m, 13H), 7.14−7.07 (m, 2H), 4.89 (d, *J* = 11.3 Hz, 1H), 4.87−4.83 (m, 3H), 4.82 (d, *J* = 10.4 Hz, 1H), 4.61 (d, *J* = 11.9 Hz,1H), 4.58 (d, *J* = 10.7 Hz, 1H), 4.54 (d, *J* = 11.9 Hz, 1H), 4.19−4.13 (m, 1H), 4.08−4.01 (m, 2H), 3.85 (d, *J* = 11.0 Hz, 3H), 3.85−3.75 (m, 2H), 3.73 (dd, *J* = 11.3 and 1.2 Hz, 1H), 3.42 (s, 3H), 1.00−0.26 (m, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) 138.2 (C_q), 137.9 (C_q), 137.7 (C_q), 128.7 (4× CH), 128.6 (2× CH), 128.1 (CH), 128.1 (2× CH), 128.0 (2× CH), 128.0 (CH), 127.9 (CH), 127.6 (2× CH), 98.3 (d, *J* = 3.3 Hz, CH_2), 82.6 (CH), 77.7 (CH), 76.6 (d, *J* = 10.4 Hz, CH), 76.5 (CH_2), 75.9 (CH_2), 74.9 (d, *J* = 56.5 Hz, CH), 73.8 (CH_2), 68.7 (d, *J* = 7.7 Hz, CH_2), 57.1 (CH_3), 55.1 (d, *J* = 2.7 Hz, CH_3); ^{31}P NMR (122 MHz, $CDCl_3$) 135.4−132.4 (m) ppm; HRMS (ESI-TOF) calcd for $C_{29}H_{42}BNO_7P$ $[M + NH_4]^+$ 558.2792, found 558.2791.

(2*S*,3*S*,4*S*,5*S*,6*R*)-3-(Allyloxy)-4,5-bis(benzyloxy)-6-((benzyloxy)methyl)-2-boranyl-2-methoxy-1,2-oxaphosphinane 9gα. To a solution of **6gα** (100 mg, 0.2 mmol) in THF (2 mL) were added at −78 °C a solution of NaHMDS in THF (1M) (0.24 mL, 0.24 mmol, 1.2 equiv) and allylbromide (0.035 mL, 0,4 mmol, 2 equiv). The resulting mixture was stirred at −10 °C overnight. The reaction mixture was warmed to 10 °C, and additional solution of NaHMDS in THF (1M) (0.08 mL, 0.08 mmol, 0.4 equiv) and allylbromide (9 μL, 0,1 mmol, 0.5 equiv) were added, and the reaction was stirred for 6 h. A saturated solution of NH_4Cl was added to the reaction, and the two layers were separated. Aqueous layer was extracted three times with EtOAc. Combined organic layers were washed with brine, dried over $MgSO_4$, filtered and concentrated. The crude mixture was purified on silica gel (eluent: EtOAc/heptane 5:95) yielding **9gα** as a colorless oil (62 mg, 0.12 mmol, 58%): R_f = 0.44 (EtOAc/heptane 2:8); $[\alpha]^{24}_D$ = +52.4 (*c* 0.5, $CHCl_3$); IR (neat) ν_{max} 3064, 3031, 2925, 2869, 2397, 1454, 1064, 1025, 990, 974, 736, 697 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) 7.37−7.24 (m, 13H), 7.17−7.10 (m, 2H), 5.99−5.88 (ddt, *J* = 17.1, 10.4, and 6.1 Hz, 1H), 5.32 (dd, *J* = 17.1 and 1.2 Hz, 1H), 5.23 (dd, *J* = 10.4 Hz, 1H), 4.91 (d, *J* = 10.7 Hz, 1H), 4.84 (d, *J* = 10.7 Hz, 1H), 4.81 (d, *J* = 10.7 Hz,1H), 4.60 (d, *J* = 11.9 Hz, 1H), 4.57 (d, *J* = 10.4 Hz, 1H), 4.53 (d, *J* = 12.2 Hz, 1H), 4.39 (dd, *J* = 11.9 and 5.8 Hz, 1H), 4.26 (dd, *J* = 12.2 and 6.1 Hz, 1H), 4.18−4.12 (m, 1H), 4.00 (td, *J* = 9.8 and 1.5 Hz, 1H), 3.83 (d, *J* = 11.0 Hz, 3H), 3.84−3.80 (m, 1H), 3.78−3.70 (m, 3H), 1.02−0.27 (m, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) 138.4 (C_q), 137.9 (C_q), 137.9 (C_q), 134.0 (CH), 128.6 (6× CH), 128.1 (CH), 128.0 (6× CH), 128.0 (CH), 128.0 (CH), 119.0 (CH_2), 82.6 (CH), 78.8 (d, *J* = 56.0 Hz, CH), 77.4 (CH),76.7 (CH_2), 76.4 (d, *J* = 10.4 Hz, CH), 75.9 (CH_2), 74.9 (d, *J* = 2.2 Hz, CH_2), 73.8 (CH_2), 68.8 (d, *J* = 7.7 Hz, CH_2), 55.2 (d, *J* = 3.3 Hz, CH_3); ^{31}P NMR (122 MHz, $CDCl_3$) 134.6−130.9 (m) ppm; HRMS (ESI-TOF) calcd for $C_{30}H_{38}BNaO_6P$ $[M + Na]^+$ 559.2397, found 559.2399.

