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1,3-Dipolar Cycloaddition of 3-Amino Oxindole-Based Azomethine Ylides and O-Vinylphosphonylated Salicylaldehydes for Diastereoselective Synthesis of Oxindole Spiro-*P*,*N*-polycyclic Heterocycles

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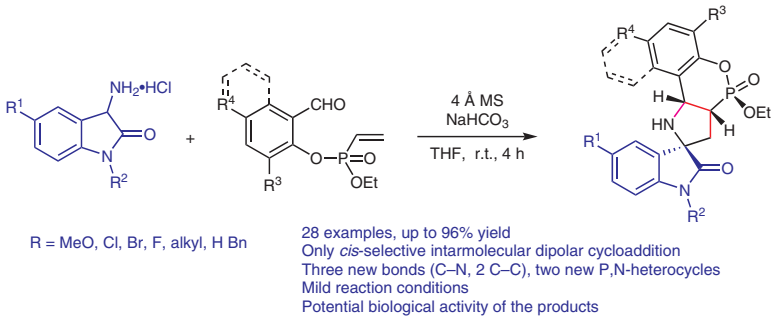

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Abstract An efficient stereoselective assembly strategy for the construction of pyrrolidin-2,3′-oxindole *cis*-fused phosphadihydrocoumarins was established. The process involves the condensation of O-vinylphosphonylated salicylaldehydes and 3-amino oxindoles followed by intermolecular cycloaddition with high diastereoselectivity and atom economy.

Key words 3-amino oxindole, azomethine ylide, dipolar cycloaddition, pyrrolidin-2,3′-oxindoles, *cis*-fused phosphadihydrocoumarins, O-vinylphosphonylated salicylaldehyde

Important challenges of contemporary synthetic chemistry include the creation of complex molecular entities with potential bioactivities by employing atom- and step-economical reaction routes. The application of efficient convergent assembly strategies should be one of the most useful ways of achieving these goals.[1]

Pyrrolidin-2,3′-oxindoles, as a representative of spirooxindole compounds, are notable heterocyclic frameworks because of their widespread occurrence in numerous natural products[2] and synthetic compounds exhibiting versatile bioactivities, such as anticancer,[3] antibacterial,[4] and MDM2 inhibitor action (Figure 1).[5] On the other hand, phosphorus-containing heterocyclic compounds have also been fascinating because of their ubiquity in biological systems and because new bioactivities have been discovered.[6] For example, phosphadihydrocoumarin or phosphonosugar possess phosphinolactone structural cores, which can be regarded as a surrogate of lactol and have shown various biological activities, such as antitumor,[7] phosphorylase inhibitor,[8] and antiproliferative activities (Figure 1).[9] Considering that assembling these dissimilar privileged scaffolds in a single framework to yield hybrid molecules is an interesting strategy for drug discovery, we envisioned that the integration of these two frameworks of pyrrolidin-2,3′-oxindoles and phosphadihydrocoumarins would produce structurally complex and diverse new molecules.

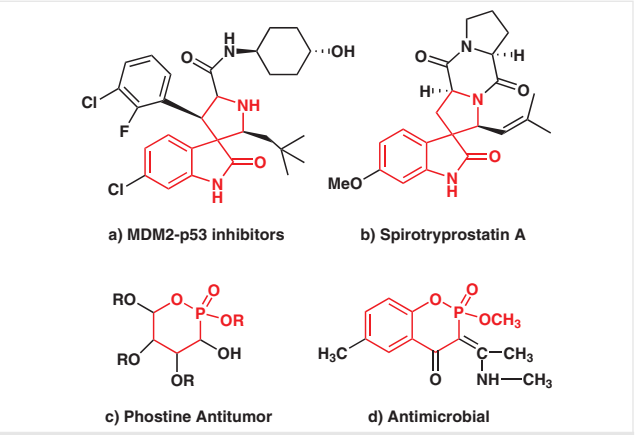

Figure 1 Representative bioactive molecules containing the spiro-[pyrrolidin-2,3′-oxindole] or oxaphosphinanes core

Owing to its significant medicinal implications, many methods have been developed for the synthesis of spirocyclic oxindole over the past decades.[10] Among the varied synthetic approaches to these compounds, the 1,3-dipolar cycloaddition reactions of 3-aminooxindole-derived azomethine ylides with various dipolarophiles such as nitroalkenes,[11] α,β-enones,[12] α,β-ynones,[13] 3-nitrochromenes[14] and indolenines[15] for the construction of the spirocyclic frameworks has provided the most efficient and direct methods (Scheme 1). However, reports on a consecutive condensation/intramolecular cycloaddition of 3-aminooxindole-derived azomethine ylides and bifunctional dipolarophiles to access the oxindole-fused spiro-*P*,*N*-heterocycles are scarce. Our group has been interested in using

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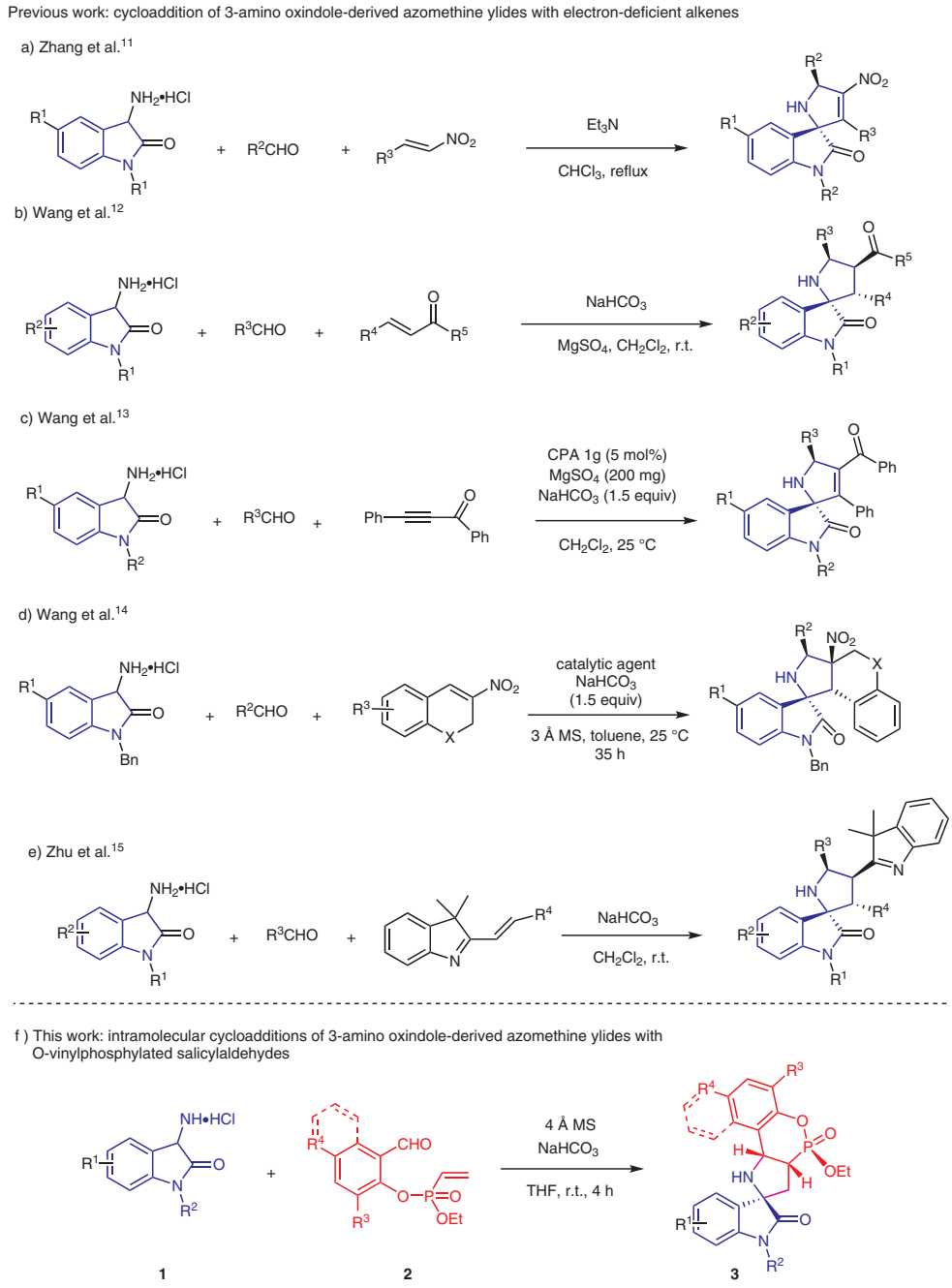
O-vinyl phosphonylated salicylaldehydes as bifunctional dipolarophiles though a condensation/intramolecular cycloaddition cascade reaction for the synthesis of complex phosphorus-containing fused heterocycles.[16] Herein, we describe our latest work on condensation of O-vinylphophonylated salicylaldehydes and 3-aminooxindoles followed by intramolecular 1,3-dipoar cycloaddition to efficiently generate such scaffolds with high diastereoselectivity (Scheme 1).

Originally, the reaction conditions from our previously published work[16] were adopted as the starting point for the development of this cascade condensation/intramolecular cycloaddition of 3-amino oxindole hydrochloride salt **1a** and O-vinylphosphylated salicylaldehyde **2a**. The reaction was carried out at room temperature in THF for 4 hours; the base ($NaHCO_3$) was used to scavenge HCl. To our delight, the product **3a** was obtained in 66% yield with high diastereoselectivity (99:1 d.r.; Table 1, entry 1), which prompted us



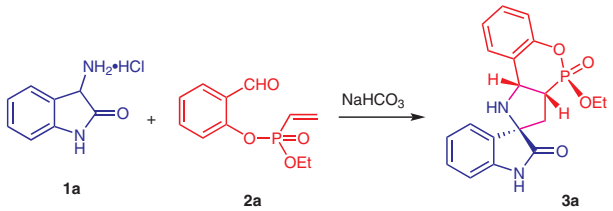
Scheme 1 Previous and proposed work

to further improve the reaction conditions. First, we tried to use different type of additives in THF (entries 2–8). When molecular sieves (4 Å) were added into the reaction system, the yield of **3a** clearly increased (entry 2), which indicated that molecular sieves were beneficial, probably by promoting the dehydration during the condensation of **1a** and **2a**. Subsequently, considering that the Lewis acidic catalyst might promote the reaction, we replaced molecular sieves 4 Å with Cu $(CF_3SO_3)_2$, $CuCl_2$, CuI, $ZnCl_2$, $AlCl_3$, and $BF_3{\cdot}Et_2O$, but found no significant improvement in the yield (entries 3–8). Next, we tested the effect of the temperature on the condensation/intramolecular cyclization (entries 9 and 10). Lowering the reaction temperature to 10 °C led to a lower yield (entry 10), while elevating the reaction temperature to 50 °C resulted in a slight decrease of the yield (entry 9). Finally, we also tried other solvents including CH_2Cl_2, $CHCl_3$, CH_3CN, CH_3OH and toluene at room temperature in the presence of molecular sieves (4 Å), but they did not give more satisfactory results than in THF (entries 11–15). Thus, the optimal reaction conditions were selected as summarized in Table 1, entry 2. Notably, these conditions seemingly have no clear influence on the diastereomeric ratios.

