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Palladium-Catalyzed C-H Bond Functionalization Reactions Using Phosphate/Sulfonate Hypervalent Iodine Reagents

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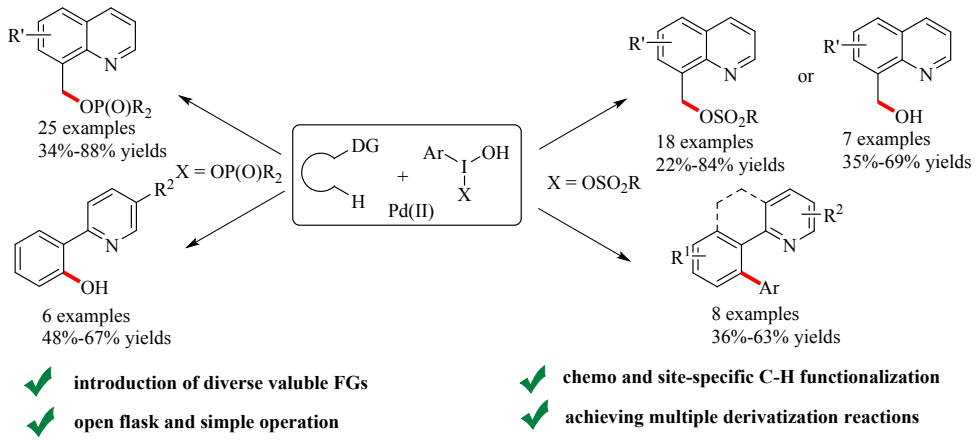


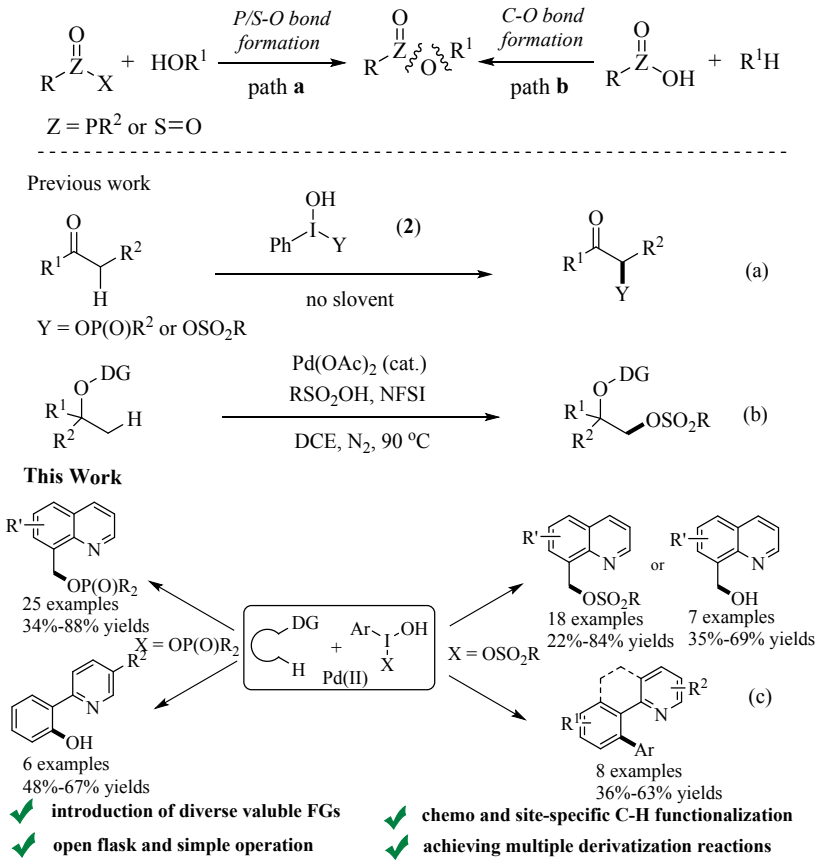
ABSTRACT: A new and operationally simple approach for palladium-catalyzed C-H functionalization reactions utilizing an organophosphorus/sulfonate hypervalent iodine reagent as both an oxidant and the source of a functional group has been developed. Through this method, the oxidative phosphorylation, sulfonation and hydroxylation unactivated benzyl C(sp^3)-H bonds, along with the hydroxylation and arylation of aryl C(sp^2)-H bonds, are successfully realized under mild conditions and with excellent site-selectivity. The versatile C-OSO_2R bond provides a platform for a wide array of subsequent diversification reactions.

INTRODUCTION

Phosphates and sulfonates, not only widely exist in a variety of important biologically active molecules (e.g., nucleic acids, proteins, carbohydrates, lipids, coenzymes, and steroids),[1] but also have extensive applications in the fields of pharmaceutical chemistry[2] and agrochemicals[3] as well as analytical chemistry.[4] In addition, these key structures are also useful in organic synthesis,[5] for example, sulfonates are often utilized as the synthons for S_N2 reactions. For

these reasons, the development of simple and effective synthetic methods for their preparation is of great importance. Historically, the primary means of introducing these important functional groups involve P/S-O bond formation, which is typically accomplished by the nucleophilic substitution of an appropriate phosphoryl/sulfonyl-GLG (GLG: good leaving group) moiety with a suitable alcohol or phenol (Scheme 1**,** path a).[6,7] However, this strategy suffers from some drawbacks, including the use of tedious multistep procedures, harsh reaction conditions and hazardous phosphoryl halides. A more convenient method to access these useful structures involving the direct transformation of an unactivated C-H bond into a C-OP(O)R_2/OSO_2R bond is highly desirable (Scheme 1, path b).[8] While metal-free α-phosphorylation and α-sulfonation reactions of carbonyl compounds mediated by the corresponding phosphate and sulfonate hypervalent iodine reagents were successively reported by Togo's group and Wirth's group in 2002 and 2005 (Scheme 1a),[9] the substrate scopes were limited to the ketones. Subsequently in 2015, Dong and co-workers described an elegant approach for the synthesis of β-sulfonyloxylated alcohols through a palladium-catalyzed regioselective C(sp^3)-H bond functionalization of masked alcohols (Scheme 1b).[10] However, the reaction was performed under harsh reaction conditions. Hence, the realization of a broadly applicable C-H bond phosphorylation and sulfonation in a mild and atom-economic manner is still urgently needed.

Scheme 1 Synthetic strategies for accessing sulfonates/phosphates.



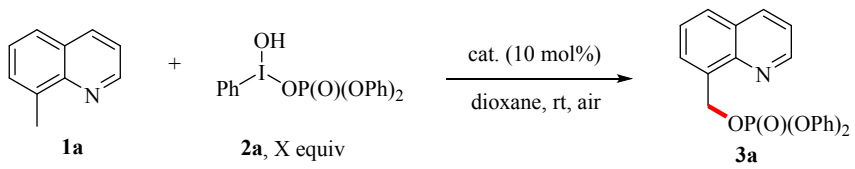
On the other hand, in the past few decades, significant advances have been made in catalytic C-H oxygenations, which have successfully introduced a series of valuable oxygen groups such as OH,[11] OCOR,[12] and OR.[13] In contrast to these strongly nucleophilic groups, however, the installation of weakly nucleophilic and good leaving groups, such as $OP(O)R_2$ and OSO_2R, to a specific position still faces a number of challenges. First, the complexity of such a catalytic system and the exceedingly low nucleophilicity of $OP(O)R_2$ and OSO_2R anions, make the proposed phosphorylation and sulfonation likely to suffer from competition from other potential nucleophiles. Second, due to the high reactivity of the target phosphates and sulfonates, product stability during the reaction must be considered and will necessitate relatively mild and simple catalytic systems.

Herein, we reveal a new and efficient approach for the direct, palladium-catalyzed, benzyl C(sp^3)-H phosphorylation/sulfonation of 8-methylquinolines,[14] in which an organophosphorus/sulfonate hypervalent iodine reagent is used as both an oxidant and the source of a functional group. In addition, pyridyl-directed aryl C(sp^2)-H bond hydroxylation and arylation are also conveniently achieved via the current method (Scheme 1c).

RESULTS AND DISCUSSION

The reaction was initially investigated by using **1a** as the model substrate, $Pd(OAc)_2$ as the catalyst, $PhI(OH)P(O)(OPh)_2$ (**2a**) as the oxidant and dioxane as the solvent at room temperature in air. To our delight, desired product **3a** was obtained in 58% yield (Table 1, entry 1). Among the catalysts that were tested, $Pd(OAc)_2$ displayed the best efficiency (entries 2-4). The presence of additives had an important effect on the reaction. While the addition of 4Å MS could significantly increase the conversion of the reaction (entry 5), other additives such as an acid (e.g. PivOH) or a base (e.g. K_2CO_3) did not improve the yield of the reaction (entries 6-7). Moreover, increasing the amount of the oxidant increased the yields of **3a** (entries 8-10). When the amount of the oxidant reached 2.4 equiv, **3a** was obtained in 87% isolated yield. However, continuing to increase the amount of oxidant did not further increased the yield of **3a** (entry 11). In addition, lowering the catalyst loading to 5 mol% reduced the yield of **3a** to 74% (entry 12). To verify the role of the molecular sieves, 5 equiv of H_2O was added, and the yield of **3a** significantly decreased (entry 13). Meanwhile, **3a** was obtained in 85% yield when the reaction was performed under Ar (entry 14). Consequently, the optimum reaction conditions were determined to be **1a** (0.2 mmol) in the presence of $Pd(OAc)_2$ (10 mol%), **2a** (2.4 equiv), 4Å MS (175 mg) in dioxane (1 mL) at room temperature open to air.

Table 1. Optimization of the Reaction Conditions [a]



1a **2a**, X equiv **3a**

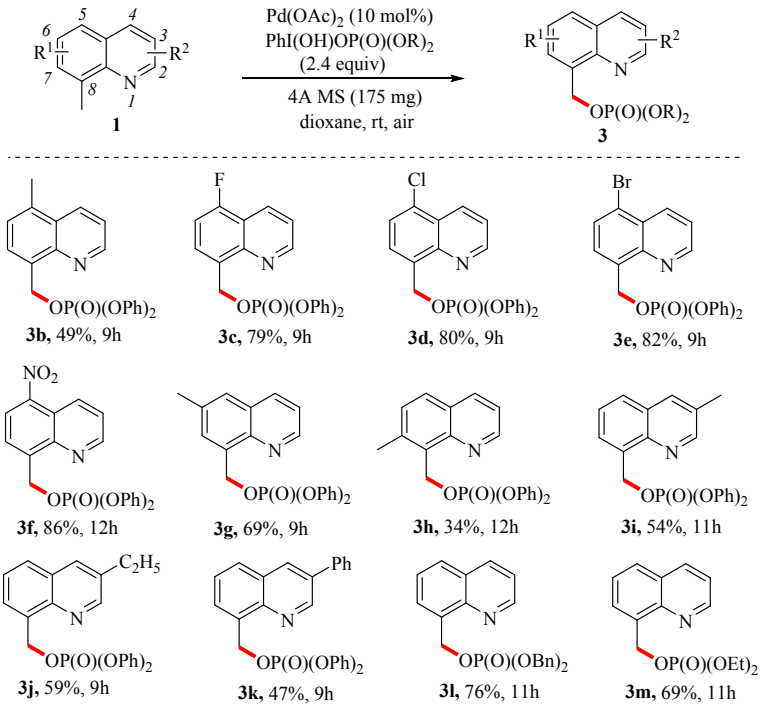
Entry	Catalyst	X	Additive	Yield [%][b]
1	$Pd(OAc)_2$	1.5	-	**3a**, 58%
2	$Pd(OCOCF_3)_2$	1.5	-	**3a**, 37%
3	$PdCl_2$	1.5	-	**3a**, 32%
4	$Pd(PPh_3)_4$	1.5	-	**3a**, <5%
5[c]	$Pd(OAc)_2$	1.5	4Å MS	**3a**, 68%
6[d]	$Pd(OAc)_2$	1.5	PivOH	**3a**, 53%
7[e]	$Pd(OAc)_2$	1.5	K_2CO_3	**3a**, 59%
8[c]	$Pd(OAc)_2$	1.8	4Å MS	**3a**, 76%
9[c]	$Pd(OAc)_2$	2.1	4Å MS	**3a**, 81%
10[c]	$Pd(OAc)_2$	2.4	4Å MS	**3a**, 87%
11[c]	$Pd(OAc)_2$	2.5	4Å MS	**3a**, 84%
12[c]	$Pd(OAc)_2$	2.4	4Å MS	**3a**, 74%
13[c, g]	$Pd(OAc)_2$	2.4	4Å MS, H_2O	**3a**, 78%
14[h]	$Pd(OAc)_2$	2.4	-	**3a**, 85%

[a] Reaction conditions: **1a** (0.2 mmol), catalyst (10 mol%), solvent (1 mL). [b] Isolated yields. [c] 4Å MS (175 mg) was added. [d] 1 equiv. of acid was added. [e] 1 equiv. of base was added. [f] 5 mol% of catalyst was used. [g] 5 equiv of H_2O was added. [h] in Ar.