Triethylammonium (2*S*,3*S*,4*S*,5*S*,6*R*)-4,5-bis(benzyloxy)-6-((benzyloxy)methyl)-2-boranyl-3-(methoxymethoxy)-1,2-oxaphosphinan-2-olate 11gα. To a solution of **8gα** (146 mg, 0.27 mmol) in THF (3 mL) were added thiophenol (0.56 mL, 5.4 mmol, 20 equiv) and triethylamine (0.76 mL, 5.4 mmol, 20 equiv). The resulting mixture was stirred at rt for 4 days. $CHCl_3$ and triethylammonium buffer (1 N) were added to the reaction, and the two layers were separated. Aqueous layer was extracted three times with $CHCl_3$. Combined organic layers were washed three times with triethylammonium buffer (1 N), dried over $MgSO_4$, filtered and concentrated. The crude mixture was purified on silica gel (eluent: CH_2Cl_2 then CH_2Cl_2/MeOH/NEt_3 100:1:1) yielding **11gα** as a colorless oil (147 mg, 0.234 mmol, 87%): R_f = 0.54 (CH_2Cl_2/MeOH 9:1); $[\alpha]^{24}_D$ = +18.3 (*c* 0.5, $CHCl_3$); IR (neat) ν_{max} 2922, 2383, 1453, 1397, 1359, 1059, 1026, 999, 957, 918, 750, 737, 697 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) 7.37−7.22 (m, 13H), 7.19−7.12 (m, 2H), 4.98−4.85 (m, 4H), 4.83 (d, *J* = 10.7 Hz, 1H), 4.56 (d, *J* = 10.4 Hz, 1H), 4.54 (d, *J* = 12.2 Hz,1H), 4.51 (d, *J* = 11.6 Hz, 1H), 4.33−4.26 (m, 1H), 4.03 (td, *J* = 9.8 and 2.4 Hz, 1H), 3.84−3.76 (m, 2H), 3.74 (dd, *J* = 10.4 and 5.8 Hz, 1H), 3.58 (t, *J* = 9.8 Hz, 1H), 3.43 (s, 3H), 3.00−2.88 (m, 6H), 1.22 (t, *J* = 7.3 Hz), 0.91−0.11 (m, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) 139.1 (C_q), 138.6 (C_q), 138.3 (C_q), 128.6 (2× CH), 128.5 (4× CH), 128.2 (2× CH), 128.1 (2× CH), 127.9 (CH), 127.7 (CH), 127.6 (2× CH), 127.5 (CH), 98.1 (d, *J* = 3.3 Hz, CH_2), 83.9 (CH), 79.7 (CH), 78.6 (d, *J* = 49.4 Hz, CH), 75.9 (CH_2), 75.6 (CH_2), 73.7 (CH_2), 72.6 (d, *J* = 8.8 Hz, CH), 70.6 (d, *J* = 7.1 Hz, CH_2), 56.6 (CH_3), 45.5 (CH_2), 9.0 (CH_3); ^{31}P NMR (122 MHz, $CDCl_3$) 102.8−100.1 (m) ppm; HRMS (ESI-TOF) calcd for $C_{28}H_{35}BO_7P$ $[M\text{-}HNEt_3]^-$ 525.2219, found 525.2206.