After establishing the optimal reaction conditions, we next examined the scope of this tandem reaction by variation of the substitution patterns on the O-vinylphosphonylated salicylaldehydes **2** and 3-amino oxindoles **1** (Scheme 2). In general, variation of the different substitution patterns on the phenyl ring of O-vinylphosphonylated salicylaldehydes (R^3, R^4 groups) gave structurally diversified spiropyrrolidin-2,3′-oxindoles *cis*-fused phosphadihydrocoumarin derivatives **3** in satisfactory yields. Regardless of the substituent position (*ortho*, *meta* or *para*) and the electronic nature (electron-donating MeO or electron-withdrawing Cl) of the substituent on the phenyl ring moiety, the desired products **3a–z** were obtained in good yields (67–96%) and with excellent diastereoselectivity (d.r. > 99:1) as the *cis*-fused diastereomer. In detail, the electron-donating O-vinylphosphonylated salicylaldehydes afforded moderately lower yields (**3x**, **3i**, **3q**). The linear or branched aliphatic groups on O-vinylphosphonylated salicylaldehydes **2** are also competent, giving excellent results (**3e**, **3k**, **3l**). The scope of the reaction with respect to the bis-substituted substituents on the O-vinylphosphonylated salicylaldehyde **2** was then studied. The substrates containing electron-donating groups (methyl groups) on the phenyl ring imposed no clear effect on the reactivity and gave excellent yields and similar high diastereoselectivities (**3g**, **3t**), while substrates with electron-withdrawing groups (Cl, Br) did not work. In addition, 2-O-vinylphosphonylated naphthaldehyde **2z2**, derived from β-hydroxy-naphthaldehyde also participated in the reaction smoothly with good yield to give single diastereomers (**3z2**). Next, we switched to explore the effect on the results of the substituents (R^1) on the benzene ring of 3-aminooxindoles **1**. 3-Aminooxindoles **1** with electron-withdrawing or electron-donating groups such as fluoro, bromo, and methyl groups at the 5-position reacted smoothly to afford the desired products with excellent yields and diastereoselectivities (**3v–z** and **3p–u**), while a nitro group at the same position fail to afford the desired product. Furthermore, both the N-unprotected and N-benzyl protected 3-aminooxindoles **1** were found to react smoothly with good yields. Notably, only one *cis*-diastereoisomer was formed for most of the above cases, although the products contained four stereocenters including three carbon and one phosphorus stereocenters. The relative configuration of **3a** was unequivocally assigned by X-ray diffraction (Figure 2; see also the Supporting Information),[16] and those of other products **3** were determined by analogy.

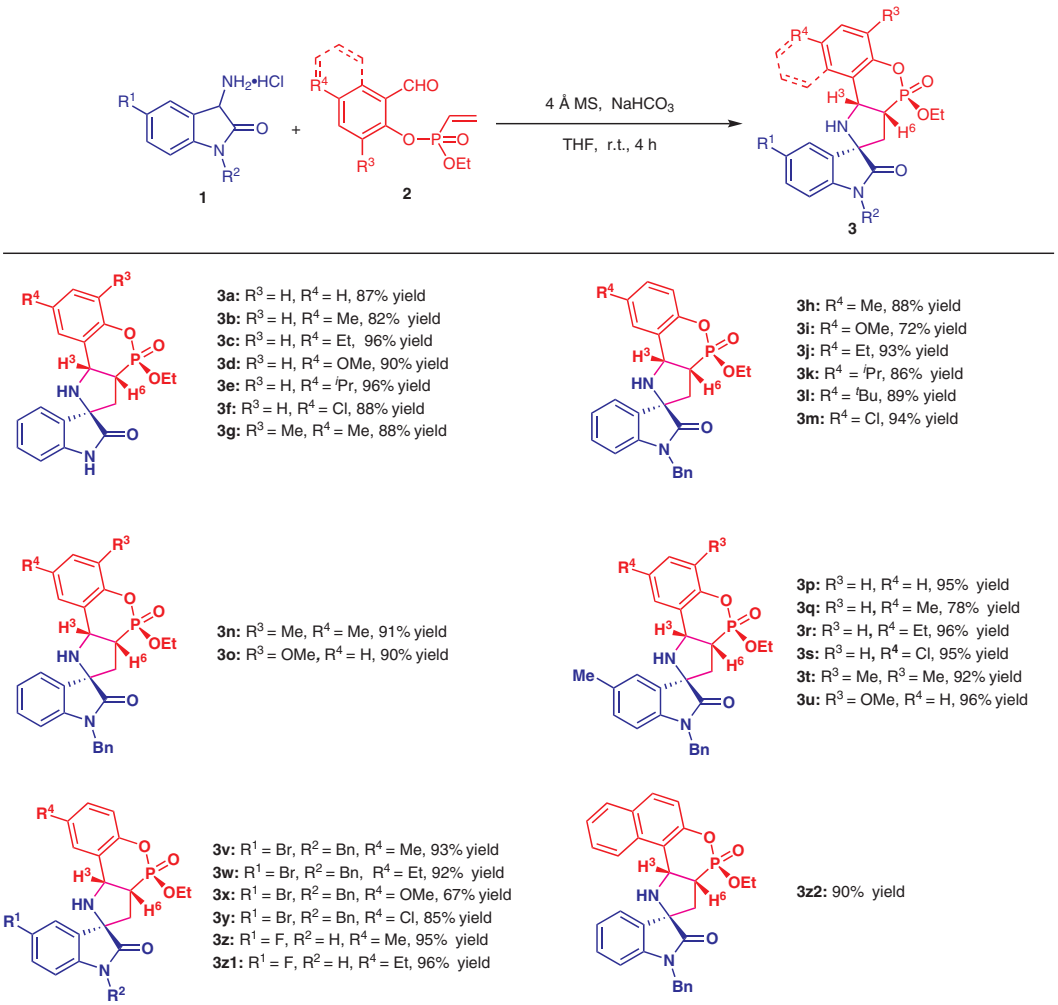
The structures of all products **3** were unambiguously assigned by ^1H, ^{13}C and ^{31}P NMR spectroscopy and HRMS. The ^1H NMR spectrum of all products **3** showed a double doublet at δ = 5.04–5.23 ppm and double quartet at δ = 3.14–3.28 ppm, respectively, for the vicinal two atoms H^3 and H^6 in the oxophosphorus heterocycle moiety due to coupling with adjacent phosphorus atoms ($^3J_{P-C-C-H}$ value of 12.2–

Table 1 Optimization of the Reaction Conditions[a]



Entry	Solvent	Additive[b]	Temp (°C)	Time (h)	Yield (%)[c]	dr[d]
1	THF	none	r.t	4	66	>99:1
2	THF	4 Å MS	r.t	4	87	>99:1
3	THF	Cu $(CF_3SO_3)_2$	r.t	4	80	>99:1
4	THF	$CuCl_2$	r.t.	4	72	>99:1
5	THF	CuI	r.t	4	60	>99:1
6	THF	$ZnCl_2$	r.t	4	70	>99:1
7	THF	$AlCl_3$	r.t	4	60	>99:1
8	THF	$BF_3{\cdot}Et_2O$	r.t	4	70	>99:1
9	THF	4 Å MS	50	4	80	>99:1
10	THF	4 Å MS	10	4	60	>99:1
11	CH_2Cl_2	4 Å MS	r.t	4	70	>99:1
12	$CHCl_3$	4 Å MS	r.t.	4	65	>99:1
13	MeCN	4 Å MS	r.t	4	77	>99:1
14	MeOH	4 Å MS	r.t	4	61	>99:1
15	toluene	4 Å MS	r.t	4	40	>99:1

[a] Reaction conditions: **1a** (0.3 mmol, 1.5 equiv), **2a** (0.2 mmol 1 equiv), $NaHCO_3$ (0.2 mmol, 1 equiv) and catalyst (20 mmol%) in anhydrous solvent (2 mL).
[b] Reactions 8–11,14 conditions: 100 mg 4 Å MS; Lewis acid 20 mmol%.
[c] Isolated yield.
[d] The dr was determined by ^{31}PNMR spectroscopic analysis of the crude products.



Scheme 2 Reaction scope. *Reagents and conditions*: **1** (0.3 mmol, 1.5 equiv), **2** (0.2 mmol, 1 equiv), $NaHCO_3$ (0.2 mmol, 1 equiv) and 100 mg 4 Å MS in anhydrous THF solvent (2 mL) at room temperature for 4 h; isolated yields are given.

16.9 Hz; J_{H3-H6} value of 7.4–8.4 Hz). The ^{13}C NMR signal of the carbon atom close to phosphorus was a doublet at δ = 35.1–36.7 ppm with $^1J_{C-P}$ values of 134–135.8 Hz. Based on the above spectra analysis and deducing from the smaller coupling constant value of the ring juncture protons (J_{H3-H6} = 7.4–8.4 Hz), the relative configurations of product **3** was assigned as *cis* at the newly formed ring junction. The ^1H NMR spectral data was also consistent with the structure derived from the X-ray diffraction data (Figure 2).