With the optimized conditions in hand, the reactions between substrates **1a-1m** and phosphate hypervalent iodine species were first tested. As shown in **Table 2**, the substrates bearing electron-withdrawing substitutes such as F, Cl, Br, and NO_2 at the 5-position were tolerated and gave corresponding products **3c-3f** in good yields. However, when the substrates possessed electron-donating groups, the yields were sharply decreased (**3b**, **3g-3k**). These results indicated that the electronic properties of the substituents are crucial to the reaction. When the 7-position of the substrate was blocked by a substituent (e.g., methyl), the yield was obviously reduced, possibly due to steric hinderance (**3h**). Moreover, when the oxidant was replaced by

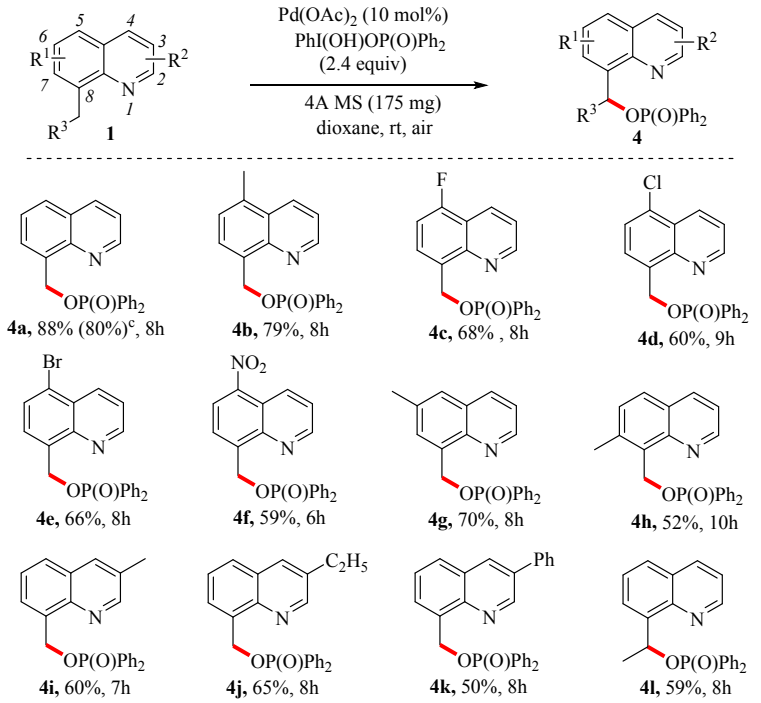
dibenzyl or diethyl phosphate hypervalent iodine, corresponding products **3l** and **3m** were isolated in 76% and 69% yields, respectively.

Table 2 Phosphate esterification of 8-methylquinolines [a, b]



[a] Reaction conditions: **1** (0.2 mmol), $Pd(OAc)_2$ (0.02 mmol), oxidant (0.48 mmol), 4Å MS (175 mg), dioxane (1 mL) at rt for 9-12 h in air. [b] Isolated yields.

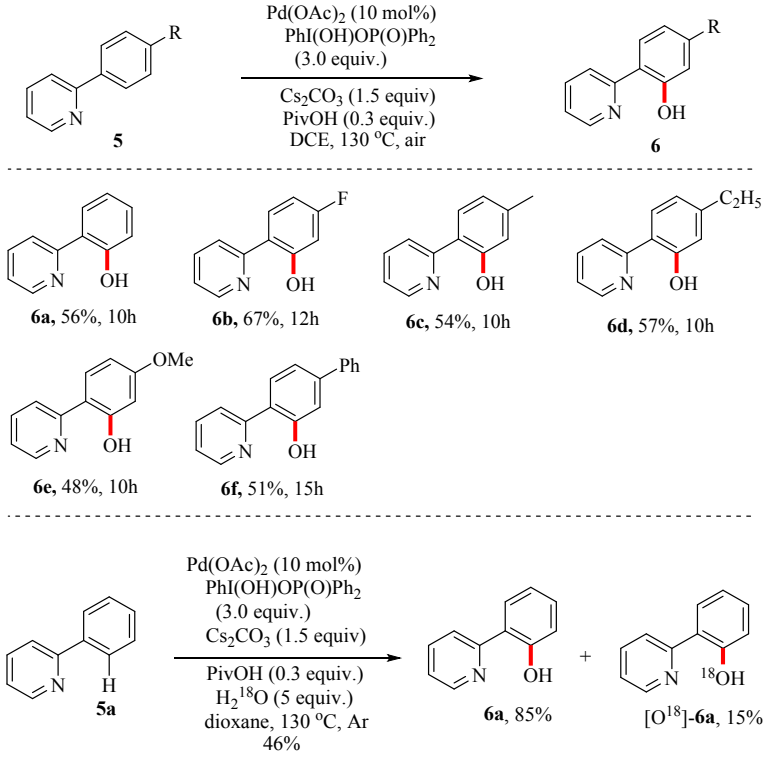
Table 3 Phosphinic esterification of 8-methylquinolines [a, b]



[a] Reaction conditions: **1** (0.2 mmol), $Pd(OAc)_2$ (0.02 mmol), oxidant (0.48 mmol), 4Å MS (175 mg), dioxane (1 mL) at rt for 6-10 h in air. [b] Isolated yields. [c] 2.0 mmol scale.

Phosphinic hypervalent-iodines were subsequently evaluated (Table 3). Regardless of if the substrates possessed electron-donating groups such as a methyl substituent, or electron-withdrawing substituents, such as F, Cl, Br, or NO_2, the reaction proceeded smoothly and afforded target products **4a**-**4k** in moderate to good yields. However, the phosphate product was not obtained when a strong electron-donating group such as OMe was present on the substrate. To our delight, when the primary C-H bond was replaced with a secondary C-H bond at the 8-position of the substrate, the reaction still occurred and gave product **4l** in 59% yield. However, when converting to more sterically hindered tertiary C-H bonds, the reaction did not proceed. To prove the practicality of this approach, a 2.0 mmol scale reaction was carried out, and product **4a** was isolated in a yield of 80%, which was comparable to that of the small-scale reaction.

Table 4 Hydroxylation of 2-phenylpyridines [a, b]

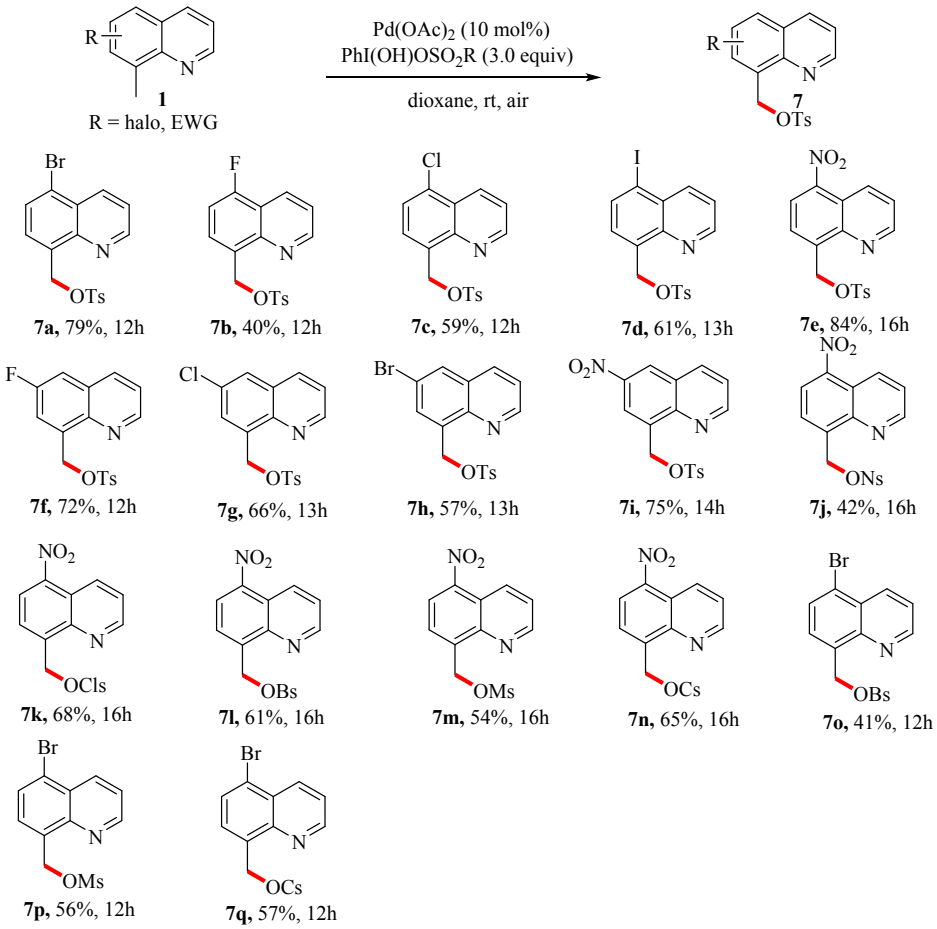


[a] Reaction conditions: **5** (0.2 mmol), $Pd(OAc)_2$ (0.02 mmol), oxidant (0.6 mmol), Cs_2CO_3 (0.3 mmol), PivOH (0.06 mmol), DCE (1 mL) at 130 °C for 10-15 h in air. [b] Isolated yields.

When 2-phenylpyridines **5** were utilized as substrates, an OH group other than the $OP(O)Ph_2$ group was unexpectedly introduced (Table 4).[15] Substrates bearing the electron-donating groups such as Me, Et, OMe, and Ph substituents or the electron-withdrawing groups such as F substituent at *para*-position of the benzene smoothly underwent the reaction and produced target products **6a**-**6f** in moderate to good yields. Moreover, when 5 equiv. of $H_2{}^{18}O$ was added to the reaction, products **6a** and [O^{18}]-**6a** were obtained in an approximate ratio of 5.7 (see SI),

indicating that the oxygen atom in the hydroxy product likely originated from the phosphinic hypervalent iodine rather than adventitious H_2O.

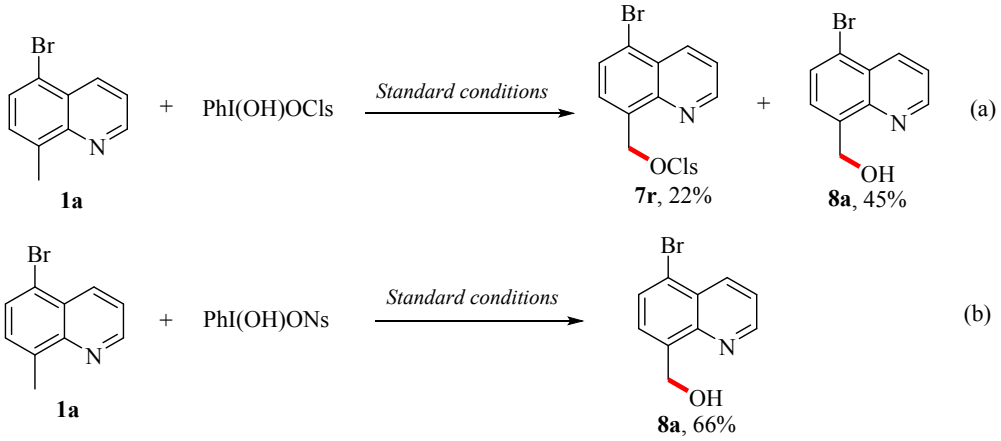
Table 5 Sulfonation of 8-methylquinolines [a, b]



[a] Reaction conditions: **1** (0.2 mmol), $Pd(OAc)_2$ (0.02 mmol), oxidant (0.60 mmol), dioxane (1 mL) for 12-16 h. [b] Isolated yields. [c] Ns, 4-NO_2-$C_6H_4SO_2$; Cls, 4-Cl-$C_6H_4SO_2$; Bs, $C_6H_5SO_2$; Ms, $MeSO_2$; Cs, (1R)-10-camphorylsulfonyl.

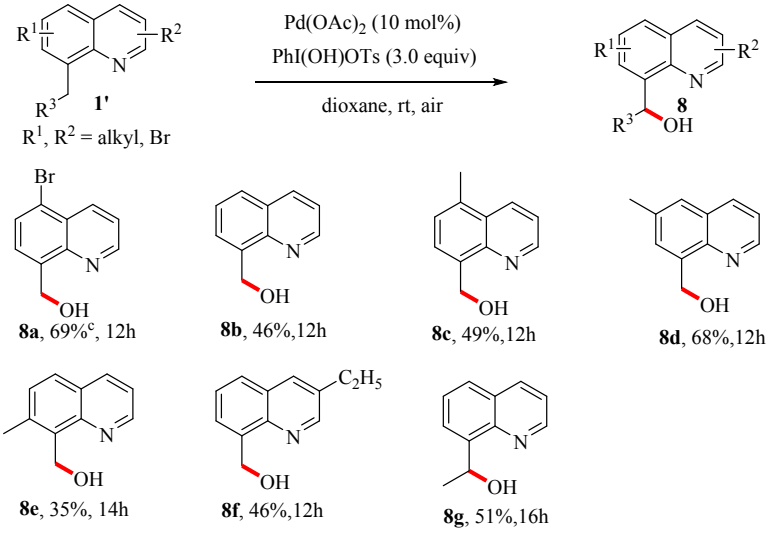
When sulfonate hypervalent iodine reagents were used as the oxidant, the reactions proceeded smoothly, and the results are presented in **Table 5**. The OTs products were produced in moderate to excellent yields from reactions with substrates bearing electron-withdrawing substituents under similar conditions (**7a-7i**). Preliminary screenings indicated that more strongly electron-withdrawing substituents (e.g., NO_2 versus F, Cl, Br, and I) favored the reaction. Other sulfonate hypervalent iodine species were examined, and various sulfonates (e.g., ONs, OCls, OBs, OMs, and OCs) were expediently introduced in moderate to good yields when using substrates bearing a NO_2 group at the 5-position (**7j-7n**). However, when the 5-position of the substrate was taken up by a Br group, some changes had occurred. For alkyl or phenyl sulfonates, the expected products were obtained (**7o-7q**); however, when the *para*-position of the sulfonates were substituted with electron-withdrawing groups such Cl or NO_2, the OH product was obtained as the major or only product (Scheme **2a** and **2b**).