Triethylammonium (2*S*,3*S*,4*S*,5*S*,6*R*)-3-(allyloxy)-4,5-bis(benzyloxy)-6-((benzyloxy)methyl)-2-boranyl-1,2-oxaphosphinan-2-olate 12gα. To a solution of **9gα** (40.8 mg, 0.076 mmol) in THF (0.8 mL) were added thiophenol (0.156 mL, 1.52 mmol, 20 equiv) and triethylamine (0.212 mL, 1.52 mmol, 20 equiv). The resulting mixture was stirred at rt for 60 h. $CHCl_3$ and triethylammonium buffer (1 N) were added to the reaction, and the two layers were separated. Aqueous layer was extracted three times with $CHCl_3$. Combined organic layers were dried over $MgSO_4$, filtered and concentrated. The crude mixture was purified on silica gel (eluent: CH_2Cl_2 then CH_2Cl_2/MeOH/NEt_3 100:1:1) yielding **12gα** as a colorless oil (36.5 mg, 0.059 mmol, 78%): R_f = 0.50 (CH_2Cl_2/MeOH 9:1); $[\alpha]^{24}_D$ = +21.7 (*c* 1.6, $CHCl_3$); IR (neat) ν_{max} 3031, 2982, 2918, 2867, 2385, 1454, 1115, 1070, 1046, 990, 957, 749, 739, 699 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) 12.89−12.54 (br s, 1H), 7.40−7.20 (m, 13H), 7.20−7.10 (m, 2H), 5.96 (ddt, *J* = 17.1, 10.4, and 5.8 Hz, 1H), 5.28 (dd, *J* = 17.1 and 1.7 Hz, 1H), 5.16−5.08 (m, 1H), 4.91 (d, *J* = 10.9 Hz, 1H), 4.83 (d, *J* = 10.7 Hz, 1H), 4.78 (d, *J* = 10.7 Hz,1H), 4.61−4.40 (m, 4H), 4.36−4.24 (m, 2H), 4.020 (td, *J* = 10.0 and 2.4 Hz, 1H), 3.79−3.70 (m, 2H), 3.60 (t, *J* = 9.8 Hz, 1H), 3.60−3.52 (m, 1H), 3.00 (q, *J* = 7.2 Hz, 6H), 1.25 (t, *J* = 7.3 Hz, 9H), 0.99−(−0.09) (m, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) 139.2 (C_q), 138.6 (C_q), 138.5 (C_q), 135.6 (CH), 128.5 (2× CH), 128.5 (2× CH), 128.5 (2× CH), 128.2 (2× CH), 128.1 (2× CH), 128.1 (2× CH), 127.7 (CH), 127.7 (CH), 127.6 (CH), 117.2 (CH_2), 83.8 (CH), 81.8 (d, *J* = 49.9 Hz, CH), 79.2 (CH),76.3 (CH_2), 75.6 (CH_2), 74.4 (d, *J* = 2.2 Hz, CH), 73.6 (CH_2), 73.1 (d, *J* = 9.3 Hz, CH_2), 70.4 (d, *J* = 7.1 Hz, CH_2), 45.5 (CH_2), 8.7 (CH_3); ^{31}P NMR (122 MHz, $CDCl_3$) 104.5−100.4 (m) ppm; HRMS (ESI-TOF) calcd for $C_{29}H_{40}BNO_6P$ $[M\text{-}HNEt_3{+}NH_4]^+$ 540.2692, found 540.2690.

(2*R*,3*R*,4*S*,5*R*,6*S*)-2-((((2*R*,3*S*,4*S*,5*S*,6*R*)-4,5-Bis(benzyloxy)-6-((benzyloxy)methyl)-3-(methoxymethoxy)-2-oxido-1,2-oxaphosphinan-2-yl)oxy)methyl)-6-methoxytetrahydro-2*H*-pyran-3,4,5-triyltribenzoate 18. To a solution of **11gα** (10 mg, 0.016 mmol) in dry toluene (1.9 mL) were added sequentially diol **13a** (9.7 mg, 0.019 mmol, 1.2 equiv), DIPEA (28 μL, 0.16 mmol, 10 equiv), DMAP (5.9 mg, 0.048 mmol, 3 equiv) and 4 Å molecular sieves (20 mg). The resulting mixture was stirred at rt for 1 h and BopCl (12.2 mg, 0.048 mmol, 3 equiv) was added. The resulting mixture was stirred at rt overnight, diluted with $CHCl_3$ and a saturated solution of $NaHCO_3$. Aqueous layer was extracted three times with $CHCl_3$. Combined organic layers were washed with brine, dried on $MgSO_4$ and concentrated under a vacuum. It was dissolved in CH_2Cl_2 (10 mL) and *m*-CPBA was added (wet solid containing 77 wt % in *m*-CPBA, 27.6 mg, 0.16 mmol). The resulting solution was stirred for 30 min at room temperature. An aqueous saturated solution of $Na_2S_2O_3$ and CH_2Cl_2 were added to the mixture, and the layers were separated. Aqueous layer was extracted twice by CH_2Cl_2. Combined organic layers were dried over $MgSO_4$, filtered and evaporated. Purification on silica gel (eluent: heptane/EtOAc 7:3, then 6:4 and finally 1:1) yielded a mixture of **18gβ** and **18gα** as a colorless oil (10.8 mg, 0.0106 mmol, 66%): IR (neat) ν_{max} 3014, 