Based on the above results and on previous reports,[17] we propose a possible mechanism (Scheme 3). The reaction is initiated through the condensation reaction between O-vinylphosphonylated salicylaldehyde **2** and 3-aminooxindole **1** to give 'S'-shaped *E*-form azomethine ylide intermediates, which presumably exists in two transient states: *exo*-form (*exo*-TS) and *endo*-form (*endo*-TS). The *endo*-form is more stable than the *exo*-form because it experiences less steric hindrance and electrostatic repulsions, and it becomes the preferential intermediate. Subsequently, intramolecular *endo*-cycloaddition reaction takes place in only a *cis*-selective mode to produce pyrrolidin-2,3′-oxindoles *cis*-fused phosphadihydrocoumarin **3**. Finally, the epimerization of the cycloadducts at the phosphorus stereocenter

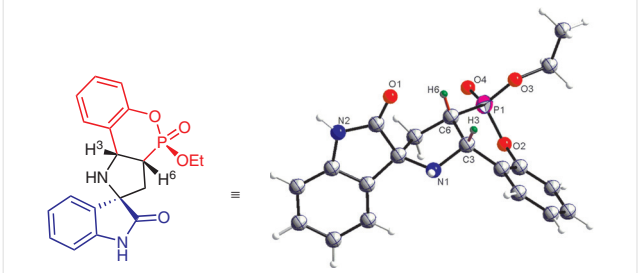
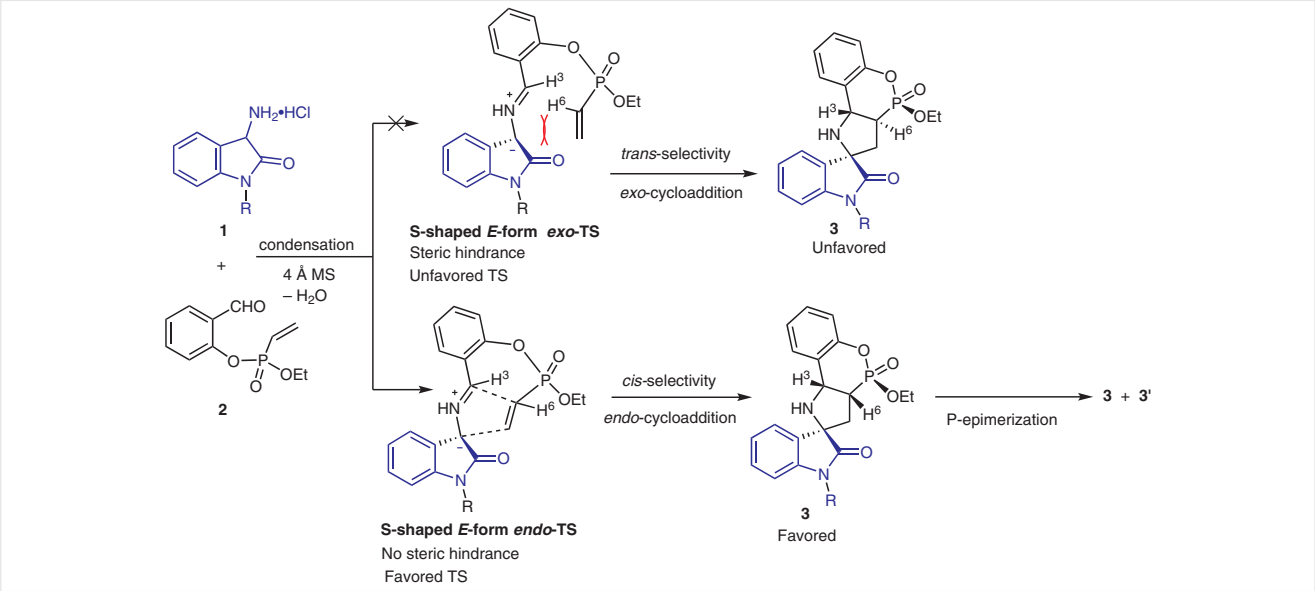


Figure 2 The single-crystal X-ray structure of compound **3a**



Scheme 3 A plausible reaction pathway

results in the two diastereomers **3** and **3′** with *cis*-configuration.

In summary, we have developed an efficient method for the construction of pyrrolidin-2,3′-oxindole *cis*-fused phosphadihydrocoumarin frameworks through a cascade condensation / intermolecular 1,3-dipolar cycloaddition reaction of 3-aminooxindoles with O-vinylphosphonylated salicylaldehydes. This cascade reaction creates two new P,N-heterocycles with four stereocenters by generating two C–C bonds and one C–N bond under mild reaction conditions, with high diastereoselectivity and atom economy.

The reactions were monitored by thin-layer chromatography (TLC) using silica gel GF254. All compounds were fully characterized based on their spectroscopic data. The NMR spectra were recorded with a Bruker Avance III (^{1}H NMR: 400 MHz, ^{13}C NMR: 100 MHz, ^{31}P NMR: 162 MHz external standard 85% H_3PO_4), chemical shifts (δ) are expressed in ppm, and *J* values are given in Hz. $CDCl_3$ and DMSO-d_6 were used as solvents. High-resolution mass spectra (HRMS) were recorded with an LCMS-IT-TOF. All chemicals and solvents were used as received without further purification unless otherwise stated. Column chromatography was performed on silica gel (200–300 mesh).

Synthesis of 3; General Procedure

In a Schlenk tube, anhydrous THF (2 mL) was added to a mixture of 3-aminooxindole **1** (0.3 mmol), ethyl (2-formylphenyl) vinylphosphonate **2** (0.2 mmol), $NaHCO_3$ (0.2 mmol), and 4 Å MS (100 mg) under a nitrogen atmosphere. The mixture was stirred at r.t. for 4 h (**2** was completely consumed as indicated by TLC), then purified by column chromatography (silica gel, EtOAc/PE = 1:1) to give pure **3**.

(±)-4-Ethoxy-1,3,3a,9b-tetrahydrospiro[benzo[5,6][1,2]oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-Oxide (3a)

Yield: 64.4 mg (87%); white oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.66 (s, 1 H), 7.39 (dd, *J* = 7.7, 1.7 Hz, 1 H), 7.29–7.18 (m, 1 H), 7.13–7.03 (m, 2 H), 7.00 (dd, *J* = 8.2, 1.2 Hz, 1 H), 6.91–6.80 (m, 2 H), 6.75 (d, *J* = 7.7 Hz, 1 H), 5.09 (dd, $^3J_{P-C-C-H}$ = 14.1, $^3J_{H-C-C-H}$ = 7.8 Hz, 1 H), 4.42–4.08 (m, 2 H), 3.44–3.11 (m, 1 H), 2.68–2.39 (m, 3 H), 1.24 (t, *J* = 7.1 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 182.0, 149.9 (d, $^2J_{P-O-C}$ = 6.5 Hz), 140.6, 131.5, 130.9, 129.7, 129.1, 125.8 (d,$^3J_{P-O-C-C}$ = 11.5 Hz), 124.6, 124.2, 123.3, 119.5 (d, $^3J_{P-O-C-C}$ = 6.5 Hz), 110.0, 67.8 (d, $^3J_{P-C-C-C}$ = 10.7 Hz), 62.6 (d, $^2J_{P-O-C}$ = 7.1 Hz), 61.1 (d, $^2J_{P-C-C}$ = 3.7 Hz), 37.7, 35.8 (d, J_{P-C} = 134.6 Hz), 16.4 (d, $^3J_{P-O-C-C}$ = 5.6 Hz).

^{31}P NMR (162 MHz, $CDCl_3$): δ = 25.42 (s).

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{19}H_{20}N_2O_4P$: 371.1155; found: 371.1177.

(±)-4-Ethoxy-8-methyl-1,3,3a,9b-tetrahydrospiro[benzo[5,6][1,2]-oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-Oxide (3b)

Yield: 63.0 mg (82%); yellow oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.10 (s, 1 H), 7.23 (d, *J* = 2.2 Hz, 1 H), 7.16–7.04 (m, 2 H), 7.01–6.90 (m, 2 H), 6.90–6.85 (m, 1 H), 6.81 (d, *J* = 7.7 Hz, 1 H), 5.11 (dd, $^3J_{P-C-C-H}$ = 14.7, $^3J_{H-C-C-H}$ = 7.9 Hz, 1 H), 4.30–4.15 (m, 2 H), 3.30–3.16 (m, 1 H), 2.68–2.51 (m, 3 H), 2.27 (s, 3 H), 1.28 (t, *J* = 7.1 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 182.1, 147.8 (d, $^2J_{P-O-C}$ = 6.3 Hz), 140.9, 134.2, 131.4, 131.1, 130.3, 129.1, 125.3 (d, $^3J_{P-O-C-C}$ = 11.5 Hz), 124.1, 123.1, 119.2 (d, $^3J_{P-O-C-C}$ = 6.4 Hz), 110.1, 67.9 (d, $^3J_{P-C-C-C}$ = 10.5 Hz), 62.5 (d, $^2J_{P-O-C}$ = 7.0 Hz), 61.1 (d, $^2J_{P-C-C}$ = 3.7 Hz), 37.6, 35.8 (d, J_{P-C} = 134.7 Hz), 20.7, 16.4 (d, $^3J_{P-O-C-C}$ = 5.6 Hz).

^{31}P NMR (162 MHz, $CDCl_3$): δ = 25.90 (s).

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{20}H_{22}N_2O_4P$: 385.1312; found: 385.1310.

(±)-4-Ethoxy-8-ethyl-1,3,3a,9b-tetrahydrospiro[benzo[5,6][1,2]-oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-Oxide (3c)

Yield: 76.5 mg (96%); yellow oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.08 (s, 1 H), 7.20 (d, *J* = 2.2 Hz, 1 H), 7.09–6.99 (m, 2 H), 6.95–6.83 (m, 2 H), 6.82–6.71 (m, 2 H), 5.06 (dd, $^3J_{P-C-C-H}$ = 14.4, $^3J_{H-C-C-H}$ = 7.8 Hz, 1 H), 4.29–4.03 (m, 2 H), 3.33–3.03 (m, 1 H), 2.75–2.20 (m, 5 H), 1.23 (t, *J* = 7.1 Hz, 3 H), 1.11 (t, *J* = 7.6 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 181.2, 146.9 (d, $^2J_{P-O-C}$ = 6.4 Hz), 139.8, 139.6, 130.5, 129.0, 128.1 (d, $^3J_{P-O-C-C}$ = 5.1 Hz), 124.3, 124.2, 123.1, 122.1, 118.3 (d, $^3J_{P-O-C-C}$ = 6.5 Hz), 109.1, 66.9 (d, $^3J_{P-C-C-C}$ = 10.6 Hz), 61.5 (d, $^2J_{P-O-C}$ = 7.0 Hz), 60.3 (d, $^2J_{P-C-C}$ = 3.7 Hz), 36.6, 34.9 (d, J_{P-C} = 134.4 Hz), 27.1, 15.4 (d, $^3J_{P-O-C-C}$ = 5.7 Hz), 14.6.