Scheme 2 Competitive reactions.



When the substrates bearing electron-donating groups were subjected to the reaction, surprisingly, OH other than OTs products were obtained (**8a-8g**). Interestingly, for substrate **1a**, OTs product **7a** was isolated in 79% yield following purification with a more polar eluent (PE: EA = 2:1), while hydroxy product **6a** was obtained in 69% yield when using a less polar eluent (PE: EA = 20:1). Thus, the reaction not only offered a new approach for hydroxylation, but also revealed that the hydroxy source was OTs other than the OH of HTIB. To our delight, when the primary C-H bond at 8-position of the substrate was replaced by secondary C-H bond, the reaction still proceeded smoothly and gave product **6g** in 51% yield. However, when moving to more sterically hindered tertiary C-H bonds, the reaction did not occur.

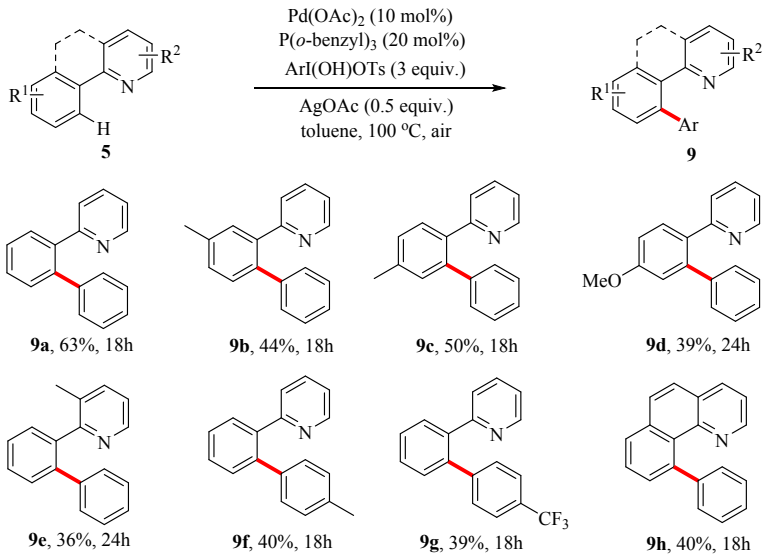
Table 6 Hydroxylation of 8-methylquinolines [a, b]



[a] Reaction conditions: **1** (0.2 mmol), $Pd(OAc)_2$ (0.02 mmol), oxidant (0.60 mmol), dioxane (1 mL) for 12-16 h. [b] Isolated yields. [c] Less polar developing solvent (PE: EA = 20:1) was used during the column chromatography.

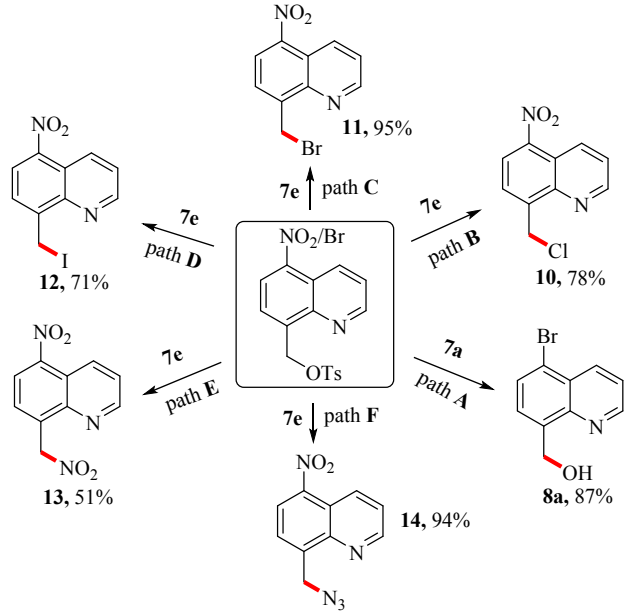
The reactions between 2-phenylpyridine analogues and sulfonate hypervalent iodine species are also discussed (Table 7). In this process, an aryl group other than the OTs of the sulfonate hypervalent iodine was unexpectedly introduced, thus affording an alternative method for arylation.[16]

Table 7 Arylation of 2-phenylpyridines [a, b]



[a] Reaction conditions: **6** (0.2 mmol), $Pd(OAc)_2$ (0.02 mmol), ligand (0.04 mmol), oxidant (0.60 mmol), AgOAc (0.1 mmol), toluene (1 mL) for 18-24 h. [b] Isolated yields.

Scheme 3 Synthetic applications.[a]



[a] Conditions: (a) **5a** (0.2 mmol), SiO_2 (0.6 mmol), PE : EA = 1mL : 0.05 mL, rt, 5 h; (b) **5e** (0.2 mmol), *t*-BuCl (0.24 mmol), [pmIm]Br (0.4 mmol), 60 °C, 4 h; (c) **5e** (0.2 mmol), *t*-BuBr (0.24 mmol), [pmIm]Br (0.4 mmol), sonication, 0.5 h; (d) **5e** (0.2 mmol), *t*-BuI (0.24 mmol), [pmIm]Br (0.4 mmol), sonication, 0.5 h; (e) **5e** (0.2 mmol), $AgNO_3$ (0.4 mmol), *t*-AmOH, 120 °C, 6 h; (f) **5e** (0.2 mmol), NaN_3 (0.3 mmol), THF/H_2O, reflux, 3 h. [b] Isolated yields.

The synthetic utility of the OTs products was exemplified by further transformations of products **7a/7e** (Scheme 3). Substrate **7a** was hydrolyzed to product **8a** in 87% yield under reaction conditions similar to the column chromatography conditions. Given that OTs is a good leaving group, several substitution reactions were conducted.[17] *tert*-Butyl chloride, bromide and iodide in combinations with the ionic liquid [pmIm]Br had been used to convert the OTs derivative into the corresponding chloride, bromide and iodide products under sonication conditions (or heating) in good yields. In addition, the NO_2 and N_3 products were also produced by reacting the OTs derivatives with $AgNO_3$ and NaN_3, respectively.

CONCLUSIONS

In summary, by utilizing organophosphorus/sulfonate hypervalent iodine reagents as both an oxidant and the source of a functional group, we have realized a convenient and efficient approach for the direct, palladium-catalyzed C(sp^3)-H phosphorylation/sulfonation of 8-methylquinolines. Various weakly nucleophilic and good leaving groups, such as phosphates, phosphonates and sulfonates, were successfully introduced under mild conditions, providing a new strategy for the preparation of such species. However, when using the current method for 2-phenylpyridine analogues, the hydroxyl or phenyl products are unexpectedly produced.

EXPERIMENTAL SECTION

General Information. Reactions were monitored by using thin-layer chromatography (TLC) on commercial silica gel plates (GF254). Visualization of the developed plates was performed under UV lights (254 nm). Flash column chromatography was performed on silica gel (200-300 mesh). ^{1}H, ^{13}C and ^{31}P NMR spectra were recorded on a Bruker AV300，400 or 500 spectrometer. Chemical shifts (δ) were reported in ppm referenced to the $CDCl_3$ residual peak (δ 7.26) or the DMSO-d_6 residual peak (δ 2.50) for ^{1}H NMR. Chemical shifts of ^{13}C NMR were reported relative to $CDCl_3$ (δ 77.0) or D_6-DMSO (δ 39.5). Chemical shifts of ^{31}P NMR were reported relative to 85% H_3PO_4 (δ = 0). The following abbreviations were used to describe peak splitting patterns when appropriate: br s = broad singlet, s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet. Coupling constant, *J*, was reported in Hertz unit (Hz). Melting points (mp) were taken on a MEL-TEMP® apparatus and were uncorrected. High resolution mass spectra (HRMS) were obtained on an ESI-LC-MS/MS spectrometer.

Genaral procedure: Preparation of the substrates

All substrates **1a-1l** used in this work are known compounds. 8-Methylquinolines **1a**, **1l** and 2-phenylpyridines **5** are commercially available. The substrates **1b-1k** were prepared as published before, and the ^{1}H NMR spectral data matched those of previous reported.[18]

General procedure for the synthesis of the substates 1b-1h[18a-18c]

Glycerin (5.6 g, 60 mmol) was added dropwise over a period of 0.5h to a solution of substituted

aniline (50 mmol) and NaI (0.1 g, 0.6 mmol) in 80% aqueous H_2SO_4 (27 g, 220 mmol) and stirred in a 140 ºC oil-bath. The mixture was then heated at 140-145 ºC for 3.5h while distilling the water formed during this period. Upon cooling to room temperature, the dark solution was carefully poured into ice (50 g) and then neutralized with 25% NaOH (55 g, 0.34 mol) to basic pH 8~11. The mixture was extracted with ethyl acetate (3×50 mL). The combined organic solution was washed with water (2×50 mL), brine (50 mL), dried with anhydrous sodium sulfate, and concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (petroleum ether/EtOAc = 8:1) to afford the corresponding substituted 8-methyl-quinoline **1b-1h**.

General procedure for the synthesis of the substates 1i-1j[18d-18e]

Unsaturated aldehyde (5.6 g, 60 mmol) was added dropwise over a period of 0.5h to a solution of substituted aniline (50 mmol) and NaI (0.1 g, 0.6 mmol) in 80% aqueous H_2SO_4 (27 g, 220 mmol) and stirred in a 110 ºC oil-bath. The mixture was then heated at 110 ºC for 2h while distilling the water formed during this period. Upon cooling to room temperature, the dark solution was carefully poured into ice (50 g) and then neutralized with 25% NaOH (55 g, 0.34 mol) to basic pH 8~11. The mixture was extracted with ethyl acetate (3×50 mL). The combined organic solution was washed with water (2×50 mL), brine (50 mL), dried with anhydrous sodium sulfate, and concentrated under reduced pressure. The crude product was purified by column chromatography on silica gel (petroleum ether/EtOAc = 8:1) to give the corresponding substituted 8-methyl-quinoline **1i-1j**.

General procedure for the synthesis of the substate 1k[18f]

Aniline (5.0 mmol) and styrene oxide (10.0 mmol) were added to a mixture of $MeSO_3H$ (1.5 mL) and Al_2O_3 (0.5 g). The mixture was stirred at room temperature in solvent-free conditions for 0.5 h. After completion of the reaction, the mixture was diluted with ethyl acetate, and filtered. The filtrate was washed with a solution of $NaHCO_3$ (5%; 3 x 30 mL) and then 150 mL deionized water. The solution was dried over magnesium sulfate; the solvent was evaporated to give the crude product, which was purified by silica gel column chromatography employing petroleum ether/ethyl acetate (8:1) as eluent.

Genaral procedure: Palladium-Catalyzed phosphorylation/sulfonation reactions of 8-methylquinolines

[Caution] *Since the hypervalent iodine reagents are generally explosive, so please operate them in a fume hood.*

Procedure A: A oven-dried 15 mL Schlenk tube was charged with a mixture of **1** (0.2 mmol), $Pd(OAc)_2$ (10 mol%), oxidant (0.48 mmol), 4Å MS (175 mg) in dioxane (1.0 mL) and was stirred at room temperature for 6-12 h. After the reaction was complete (as determined by TLC analysis), the reaction was cooled to room temperature and 10 mL of water was added. Then, the mixture was extracted with ethyl acetate (10 mL × 3). The combined organic layers were washed with saturated

brine and dried by anhydrous Na_2SO_4. The solvent was evaporated under reduced pressure, and the residue was purified on a silica gel column (petroleum ether/ethyl acetate = 4:1) to afford the targeted products **3a-3m** or **4a-4l**.

Diphenyl (quinolin-8-ylmethyl) phosphate (3a)

Yield: 87% (68.1 mg), Yellow oil, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.92 (d, *J* = 4.2 Hz, 1H), 8.17 (d, *J* = 8.4 Hz, 1H), 7.82 (t, *J* = 8.1 Hz, 2H), 7.53 (t, *J* = 7.7 Hz, 1H), 7.47-7.42 (m, 1H), 7.35-7.24 (m, 8H), 7.18 (t, *J* = 7.1 Hz, 2H), 6.09 (d, *J* = 8.1 Hz, 2H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 150.6 (d, *J* = 7.1 Hz), 149.8, 145.5, 136.2, 133.5 (d, *J* = 7.4 Hz), 129.7, 128.2 (d, *J* = 16.1 Hz), 128.0, 126.3, 125.3, 121.4, 120.2 (d, *J* = 4.9 Hz), 67.3 (d, *J* = 5.6 Hz); ^{31}P NMR (121 MHz, $CDCl_3$): δ -11.69; IR (KBr): *v* 3070, 3015, 2952, 1594, 1487, 1290, 1215, 1187, 1163, 876, 823, 789, 764; HRMS (ESI-TOF) m/z: $[M+Na]^+$ Calcd for $C_{22}H_{18}NO_4PNa$ 414.0866, Found 414.0870.