2966, 2928, 2870, 1729, 1452, 1260, 1106, 1093, 1068, 1052, 1027, 999, 748, 709, 667 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) 8.00−7.95 (m, 4H), 7.95−7.91 (m, 4H), 7.87−7.82 (m, 4H), 7.54−7.45 (m, 4H), 7.44−7.22 (m, 40H), 7.16−7.10 (m, 4H), 6.20−6.12 (m, 2H), 5.57 (t, *J* = 9.8 Hz, 1H), 5.52 (t, *J* = 9.8 Hz, 1H), 5.29−5.20 (m, 4H), 4.90−4.79 (m, 6H), 4.77 (s, 2H), 4.62−4.54 (m, 4H), 4.51−4.43 (m, 4H), 4.36−4.24 (m, 5H), 4.14 (dd, *J* = 10.8 and 8.8 Hz, 1H), 4.11−3.98 (m, 5H), 3.88−3.78 (m, 3H), 3.75 (dt, *J* = 11.3 and 3.2 Hz, 1H), 3.72−3.40 (m, 3H), 3.47 (s, 3H), 3.44 (s, 3H), 3.39 (s, 3H), 3.33 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) 166.0 (C_q), 166.0 (C_q), 166.0 (2× C_q), 165.5 (C_q), 165.4 (C_q), 138.4 (C_q), 138.2

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(C_q), 138.0 (C_q), 138.0 (2× C_q), 137.9 (C_q), 133.7 (CH), 133.6 (CH), 133.6 (CH), 133.6 (CH), 133.3 (CH), 133.3 (CH), 130.1 (4× CH), 130.1 (2× CH), 130.1 (2× CH), 129.9 (2× CH), 129.9 (2× CH), 129.4 (CH), 129.4 (CH), 129.3 (CH), 129.2 (CH), 129.1 (CH), 128.9 (CH), 128.7 (2× CH), 128.6 (6× CH), 128.6 (6× CH), 128.6 (4× CH), 128.5 (3× CH), 128.0 (2× CH), 128.0 (3× CH), 128.0 (2× CH), 127.9 (3× CH), 127.9 (5× CH), 97.8 (d, J = 1.8 Hz, CH_2), 97.6 (d, J = 1.8 Hz, CH_2), 97.2 (CH), 97.1 (CH), 84.0 (d, J = 4.6 Hz, CH), 84.0 (CH), 77.9 (CH), 77.0 (d, J = 5.5 Hz, CH), 76.6 (CH_2), 76.5 (CH_2), 75.7 (CH), 75.6 (CH_2), 75.6 (CH_2), 75.5 (CH), 73.8 (CH_2), 73.7 (CH_2), 73.4 (d, J = 143.9 Hz, CH), 72.4 (d, J = 143.9 Hz, CH), 72.2 (CH), 72.2 (CH), 70.5 (2× CH), 69.4 (CH), 69.4 (CH), 68.9 (d, J = 6.4 Hz, CH), 68.8 (d, J = 6.4 Hz, CH), 68.6 (d, J = 10.1 Hz, CH_2), 68.5 (d, J = 10.1 Hz, CH_2), 65.9 (d, J = 7.3 Hz, CH_2), 65.3 (d, J = 4.4 Hz, CH_2), 56.4 (CH_3), 56.3 (CH_3), 56.0 (CH_3), 55.9 (CH_3). ^{31}P NMR (202 MHz, $CDCl_3$) 21.5 and 17.2 ppm; HRMS (ESI-TOF) calcd for $C_{56}H_{58}O_{16}P$ $[M + H]^+$ 1017.3462, found 1017.3503.

((2*S*,3*R*,4*S*,5*S*,6*R*)-3-Acetoxy-4,5-bis(benzyloxy)-2-methoxy-2-oxido-1,2-oxaphosphinan-6-yl)methyl acetate 20m*β*. To a solution of **19m*β*** (90 mg, 0.181 mmol) in Ac_2O (1 mL) was added TFA (0.2 mL), and the resulting solution was stirred at room temperature for 6 h and then concentrated under a vacuum. Purification on silica gel (eluent: EtOAc/heptane, 1:1) afforded the known diester **20m*β*** (80 mg, 0.163 mmol, 90%) as a colorless oil for which data correspond to those previously reported.[10]

(2*R*,3*S*,4*S*,5*S*,6*R*)-4,5-Bis(benzyloxy)-6-(hydroxymethyl)-2-methoxy-2-oxido-1,2-oxaphosphinan-3-yl acetate 22g*α* **and (2*R*,3*S*,4*S*,5*S*,6*R*)-4,5-Bis(benzyloxy)-3-hydroxy-6-(hydroxymethyl)-2-methoxy-1,2-oxaphosphinane 2-oxide 21g*α*.** To a solution of phosphonate **19g*α*** (227 mg, 0.42 mmol) in Ac_2O (2.0 mL) was added TFA (0.4 mL), and the resulting solution was stirred at room temperature for 7 h and then concentrated under a vacuum. Purification on silica gel (eluent: EtOAc/heptane, 1:2) afforded the diester **20g*α*** (215 mg, 0.42 mmol, quant.), which was directly engaged in the next step. It was dissolved in MeOH (7 mL) and 4 Å molecular sieves (freshly activated, 300 mg) was added. The resulting mixture was stirred at room temperature for 24 h and then filtered on Celite and concentrated under a vacuum. Purification on silica gel (eluent: EtOAc/heptane, 1:1 then EtOAc) afforded monoester **22g*α*** (60 mg, 0.147 mmol, 35%) and diol **21g*α*** (50 mg, 0.11 mmol, 26%) as colorless oils that solidified upon standing. Data