^{31}P NMR (162 MHz, $CDCl_3$): δ = 25.74 (s).

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{21}H_{24}N_2O_4P$: 399.1468; found: 399.1494.

(±)-4-Ethoxy-8-methoxy-1,3,3a,9b-tetrahydrospiro[benzo[5,6][1,2]-oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-Oxide (3d)

Yield: 72.1 mg (90%); yellow oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.06 (s, 1 H), 7.11 (t, *J* = 7.7 Hz, 1 H), 7.00–6.94 (m, 3 H), 6.88 (t, *J* = 7.5 Hz, 1 H), 6.85–6.77 (m, 2 H), 5.10 (dd, $^3J_{P-C-C-H}$ = 16.6, $^3J_{H-C-C-H}$ = 8.6 Hz, 1 H), 4.29–4.13 (m, 2 H), 3.73 (s, 3 H), 3.12–3.18 (m, 1 H), 2.70–2.55 (m, 2 H), 2.52–2.42 (m, 1 H), 1.28 (t, *J* = 7.1 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 182.1, 156.2, 143.5 (d, $^2J_{P-O-C}$ = 6.4 Hz), 140.8, 131.4, 129.1, 126.7 (d, $^3J_{P-O-C-C}$ = 11.2 Hz), 124.1, 123.1, 120.3 (d, $^3J_{P-O-C-C}$ = 6.4 Hz), 115.8, 114.7, 110.1, 67.9 (d, $^3J_{P-C-C-C}$ = 10.9 Hz), 62.5 (d, $^2J_{P-O-C}$ = 6.9 Hz), 61.3 (d, $^2J_{P-C-C}$ = 3.6 Hz), 55.7, 37.7, 35.6 (d, J_{P-C} = 135.1 Hz), 16.4 (d, $^3J_{P-O-C-C}$ = 5.6 Hz).

^{31}P NMR (162 MHz, $CDCl_3$): δ = 25.96 (s).

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{20}H_{22}N_2O_5P$: 401.1261; found: 401.1280.

(±)-4-Ethoxy-8-isopropyl-1,3,3a,9b-tetrahydrospiro[benzo[5,6][1,2]-oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-Oxide (3e)

Yield: 79.2 mg (96%); light-yellow oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.01 (s, 1 H), 7.32 (d, *J* = 2.3 Hz, 1 H), 7.18–7.07 (m, 2 H), 7.00–6.96 (m, 1 H), 6.90–6.83 (m, 2 H), 6.82 (d, *J* = 7.9 Hz, 1 H), 5.13 (dd, $^3J_{P-C-C-H}$ = 14.1, $^3J_{H-C-C-H}$ = 7.7 Hz, 1 H), 4.34–4.17 (m, 2 H), 3.29–3.15 (m, 1 H), 2.91–2.80 (m, 1 H), 2.70–2.45 (m, 3 H), 1.31 (t, *J* = 7.1 Hz, 3 H), 1.20 (s, 3 H), 1.19 (s, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 182.1, 147.9 (d, $^2J_{P-O-C}$ = 6.5 Hz), 145.2, 140.8, 131.7, 129.1, 128.7, 127.7, 125.1 (d, $^3J_{P-O-C-C}$ = 11.0 Hz), 124.2, 123.1, 119.3 (d, $^3J_{P-O-C-C}$ = 6.6 Hz), 110.0, 67.9 (d, $^3J_{P-C-C-C}$ = 10.7 Hz), 62.5 (d, $^2J_{P-O-C}$ = 7.0 Hz), 61.4 (d, $^2J_{P-C-C}$ = 3.6 Hz), 37.7, 36.1 (d, J_{P-C} = 134.1 Hz), 33.6, 24.0, 24.0, 16.4 (d, $^3J_{P-O-C-C}$ = 5.5 Hz).

^{31}P NMR (162 MHz, $CDCl_3$): δ = 25.56 (s).

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{22}H_{26}N_2O_4P$: 413.1625; found: 413.1691.

(±)-8-Chloro-4-ethoxy-1,3,3a,9b-tetrahydrospiro[benzo[5,6][1,2]-oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-Oxide (3f)

Yield: 71.1 mg (88%); light-yellow oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.45 (s, 1 H), 7.41 (d, *J* = 2.6 Hz, 1 H), 7.24–7.17 (m, 1 H), 7.12–7.07 (m, 1 H), 6.99–6.84 (m, 3 H), 6.76 (d, *J* = 7.7 Hz, 1 H), 5.04 (dd, $^3J_{P-C-C-H}$ = 13.1, $^3J_{H-C-C-H}$ = 7.9 Hz, 1 H), 4.29–4.11 (m, 2 H), 3.30–3.14 (m, 1 H), 2.73–2.28 (m, 3 H), 1.25 (t, *J* = 7.0 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 180.8, 147.4 (d, $^2J_{P-O-C}$ = 6.3 Hz), 139.4, 130.2, 129.6, 128.7 (d, $^3J_{P-O-C-C}$ = 3.1 Hz), 128.2, 126.8, 126.7, 123.2, 122.4, 119.9 (d, $^3J_{P-O-C-C}$ = 6.6 Hz), 109.0, 66.8 (d, $^3J_{P-C-C-C}$ = 11.3 Hz), 61.8 (d, $^2J_{P-O-C}$ = 7.0 Hz), 59.6 (d, $^2J_{P-C-C}$ = 3.5 Hz), 36.6, 34.4 (d, J_{P-C} = 134.9 Hz), 15.4 (d, $^3J_{P-O-C-C}$ = 5.6 Hz).

^{31}P NMR (162 MHz, $CDCl_3$): δ = 25.07 (s).

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{19}H_{19}ClN_2O_4P$: 405.0765; found: 405.0770.

(±)-4-Ethoxy-6,8-dimethyl-1,3,3a,9b-tetrahydrospiro[benzo[5,6][1,2]-oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-Oxide (3g)

Yield: 70.1 mg (88%); yellow oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 9.08 (d, *J* = 4.4 Hz, 1 H), 7.09–7.01 (m, 2 H), 6.97 (s, 1 H), 6.89 (s, 1 H), 6.82 (t, *J* = 6.9 Hz, 1 H), 6.75 (d, *J* = 7.1 Hz, 1 H), 5.05 (dd, $^3J_{P-C-C-H}$ = 16.6, $^3J_{H-C-C-H}$ = 7.6 Hz, 1 H), 4.26–4.15 (m, 1 H), 4.12–4.03 (m, 1 H), 3.21–3.09 (m, 1 H), 2.72 (s, 1 H), 2.63–2.45 (m, 2 H), 2.20 (s, 3 H), 2.16 (s, 3 H), 1.22 (t, *J* = 6.2 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 181.2, 145.3 (d, $^2J_{P-O-C}$ = 6.8 Hz), 139.9, 132.5, 130.7, 130.2, 128.1, 127.5, 127.0 (d, $^3J_{P-O-C-C}$ = 5.7 Hz), 124.1 (d, $^3J_{P-O-C-C}$ = 11.6 Hz), 123.3, 122.1, 109.0, 66.7 (d, $^3J_{P-C-C-C}$ = 9.5 Hz), 61.3 (d, $^2J_{P-O-C}$ = 7.1 Hz), 60.3 (d, $^2J_{P-C-C}$ = 4.0 Hz), 36.5, 34.7 (d, J_{P-C} = 135.4 Hz), 19.6, 15.4 (d, $^3J_{P-O-C-C}$ = 5.6 Hz), 14.8.

^{31}P NMR (162 MHz, $CDCl_3$): δ = 26.73 (s).

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{21}H_{24}N_2O_4P$: 399.1468; found: 399.1490.

(±)-1′-Benzyl-4-ethoxy-8-methyl-1,3,3a,9b-tetrahydrospiro[benzo[5,6]-[1,2]oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-Oxide (3h)

Yield: 83.5 mg (88%); white oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.28–7.20 (m, 6 H), 7.08–6.97 (m, 3 H), 6.93–6.85 (m, 2 H), 6.60 (d, *J* = 7.8 Hz, 1 H), 5.12 (dd, $^3J_{P-C-C-H}$ = 14.9, $^3J_{H-C-C-H}$ = 7.9 Hz, 1 H), 4.96–4.85 (m, 1 H), 4.76–4.66 (m, 1 H), 4.27–4.10 (m, 2 H), 3.29–3.16 (m, 1 H), 2.69–2.47 (m, 3 H), 2.24 (s, 3 H), 1.25 (t, *J* = 7.1 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 179.9, 147.8 (d, $^2J_{P-O-C}$ = 6.3 Hz), 142.4, 135.6, 134.1, 131.1, 130.9, 130.3, 129.1, 128.9 (2C), 127.7, 127.2 (2C), 125.2 (d, $^3J_{P-O-C-C}$ = 11.4 Hz), 123.9, 123.5, 119.3 (d, $^3J_{P-O-C-C}$ = 6.4 Hz), 109.1, 67.6 (d, $^3J_{P-C-C-C}$ = 10.4 Hz), 62.5 (d, $^2J_{P-O-C}$ = 7.0 Hz), 61.4 (d, $^2J_{P-C-C}$ = 3.8 Hz), 43.7, 37.9, 35.9 (d, J_{P-C} = 134.6 Hz), 20.7, 16.4 (d, $^3J_{P-O-C-C}$ = 5.6 Hz).

^{31}P NMR (162 MHz, $CDCl_3$): δ = 25.55 (s).