(5-methylquinolin-8-yl)methyl diphenyl phosphate (3b)

Yield: 49% (39.7 mg), Yellow oil, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.92 (d, *J* = 4.2 Hz, 1H), 8.34 (d, *J* = 8.4 Hz, 1H), 7.12 (d, *J* = 7.2 Hz, 1H), 7.49-7.45 (m, 1H), 7.37-7.14 (m, 11H), 6.04 (d, *J* = 8.1 Hz, 2H), 2.69 (s, 3H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 150.6 (d, *J* = 7.1 Hz), 149.3, 145.8, 135.3, 132.6, 131.5 (d, *J* = 7.1 Hz), 129.7, 128.1, 127.4, 126.6, 125.2, 121.0, 120.2 (d, *J* = 4.9 Hz), 67.5 (d, *J* = 5.6 Hz), 18.7; ^{31}P NMR (121 MHz, $CDCl_3$): δ -10.58; IR (KBr): *v* 3065, 2922, 2853, 1594, 1491, 1412, 1240, 1203, 1160, 848, 771, 719; HRMS (ESI-TOF) m/z: $[M+Na]^+$ Calcd for $C_{23}H_{20}NO_4PNa$ 428.1022, Found 428.1025.

(5-fluoroquinolin-8-yl)methyl diphenyl phosphate (3c)

Yield: 79% (64.7 mg), Colorless oil, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.95 (d, *J* = 3.3 Hz, 1H), 8.42 (d, *J* = 8.4 Hz, 1H), 7.75 (t *J* = 6.6 Hz, 1H), 7.51-7.47 (m, 1H), 7.33-7.15 (m, 11H), 5.99 (d, *J* =8.4 Hz, 2H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$): δ 157.9 (d, J_{CF} = 254.9 Hz), 150.6 (t, *J* = 11.0 Hz), 146.2 (d, *J* = 3.1 Hz), 129.7, 129.4 (d, *J* = 4.5 Hz), 128.4 (d, *J* = 9.1 Hz), 125.2, 121.4 (d, *J* = 2.8 Hz), 120.1 (d, *J* = 4.9 Hz), 118.8 (d, *J* = 16.5 Hz), 109.7 (d, *J* = 19.4 Hz), 66.8 (d, *J* = 5.6 Hz); ^{31}P NMR (121 MHz, $CDCl_3$): δ -11.68; IR (KBr): *v* 3050, 2962, 2930, 1599, 1489, 1409, 1287, 1217, 1185, 1160, 898, 868, 776, 756; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{22}H_{18}FNO_4P$ 410.0952, Found 410.0954.

(5-chloroquinolin-8-yl)methyl diphenyl phosphate (3d)

Yield: 80% (68.1 mg), Yellow oil, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.95 (d, *J* = 3.3 Hz, 1H), 8.59 (d, *J* = 8.7 Hz, 1H), 7.73 (d, *J* = 7.5 Hz, 1H), 7.61-7.54 (m, 2H), 7.34-7.16 (m, 10H), 6.02 (d, *J* =8.4 Hz, 2H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$): δ 150.5 (d, *J* = 6.9 Hz), 150.3, 146.0, 133.0, 131.6, 129.7, 127.8, 126.3, 126.0, 125.3, 122.1, 120.1 (d, *J* = 4.9 Hz), 66.9 (d, *J* = 5.5 Hz); ^{31}P NMR (121 MHz, $CDCl_3$): δ -11.72; IR (KBr): *v* 3047, 2932, 2848, 1587, 1489,

1444, 1282, 1220, 1187, 1162, 871, 848, 774, 754; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{22}H_{18}ClNO_4P$ 426.0656, Found 426.0658.

(5-bromoquinolin-8-yl)methyl diphenyl phosphate (3e)

Yield: 82% (77.1 mg), Pale yellow oil, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.72 (d, *J* = 4.2 Hz, 1H), 8.47 (d, *J* = 8.6 Hz, 1H), 7.75 (d, *J* = 7.8 Hz, 1H), 7.63 (d, *J* = 7.8 Hz, 1H), 7.50-7.46 (m, 1H), 7.33-7.23 (m, 8H), 7.16 (t, *J* =7.1 Hz, 2H), 6.00 (d, *J* = 8.1 Hz, 2H); $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 150.5 (t, *J* = 7.1 Hz), 145.9, 135.5, 133.7 (d, *J* = 7.3 Hz), 130.0, 129.8 (d, *J* = 0.5 Hz), 128.2, 127.2, 125.4 (d, *J* = 1.1 Hz), 122.5, 122.2, 120.1 (d, *J* = 5.0 Hz), 67.0 (d, *J* = 5.4 Hz); ^{31}P NMR (121 MHz, $CDCl_3$): δ -11.71; IR (KBr): *v* 3097, 3057, 3042, 2942, 1589, 1482, 1452, 1295, 1215, 1187, 1145, 871, 828, 776, 761; HRMS (ESI-TOF) m/z: $[M+Na]^+$ Calcd for $C_{22}H_{17}BrNO_4PNa$ 491.9961, Found 491.9955.

(5-nitroquinolin-8-yl)methyl diphenyl phosphate (3f)

Yield: 86% (75.1 mg), Yellow oil, R_f = 0.35 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, $CDCl_3$): δ 9.01 (t, *J* = 7.7 Hz, 2H), 8.34 (d, *J* = 7.8 Hz, 1H), 7.87 (d, *J* = 8.1 Hz, 1H), 7.71-7.67 (m, 1H), 7.38-7.20 (m, 10H), 6.12 (d, *J* = 7.8 Hz, 2H); $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 150.7, 150.4 (d, *J* = 7.1 Hz), 145.0 (d, *J* = 14.0 Hz), 141.6 (d, *J* = 7.7 Hz), 132.2, 129.9, 125.5, 124.8, 124.4, 124.2, 120.7, 120.1 (d, *J* = 4.9 Hz), 66.9 (d, *J* = 5.0 Hz); ^{31}P NMR (121 MHz, $CDCl_3$): δ -11.78; IR (KBr): *v* 3072, 3057, 3040, 2965, 1591, 1524, 1479, 1452, 1404, 1292, 1212, 1180, 1155, 871, 851, 834, 799, 774, 721; HRMS (ESI-TOF) m/z: $[M+Na]^+$ Calcd for $C_{22}H_{17}N_2O_6PNa$ 459.0716, Found 459.0710.

(6-methylquinolin-8-yl)methyl diphenyl phosphate (3g)

Yield: 69% (55.9 mg), Yellow oil, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, DMSO): δ 8.87 (d, *J* = 4.1 Hz, 1H), 8.29 (d, *J* = 8.4 Hz, 1H), 7.75 (s, 1H), 7.57-7.53 (m, 2H), 7.44-7.39 (m, 4H), 7.27-7.22 (m, 6H), 5.92 (d, *J* = 8.1 Hz, 2H), 2.44 (s, 3H); $^{13}C\{^1H\}$ NMR (75 MHz, DMSO): δ 152.1 (d, *J* = 6.9 Hz), 147.8, 141.3, 139.2, 138.2, 137.3, 130.6, 130.0, 128.6, 126.0, 124.4, 122.0, 120.4 (d, *J* = 5.0 Hz), 59.9, 21.8; ^{31}P NMR (121 MHz, $CDCl_3$): δ -12.34; IR (KBr): *v* 3072, 2918, 2853, 1589, 1489, 1439, 1290, 1160, 1122, 868, 776, 711; HRMS (ESI-TOF) m/z: $[M+Na]^+$ Calcd for $C_{23}H_{20}NO_4PNa$ 428.1027, Found 428.1034.

(7-methylquinolin-8-yl)methyl diphenyl phosphate (3h)

Yield: 34% (27.6 mg), Yellow oil, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.93 (d, *J* = 4.2 Hz, 1H), 8.12 (d, *J* = 8.3 Hz, 1H), 7.76 (d, *J* = 8.4 Hz, 1H), 7.42-7.36 (m, 2H), 7.31-7.12 (m, 10H), 6.20 (d, *J* = 6.9 Hz, 2H), 2.61 (s, 3H); $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 150.7 (d, *J* = 7.1 Hz), 150.1, 146.8, 140.8, 135.9, 130.1, 129.8, 129.6, 128.8, 126.5, 125.0, 120.5, 120.2 (d, *J* = 5.0 Hz), 63.1 (d, *J* = 5.7 Hz), 19.7; ^{31}P NMR (121 MHz, $CDCl_3$): δ -11.88; IR (KBr): *v* 3050, 2920, 2850, 1594, 1482, 1437, 1285, 1220, 1190, 1163, 831, 776, 749; HRMS (ESI-TOF) m/z: $[M+Na]^+$ Calcd for $C_{23}H_{20}NO_4PNa$ 428.1022, Found 428.1023.

(3-methylquinolin-8-yl)methyl diphenyl phosphate (3i)

Yield: 54% (43.8 mg), Yellow oil, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.75 (d, *J* = 1.5 Hz, 1H), 7.89 (s, 1H), 7.76-7.70 (m, 2H), 7.48 (t, *J* = 7.7 Hz, 1H), 7.34-7.24 (m, 8H), 7.17 (t, *J* = 7.1 Hz, 2H), 6.07 (d, *J* = 8.1 Hz, 2H), 2.51 (s, 3H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 151.8, 150.6 (d, *J* = 7.1 Hz), 143.8, 134.8, 133.2 (d, *J* = 7.3 Hz), 130.9, 129.7, 127.8 (d, *J* = 10.3 Hz), 127.1, 126.3, 125.3 (d, *J* = 1.0 Hz), 120.2 (d, *J* = 5.0 Hz), 67.4 (d, *J* = 5.6 Hz), 18.7; ^{31}P NMR (121 MHz, $CDCl_3$): δ -11.74; IR (KBr): *v* 3065, 2922, 2850, 1586, 1544, 1489, 1439, 1290, 1217, 1187, 1165, 881, 768, 711; HRMS (ESI-TOF) m/z: $[M+Na]^+$ Calcd for $C_{23}H_{20}NO_4PNa$ 428.1022, Found 428.1018.

(3-ethylquinolin-8-yl)methyl diphenyl phosphate (3j)

Yield: 59% (49.5 mg), Yellow oil, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.79 (d, *J* = 2.4 Hz, 1H), 7.92 (d, *J* = 2.1 Hz, 1H), 7.77-7.74 (m, 2H), 7.52-7.47 (m, 1H), 7.34-7.24 (m, 8H), 7.20-7.14 (m, 2H), 6.08 (d, *J* = 8.1 Hz, 2H), 2.89-2.81 (m, 2H), 1.36 (t, *J* = 7.5 Hz, 3H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 151.3, 150.6 (d, *J* = 7.1 Hz), 144.0, 137.0, 133.6, 133.2 (d, *J* = 7.3 Hz), 129.7, 127.9 (d, *J* = 6.1 Hz), 127.2, 126.3, 125.2 (d, *J* = 1.1 Hz,), 120.2 (d, *J* = 5.0 Hz), 67.4 (d, *J* = 5.6 Hz), 26.2, 15.2; ^{31}P NMR (121 MHz, $CDCl_3$): δ -11.72; IR (KBr): *v* 3072, 2967, 2925, 2870, 1589, 1489, 1457, 896, 876, 828, 776; HRMS (ESI-TOF) m/z: $[M+K]^+$ Calcd for $C_{24}H_{22}NO_4PK$ 458.0918, Found 458.0926.

Diphenyl ((3-phenylquinolin-8-yl)methyl) phosphate (3k)

Yield: 47% (43.9 mg), Yellow oil, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.15 (d, *J* = 1.2 Hz, 1H), 8.28 (d, *J* = 1.2 Hz, 1H), 7.83 (d, *J* = 10.2 Hz, 2H), 7.70 (t, *J* = 3.6 Hz, 2H), 7.55-7.52 (m, 3H), 7.46-7.43 (m, 1H), 7.31-7.23 (m, 8H), 7.15 (t, *J* = 3.6 Hz, 2H), 6.09 (d, *J* = 4.2 Hz, 2H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 150.6 (d, *J* = 7.1 Hz), 149.3, 144.6, 137.7, 134.1, 133.5 (d, *J* = 7.1 Hz), 133.3, 129.7, 129.3, 128.5, 128.3, 128.1, 127.8, 127.4, 126.8, 125.3, 120.2 (d, *J* = 4.9 Hz), 67.3 (d, *J* = 5.6 Hz); ^{31}P NMR (121 MHz, $CDCl_3$): δ -11.71; IR (KBr): *v* 3067, 2922, 2850, 1584, 1484, 1444, 1285, 1215, 1187, 1162, 898, 871, 826, 771; HRMS (ESI-TOF) m/z: $[M+Na]^+$ Calcd for $C_{28}H_{22}NO_4PNa$ 490.1179, Found 490.1187.

Dibenzyl (quinolin-8-ylmethyl) phosphate (3l)

Yield: 76% (63.7 mg), Pale yellow oil, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.90 (t, *J* = 2.4 Hz, 1H), 8.16 (d, *J* = 8.4 Hz, 1H), 7.79 (d, *J* = 7.8 Hz, 2H), 7.52 (t, *J* = 7.8 Hz, 1H), 7.45-7.33 (m, 11H), 5.85 (d, *J* = 7.5 Hz, 2H), 5.11 (d, *J* = 7.8 Hz, 4H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 149.8, 145.6, 136.2, 135.9 (d, *J* = 7.1 Hz), 134.1 (d, *J* = 7.6 Hz), 128.5 (d, *J* = 7.6 Hz), 128.0 (d, *J* = 11.0 Hz), 126.3, 121.3, 69.3 (d, *J* = 5.5 Hz), 66.0 (d, *J* = 5.0 Hz); ^{31}P NMR (121 MHz, $CDCl_3$): δ -0.73; IR (KBr): *v* 3032, 2920, 2853, 1596, 1502, 1454, 1275, 1215, 1187, 876, 821, 786, 736; HRMS (ESI-TOF) m/z: $[M+Na]^+$ Calcd for $C_{24}H_{22}NO_4PNa$ 442.1179, Found 442.1183.