for **22g*α***: $[\alpha]^{23}_D$ = +42.7 (c 0.6, $CHCl_3$); IR (neat) ν_{max} 3408, 3064, 3032, 2929, 1757, 1455, 1370, 1291, 1214, 1046, 1019, 993, 871, 741, 699 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.40−7.23 (m, 10H), 5.55 (d, J = 10.4 Hz, 1H), 4.87 (d, J = 10.7 Hz, 2H), 4.71 (t, J = 12.2 Hz, 2H), 4.08−3.79 (m, 5H), 3.89 (d, J = 10.7 Hz, 3H), 2.93−2.39 (br s, 1H), 2.01 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 169.0 (C_q), 137.9 (C_q), 137.5 (C_q), 128.7 (2× CH), 128.7 (2× CH), 128.3 (2× CH), 128.2 (2× CH), 128.0 (CH), 127.8 (CH), 82.6 (d, J = 8.2 Hz, CH), 78.3 (d, J = 5.5 Hz, CH), 77.5 (CH), 76.1 (CH_2), 75.8 (CH_2), 68.1 (d, J = 146.6 Hz, CH), 61.5 (d, J = 9.9 Hz, CH_2), 53.7 (d, J = 6.6 Hz, CH_3), 20.6 (CH_3). ^{31}P NMR (202 MHz, $CDCl_3$) δ 15.9 ppm; HRMS (ESI-TOF) calcd for $C_{22}H_{31}NO_8P$ 468.1787 $[M + NH_4]^+$, found 468.1776. Data for **21g*α***: $[\alpha]^{23}_D$ = +34.8 (c 0.6, $CHCl_3$); IR (neat) ν_{max} 3334, 3064, 3032, 2923, 2872, 1455, 1271, 1217, 1134, 1103, 1049, 1025, 991, 863, 735, 698 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.43−7.22 (m, 10H), 4.98 (d, J = 10.7 Hz, 1H), 4.89 (d, J = 10.4 Hz, 1H), 4.87 (d, J = 10.7 Hz, 1H), 4.68 (d, J = 10.7 Hz, 1H), 4.23−4.15 (m, 1H), 4.00−3.73 (m, 5H), 3.91 (d, J = 10.4 Hz, 3H), 3.38−2.50 (br s, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 138.4 (C_q), 137.8 (C_q), 128.7 (2× CH), 128.6 (2× CH), 128.3 (2× CH), 128.2 (3× CH), 128.0 (CH), 84.3 (d, J = 9.9 Hz, CH), 78.0 (d, J = 4.9 Hz, CH), 76.9 (CH), 76.6 (CH_2), 75.7 (CH_2), 69.7 (d, J = 143.3 Hz, CH), 61.5 (d, J = 9.3 Hz, CH_2), 54.2 (d, J = 7.1 Hz, CH_3). ^{31}P NMR (202 MHz, $CDCl_3$) δ 20.9 ppm; HRMS (ESI-TOF) calcd for $C_{20}H_{25}NaO_7P$ $[M + Na]^+$ 431.1236, found 431.1215.

(2S,3*R*,4*S*,5*S*,6*R*)-4,5-Bis(benzyloxy)-3-hydroxy-6-(hydroxymethyl)-2-methoxy-1,2-oxaphosphinane 2-oxide 21m*β* **and (2*R*,3*R*,4*S*,5*S*,6*R*)-4,5-Bis(benzyloxy)-3-hydroxy-6-(hydroxymethyl)-2-methoxy-1,2-oxaphosphinane 2-oxide 21m*α*.** To a solution of diester **20m*β*** (80 mg, 0.163 mmol) in MeOH (1 mL) was added NaOMe (7 wt % solution in MeOH, 2 drops), and the resulting mixture was stirred at room temperature for 4 h. It was then quenched by addition of Amberlite H^+ resin, filtered and evaporated. Purification on silica gel (eluent: EtOAc) afforded the diol **21m*β*** (30 mg, 0.073 mmol, 45%) and diol **21m*α*** (32 mg, 0.078 mmol, 48%) as colorless oils. Data for **21m*β***: $[\alpha]^{23}_D$ = +3.30 (c 1, $CHCl_3$); IR (neat) ν_{max} 3328, 2926, 1455, 1218, 1091, 1028, 989 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.40−7.29 (m, 10H), 4.91 (d, J = 10.9 Hz, 1H), 4.72 (s, 2H), 4.69 (d, J = 10.9 Hz, 1H), 4.45 (dd, J = 2.7 and 9.8 Hz, 1H), 4.27−4.18 (m, 1H), 4.15 (dd, J = 2.8 and 9.1 Hz, 1H), 4.09 (d, J = 9.4 Hz, 1H), 3.93 (d, J = 10.7 Hz, 3H), 3.91−3.86 (m, 2H), 2.80−2.53 (br s, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 137.9 (C_q), 137.3 (C_q), 128.8 (2× CH), 128.7 (2× CH), 128.4 (CH), 128.2 (2× CH), 128.1 (CH), 128.1 (2× CH), 81.6 (d, J = 6.6 Hz, CH), 77.1 (d, J = 3.3 Hz, CH), 75.7 (CH_2), 73.4 (d, J = 1.6 Hz), 72.7 (CH_2), 64.8 (d, J = 146.0 Hz, CH), 61.9 (d, J = 9.3 Hz, CH_2), 54.8 (d, J = 6.6 Hz, CH_3). ^{31}P NMR (202 MHz, $CDCl_3$) δ 21.6 ppm; HRMS (ESI-TOF) calcd for $C_{20}H_{26}O_7P$ 409.1416 $[M + H]^-$, found 409.1425. Data for **21m*α***: $[\alpha]^{23}_D$ = +20.5 (c 1.3, $CHCl_3$); IR (neat) ν_{max} 3348, 2925, 1455, 1260, 1090, 1027, 997 