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{27}H_{28}N_2O_4P$: 475.1781; found: 475.1793.

(±)-1′-Benzyl-4-ethoxy-8-methoxy-1,3,3a,9b-tetrahydro-spiro[benzo[5,6][1,2]oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-Oxide (3i)

Yield: 70.6 mg (72%); white oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.30–7.17 (m, 5 H), 7.08–7.00 (m, 2 H), 6.95–6.86 (m, 3 H), 6.79 (d, *J* = 8.3 Hz, 1 H), 6.61 (d, *J* = 7.4 Hz, 1 H), 5.11 (dd, $^3J_{P-C-C-H}$ = 14.5, $^3J_{H-C-C-H}$ = 7.4 Hz, 1 H), 4.93–4.89 (m, 1 H), 4.73–4.69 (m, 1 H), 4.28–4.10 (m, 2 H), 3.70 (s, 3 H), 3.33–3.19 (m, 1 H), 2.68–2.47 (m, 2 H), 2.14 (s, 1 H), 1.27–1.22 (m, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 178.9, 155.2, 142.7 (d, $^2J_{P-O-C}$ = 6.5 Hz), 141.4, 134.6, 129.9, 128.1, 127.9 (2C), 126.7, 126.2 (2C), 125.5 (d, $^3J_{P-O-C-C}$ = 11.2 Hz), 123.0, 122.5, 119.4 (d, $^3J_{P-O-C-C}$ = 6.3 Hz), 115.0,

113.6, 108.1, 66.6 (d, $^3J_{P-C-C-C}$ = 10.7 Hz), 61.4 (d, $^2J_{P-O-C}$ = 7.0 Hz), 60.5 (d, $^2J_{P-C-C}$ = 3.7 Hz), 54.7, 42.8, 37.0, 34.9 (d, J_{P-C} = 135.0 Hz), 15.4 (d, $^3J_{P-O-C-C}$ = 5.7 Hz).

^{31}P NMR (162 MHz, $CDCl_3$): δ = 25.56 (s).

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{27}H_{28}N_2O_5P$: 491.1730; found: 491.1722.

(±)-1′-Benzyl-4-ethoxy-8-ethyl-1,3,3a,9b-tetrahydrospiro[benzo-[5,6][1,2]oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-Oxide (3j)

Yield: 90.9 mg (93%); yellow oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.27–7.19 (m, 6 H), 7.11–7.01 (m, 2 H), 6.99–6.89 (m, 2 H), 6.85 (t, *J* = 7.5 Hz, 1 H), 6.60 (d, *J* = 7.8 Hz, 1 H), 5.12 (dd, $^3J_{P-C-C-H}$ = 14.8, $^3J_{H-C-C-H}$ = 7.8 Hz, 1 H), 4.94–4.87 (m, 1 H), 4.73–4.67 (m, 1 H), 4.27–4.10 (m, 2 H), 3.27–3.15 (m, 1 H), 2.74–2.59 (m, 1 H), 2.59–2.59 (m, 4 H), 1.25 (t, *J* = 7.0 Hz, 3 H), 1.13 (t, *J* = 7.6 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 179.9, 148.0 (d, $^2J_{P-O-C}$ = 6.4 Hz), 142.4, 140.5, 135.6, 131.1, 130.0, 129.2, 129.1, 128.9 (2C), 127.7, 127.2 (2C), 125.1 (d, $^3J_{P-O-C-C}$ = 11.3 Hz), 124.0, 123.5, 119.3 (d, $^3J_{P-O-C-C}$ = 6.5 Hz), 109.1, 67.6 (d, $^3J_{P-C-C-C}$ = 10.3 Hz), 62.5 (d, $^2J_{P-O-C}$ = 7.1 Hz), 61.5 (d, $^2J_{P-C-C}$ = 3.8 Hz), 43.8, 38.0, 36.1 (d, J_{P-C} = 134.3 Hz), 28.2, 16.4 (d, $^3J_{P-O-C-C}$ = 5.6 Hz), 15.7.

^{31}P NMR (162 MHz, $CDCl_3$): δ = 25.36 (s).

HRMS (ESI): *m*/*z* [M + K]$^+$ calcd for $C_{28}H_{29}N_2KO_4P$: 522.1497; found: 522.1510.

(±)-1′-Benzyl-4-ethoxy-8-isopropyl-1,3,3a,9b-tetrahydro-spiro[benzo[5,6][1,2]oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-Oxide (3k)

Yield: 86.4 mg (86%); light-yellow oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.30–7.16 (m, 6 H), 7.09 (dd, *J* = 8.4, 2.2 Hz, 1 H), 7.08–6.99 (m, 1 H), 6.97–6.86 (m, 2 H), 6.82 (t, *J* = 7.5 Hz, 1 H), 6.59 (d, *J* = 7.8 Hz, 1 H), 5.12 (dd, $^3J_{P-C-C-H}$ = 14.4, $^3J_{H-C-C-H}$ = 7.7 Hz, 1 H), 4.94–4.87 (m, 1 H), 4.74–7.65 (m, 1 H), 4.30–4.09 (m, 2 H), 3.26–3.14 (m, 1 H), 2.87–2.74 (m, 2 H), 2.71–2.37 (m, 2 H), 1.27–1.13 (m, 9 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 179.9, 148.0 (d, $^2J_{P-O-C}$ = 6.5 Hz), 145.2, 142.3, 135.6, 131.2, 129.1, 128.9 (2C), 128.7, 127.8, 127.2 (2C), 125.0, 124.9, 124.0, 123.4, 119.3 (d, $^3J_{P-O-C-C}$ = 6.6 Hz), 109.1, 67.6 (d, $^3J_{P-C-C-C}$ = 10.6 Hz), 62.5 (d, $^2J_{P-O-C}$ = 6.9 Hz), 61.6 (d, $^2J_{P-C-C}$ = 3.7 Hz), 43.8, 38.0, 36.2 (d, J_{P-C} = 134.0 Hz), 33.6, 24.1, 16.5 (d, $^3J_{P-O-C-C}$ = 5.7 Hz), 14.2.

^{31}P NMR (162 MHz, $CDCl_3$): δ = 25.24 (s).

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{29}H_{32}N_2O_4P$: 503.2094; found: 503.2099.

(±)-1′-Benzyl-8-(*tert*-butyl)-4-ethoxy-1,3,3a,9b-tetrahydro-spiro[benzo[5,6][1,2]oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-Oxide (3l)

Yield: 91.9 mg (89%); light-yellow oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.43 (d, *J* = 2.4 Hz, 1 H), 7.31–7.15 (m, 6 H), 7.13–6.98 (m, 1 H), 7.01–6.88 (m, 2 H), 6.83 (t, *J* = 7.5 Hz, 1 H), 6.60 (d, *J* = 7.8 Hz, 1 H), 5.13 (dd, $^3J_{P-C-C-H}$ = 14.6, $^3J_{H-C-C-H}$ = 7.6 Hz, 1 H), 4.96–4.88 (m, 1 H), 4.77–4.63 (m, 1 H), 4.37–4.03 (m, 2 H), 3.34–3.09 (m, 1 H), 2.76–2.40 (m, 2 H), 2.10 (s, 1 H), 1.22 (s, 12 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 179.0, 146.7 (d, $^2J_{P-O-C}$ = 6.3 Hz), 146.4, 141.3, 134.6, 130.2, 128.0, 127.9 (2C), 126.7 (d, $^3J_{P-O-C-C}$ = 5.0 Hz), 126.2 (2C), 125.8, 125.5, 123.5 (d, *J* = 11.1 Hz), 123.1, 122.4, 117.9 (d, $^3J_{P-O-C-C}$ = 6.5 Hz), 108.1, 66.6 (d, $^3J_{P-C-C-C}$ = 10.5 Hz), 61.5 (d, $^2J_{P-O-C}$ = 6.9 Hz), 60.7 (d, $^2J_{P-C-C}$ = 3.7 Hz), 42.7, 37.0, 35.2 (d, J_{P-C} = 134.0 Hz), 33.4, 30.4 (3C), 15.4 (d, $^3J_{P-O-C-C}$ = 5.5 Hz).

^{31}P NMR (162 MHz, $CDCl_3$): δ = 25.37 (s).

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{30}H_{34}N_2O_4P$: 517.2251; found: 517.2263.

(±)-1′-Benzyl-8-chloro-4-ethoxy-1,3,3a,9b-tetrahydrospiro[benzo[5,6][1,2]oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-Oxide (3m)

Yield: 93.0 mg (94%); white oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.43 (d, *J* = 2.6 Hz, 1 H), 7.29–7.17 (m, 6 H), 7.10–7.04 (m, 1 H), 6.97–6.85 (m, 3 H), 6.62 (d, *J* = 7.8 Hz, 1 H), 5.10 (dd, $^3J_{P-C-C-H}$ = 13.1, $^3J_{H-C-C-H}$ = 7.9 Hz, 1 H), 4.94–4.85 (m, 1 H), 4.77–4.67 (m, 1 H), 4.34–4.09 (m, 2 H), 3.33–3.20 (m, 1 H), 2.78 (s, 1 H), 2.69–2.41 (m, 2 H), 1.26 (t, *J* = 7.1 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 178.8, 147.4 (d, $^2J_{P-O-C}$ = 6.5 Hz), 141.3, 134.5, 129.6, 128.7, 128.2, 127.9 (2C), 126.8, 126.2 (2C), 122.7 (d, $^3J_{P-O-C-C}$ = 28.9 Hz), 119.9 (d, $^3J_{P-O-C-C}$ = 6.6 Hz), 108.2, 66.6 (d, $^2J_{P-O-C}$ = 11.6 Hz), 61.8 (d, $^2J_{P-C-C}$ = 6.9 Hz), 59.8, 42.8, 36.9, 34.6 (d, J_{P-C} = 134.9 Hz), 15.4 (d, $^3J_{P-O-C-C}$ = 5.7 Hz).

^{31}P NMR (162 MHz, $CDCl_3$): δ = 24.74 (s).

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{26}H_{25}ClN_2O_4P$: 495.1235; found: 495.1251.