Diethyl (quinolin-8-ylmethyl) phosphate (3m)

Yield: 69% (40.8 mg), Yellow oil, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.91 (d, *J* = 3.9 Hz, 1H), 8.16 (d, *J* = 8.1 Hz, 1H), 7.89 (d, *J* = 6.9 Hz, 1H), 7.79 (d, *J* = 7.8 Hz, 1H), 7.56 (t, *J* = 7.5 Hz, 1H), 7.45-7.41 (m, 1H), 5.83 (d, *J* = 7.2 Hz, 2H), 4.21-4.11 (m, 4H), 1.32 (t, *J* = 6.9 Hz, 6H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 149.7, 145.5, 136.2, 134.4 (d, *J* = 7.5 Hz), 127.9, 127.7, 126.3, 121.3, 65.7 (d, *J* = 5.0 Hz), 63.9 (d, *J* = 5.7 Hz), 16.1 (d, *J* = 6.8 Hz); ^{31}P NMR (121 MHz, $CDCl_3$): δ -0.82; IR (KBr): *v* 2980, 2930, 2905, 1596, 1559, 1499, 1462, 1265, 1162, 876, 826, 791; HRMS (ESI-TOF) m/z: $[M+Na]^+$ Calcd for $C_{14}H_{18}NO_4PNa$ 318.0866, Found 318.0874.

Quinolin-8-ylmethyl diphenylphosphinate (4a)

Yield: 88% (63.3 mg), Pale yellow oil, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.84 (d, *J* = 2.1 Hz, 1H), 8.13 (d, *J* = 4.2 Hz, 1H), 7.95-7.88 (m, 5H), 7.75 (d, *J* = 3.9 Hz, 1H), 7.55-7.48 (m, 3H), 7.44-7.38 (m, 5H), 5.83 (d, *J* = 3.6 Hz, 2H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 149.6, 145.6, 136.1, 134.9 (d, *J* = 7.0 Hz), 132.5, 132.1 (d, *J* = 2.8 Hz), 131.8 (d, *J* = 10.1 Hz), 130.7, 128.5 (d, *J* = 13.1 Hz), 127.8 (d, *J* = 10.4 Hz), 126.3, 121.2, 63.3 (d, *J* = 5.0 Hz); ^{31}P NMR (121 MHz, $CDCl_3$): δ 32.42; IR (KBr): *v* 3049, 2930, 2863, 1589, 1576, 1496, 1437, 1222, 1160, 1125, 863, 833, 786, 749, 729; HRMS (ESI-TOF) m/z: $[M+Na]^+$ Calcd for $C_{22}H_{18}NO_2PNa$ 382.0967, Found 382.0970.

(5-methylquinolin-8-yl)methyl diphenylphosphinate (4b)

Yield: 79% (59.0 mg), Pink oil, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.85 (d, *J* = 3.9 Hz, 1H), 8.28 (d, *J* = 8.7 Hz, 1H), 7.95-7.89 (m, 4H), 7.82 (d, *J* = 7.5 Hz, 1H), 7.53-7.35 (m, 8H), 5.82 (d, *J* = 7.5 Hz, 2H), 2.65 (s, 3H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 149.1, 146.0, 134.7, 132.8 (d, *J* = 7.1 Hz), 132.5 (d, *J* = 4.4 Hz), 132.1 (d, *J* = 2.8 Hz), 131.8 (d, *J* = 10.1 Hz), 130.8, 128.5 (d, *J* = 13.1 Hz), 127.8, 127.3, 126.7, 120.8, 63.5 (d, *J* = 5.1 Hz), 18.6; ^{31}P NMR (121 MHz, $CDCl_3$): δ 32.16; IR (KBr): *v* 3069, 3015, 2927, 1596, 1501, 1434, 1227, 1175, 1128, 1113, 851, 826, 774, 746, 724; HRMS (ESI-TOF) m/z: $[M+K]^+$ Calcd for $C_{23}H_{20}NO_2PK$ 412.0863, Found 412.0865.

(5-fluoroquinolin-8-yl)methyl diphenylphosphinate (4c)

Yield: 68% (51.3 mg), Yellow oil, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.91 (d, *J* = 3.0 Hz, 1H), 8.41 (d, *J* = 8.1 Hz, 1H), 7.92-7.86 (m, 5H), 7.52-7.45 (m, 7H), 7.21 (t, *J* = 8.7 Hz, 1H), 5.78 (d, *J* = 7.5 Hz, 2H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$): δ 157.6 (d, J_{CF} = 254.3 Hz), 150.4, 146.2, 132.1 (d, *J* = 2.8 Hz), 131.8 (d, *J* = 10.3 Hz), 131.0, 129.4 (d, *J* = 4.6 Hz), 128.5 (d, *J* = 13.1 Hz), 128.2 (d, *J* = 9.0 Hz), 121.3 (d, *J* = 2.8 Hz), 118.7 (d, *J* = 16.4 Hz), 109.8 (d, *J* = 19.3 Hz), 62.9 (d, *J* = 5.0 Hz); ^{31}P NMR (121 MHz, $CDCl_3$): δ 32.56; IR (KBr): *v* 3017, 2918, 2848, 1594, 1474, 1437, 1407, 1222, 1130, 863, 798, 751, 729; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{22}H_{18}FNO_2P$ 378.1054, Found 378.1057.

(5-chloroquinolin-8-yl)methyl diphenylphosphinate (4d)

Yield: 60% (47.3 mg), Yellow oil, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.90 (d, *J* = 3.3 Hz, 1H), 8.57 (d, *J* = 8.4 Hz, 1H), 7.94-7.87 (m, 5H), 7.63 (d, *J* = 7.5 Hz, 1H), 7.53-7.46 (m, 7H), 5.81 (d, *J* = 7.5 Hz, 2H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$): δ 150.1, 146.1, 134.3 (d, *J* = 11.6 Hz), 133.0, 132.2 (d, *J* = 4.9 Hz), 131.8 (d, *J* = 17.0 Hz), 131.2, 130.5, 128.6 (d, *J* = 21.9 Hz), 127.7, 126.4, 125.9, 122.0, 63.0 (d, *J* = 8.1 Hz); ^{31}P NMR (121 MHz, $CDCl_3$): δ 32.69; IR (KBr): *v* 3052, 2920, 2848, 1576, 1494, 1437, 1220, 1122, 1113, 853, 816, 749, 729; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{22}H_{18}ClNO_2P$ 394.0758, Found 394.0760.

(5-bromoquinolin-8-yl)methyl diphenylphosphinate (4e)

Yield: 66% (57.9 mg), Pale yellow oil, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.84 (d, *J* = 4.1 Hz, 1H), 8.48 (t, *J* = 7.5 Hz, 1H), 7.93-7.87 (m, 4H), 7.87 (s, 2H), 7.54-7.41 (m, 7H), 5.79 (d, *J* = 7.5 Hz, 2H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 150.1, 146.1, 135.6, 135.0 (d, *J* = 7.0 Hz), 132.3 (d, *J* = 2.9 Hz), 131.8 (d, *J* = 10.2 Hz), 130.4, 130.1, 128.6 (d, *J* = 13.1 Hz), 128.1, 127.2, 122.3, 121.7, 63.0 (d, *J* = 5.0 Hz); ^{31}P NMR (121 MHz, $CDCl_3$): δ 32.81; IR (KBr): *v* 3052, 3012, 2940, 2865, 1589, 1571, 1491, 1437, 1220, 1125, 1110, 853, 771, 736, 724; HRMS (ESI-TOF) m/z: $[M+Na]^+$ Calcd for $C_{22}H_{17}BrNO_2PNa$ 460.0072, Found 460.0075.

(5-nitroquinolin-8-yl)methyl diphenylphosphinate (4f)

Yield: 59% (47.7 mg), Yellow oil, R_f = 0.30 (petroleum ether / ethyl acetate = 4:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.98 (d, *J* = 8.9 Hz, 1H), 8.90 (d, *J* = 4.1 Hz, 1H), 8.39 (d, *J* = 7.8 Hz, 1H), 8.07 (d, *J* = 7.8 Hz, 1H), 7.96-7.89 (m, 4H), 7.64-7.60 (m, 1H), 7.56-7.45 (m, 6H), 5.88 (d, *J* = 7.5 Hz, 2H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 150.5, 144.9 (d, *J* = 10.7 Hz), 143.0 (d, *J* = 6.9 Hz), 132.5 (d, *J* = 2.8 Hz), 132.2, 131.8 (t, *J* = 6.9 Hz), 130.1, 128.7 (d, *J* = 13.1 Hz), 124.9, 124.6, 124.0, 120.6, 63.2 (d, *J* = 4.7 Hz); ^{31}P NMR (121 MHz, $CDCl_3$): δ 33.38; IR (KBr): *v* 3104, 3052, 2945, 1589, 1506, 1439, 1404, 1230, 1192, 1130, 861, 833, 803, 721; HRMS (ESI-TOF) m/z: $[M+K]^+$ Calcd for $C_{22}H_{17}N_2O_4PK$ 443.0558, Found 443.0564.

(6-methylquinolin-8-yl)methyl diphenylphosphinate (4g)

Yield: 70% (52.3 mg), Yellow oil, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.83 (d, *J* = 4.2 Hz, 1H), 8.05 (d, *J* = 8.3 Hz, 1H), 7.61 (s, 1H), 7.53 (s, 1H), 7.40-7.25 (m, 9H), 7.20-7.15 (m, 2H), 6.06 (d, *J* = 8.1 Hz, 2H), 2.47 (s, 3H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 150.6 (d, *J* = 7.1 Hz), 148.9, 144.1, 136.1, 135.5, 133.0 (d, *J* = 7.2 Hz), 130.2, 129.7, 128.1, 127.0, 125.3 (d, *J* = 1.1 Hz), 121.4, 120.2 (d, *J* = 5.0 Hz), 67.3 (d, *J* = 5.6 Hz), 21.7; ^{31}P NMR (121 MHz, $CDCl_3$): δ 32.35; IR (KBr): *v* 3059, 2930, 2855, 1589, 1496, 1434, 1263, 1227, 1130, 1115, 861, 828, 768, 726, 701; HRMS (ESI-TOF) m/z: $[M+K]^+$ Calcd for $C_{23}H_{20}NO_2PK$ 412.0863, Found 412.0871.

(7-methylquinolin-8-yl)methyl diphenylphosphinate (4h)

Yield: 52% (38.8 mg), Yellow oil, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^{1}H NMR (300

MHz, $CDCl_3$): δ 8.92 (d, *J* = 4.1 Hz, 1H), 8.09 (d, *J* = 8.1 Hz, 1H), 7.74 (d, *J* = 8.4 Hz, 1H), 7.40-7.34 (m, 2H), 7.31-7.22 (m, 8H), 7.15 (t, *J* = 6.9 Hz, 2H), 6.21 (d, *J* = 6.9 Hz, 2H), 2.60 (s, 3H); $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 150.7 (d, *J* = 7.1 Hz), 150.1, 149.9, 140.7, 135.9, 130.1 (d, *J* = 7.7 Hz), 129.7 (d, *J* = 9.8 Hz), 128.9, 126.5, 125.1, 120.6, 120.2 (d, *J* = 4.9 Hz), 63.1 (d, *J* = 5.9 Hz), 19.7; ^{31}P NMR (121 MHz, $CDCl_3$): δ 31.79; IR (KBr): *v* 3055, 2922, 2850, 1501, 1464, 1437, 1222, 1130, 1110, 876, 833, 793, 729; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{23}H_{21}NO_2P$ 374.1304, Found 374.1309.

Methyl 3-benzoylimidazo[1,2-a]pyridine-7-carboxylate (4i)

Yield: 60% (44.8 mg), Yellow oil, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.68 (s, 1H), 7.95-7.85 (m, 6H), 7.66 (d, *J* = 8.1 Hz, 1H), 7.51-7.42 (m, 7H), 5.83 (d, *J* = 7.2 Hz, 2H), 2.45 (s, 3H); $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 151.5, 143.8, 134.8, 134.5 (d, *J* = 7.1 Hz), 132.4, 132.2 (d, *J* = 2.8 Hz), 131.8 (d, *J* = 10.2 Hz), 130.6 (d, *J* = 6.2 Hz), 128.5 (d, *J* = 13.1 Hz), 127.8, 127.2, 126.8, 126.3, 63.4 (d, *J* = 5.1 Hz), 18.7; ^{31}P NMR (121 MHz, $CDCl_3$): δ 32.46; IR (KBr): *v* 3049, 2930, 2862, 1589, 1499, 1482, 1437, 1227, 1128, 1110, 896, 838, 821, 769, 729; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{23}H_{21}NO_2P$ 374.1304, Found 374.1313.