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.40−7.20 (m, 10H), 4.89 (d, J = 10.6 Hz, 1H), 4.73 (d, J = 11.8 Hz, 1H), 4.64 (d, J = 11.7 Hz, 1H), 4.63 (d, J = 10.6 Hz, 1H), 4.33 (dd, J = 3.0 and 8.5 Hz, 1H), 4.12 (t, J = 9.5 Hz, 1H), 3.91−7.78 (m, 4H), 3.71 (d, J = 10.5 Hz, 3H), 3.27 (br s, 1H), 2.32 (br s, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 138.0 (C_q), 137.7 (C_q), 128.7 (2× CH), 128.6 (2× CH), 128.3 (2× CH), 128.2 (3× CH), 128.1 (CH), 81.1 (d, J = 6.0 Hz, CH), 78.6 (d, J = 6.0 Hz, CH), 75.8 (CH_2), 73.0 (d, J = 2.7 Hz), 72.2 (CH_2), 63.6 (d, J = 144.4 Hz, CH), 62.0 (d, J = 8.8 Hz, CH_2), 52.6 (d, J = 7.7 Hz, CH_3). ^{31}P NMR (202 MHz, $CDCl_3$) δ 21.3 ppm; HRMS (ESI-TOF) calcd for $C_{20}H_{26}O_7P$ 409.1416 $[M + H]^-$, found 409.1423.

(2*S*,3*S*,4*S*,5*S*,6*R*)-2-(((2*R*,3*S*,4*S*,5*S*,6*R*)-3-Acetoxy-4,5-bis(benzyloxy)-2-methoxy-2-oxido-1,2-oxaphosphinan-6-yl)methoxy)-4,5-bis(benzyloxy)-6-((benzyloxy)methyl)-2-oxido-1,2-oxaphosphinan-3-yl acetate 23g*β*. To a solution of **10g*α*** (66.0 mg, 0.106 mmol) in dry THF (4 mL) were added sequentially 4 Å molecular sieves (110 mg), phostone **22g*α*** (57.5 mg, 0.128 mmol, 1.2 equiv), DIPEA (185 μL, 1.065 mmol, 10 equiv), DMAP (39 mg, 0.319 mmol, 3 equiv) and Bop-Cl (81.5 mg, 0.319 mmol, 3 equiv), and the resulting mixture was stirred at rt overnight, filtered on a pad of silica gel and then concentrated under a vacuum. It was dissolved in CH_2Cl_2 (10 mL), and *m*-CPBA was added (wet solid containing 77 wt % in *m*-CPBA, 224 mg, 1.0 mmol). The resulting solution was stirred for 10 min at room temperature. An aqueous saturated solution of $Na_2S_2O_3$ and CH_2Cl_2 were added to the mixture, and the layers were separated. Aqueous layer was extracted twice by CH_2Cl_2. Combined organic layers were dried over $MgSO_4$, filtered and evaporated. Purification on silica gel (eluent: EtOAc/heptane 1:1) yielded **23g*β*** as a colorless oil (75 mg, 0.0782 mmol, 74%): $[\alpha]^{23}_D$ = +26.0 (c 0.51, $CHCl_3$); IR (neat) ν_{max} 3032, 2926, 1753, 1454, 1265, 1214, 1046, 1026, 979 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.40−7.23 (m, 23H), 7.19−7.08 (m, 2H), 5.53 (t, J = 10.5 Hz, 1H), 5.33 (t, J = 10.0 Hz, 1H), 4.88 (d, J = 11.4 Hz, 1H), 4.87 (d, J = 10.5 Hz, 1H), 4.86 (d, J = 12.7 Hz, 1H), 4.85 (d, J = 10.7 Hz, 1H), 4.74 (d, J = 12.6 Hz, 1H), 4.70 (d, J = 11.7 Hz, 1H), 4.69 (d, J = 12.0 Hz, 1H), 4.66 (d, J = 10.6 Hz, 1H), 4.63 (d, J = 10.7 Hz, 1H), 4.53−4.45 (m, 1H), 4.52 (d, J = 12.0 Hz, 1H), 4.36−4.24 (m, 2H), 4.17−4.07 (m, 2H), 4.02−3.88 (m, 2H), 3.87−3.85 (m, 1H), 3.87 (d, J = 10.5 Hz, 3H), 3.78−3.69 (m, 2H), 2.00 (s, 6H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 169.8 (d, J = 3.3 Hz, C_q), 168.9 (d, J = 4.4 Hz, C_q), 138.0 (C_q), 137.9 (C_q), 137.7 (C_q), 137.7 (C_q), 137.2 (C_q), 128.8 (2× CH), 128.7 (2× CH), 128.6 (5× CH), 128.5 (2× CH), 128.4 (CH), 128.3 (2× CH), 128.1 (3× CH), 128.0 (2× CH), 127.9 (2× CH), 127.5 (2× CH), 127.7 (2× CH), 82.7 (d, J = 7.7 Hz, CH), 82.5 (d, J = 11.0 Hz, CH), 77.8 (CH), 77.4 (CH), 76.3 (CH_2), 76.2 (CH_2), 76.0 (d, J = 2.7 Hz, CH), 75.8 (CH_2), 75.6 (dd, J = 4.9 and 7.1 Hz, CH), 73.7 (CH_2), 68.2 (d, J = 145.5 Hz, CH), 68.2 (d, J = 9.3 Hz, CH_2), 68.0 (d, J = 146.6 Hz, CH), 65.4 (dd, J = 6.6 and 10.4 Hz, CH_2), 53.7 (d, J = 6.6 Hz, CH_3), 20.7 (CH_3), 20.6 (CH_3). ^{31}P NMR (202 MHz, $CDCl_3$) δ 18.1, 14.4 ppm; HRMS (ESI-

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TOF) calcd for $C_{50}H_{60}NO_{15}P_2$ $[M + NH_4]^+$ 976.3438, found 976.3439.