(±)-1′-Benzyl-4-ethoxy-6,8-dimethyl-1,3,3a,9b-tetrahydro-spiro[benzo[5,6][1,2]oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-Oxide (3n)

Yield: 88.9 mg (91%); white oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.35–7.25 (m, 5 H), 7.19 (d, *J* = 7.3 Hz, 1 H), 7.14–7.08 (m, 2 H), 7.02–6.92 (m, 2 H), 6.67 (d, *J* = 7.9 Hz, 1 H), 5.20 (dd, $^3J_{P-C-C-H}$ = 16.6, $^3J_{H-C-C-H}$ = 7.6 Hz, 1 H), 5.00–4.93 (m, 1 H), 4.82–4.74 (m, 1 H), 4.37–4.23 (m, 1 H), 4.24–4.11 (m, 1 H), 3.35–3.22 (m, 1 H), 2.91–2.60 (m, 3 H), 2.30 (s, 3 H), 2.26 (s, 3 H), 1.31 (t, *J* = 7.1 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 180.0, 146.4 (d, $^2J_{P-O-C}$ = 6.8 Hz), 142.4, 135.7, 133.5, 131.8, 130.8, 129.1, 128.9 (2C), 128.6, 128.1 (d, $^3J_{P-O-C-C}$ = 5.6 Hz), 127.7, 127.2 (2C), 125.0 (d, $^3J_{P-O-C-C}$ = 11.5 Hz), 124.1, 123.5, 109.1, 67.4 (d, $^3J_{P-C-C-C}$ = 9.5 Hz), 62.3 (d, $^2J_{P-O-C}$ = 6.9 Hz), 61.5 (d, $^2J_{P-C-C}$ = 4.1 Hz), 43.7, 37.9, 35.9 (d, J_{P-C} = 135.3 Hz), 20.6, 16.4 (d, $^3J_{P-O-C-C}$ = 5.7 Hz), 15.9.

^{31}P NMR (162 MHz, $CDCl_3$): δ = 26.41 (s).

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{28}H_{30}N_2O_4P$: 489.1938; found: 489.1959.

(±)-1′-Benzyl-4-ethoxy-6-methoxy-1,3,3a,9b-tetrahydro-spiro[benzo[5,6][1,2]oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-oxide (3o)

Yield: 88.3 mg (90%); yellow oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.43–7.23 (m, 6 H), 7.19–7.03 (m, 3 H), 6.94 (q, *J* = 7.6 Hz, 2 H), 6.67 (d, *J* = 7.8 Hz, 1 H), 5.23 (dd, $^3J_{P-C-C-H}$ = 16.7, $^3J_{H-C-C-H}$ = 7.9 Hz, 1 H), 5.00–4.92 (m, 1 H), 4.83–4.74 (m, 1 H), 4.40–4.11 (m, 2 H), 3.90 (s, 3 H), 3.50–3.16 (m, 1 H), 2.87–2.52 (m, 3 H), 1.40–1.26 (m, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 180.0, 149.7 (d, $^2J_{P-O-C}$ = 5.4 Hz), 142.4, 139.7 (d, $^3J_{P-O-C-C}$ = 6.3 Hz), 135.6, 130.8, 129.1, 128.9 (2C), 127.7, 127.2 (2C), 127.1, 127.0, 124.2 (d, $^3J_{P-O-C-C}$ = 23.4 Hz), 123.5, 121.9,

112.2, 109.1, 67.4 (d, $^3J_{P-C-C-C}$ = 9.6 Hz), 62.6 (d, $^2J_{P-O-C}$ = 7.0 Hz), 61.5 (d, $^2J_{P-C-C}$ = 4.3 Hz), 56.2, 43.7, 37.8, 36.0 (d, J_{P-C} = 135.7 Hz), 16.3 (d, $^3J_{P-O-C-C}$ = 5.7 Hz).

^{31}P NMR (162 MHz, $CDCl_3$): δ = 26.13 (s).

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{27}H_{28}N_2O_5P$: 491.1730; found: 491.1744.

(±)-1′-Benzyl-4-ethoxy-5′-methyl-1,3,3a,9b-tetrahydrospiro[benzo[5,6][1,2]oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-Oxide (3p)

Yield: 90.2 mg (95%); white oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.40 (d, *J* = 7.7 Hz, 1 H), 7.30–7.16 (m, 6 H), 7.09 (t, *J* = 7.5 Hz, 1 H), 7.01 (d, *J* = 8.1 Hz, 1 H), 6.83 (d, *J* = 7.9 Hz, 1 H), 6.70 (s, 1 H), 6.48 (d, *J* = 7.9 Hz, 1 H), 5.16 (dd, $^3J_{P-C-C-H}$ = 14.3, $^3J_{H-C-C-H}$ = 8.0 Hz, 1 H), 4.91–4.84 (m, 1 H), 4.72–4.64 (m, 1 H), 4.32–4.08 (m, 2 H), 3.32–3.19 (m, 1 H), 2.77–2.44 (m, 3 H), 2.09 (s, 3 H), 1.24 (t, *J* = 7.1 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 179.8, 150.1 (d, $^2J_{P-O-C}$ = 6.2 Hz), 139.9, 135.7, 133.1, 130.9, 130.8, 129.7, 129.3, 128.9 (2C), 127.7, 127.2 (2C), 125.9 (d, $^3J_{P-O-C-C}$ = 11.5 Hz), 124.7, 124.5, 119.6 (d, $^3J_{P-O-C-C}$ = 6.4 Hz), 108.9, 67.7 (d, $^3J_{P-C-C-C}$ = 10.8 Hz), 62.5 (d, $^2J_{P-O-C}$ = 7.0 Hz), 61.2 (d, $^2J_{P-C-C}$ = 3.8 Hz), 43.7, 37.9, 35.9 (d, J_{P-C} = 134.7 Hz), 21.0, 16.4 (d, $^3J_{P-O-C-C}$ = 5.6 Hz).

^{31}P NMR (162 MHz, $CDCl_3$): δ = 25.49 (s).

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{27}H_{28}N_2O_4P$: 475.1781; found: 475.1793.

(±)-1′-Benzyl-4-ethoxy-5′,8-dimethyl-1,3,3a,9b-tetrahydrospiro[benzo[5,6][1,2]oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-Oxide (3q)

Yield: 76.2 mg (78%); yellow oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.25–7.16 (m, 6 H), 7.04 (d, *J* = 8.3 Hz, 1 H), 6.90 (d, *J* = 8.3 Hz, 1 H), 6.83 (d, *J* = 7.3 Hz, 1 H), 6.72 (d, *J* = 1.7 Hz, 1 H), 6.47 (d, *J* = 7.9 Hz, 1 H), 5.12 (dd, $^3J_{P-C-C-H}$ = 14.6, $^3J_{H-C-C-H}$ = 8.0 Hz, 1 H), 4.92–4.83 (m, 1 H), 4.73–4.64 (m, 1 H), 4.31–4.07 (m, 2 H), 3.30–3.16 (m, 1 H), 2.69–2.41 (m, 3 H), 2.23 (s, 3 H), 2.09 (s, 3 H), 1.24 (t, *J* = 7.1 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 179.8, 147.9 (d, $^2J_{P-O-C}$ = 6.4 Hz), 140.0, 135.7, 134.1, 133.0, 131.2, 130.9, 130.3, 129.3, 128.8 (2C), 127.7, 127.2 (2C), 125.4 (d, $^3J_{P-O-C-C}$ = 11.6 Hz), 124.7, 119.3 (d, $^3J_{P-O-C-C}$ = 6.3 Hz), 108.9, 67.7 (d, $^3J_{P-C-C-C}$ = 10.6 Hz), 62.4 (d, $^2J_{P-O-C}$ = 7.0 Hz), 61.3 (d, $^2J_{P-C-C}$ = 3.8 Hz), 43.7, 37.9, 35.9 (d, J_{P-C} = 134.5 Hz), 21.0, 20.7, 16.4 (d, $^3J_{P-O-C-C}$ = 5.6 Hz).

^{31}P NMR (162 MHz, $CDCl_3$): δ = 25.78 (s).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{28}H_{29}N_2NaO_4P$: 511.1757; found: 511.1764.

(±)-1′-Benzyl-4-ethoxy-8-ethyl-5′-methyl-1,3,3a,9b-tetrahydrospiro[benzo[5,6][1,2]oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-Oxide (3r)

Yield: 96.4 mg (96%); yellow oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.30–7.15 (m, 6 H), 7.06 (dd, *J* = 8.3, 2.3 Hz, 1 H), 6.91 (d, *J* = 8.3 Hz, 1 H), 6.82 (dd, *J* = 8.0, 1.8 Hz, 1 H), 6.67 (s, 1 H), 6.47 (d, *J* = 7.9 Hz, 1 H), 5.12 (dd, $^3J_{P-C-C-H}$ = 13.9, $^3J_{H-C-C-H}$ = 7.9 Hz, 1 H), 4.91–4.81 (m, 1 H), 4.70–4.63 (m, 1 H), 4.31–4.05 (m, 2 H), 3.28–3.13 (m, 1 H), 2.67–2.40 (m, 5 H), 2.07 (s, 3 H), 1.23 (t, *J* = 7.1 Hz, 3 H), 1.12 (t, *J* = 7.6 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 179.8, 148.0 (d, $^2J_{P-O-C}$ = 6.4 Hz), 140.5, 140.0, 135.7, 133.0, 131.1, 130.1, 129.3, 129.1, 128.8 (2C), 127.7, 127.2 (2C), 125.3 (d, $^3J_{P-O-C-C}$ = 11.2 Hz), 124.7, 119.3 (d, $^3J_{P-O-C-C}$ = 6.5 Hz), 108.9, 67.8 (d, $^3J_{P-C-C-C}$ = 10.9 Hz), 62.5 (d, $^2J_{P-O-C}$ = 7.0 Hz), 61.4 (d, $^2J_{P-C-C}$ = 3.6 Hz), 43.8, 38.0, 36.1 (d, J_{P-C} = 134.2 Hz), 28.2, 21.0, 16.4 (d, $^3J_{P-O-C-C}$ = 5.6 Hz), 15.7.

^{31}P NMR (162 MHz, $CDCl_3$): δ = 25.46 (s).

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{29}H_{32}N_2O_4P$: 503.2094; found: 503.2089.