(3-ethylquinolin-8-yl)methyl diphenylphosphinate (4j)

Yield: 65% (50.4 mg), Yellow oil, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.73 (d, *J* = 1.8 Hz, 1H), 7.95-7.87 (m, 6H), 7.70 (d, *J* = 8.1 Hz, 1H), 7.53-7.40 (m, 7H), 5.85 (d, *J* = 6.9 Hz, 2H), 2.84-2.77 (m, 2H), 1.32 (t, *J* = 7.5 Hz, 3H); $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 151.0, 144.1, 136.8, 134.5 (d, *J* = 7.1 Hz), 133.5, 132.4, 132.2 (d, *J* = 2.8 Hz), 131.8 (d, *J* = 10.1 Hz), 130.6, 128.5 (d, *J* = 13.1 Hz), 127.9, 127.4, 126.9, 126.3, 63.4 (d, *J* = 5.1 Hz), 26.2, 15.2; ^{31}P NMR (121 MHz, $CDCl_3$): δ 32.27; IR (KBr): *v* 3050, 2957, 2895, 1589, 1486, 1444, 1215, 1130, 1113, 868, 729, 701; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{24}H_{23}NO_2P$ 388.1461, Found 388.1469.

(3-phenylquinolin-8-yl)methyl diphenylphosphinate (4k)

Yield: 50% (43.6 mg), Yellow oil, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, $CDCl_3$): δ 9.14 (d, *J* = 1.8 Hz, 1H), 8.30 (d, *J* = 2.1 Hz, 1H), 7.98-7.92 (m, 5H), 7.85 (d, *J* = 8.1 Hz, 1H), 7.72 (d, *J* = 7.5 Hz, 2H), 7.63-7.44 (m, 10H), 5.90 (d, *J* = 7.2 Hz, 2H); $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 149.1, 144.7, 137.8, 134.8 (d, *J* = 7.1 Hz), 133.9, 133.3, 132.5, 132.2 (d, *J* = 2.8 Hz), 131.8 (d, *J* = 10.1 Hz), 130.7, 129.2, 128.6 (d, *J* = 13.1 Hz), 128.1 (d, *J* = 11.9 Hz), 127.8 (d, *J* = 10.2 Hz), 127.4, 126.8, 63.3 (d, *J* = 5.0 Hz); ^{31}P NMR (121 MHz, $CDCl_3$): δ 32.44; IR (KBr): *v* 3054, 2922, 2865, 1584, 1484, 1437, 1275, 1222, 1128, 1110, 866, 769, 729; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{28}H_{23}NO_2P$ 436.1461, Found 436.1470.

1-(quinolin-8-yl)ethyl diphenylphosphinate (4l)

Yield: 59% (44.1 mg), Colorless oil, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.75 (d, *J* = 1.8 Hz, 1H), 8.08 (d, *J* = 4.2 Hz, 1H), 8.01 (d, *J* = 3.6 Hz, 1H), 7.91-7.88

(m, 2H), 7.73-7.70 (m, 3H), 7.56 (t, J = 3.9 Hz, 1H), 7.51 (t, J = 3.6 Hz, 1H), 7.46-7.43 (m, 2H), 7.36-7.31 (m, 2H), 7.26-7.23 (m, 2H), 6.81-6.76 (m, 1H), 1.79 (d, J = 3.3 Hz, 3H); $^{13}C\{^{1}H\}$ NMR (75 MHz, $CDCl_3$): δ 149.3, 144.5, 141.1 (d, J = 4.6 Hz), 136.0, 133.3, 132.7, 132.0 (d, J = 2.8 Hz), 131.8 (d, J = 2.6 Hz), 131.7 (d, J = 2.6 Hz), 131.5, 130.9, 128.5, 128.3 (d, J = 6.2 Hz), 128.1, 128.0, 127.4, 126.4, 125.7, 121.0, 70.9 (d, J = 5.3 Hz), 25.2; ^{31}P NMR (121 MHz, $CDCl_3$): δ 30.57; IR (KBr): ν 3060, 2972, 2855, 1594, 1576, 1499, 1437, 1250, 1160, 1127, 826, 811, 754, 724; HRMS (ESI-TOF) m/z: $[M+Na]^+$ Calcd for $C_{23}H_{20}NO_2PNa$ 396.1124, Found 396.1121.

General Procedure for the Synthesis of 4a in a 2.0 mmol Scale.

A oven-dried 100 mL Schlenk tube was charged with a mixture of **1a** (2.0 mmol), $Pd(OAc)_2$ (10 mol%), oxidant (4.8 mmol), 4Å MS (1750 mg) in dioxane (10.0 mL) and was stirred at room temperature for 8 h. After the reaction was complete (as determined by TLC analysis), the reaction was cooled to room temperature and 100 mL of water was added. Then, the mixture was extracted with ethyl acetate (30 mL × 3). The combined organic layers were washed with saturated brine and dried by anhydrous Na_2SO_4. The solvent was evaporated under reduced pressure, and the residue was purified on a silica gel column (petroleum ether/ethyl acetate = 4:1) to afford the targeted product **4a** in 80% yield (573 mg).

Procedure B: A 15 mL Schlenk tube was charged with a mixture of **5** (0.2 mmol), $Pd(OAc)_2$ (10 mol%), oxidant (0.60 mmol), C_2CO_3 (0.3 mmol), PivOH (0.06 mmol) in DCE (1.0 mL) and was stirred in a 130 ^{o}C oil-bath for 10-15 h. After the reaction was complete (as determined by TLC analysis), the reaction was cooled to room temperature and 10 mL of water was added. Then, the mixture was extracted with ethyl acetate (10 mL × 3). The combined organic layers were washed with saturated brine and dried by anhydrous Na_2SO_4. The solvent was evaporated under reduced pressure, and the residue was purified on a silica gel column (petroleum ether/ethyl acetate = 2:1) to afford the targeted products **6a-6f.**

2-(pyridin-2-yl)phenol (6a)[15]

Yield: 56% (19.2 mg), Pale yellow oil, R_f = 0.40 (petroleum ether/ethyl acetate = 2:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 14.40 (br s, 1H), 8.53 (d, J = 4.2 Hz, 1H), 7.94 (d, J = 8.4 Hz, 1H), 7.88-7.81 (m, 2H), 7.36-7.25 (m, 2H), 7.06 (d, J = 8.4 Hz, 1H), 6.93 (d, J = 6.9 Hz, 1H); $^{13}C\{^{1}H\}$ NMR (125 MHz, $CDCl_3$): δ 160.0, 157.9, 145.9, 137.7, 131.5, 126.1, 121.5, 119.1, 118.8, 118.7, 118.6.

5-fluoro-2-(pyridin-2-yl)phenol (6b)[15]

Yield: 67% (25.4 mg), Mp 102-103 ^{o}C, Yellow solid, R_f = 0.40 (petroleum ether/ethyl acetate = 2:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 14.84 (br s, 1H), 8.50 (d, J = 4.8 Hz, 1H), 7.86-7.75 (m, 3H), 7.26 (t, J = 3.3 Hz, 1H), 6.74 (d, J = 10.5 Hz, 1H), 6.68-6.61 (m, 1H); $^{13}C\{^{1}H\}$ NMR (125 MHz, $CDCl_3$): δ 165.7, 163.7, 162.1, 162.0, 157.3, 145.7, 137.9, 127.6, 127.5, 121.4, 118.8, 115.4, 106.4, 106.2, 105.3, 105.1.

5-methyl-2-(pyridin-2-yl)phenol (6c)[15]

Yield: 54% (20.0 mg), Colorless oil, R_f = 0.40 (petroleum ether/ethyl acetate = 2:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 14.36 (br s, 1H), 8.50 (d, *J* = 3.9 Hz, 1H), 7.91-7.80 (m, 2H), 7.70 (d, *J* = 8.1 Hz, 1H), 7.22 (t, *J* = 6.0 Hz, 1H), 6.87 (s, 1H), 6.75 (d, *J* = 7.8 Hz, 1H), 2.37 (s, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$): δ 159.9, 158.0, 145.8, 142.1, 137.6, 125.9, 121.0, 119.9, 118.9, 118.7, 116.3, 21.4.

5-ethyl-2-(pyridin-2-yl)phenol (6d)[15]

Yield: 57% (22.7 mg), Yellow oil, R_f = 0.40 (petroleum ether/ethyl acetate = 2:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 14.35 (br s, 1H), 8.51 (d, *J* = 3.3 Hz, 1H), 7.91-7.80 (m, 2H), 7.73 (d, *J* = 8.1 Hz, 1H), 7.23 (t, *J* = 5.1 Hz, 1H), 6.90 (s, 1H), 6.78 (d, *J* = 7.8 Hz, 1H), 2.70-2.63 (m, 2H), 1.28 (t, *J* = 7.5 Hz, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$): δ 160.0, 158.0, 148.4, 145.8, 137.6, 126.0, 121.0, 118.7, 117.6, 116.5, 28.7, 15.1.

5-methoxy-2-(pyridin-2-yl)phenol (6e)[15]

Yield: 48% (19.3 mg), Pale yellow oil, R_f = 0.40 (petroleum ether/ethyl acetate = 2:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 14.76 (br s, 1H), 8.46 (d, *J* = 3.6 Hz, 1H), 7.80 (t, *J* =3.3 Hz, 2H), 7.72 (d, *J* = 9.0 Hz, 1H), 7.20-7.16 (m, 1H), 6.57-6.50 (m, 2H), 3.85 (s, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$): δ 162.4, 161.9, 157.9, 145.6, 137.6, 127.1, 120.5, 118.2, 112.1, 106.6, 102.2, 55.3.

4-(pyridin-2-yl)-[1,1'-biphenyl]-3-ol (6f)[15]

Yield: 51% (25.2 mg), Mp 144-145 °C, White solid, R_f = 0.40 (petroleum ether/ethyl acetate = 2:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 14.51 (br s, 1H), 8.55 (d, *J* = 3.9 Hz, 1H), 7.97 (d, *J* =8.4 Hz, 1H), 7.89 (d, *J* = 8.4 Hz, 2H), 7.69 (d, *J* =7.5 Hz, 2H), 7.48 (t, *J* = 6.9 Hz, 2H), 7.40 (d, *J* = 6.6 Hz, 1H), 7.30 (d, *J* =9.9 Hz, 2H), 7.20 (d, *J* = 8.1 Hz, 1H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$): δ 160.3, 157.7, 145.9, 144.2, 140.3, 137.8, 128.8, 127.7, 127.0, 126.5, 121.4, 119.0, 117.8, 117.7, 116.9.

Procedure C: A oven-dried 15 mL Schlenk tube was charged with a mixture of **1** (0.2 mmol), $Pd(OAc)_2$ (10 mol%), oxidant (0.60 mmol) in dioxane (1.0 mL) and was stirred at room temperature for 12-16 h. After the reaction was complete (as determined by TLC analysis), the reaction was cooled to room temperature and 10 mL of water was added. Then, the mixture was extracted with ethyl acetate (10 mL × 3). The combined organic layers were washed with saturated brine and dried by anhydrous Na_2SO_4. The solvent was evaporated under reduced pressure, and the residue was purified on a silica gel column (petroleum ether/ethyl acetate = 4:1) to afford the targeted products **7a-7r**.

(5-bromoquinolin-8-yl)methyl 4-methylbenzenesulfonate (7a)

Yield: 79% (62.0 mg), Mp 114-116 °C, White solid, R_f = 0.50 (petroleum ether / ethyl acetate = 4:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.85 (d, *J* = 4.2 Hz, 1H), 8.52 (d, *J* = 8.4 Hz, 1H), 7.83 (t, *J* = 8.4 Hz, 3H), 7.67 (d, *J* = 7.8 Hz, 1H), 7.55-7.50 (m, 1H), 7.31 (d, *J* = 8.1 Hz, 2H), 5.78 (s, 2H), 2.44 (s, 3H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 150.4, 146.1, 144.7, 135.6, 133.2, 132.2, 130.0, 129.7, 128.9, 128.1, 127.3, 122.6, 122.5, 68.2, 21.6; IR (KBr): *v* 3087, 2920, 2853, 1586, 1491, 1459, 1439, 1295, 1200,

1120, 871, 813, 778, 759; HRMS (ESI-TOF) m/z: $[M+Na]^+$ Calcd for $C_{17}H_{14}BrNO_3SNa$ 413.9770, Found 413.9766.

(5-fluoroquinolin-8-yl)methyl 4-methylbenzenesulfonate (7b)

Yield: 40% (26.5 mg), Colorless oil, R_f = 0.50 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.88 (s, 1H), 8.41 (d, *J* = 8.1 Hz, 1H), 7.85 (d, *J* = 7.8 Hz, 2H), 7.75 (t, *J* = 6.9 Hz, 1H), 7.50-7.46 (m, 1H), 7.30 (t, *J* = 4.8 Hz, 2H), 7.20 (t, *J* = 8.7 Hz, 1H), 5.76 (s, 2H), 2.44 (s, 3H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$): δ 158.1 (d, J_{CF} = 255.8 Hz), 150.7, 146.2, 144.6, 133.5, 129.6, 129.5, 129.2, 129.1, 128.1, 121.5, 118.9, 109.8, 109.7, 68.1, 21.6; IR (KBr): *v* 2922, 2850, 1556, 1491, 1477, 1409, 1205, 1180, 1122, 871, 843, 816, 786; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{17}H_{15}FNO_3S$ 332.0751, Found 332.0745.

(5-chloroquinolin-8-yl)methyl 4-methylbenzenesulfonate (7c)

Yield: 59% (41.0 mg), Pale yellow oil, R_f = 0.50 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.87 (t, *J* = 2.7 Hz, 1H), 8.55 (t, *J* = 7.2 Hz, 1H), 7.84 (d, *J* = 8.1 Hz, 2H), 7.73 (d, *J* = 7.8 Hz, 1H), 7.60 (d, *J* = 7.8 Hz, 1H), 7.55-7.50 (m, 1H), 7.31 (d, *J* = 8.1 Hz, 2H), 5.78 (s, 2H), 2.44 (s, 3H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$): δ 150.3, 146.0, 144.7, 133.3, 133.0, 132.0, 131.4, 129.7, 128.5, 128.1, 126.2, 126.0, 122.2, 68.2, 21.6; IR (KBr): *v* 3092, 2920, 2853, 1591, 1571, 1496, 1449, 1290, 1172, 1120, 858, 826, 778, 731; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{17}H_{15}ClNO_3S$ 348.0456, Found 348.0452.