(2*S*,3*S*,4*S*,5*S*,6*R*)-4,5-Bis(benzyloxy)-6-((benzyloxy)methyl)-2-(((2*R*,3*S*,4*S*,5*S*,6*R*)-4,5-bis(benzyloxy)-3-hydroxy-2-methoxy-2-oxido-1,2-oxaphosphinan-6-yl)methoxy)-2-oxido-1,2-oxaphosphinan-3-yl acetate 24g*β*. To a solution of **10g*α*** (10.0 mg, 0.016 mmol) in dry THF (0.8 mL) were added sequentially 4 Å molecular sieves (20 mg), diol **21g*α*** (8 mg, 0.0192 mmol, 1.2 equiv), DIPEA (28 μL, 0.16 mmol, 10 equiv), DMAP (6.0 mg, 0.048 mmol, 3 equiv) and Bop-Cl (12.0 mg, 0.048 mmol, 3 equiv), and the resulting mixture was stirred at rt overnight, filtered on a pad of silica gel and then concentrated under a vacuum. It was dissolved in CH_2Cl_2 (1 mL) and *m*-CPBA was added (wet solid containing 77 wt % in *m*-CPBA, 36 mg, 0.16 mmol). The resulting solution was stirred for 30 min at room temperature. An aqueous saturated solution of $Na_2S_2O_3$ and CH_2Cl_2 were added to the mixture, and the layers were separated. Aqueous layer was extracted twice by CH_2Cl_2. Combined organic layers were dried over $MgSO_4$, filtered and evaporated. Purification on silica gel (eluent: EtOAc) yielded **24g*β*** as a colorless oil (9.2 mg, 0.010 mmol, 58%): $[\alpha]^{23}_D$ = +36.3 (*c* 0.92, $CHCl_3$); IR (neat) ν_{max} 3294, 2925, 1753, 1455, 1367, 1220, 1054, 1028, 992 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 7.37−7.20 (m, 22H), 7.17−7.10 (m, 2H), 5.36 (t, *J* = 10.1 Hz, 1H), 4.90 (d, *J* = 11.0 Hz, 1H), 4.87 (d, *J* = 10.2 Hz, 1H), 4.86 (d, *J* = 11.2 Hz, 1H), 4.84 (d, *J* = 12.1 Hz, 1H), 4.82 (d, *J* = 11.2 Hz, 1H), 4.71 (d, *J* = 11.5 Hz, 1H), 4.62 (d, *J* = 10.1 Hz, 1H), 4.60 (d, *J* = 12.0 Hz, 1H), 4.60 (d, *J* = 10.4 Hz, 1H), 4.47 (d, *J* = 12.0 Hz, 1H), 4.47−4.42 (m, 1H), 4.36−4.28 (m, 2H), 4.13 (dt, *J* = 2.4 and 10.1, 1H), 4.10−4.01 (m, 2H), 3.95 (t, *J* = 9.6 Hz, 1H), 3.91−3.80 (m, 2H), 3.88 (d, *J* = 10.4 Hz, 3H), 3.74 (dd, *J* = 1.9 and 11.2 Hz, 1H), 3.62 (t, *J* = 9.8 Hz, 1H), 3.40 (br s, 1H), 1.98 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 169.9 (d, *J* = 3.7 Hz), 138.2 (C_q), 138.1 (C_q), 137.9 (C_q), 137.8 (C_q), 137.5 (C_q), 128.8 (3× CH), 128.8 (2× CH), 128.7 (4× CH), 128.6 (2× CH), 128.3 (CH), 128.2 (2× CH), 128.2 (CH), 128.1 (2× CH), 128.0 (2× CH), 128.0 (2× CH), 128.0 (2× CH), 127.8 (2× CH), 84.3 (d, *J* = 8.2 Hz, CH), 82.6 (d, *J* = 11.9 Hz, CH), 77.9 (CH), 77.0 (CH), 76.4 (CH_2), 76.3 (CH_2), 76.1 (d, *J* = 1.8 Hz, CH), 75.8 (CH_2), 75.7 (CH_2), 75.5 (dd, J = 4.6 and 6.4 Hz, CH), 73.7 (CH_2), 69.7 (d, *J* = 144.8 Hz, CH), 68.3 (d, *J* = 10.1 Hz, CH_2), 68.0 (d, *J* = 146.6 Hz, CH), 65.9 (d, *J* = 6.4 and 7.3 Hz, CH_2), 54.0 (d, *J* = 7.3 Hz, CH_3), 20.7 (CH_3). ^{31}P NMR (202 MHz, $CDCl_3$) δ 18.9, 18.3 ppm; HRMS (ESI-TOF) calcd for $C_{48}H_{58}NO_{14}P_2$ $[M + NH_4]^+$ 934.3333, found 394.3364.