(±)-1′-Benzyl-8-chloro-4-ethoxy-5′-methyl-1,3,3a,9b-tetrahydrospiro[benzo[5,6][1,2]oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-Oxide (3s)

Yield: 96.7 mg (95%); yellow oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.48–7.39 (m, 1 H), 7.29–7.16 (m, 6 H), 6.96 (d, *J* = 8.7 Hz, 1 H), 6.86 (d, *J* = 8.1 Hz, 1 H), 6.71 (s, 1 H), 6.50 (d, *J* = 8.0 Hz, 1 H), 5.11 (dd, $^3J_{P-C-C-H}$ = 12.9, $^3J_{H-C-C-H}$ = 8.0 Hz, 1 H), 4.92–4.83 (m, 1 H), 4.75–4.67 (m, 1 H), 4.25–4.13 (m, 2 H), 3.33–3.20 (m, 1 H), 2.69–2.37 (m, 2 H), 2.12 (s, 3 H), 1.84 (s, 1 H), 1.26 (t, *J* = 7.1 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 179.7, 148.5 (d, $^2J_{P-O-C}$ = 6.3 Hz), 139.9, 135.6, 133.2, 130.7, 130.6, 129.7, 129.6, 129.4, 128.9 (2C), 127.7, 127.2 (2C), 124.7, 120.1, 120.9, 109.0, 67.7 (d, $^3J_{P-C-C-C}$ = 11.6 Hz), 62.8 (d, $^2J_{P-O-C}$ = 7.0 Hz), 60.7, 43.8, 37.8, 35.6 (d, J_{P-C} = 134.7 Hz), 21.0, 16.4 (d, $^3J_{P-O-C-C}$ = 5.9 Hz).

^{31}P NMR (162 MHz, $CDCl_3$): δ = 25.01 (s).

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{27}H_{27}ClN_2O_4P$: 509.1391; found: 509.1384.

(±)-1′-Benzyl-4-ethoxy-5′,6,8-trimethyl-1,3,3a,9b-tetrahydrospiro[benzo[5,6][1,2]oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-Oxide (3t)

Yield: 92.5 mg (92%); yellow oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.30–7.16 (m, 5 H), 7.00 (s, 1 H), 6.90 (d, *J* = 7.5 Hz, 2 H), 6.83 (d, *J* = 8.0 Hz, 1 H), 6.46 (d, *J* = 8.1 Hz, 1 H), 5.13 (dd, $^3J_{P-C-C-H}$ = 16.8, $^3J_{H-C-C-H}$ = 8.1 Hz, 1 H), 4.90–4.82 (m, 1 H), 4.70–4.63 (m, 1 H), 4.27–4.05 (m, 2 H), 3.26–3.14 (m, 1 H), 2.68–2.49 (m, 3 H), 2.22 (s, 3 H), 2.18 (s, 3 H), 2.11 (s, 3 H), 1.22 (t, *J* = 7.1 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 179.9, 146.4 (d, $^2J_{P-O-C}$ = 6.9 Hz), 140.0, 135.8, 133.5, 133.0, 131.7, 130.6, 129.3, 128.8 (2C), 128.6, 128.1 (d, $^3J_{P-O-C-C}$ = 5.7 Hz), 127.7, 127.2 (2C), 125.1 (d, $^3J_{P-O-C-C}$ = 11.7 Hz), 124.8, 108.9, 67.5 (d, $^3J_{P-C-C-C}$ = 9.6 Hz), 62.2 (d, $^2J_{P-O-C}$ = 7.0 Hz), 61.4 (d, $^2J_{P-C-C}$ = 4.1 Hz), 43.7, 37.8, 35.8 (d, J_{P-C} = 135.3 Hz), 21.0, 20.6, 16.4 (d, $^3J_{P-O-C-C}$ = 5.7 Hz), 15.9.

^{31}P NMR (162 MHz, $CDCl_3$): δ = 26.68 (s).

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{29}H_{32}N_2O_4P$: 503.2049; found: 503.2104.

(±)-1′-Benzyl-4-ethoxy-6-methoxy-5′-methyl-1,3,3a,9b-tetrahydrospiro[benzo[5,6][1,2]oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-Oxide (3u)

Yield: 96.9 mg (96%); yellow oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.18 (s, 5 H), 7.02–6.92 (m, 2 H), 6.87 (s, 1 H), 6.82 (s, 2 H), 6.46 (d, *J* = 6.2 Hz, 1 H), 5.19–5.10 (m, 1 H), 4.87–4.79 (m, 1 H), 4.70–4.60 (m, 1 H), 4.28–4.06 (m, 2 H), 3.79 (s, 3 H), 3.32–3.05 (m, 1 H), 2.68–2.44 (m, 3 H), 2.08 (s, 3 H), 1.20 (t, *J* = 6.3 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 179.9, 149.7 (d, $^2J_{P-O-C}$ = 5.2 Hz), 140.0, 139.8, 139.7, 135.8, 133.0, 130.6, 129.3, 128.8 (2C), 127.6, 127.2 (2C), 124.8, 124.3, 122.0, 112.2, 108.9, 67.5 (d, $^3J_{P-C-C-C}$ = 9.7 Hz), 62.5 (d, $^2J_{P-O-C}$ = 7.0 Hz), 61.3 (d, $^2J_{P-C-C}$ = 4.4 Hz), 56.2, 43.7, 37.8, 35.8 (d, J_{P-C} = 135.7 Hz), 21.0, 16.3 (d, $^3J_{P-O-C-C}$ = 5.7 Hz).

^{31}P NMR (162 MHz, $CDCl_3$): δ = 26.59 (s).

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{28}H_{30}N_2O_5P$: 505.1887; found: 505.1891.

(±)-1′-Benzyl-5′-bromo-4-ethoxy-8-methyl-1,3,3a,9b-tetrahydrospiro[benzo[5,6][1,2]oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-Oxide (3v)

Yield: 102.9 mg (93%); white oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.29–7.16 (m, 5 H), 7.08–6.93 (m, 3 H), 6.93–6.82 (m, 2 H), 6.59 (d, *J* = 7.8 Hz, 1 H), 5.11 (dd, $^3J_{P-C-C-H}$ = 15.0, $^3J_{H-C-C-H}$ = 7.8 Hz, 1 H), 4.92–4.83 (m, 1 H), 4.74–4.66 (m, 1 H), 4.28–4.06 (m, 2 H), 3.29–3.16 (m, 1 H), 2.73–2.43 (m, 3 H), 2.23 (s, 3 H), 1.24 (t, *J* = 7.2 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 180.0, 148.0 (d, $^2J_{P-O-C}$ = 6.5 Hz), 142.5, 135.7, 134.2, 131.2, 131.0, 130.4, 129.2, 129.0 (2C), 127.8, 127.3 (2C), 125.3 (d, $^3J_{P-O-C-C}$ = 11.5 Hz), 124.0, 123.6, 119.4 (d, $^3J_{P-O-C-C}$ = 6.6 Hz), 109.2, 67.7 (d, $^3J_{P-C-C-C}$ = 10.3 Hz), 62.6 (d, $^2J_{P-O-C}$ = 7.0 Hz), 61.5 (d, $^2J_{P-C-C}$ = 3.8 Hz), 43.8, 38.0, 36.1 (d, J_{P-C} = 134.4 Hz), 20.8, 16.5 (d, $^3J_{P-O-C-C}$ = 5.7 Hz).

^{31}P NMR (162 MHz, $CDCl_3$): δ = 25.57 (s).

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{27}H_{27}BrN_2O_4P$: 553.0886; found: 533.0879.

(±)-1′-Benzyl-5′-bromo-4-ethoxy-8-ethyl-1,3,3a,9b-tetrahydrospiro[benzo[5,6][1,2]oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-oxide (3w)

Yield: 104.4 mg (92%); light-yellow oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.26–7.17 (m, 5 H), 7.09–6.99 (m, 2 H), 6.97–6.88 (m, 2 H), 6.83 (t, *J* = 7.5 Hz, 1 H), 6.59 (d, *J* = 7.8 Hz, 1 H), 5.12 (dd, $^3J_{P-C-C-H}$ = 14.7, $^3J_{H-C-C-H}$ = 7.8 Hz, 1 H), 4.93–4.86 (m, 1 H), 4.72–4.66 (m, 1 H), 4.29–4.01 (m, 2 H), 3.27–3.15 (m, 1 H), 2.74–2.40 (m, 5 H), 1.24 (t, *J* = 7.0 Hz, 3 H), 1.12 (t, *J* = 7.6 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 179.9, 148.0 (d, $^2J_{P-O-C}$ = 6.3 Hz), 142.4, 140.5, 135.6, 131.1, 130.0, 129.2, 129.1, 128.9 (2C), 127.7, 127.2 (2C), 125.2 (d, $^3J_{P-O-C-C}$ = 11.1 Hz), 124.0, 123.5, 119.3 (d, $^3J_{P-O-C-C}$ = 6.5 Hz), 109.1, 67.6 (d, $^3J_{P-C-C-C}$ = 10.5 Hz), 62.5 (d, $^2J_{P-O-C}$ = 7.0 Hz), 61.5 (d, $^2J_{P-C-C}$ = 3.7 Hz), 43.8, 38.0, 36.1 (d, J_{P-C} = 134.4 Hz), 28.2, 16.4 (d, $^3J_{P-O-C-C}$ = 5.5 Hz), 15.7.

^{31}P NMR (162 MHz, $CDCl_3$): δ = 25.40 (s).

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{28}H_{29}BrN_2O_4P$: 567.1043; found: 567.1053.