(5-iodoquinolin-8-yl)methyl 4-methylbenzenesulfonate (7d)

Yield: 61% (53.6 mg), Pale yellow oil, R_f = 0.50 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.84 (d, *J* = 2.7 Hz, 1H), 8.39 (d, *J* = 8.7 Hz, 1H), 8.11 (d, *J* = 7.8 Hz, 1H), 7.83 (d, *J* = 8.1 Hz, 2H), 7.55-7.49 (m, 2H), 7.29 (d, *J* = 7.5 Hz, 2H), 5.78 (s, 2H), 2.43 (s, 3H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$): δ 150.3, 144.7, 141.2, 137.6, 133.3, 133.0, 129.9, 129.7, 128.9, 128.0, 126.1, 123.0, 99.1, 68.0, 21.6; IR (KBr): *v* 3090, 2918, 2850, 1594, 1559, 1494, 1447, 1290, 1165, 1120, 861, 811, 778, 719; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{17}H_{15}INO_3S$ 439.9812, Found 439.9808.

(5-nitroquinolin-8-yl)methyl 4-methylbenzenesulfonate (7e)

Yield: 84% (60.2 mg), Mp 94-96 °C, Yellow solid, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, $CDCl_3$): δ 9.00-8.94 (m, 2H), 8.36 (d, *J* = 8.1 Hz, 1H), 7.94-7.88 (m, 3H), 7.69-7.64 (m, 1H), 7.36 (d, *J* = 8.1 Hz, 2H), 5.86 (s, 2H), 2.46 (s, 3H); $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 150.7, 145.2, 144.9, 140.1, 132.8, 132.2, 129.9, 128.1, 125.4, 124.3, 124.2, 120.7, 67.9, 21.7; IR (KBr): *v* 3104, 2922, 2853, 1594, 1521, 1504, 1442, 1245, 1192, 1170, 1157, 858, 811, 778, 731; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{17}H_{15}N_2O_5S$ 359.0696, Found 359.0699.

(6-fluoroquinolin-8-yl)methyl 4-methylbenzenesulfonate (7f)

Yield: 72% (47.7 mg), Mp 103-104 °C, White solid, R_f = 0.50 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.79 (t, *J* = 2.1 Hz, 1H), 8.09 (d, *J* = 8.4 Hz, 1H), 7.89 (d, *J* = 8.1 Hz,

2H), 7.60 (d, J = 8.1 Hz, 1H), 7.45-7.33 (m, 4H), 5.81 (s, 2H), 2.45 (s, 3H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$): δ 160.0 (d, J_{CF} = 247.3 Hz), 148.9, 144.9, 142.5, 135.5, 135.4, 133.1, 129.8, 128.8, 128.7, 128.1, 122.2, 118.4, 118.2, 110.9, 110.8, 67.7, 21.6; IR (KBr): v 3065, 2925, 2853, 1594, 1561, 1499, 1447, 1290, 1172, 1127, 878, 813, 783, 761; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{17}H_{15}FNO_3S$ 332.0751, Found 332.0750.

(6-chloroquinolin-8-yl)methyl 4-methylbenzenesulfonate (7g)

Yield: 66% (45.9 mg), Mp 123-124 °C, Pale yellow solid, R_f = 0.50 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.83 (d, J = 2.4 Hz, 1H), 8.06 (d, J = 8.1 Hz, 1H), 7.88 (d, J = 8.1 Hz, 2H), 7.74 (d, J =12.9 Hz, 2H), 7.47-7.42 (m, 1H), 7.34 (d, J = 7.8 Hz, 2H), 5.79 (s, 2H), 2.45 (s, 3H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$): δ 149.9, 144.8, 143.8, 135.2, 134.3, 133.2, 132.2, 129.8, 128.9, 128.6, 128.1, 126.7, 122.3, 67.7, 21.6; IR (KBr): v 3060, 2925, 2853, 1591, 1559, 1491, 1442, 1240, 1212, 1120, 873, 816, 783, 751; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{17}H_{14}ClNO_3S$ 348.0456, Found 348.0459.

(6-bromoquinolin-8-yl)methyl 4-methylbenzenesulfonate (7h)

Yield: 57% (44.7 mg), Mp 137-138 °C, White solid, R_f = 0.50 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.84 (t, J = 2.4 Hz, 1H), 8.05 (d, J = 8.4 Hz, 1H), 7.94 (s, 1H), 7.85 (t, J = 10.2 Hz, 3H), 7.46-7.42 (m, 1H), 7.33 (d, J = 8.1 Hz, 2H), 5.79 (s, 2H), 2.45 (s, 3H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$): δ 150.0, 144.8, 144.1, 135.1, 134.3, 133.2, 131.4, 130.2, 129.8, 129.1, 128.1, 122.3, 120.2, 67.6, 21.6; IR (KBr): v 3065, 2918, 2848, 1596, 1584, 1494, 1449, 1292, 1232, 1182, 1135, 861, 811, 783, 749; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{17}H_{15}BrNO_3S$ 391.9951, Found 391.9947.

(6-nitroquinolin-8-yl)methyl 4-methylbenzenesulfonate (7i)

Yield: 75% (53.8 mg), Mp 140-141 °C, Yellow solid, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, $CDCl_3$): δ 9.04 (d, J = 2.4 Hz, 1H), 8.76 (d, J = 2.1 Hz, 1H), 8.50 (s, 1H), 8.37 (d, J = 8.1 Hz, 1H), 7.91 (d, J = 8.4 Hz, 2H), 7.64-7.59 (m, 1H), 7.36 (d, J = 8.1 Hz, 2H), 5.86 (s, 2H), 2.46 (s, 3H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$): δ 153.1, 147.3, 145.2, 145.1, 138.0, 135.2, 133.0, 129.9, 128.1, 126.9, 124.6, 123.2, 121.3, 67.3, 21.6; IR (KBr): v 3097, 2922, 2848, 1591, 1534, 1491, 1444, 1240, 1210, 1180, 1137, 881, 846, 788, 741; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{17}H_{15}N_2O_5S$ 359.0696, Found 359.0702.

(5-nitroquinolin-8-yl)methyl 4-nitrobenzenesulfonate (7j)

Yield: 42% (32.7 mg), Mp 130-132 °C, Yellow solid, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, $CDCl_3$): δ 9.00 (d, J = 8.7 Hz, 1H), 8.93 (d, J = 2.4 Hz, 1H), 8.41 (d, J = 9.0 Hz, 3H), 8.22 (d, J = 8.7 Hz, 2H), 7.96 (d, J = 8.1 Hz, 1H), 7.71-7.67 (m, 1H), 5.96 (s, 2H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$): δ 150.9, 145.8, 145.1, 141.6, 138.8, 132.4, 129.5, 126.1, 124.5, 124.4, 124.1, 120.8, 68.9; IR (KBr): v 3104, 2920, 2850, 1546, 1519, 1496, 1437, 1240, 1177, 1152, 1108, 871, 856, 811, 739; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{16}H_{12}N_3O_7S$ 390.0390, Found 390.0394.

(5-nitroquinolin-8-yl)methyl 4-chlorobenzenesulfonate (7k)

Yield: 68% (51.5 mg), Mp 98-100 °C, Yellow solid, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.01 (d, *J* = 8.7 Hz, 1H), 8.94 (d, *J* = 3.6 Hz, 1H), 8.38 (d, *J* = 7.8 Hz, 1H), 7.95 (d, *J* = 8.4 Hz, 3H), 7.70-7.66 (m, 1H), 7.55 (d, *J* = 8.4 Hz, 2H), 5.89 (s, 2H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$): δ 150.8, 145.5, 145.0, 140.8, 139.5, 134.3, 132.3, 125.7, 124.3, 124.2, 120.8, 68.3; IR (KBr): *v* 3095, 2925, 2853, 1589, 1531, 1496, 1439, 1280, 1185, 1160, 1115, 861, 831, 801, 756; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{16}H_{12}ClN_2O_5S$ 379.0150, Found 379.0150.

(5-nitroquinolin-8-yl)methyl benzenesulfonate (7l)

Yield: 61% (42.0 mg), Yellow oil, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.01 (d, *J* = 8.7 Hz, 1H), 8.94 (t, *J* = 2.4 Hz, 1H), 8.37 (d, *J* = 8.1 Hz, 1H), 8.02 (d, *J* = 7.5 Hz, 2H), 7.94 (d, *J* = 7.8 Hz, 1H), 7.68 (t, *J* = 6.0 Hz, 2H), 7.58 (t, *J* = 7.8 Hz, 2H), 5.90 (s, 2H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$): δ 150.7, 145.3, 145.0, 139.9, 135.9, 134.0, 132.3, 129.3, 128.1, 125.5, 124.3, 124.2, 120.7, 68.1; IR (KBr): *v* 3107, 2920, 2848, 1589, 1519, 1501, 1447, 1245, 1185, 1157, 848, 801, 759, 734; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{16}H_{13}N_2O_5S$ 345.0540, Found 345.0540.

(5-nitroquinolin-8-yl)methyl methanesulfonate (7m)

Yield: 54% (30.5 mg), Mp 130-132 °C, Yellow solid, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.05 (t, *J* = 8.7 Hz, 2H), 8.42 (d, *J* = 7.8 Hz, 1H), 8.00 (d, *J* = 7.5 Hz, 1H), 7.75-7.70 (m, 1H), 6.05 (s, 2H), 3.20 (s, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$): δ 151.0, 145.6, 145.3, 139.7, 132.4, 126.1, 124.3, 120.9, 67.6, 37.8; IR (KBr): *v* 3012, 2920, 2848, 1591, 1516, 1464, 1409, 1260, 1160, 866, 803, 776, 724; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{11}H_{11}N_2O_5S$ 283.0383, Found 283.0383.

(5-nitroquinolin-8-yl)methyl (7,7-dimethyl-2-oxobicyclo[2.2.1]heptan-1-yl)methanesulfonate (7n)

Yield: 65% (54.4 mg), Mp 116-118 °C, Yellow solid, R_f = 0.40 (petroleum ether / ethyl acetate = 4:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.05 (t, *J* = 5.4 Hz, 2H), 8.43 (d, *J* = 8.1 Hz, 1H), 8.00 (d, *J* = 8.1 Hz, 1H), 7.74-7.70 (m, 1H), 6.13 (s, 2H), 3.85 (d, *J* = 15.0 Hz, 1H), 3.19 (d, *J* = 15.0 Hz, 1H), 2.61-2.52 (m, 1H), 2.43 (d, *J* = 18.6 Hz, 1H), 2.17-2.07 (m, 2H), 1.99 (d, *J* = 18.6 Hz, 1H), 1.80-1.71 (m, 1H), 1.53-1.44 (m, 1H), 1.16 (s, 3H), 0.93 (s, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$): δ 214.5, 150.9, 145.4, 145.2, 140.3, 132.3, 125.9, 124.4, 124.3, 120.8, 68.2, 58.1, 48.1, 47.4, 42.8, 42.5, 26.9, 25.0, 19.8, 19.7; IR (KBr): *v* 3102, 2947, 2918, 2848, 1587, 1519, 1452, 1409, 1245, 1167, 1152, 1130, 836, 813, 793, 741; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{20}H_{23}N_2O_6S$ 419.1271, Found 419.1284.

(5-bromoquinolin-8-yl)methyl benzenesulfonate (7o)

Yield: 41% (31.0 mg), Mp 98-99 °C, White solid, R_f = 0.50 (petroleum ether / ethyl acetate = 4:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.84 (d, *J* = 2.7 Hz, 1H), 8.52 (d, *J* = 8.4 Hz, 1H), 7.97 (d, *J* = 7.5 Hz, 2H), 7.82 (d, *J* = 7.8 Hz, 1H), 7.68-7.61 (m, 2H), 7.55-7.50 (m, 3H), 5.81 (s, 2H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$): δ 150.4, 146.1, 136.3, 135.7, 133.7, 132.0, 129.9, 129.1, 129.0, 128.0, 127.4, 122.8, 122.6, 68.4; IR (KBr): *v* 3060, 2922, 2848, 1586, 1571, 1491, 1444, 1230, 1192, 1175, 853, 826, 759, 736;

HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{16}H_{13}BrNO_3S$ 377.9794, Found 377.9791.

(5-bromoquinolin-8-yl)methyl methanesulfonate (7p)

Yield: 56% (35.4 mg), Mp 94-96 °C, White solid, R_f = 0.50 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.97 (d, *J* = 2.1 Hz, 1H), 8.60 (d, *J* = 8.4 Hz, 1H), 7.89 (d, *J* = 7.8 Hz, 1H), 7.75 (d, *J* = 7.5 Hz, 1H), 7.61-7.57 (m, 1H), 5.94 (s, 2H), 3.15 (s, 3H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$): δ 150.7, 146.4, 135.9, 131.9, 130.1, 129.9, 127.6, 123.3, 122.7, 68.1, 37.8; IR (KBr): *v* 3007, 2930, 2850, 1569, 1491, 1444, 1422, 1262, 1197, 1165, 866, 821, 776, 721; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{11}H_{11}BrNO_3S$ 315.9638, Found 315.9642.