(2*S*,3*S*,4*S*,5*S*,6*R*)-4,5-Bis(benzyloxy)-6-((benzyloxy)methyl)-2-(((2*R*,3*R*,4*S*,5*S*,6*R*)-4,5-bis(benzyloxy)-3-hydroxy-2-methoxy-2-oxido-1,2-oxaphosphinan-6-yl)methoxy)-2-oxido-1,2-oxaphosphinan-3-yl acetate 25g*β*. To a solution of **10g*α*** (33.2 mg, 0.051 mmol) in dry THF (1.9 mL) were added sequentially 4 Å molecular sieves (60 mg), diol **21m*β*** (25 mg, 0.06 mmol, 1.2 equiv), DIPEA (89 μL, 0.51 mmol, 10 equiv), DMAP (24.6 mg, 0.15 mmol, 3 equiv) and Bop-Cl (38.6 mg, 0.15 mmol, 3 equiv), and the resulting mixture was stirred at rt overnight, filtered on a pad of silica gel and then concentrated under a vacuum. It was dissolved in CH_2Cl_2 (1 mL), and *m*-CPBA was added (wet solid containing 77 wt % in *m*-CPBA, 88 mg, 0.51 mmol). The resulting solution was stirred for 20 min at room temperature. An aqueous saturated solution of $Na_2S_2O_3$ and CH_2Cl_2 were added to the mixture, and the layers were separated. Aqueous layer was extracted twice by CH_2Cl_2. Combined organic layers were dried over $MgSO_4$, filtered and evaporated. Purification on silica gel (eluent: EtOAc) yielded **25g*β*** as a colorless oil (29.3 mg, 0.0032 mmol, 63%): $[\alpha]^{21}_D$ = +47.5 (*c* 0.1, $CHCl_3$); IR (neat) ν_{max} 3318, 3033, 2931, 2866, 1755, 14554, 1368, 1220, 1088, 1054, 1028, 992, 736, 698 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) 7.31−7.11 (m, 23H), 7.11−7.01 (m, 2H), 5.27 (t, *J* = 10.0 Hz, 1H), 4.85−4.69 (m, 3H), 4.68−4.44 (m, 6H), 4.44−4.29 (m, 4H), 4.29−4.16 (m, 2H), 4.12−4.00 (m, 2H), 3.95 (t, *J* = 9.4 Hz, 1H), 3.90−3.72 (m, 2H), 3.82 (d, *J* = 10.5 Hz, 3H), 3.61 (d, *J* = 10.9 Hz, 1H), 2.83 (d, *J* = 21.1 Hz, 1H), 1.90 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) 170.0 (d, *J* = 3.3 Hz, C_q), 138.1 (C_q), 137.8 (C_q), 137.7 (C_q), 137.7 (C_q), 137.3 (C_q), 128.9 (2× CH), 128.7 (4× CH), 128.4 (CH), 128.2 (3× CH), 128.2 (3× CH), 128.2 (3× CH), 128.1 (CH), 128.0 (3× CH), 128.0 (3× CH), 127.7 (2× CH), 82.6 (d, *J* = 11.0 Hz, CH), 81.6 (d, *J* = 7.1 Hz, CH), 77.9 (CH), 76.3 (CH_2), 76.0 (d, *J* = 2.7 Hz, CH), 75.7 (CH_2), 75.7 (CH_2), 74.7 (dd, *J* = 6.6 and 2.7 Hz, CH), 73.7 (CH_2), 73.1 (d, *J* = 1.6 Hz, CH), 72.5 (CH_2), 68.7 (d, *J* = 145.5 Hz, CH), 68.3 (d, *J* = 10.4 Hz, CH_2), 66.1 (d, *J* = 7.1 Hz, CH_2), 65.1 (d, *J* = 144.4 Hz, CH), 55.3 (d, *J* = 7.1 Hz, CH_3), 20.7 (CH_3). ^{31}P NMR (122 MHz, $CDCl_3$) 19.3 and 17.6 ppm; HRMS (ESI-TOF) calcd for $C_{48}H_{55}O_{14}P_2$ $[M + H]^+$ 917.3067, found 917.3063.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

NMR spectra for all new compounds and CIF files for all crystallographic structures. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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