(±)-1′-Benzyl-5′-bromo-4-ethoxy-8-methoxy-1,3,3a,9b-tetrahydrospiro[benzo[5,6][1,2]oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-Oxide (3x)

Yield: 76.3 mg (67%); yellow oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.20 (s, 4 H), 7.05–6.97 (m, 2 H), 6.90 (s, 2 H), 6.85 (s, 1 H), 6.76 (d, *J* = 8.1 Hz, 1 H), 6.59 (d, *J* = 6.5 Hz, 1 H), 5.15–5.02 (m, 1 H), 4.91–4.82 (m, 1 H), 4.73–4.64 (m, 4.0 Hz, 1 H), 4.25–4.07 (m, 2 H), 3.66 (s, 3 H), 3.28–3.14 (m, 1 H), 2.74–2.40 (m, 3 H), 1.23 (t, *J* = 6.1 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 178.9, 155.2, 142.6 (d, $^2J_{P-O-C}$ = 6.3 Hz), 141.3, 134.6, 129.9, 128.1, 127.8 (2C), 126.7, 126.2 (2C), 125.6 (d, $^3J_{P-O-C-C}$ = 11.2 Hz), 122.9, 122.4, 119.3 (d, $^3J_{P-O-C-C}$ = 6.3 Hz), 114.9, 113.7, 108.1, 66.6 (d, $^3J_{P-C-C-C}$ = 10.7 Hz), 61.4 (d, $^2J_{P-O-C}$ = 7.0 Hz), 60.4 (d, $^2J_{P-C-C}$ = 3.7 Hz), 54.7, 42.7, 37.0, 34.8 (d, J_{P-C} = 135.0 Hz), 15.4 (d, $^3J_{P-O-C-C}$ = 5.5 Hz).

^{31}P NMR (162 MHz, $CDCl_3$): δ = 25.62 (s).

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{27}H_{27}BrN_2O_5P$: 569.0835; found: 569.0844.

(±)-1′-Benzyl-5′-bromo-8-chloro-4-ethoxy-1,3,3a,9b-tetrahydrospiro[benzo[5,6][1,2]oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-Oxide (3y)

Yield: 97.5 mg (85%); yellow oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.40 (s, 1 H), 7.24–7.16 (m, 5 H), 7.03 (t, *J* = 7.8 Hz, 1 H), 6.97–6.90 (m, 2 H), 6.85 (t, *J* = 7.6 Hz, 1 H), 6.59 (d, *J* = 7.7 Hz, 1 H), 5.07 (dd, $^3J_{P-C-C-H}$ = 12.2, $^3J_{H-C-C-H}$ = 8.4 Hz, 1 H), 4.91–4.83 (m, 1 H), 4.73–4.65 (m, 1 H), 4.26–4.07 (m, 2 H), 3.31–3.18 (m, 1 H), 2.80 (s, 1 H), 2.64–2.54 (m, 1 H), 2.49– 2.39 (m, 1 H), 1.23 (t, *J* = 7.1 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 179.8, 148.5 (d, $^2J_{P-O-C}$ = 6.2 Hz), 142.3, 135.6, 130.8, 130.7, 129.7, 129.2, 128.9 (2C), 127.9, 127.8, 127.2 (2C), 123.9, 123.6, 120.9, 120.9, 109.2, 67.6 (d, $^3J_{P-C-C-C}$ = 11.1 Hz), 62.8 (d, $^2J_{P-O-C}$ = 7.0 Hz), 60.8 (d, $^2J_{P-C-C}$ = 3.6 Hz), 43.8, 37.9, 35.6 (d, J_{P-C} = 134.7 Hz), 16.4 (d, $^3J_{P-O-C-C}$ = 5.5 Hz).

^{31}P NMR (162 MHz, $CDCl_3$): δ = 24.84 (s).

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{26}H_{24}BrClN_2O_4P$: 573.0340; found: 573.0364.

(±)-4-Ethoxy-5′-fluoro-8-methyl-1,3,3a,9b-tetrahydrospiro[benzo[5,6][1,2]oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-Oxide (3z)

Yield: 76.4 mg (95%); light-yellow oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.91–8.82 (m, 1 H), 7.26 (s, 1 H), 7.12 (d, *J* = 8.3 Hz, 1 H), 6.96 (d, *J* = 8.3 Hz, 1 H), 6.89–6.80 (m, 1 H), 6.73–6.68 (m, 1 H), 5.11 (dd, $^3J_{P-C-C-H}$ = 14.2, $^3J_{H-C-C-H}$ = 7.7 Hz, 1 H), 4.41–4.18 (m, 2 H), 3.21–3.08 (m, 1 H), 2.86 (s, 1 H), 2.77–2.59 (m, 1 H), 2.58–2.42 (m, 1 H), 2.31 (s, 3 H), 2.11 (s, 1 H), 1.32 (t, *J* = 7.1 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 182.1, 159.4 (d, J_{F-C} = 241.7 Hz), 147.7 (d, $^2J_{P-O-C}$ = 6.5 Hz), 136.4, 134.3, 133.4 (d, $^3J_{F-C-C-C}$ = 7.9 Hz), 131.1, 130.5, 125.0 (d, $^3J_{P-O-C-C}$ = 11.0 Hz), 119.3 (d, $^3J_{P-O-C-C}$ = 6.6 Hz), 115.5 (d, $^2J_{F-C-C}$ = 23.7 Hz), 112.3 (d, $^2J_{F-C-C}$ = 25.2 Hz), 110.7 (d, $^3J_{F-C-C-C}$ = 7.8 Hz), 68.2 (d, $^3J_{P-C-C-C}$ = 11.9 Hz), 62.6 (d, $^2J_{P-O-C}$ = 6.9 Hz), 61.3 (d, $^2J_{P-C-C}$ = 3.8 Hz), 37.8, 35.9 (d, J_{P-C} = 134.6 Hz), 20.7, 16.4 (d, $^3J_{P-O-C-C}$ = 5.6 Hz).

^{31}P NMR (162 MHz, $CDCl_3$): δ = 25.19 (s).

^{19}F NMR (377 MHz, $CDCl_3$): δ = –119.21 (s).

HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{20}H_{20}FN_2NaO_4P$: 425.1037; found: 425.1058.

(±)-4-Ethoxy-8-ethyl-5′-fluoro-1,3,3a,9b-tetrahydrospiro[benzo[5,6][1,2]oxaphosphinino[4,3-*b*]pyrrole-2,3′-indolin]-2′-one 4-Oxide (3z1)

Yield: 79.9 mg (96%); white oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.85–8.77 (m, 1 H), 7.36–7.15 (m, 1 H), 7.08 (dd, *J* = 8.2, 2.3 Hz, 1 H), 6.91 (d, *J* = 8.3 Hz, 1 H), 6.79–6.68 (m, 1 H), 6.54 (dd, *J* = 8.1, 2.6 Hz, 1 H), 5.04 (dd, $^3J_{P-C-C-H}$ = 13.4, $J_{H-C-C-H}$ =

7.6 Hz, 1 H), 4.43–4.10 (m, 2 H), 3.21–3.07 (m, 1 H), 2.81 (s, 1 H), 2.60–2.50 (m, 3 H), 2.46–2.35 (m, 1 H), 2.07 (s, 1 H), 1.25 (t, J = 7.1 Hz, 3 H), 1.13 (t, J = 7.6 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 181.0, 158.4 (d, J_{F-C} = 241.7 Hz), 146.8 (d, $^2J_{P-O-C}$ = 6.3 Hz), 139.7, 135.4 (d, $^3J_{F-C-C-C}$ = 2.2 Hz), 132.6 (d, J = 7.9 Hz), 129.0, 128.3, 123.9 (d, $^3J_{P-O-C-C}$ = 10.9 Hz), 118.3 (d, $^3J_{P-O-C-C}$ = 6.7 Hz), 114.4 (d, $^2J_{F-C-C}$ = 23.7 Hz), 111.3 (d, $^2J_{F-C-C}$ = 25.1 Hz), 109.6 (d, $^3J_{F-C-C-C}$ = 7.9 Hz), 67.2 (d, $^3J_{P-C-C-C}$ = 11.1 Hz), 61.6 (d, $^2J_{P-O-C}$ = 7.0 Hz), 60.4 (d, $^2J_{P-C-C}$ = 3.6 Hz), 36.8, 35.0 (d, J_{P-C} = 134.1 Hz), 27.1, 15.4 (d, $^3J_{P-O-C-C}$ = 5.5 Hz), 14.6.

^{31}P NMR (162 MHz, $CDCl_3$): δ = 24.90 (s).

^{19}F NMR (377 MHz, $CDCl_3$): δ = –119.30 (s).

HRMS (ESI): m/z [M + H]$^+$ calcd for $C_{21}H_{23}FN_2O_4P$: 417.1374; found: 417.1385.

(±)-1-Benzyl-4′-ethoxy-1′,3′,3a′,11c′-tetrahydrospiro[indoline-3,2′-naphtho[1′,2′:5,6][1,2]oxaphosphinino[4,3-*b*]pyrrol]-2-one 4′-Oxide (3z2)

Yield: 91.9 mg (90%); white oil.

^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.42 (dd, J = 7.7, 1.7 Hz, 1 H), 7.28–7.19 (m, 8 H), 7.13–7.01 (m, 3 H), 6.94 (d, J = 6.2 Hz, 1 H), 6.85 (t, J = 7.0 Hz, 1 H), 6.60 (d, J = 7.8 Hz, 1 H), 5.15 (dd, $^3J_{P-C-C-H}$ = 14.3, $J_{H-C-C-H}$ = 7.8 Hz, 1 H), 4.94–4.87 (m, 1 H), 4.75–4.68 (m, 1 H), 4.29–4.10 (m, 2 H), 3.78–3.47 (m, 1 H), 2.77–2.48 (m, 3 H), 1.25 (t, J = 7.1 Hz, 3 H).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 178.9, 149.0, 149.0, 141.3, 134.6, 130.0, 129.9, 128.7, 128.1, 127.9 (2C), 126.7, 126.4, 126.2 (2C), 124.8, 124.7, 123.5, 122.9, 122.5, 118.6, 118.5, 108.1, 66.6 (d, $^3J_{P-C-C-C}$ = 10.7 Hz), 61.5 (d, $^2J_{P-O-C}$ = 7.2 Hz), 60.3 (d, $^2J_{P-C-C}$ = 3.7 Hz), 42.7, 37.0, 35.0 (d, J_{P-C} = 134.5 Hz), 15.4 (d, $^3J_{P-O-C-C}$ = 5.6 Hz).

^{31}P NMR (162 MHz, $CDCl_3$): δ = 25.14 (s).

HRMS (ESI): m/z [M + H]$^+$ calcd for $C_{30}H_{28}N_2O_4P$: 511.1781; found: 511.1773.

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Supporting Information

Supporting information for this article is available online at https://doi.org/10.1055/s-0039-1691597.

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