(5-bromoquinolin-8-yl)methyl (7,7-dimethyl-2-oxobicyclo[2.2.1]heptan-1-yl)methanesulfonate (7q)

Yield: 57% (51.6 mg), Mp 108-110 °C, White solid, R_f = 0.50 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.97 (s, 1H), 8.58 (d, *J* = 8.4 Hz, 1H), 7.88 (d, *J* = 7.5 Hz, 1H), 7.75 (d, *J* = 6.9 Hz, 1H), 7.58 (d, *J* = 4.2 Hz, 1H), 6.00 (t, *J* = 12.3 Hz, 2H), 3.85 (d, *J* = 15.0 Hz, 1H), 3.16 (d, *J* = 15.0 Hz, 1H), 2.57-2.38 (m, 2H), 2.13-1.93 (m, 3H), 1.80-1.71 (m, 1H), 1.46 (d, *J* = 8.7 Hz, 1H), 1.13 (s, 3H), 0.90 (s, 3H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$): δ 214.5, 150.7, 146.4, 135.8, 132.3, 130.1, 129.7, 127.6, 123.1, 122.7, 68.3, 58.1, 48.0, 47.3, 42.8, 42.5, 26.9, 25.0, 19.9, 19.7; IR (KBr): *v* 3080, 2952, 2915, 1571, 1494, 1452, 1407, 1227, 1170, 1147, 1113, 846, 788, 754; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{20}H_{23}BrNO_4S$ 452.0526, Found 452.0521.

(5-bromoquinolin-8-yl)methyl 4-chlorobenzenesulfonate (7r)

Yield: 22% (18.2 mg), Colorless oil, R_f = 0.50 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.84 (d, *J* = 3.3 Hz, 1H), 8.54 (d, *J* = 8.4 Hz, 1H), 7.89-7.82 (m, 3H), 7.67 (d, *J* = 7.5 Hz, 1H), 7.56-7.52 (m, 1H), 7.48 (d, *J* = 8.1 Hz, 2H), 5.81 (s, 2H); $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 150.5, 140.3, 135.8, 134.8, 131.6, 129.9, 129.4, 129.3, 127.4, 123.1, 122.6, 68.7; IR (KBr): *v* 3090, 2922, 2848, 1586, 1559, 1494, 1474, 1297, 1227, 1170, 1120, 828, 778, 754, 706; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{16}H_{12}BrClNO_3S$ 411.9404, Found 411.9406.

Procedure D: A oven-dried 15 mL Schlenk tube was charged with a mixture of **1** (0.2 mmol), $Pd(OAc)_2$ (10 mol%), oxidant (0.60 mmol) in dioxane (1.0 mL) and was stirred at room temperature for 12-16 h. After the reaction was complete (as determined by TLC analysis), the reaction was cooled to room temperature and 10 mL of water was added. Then, the mixture was extracted with ethyl acetate (10 mL × 3). The combined organic layers were washed with saturated brine and dried by anhydrous Na_2SO_4. The solvent was evaporated under reduced pressure, and the residue was purified on a silica gel column (petroleum ether/ethyl acetate = 4:1) to afford the targeted products **8a**-**8g**.

(5-bromoquinolin-8-yl)methanol (8a)

Yield: 69% (32.9 mg), Mp 113-115 °C, Pale yellow solid, R_f = 0.30 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.91 (d, *J* = 4.2 Hz, 1H), 8.60 (d, *J* = 8.4 Hz, 1H), 7.80 (d, *J* = 7.8 Hz, 1H), 7.59-7.55 (m, 1H), 7.49 (d, *J* = 7.8 Hz, 1H), 5.17 (s, 2H), 4.76 (br s, 1H); $^{13}C\{^1H\}$ NMR (75

MHz, $CDCl_3$): δ 149.7, 147.7, 138.3, 136.3, 130.1, 128.1, 127.8, 122.3, 121.3, 64.2; IR (KBr): *v* 3361, 3055, 2920, 2850, 1559, 1494, 1467, 1429, 1287, 1247, 1147, 1113, 876, 831, 778, 729; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{10}H_9BrNO$ 237.9862, Found 237.9872.

Quinolin-8-ylmethanol (8b)

Yield: 46% (14.6 mg), Mp 68-70 °C, Yellow solid, R_f = 0.30 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, DMSO): δ 8.89 (d, *J* = 4.2 Hz, 1H), 8.36 (d, *J* = 8.1 Hz, 1H), 7.84 (t, *J* = 7.5 Hz, 2H), 7.63-7.53 (m, 2H), 5.17 (s, 2H); $^{13}C\{^1H\}$ NMR (75 MHz, DMSO): δ 149.9, 145.3, 140.3, 136.9, 127.9, 126.9, 126.8, 126.6, 121.8, 60.0; IR (KBr): *v* 3299, 2920, 2868, 1594, 1576, 1499, 1447, 1295, 1232, 1757, 1127, 866, 821, 783, 759; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{10}H_{10}NO$ 160.0757, Found 160.0754.

(5-methylquinolin-8-yl)methanol (8c)

Yield: 49% (17.0 mg), Pale yellow oil, R_f = 0.30 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.88 (d, *J* = 4.2 Hz, 1H), 8.37 (d, *J* = 8.4 Hz, 1H), 7.50-7.46 (m, 2H), 7.32 (d, *J* = 7.2 Hz, 1H), 5.17 (s, 2H), 2.68 (s, 3H); $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 148.5, 147.4, 136.1, 134.2, 133.3, 127.9, 127.5, 126.7, 120.7, 64.8, 18.5; IR (KBr): *v* 3366, 3207, 2963, 2918, 2850, 1599, 1501, 1457, 1409, 1292, 1235, 1210, 1152, 838, 811, 776, 709; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{11}H_{12}NO$ 174.0913, Found 174.0915.

(6-methylquinolin-8-yl)methanol (8d)

Yield: 68% (23.6 mg), Pale yellow oil, R_f = 0.30 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.81 (d, *J* = 4.2 Hz, 1H), 8.12 (d, *J* = 8.4 Hz, 1H), 7.53 (s, 1H), 7.44-7.40 (m, 2H), 5.19 (s, 2H), 2.53 (s, 3H); $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 148.1, 145.8, 137.7, 136.3, 136.1, 130.1, 128.7, 126.0, 121.2, 64.8, 21.5; IR (KBr): *v* 3361, 3259, 2920, 2848, 1584, 1494, 1467, 1439, 1247, 1205, 1120, 881, 856, 776, 701; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{11}H_{12}NO$ 174.0913, Found 174.0912.

(7-methylquinolin-8-yl)methanol (8e)

Yield: 35% (12.1 mg), Yellow oil, R_f = 0.30 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.82 (d, *J* = 3.9 Hz, 1H), 8.13 (d, *J* = 8.4 Hz, 1H), 7.64 (d, *J* = 8.4 Hz, 1H), 7.39-7.35 (m, 2H), 5.28 (s, 2H), 2.56 (s, 3H); $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 148.6, 147.6, 136.8, 136.5, 134.8, 130.2, 127.0, 126.6, 120.2, 60.5, 19.6; IR (KBr): *v* 3426, 2957, 2918, 2850, 1596, 1556, 1504, 1457, 1270, 1180, 1122, 896, 873, 836, 798; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{11}H_{12}NO$ 174.0913, Found 174.0911.

(3-ethylquinolin-8-yl)methanol (8f)

Yield: 46% (17.2 mg), Yellow oil, R_f = 0.30 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.76 (d, *J* = 2.4 Hz, 1H), 7.97 (d, *J* = 1.8 Hz, 1H), 7.72 (d, *J* = 8.4 Hz, 1H), 7.54-7.44 (m, 2H), 5.21 (s, 2H), 2.90-2.83 (m, 2H), 1.37 (t, *J* = 7.5 Hz, 3H); $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ

150.4, 145.6, 137.8, 136.8, 134.2, 128.5, 127.0, 126.8, 126.4, 64.8, 26.3, 15.2; IR (KBr): *v* 3414, 2965, 2922, 2850, 1584, 1494, 1457, 1419, 1247, 1177, 1155, 893, 871, 768, 716; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{12}H_{14}NO$ 188.1070, Found 188.1066.

1-(quinolin-8-yl)ethan-1-ol (8g)

Yield: 51% (17.7 mg), Yellow oil, R_f = 0.30 (petroleum ether / ethyl acetate = 4:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.87 (d, *J* = 4.2 Hz, 1H), 8.21 (d, *J* = 8.4 Hz, 1H), 7.75 (d, *J* = 7.8 Hz, 1H), 7.60 (d, *J* = 6.3 Hz, 1H), 7.51 (t, *J* = 7.8 Hz, 1H), 7.47-7.42 (m, 1H), 6.20 (br s, 1H), 5.52-5.45 (m, 1H), 1.76 (d, *J* = 6.6 Hz, 3H); $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 148.4, 146.5, 141.8, 137.1, 128.7, 127.1, 126.4, 120.9, 70.2, 24.1; IR (KBr): *v* 3416, 2967, 2922, 2848, 1596, 1576, 1496, 1447, 1277, 1237, 1162, 1113, 876, 826, 791, 761; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{11}H_{12}NO$ 174.0913, Found 174.0916.

Procedure E: A 15 mL Schlenk tube was charged with a mixture of **5** (0.2 mmol), $Pd(OAc)_2$ (10 mol%), ligand (0.04 mmol), sulphonate hypervalent-iodine (0.6 mmol), AgOAc (0.1 mmol) in toluene (1.0 mL) and was stirred in a 100 °C oil-bath for 12-18 h. After the reaction was complete (as determined by TLC analysis), the reaction was cooled to room temperature and 10 mL of water was added. Then, the mixture was extracted with ethyl acetate (10 mL × 3). The combined organic layers were washed with saturated brine and dried by anhydrous Na_2SO_4. The solvent was evaporated under reduced pressure, and the residue was purified on a silica gel column (petroleum ether/ethyl acetate = 8:1) to afford the targeted product **9a-9h**.

2-([1,1'-biphenyl]-2-yl)pyridine (9a) [16]

Yield: 63% (29.1 mg), Mp 73-75 °C, Yellow solid, R_f = 0.40 (petroleum ether/ethyl acetate = 8:1); ^1H NMR (300 MHz, DMSO): δ 8.55 (d, *J* = 4.8 Hz, 1H), 7.61-7.48 (m, 4H), 7.44-7.41 (m, 1H), 7.26-7.20 (m, 4H), 7.09 (t, *J* = 4.8 Hz, 2H), 6.94 (d, *J* = 7.8 Hz, 1H); $^{13}C\{^1H\}$ NMR (75 MHz, DMSO): δ 159.1, 149.7, 141.3, 140.6, 139.7, 136.1, 130.9, 130.8, 129.7, 129.0, 128.6, 128.0, 127.2, 125.3, 122.2; HRMS (ESI): Exact mass calcd for $C_{17}H_{13}N$ $[M+H]^+$, 232.1121; Found: 232.1127.

2-(4-methyl-[1,1'-biphenyl]-2-yl)pyridine (9b) [16]

Yield: 44% (21.6 mg), Pale yellow oil, R_f = 0.40 (petroleum ether/ethyl acetate = 8:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.66 (d, *J* = 4.5 Hz, 1H), 7.55 (s, 1H), 7.41-7.34 (m, 2H), 7.31-7.23 (m, 4H), 7.17-7.09 (m, 3H), 6.88 (d, *J* = 7.8 Hz, 1H), 2.47 (s, 3H); $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 159.4, 149.4, 141.3, 139.2, 137.8, 137.4, 135.2, 131.1, 130.5, 129.7, 129.3, 128.0, 126.5, 125.5, 121.3, 21.1; HRMS (ESI): Exact mass calcd for $C_{18}H_{15}N$ $[M+H]^+$, 246.1277; Found: 246.1280.

2-(5-methyl-[1,1'-biphenyl]-2-yl)pyridine (9c) [16]

Yield: 50% (24.5 mg), Pale yellow oil, R_f = 0.40 (petroleum ether/ethyl acetate = 8:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.65-8.63 (m, 1H), 7.64 (d, *J* = 7.8 Hz, 1H), 7.41-7.35 (m, 1H), 7.32-7.24 (m, 5H), 7.20-7.16 (m, 2H), 7.12-7.07 (m, 1H), 6.88 (t, *J* = 8.4 Hz, 1H), 2.47 (s, 3H); $^{13}C\{^1H\}$ NMR (75 MHz,

$CDCl_3$): δ 159.2, 149.4, 141.5, 140.5, 138.4, 136.7, 135.1, 131.3, 130.5, 129.7, 129.6, 128.4, 128.0, 127.6, 126.6, 125.4, 121.1, 21.2; HRMS (ESI): Exact mass calcd for $C_{18}H_{15}N$ $[M+H]^+$, 246.1277; Found: 246.1286.

2-(5-methoxy-[1,1'-biphenyl]-2-yl)pyridine (9d) [16]

Yield: 39% (20.4 mg), Pale yellow oil, R_f = 0.40 (petroleum ether/ethyl acetate = 8:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.63-8.61 (m, 1H), 7.68 (d, *J* = 8.4 Hz, 1H), 7.39-7.33 (m, 1H), 7.28-7.25 (m, 3H), 7.21-7.16 (m, 2H), 7.10-7.02 (m, 2H), 6.98 (d, *J* = 2.7 Hz, 1H), 6.83 (d, *J* = 7.8 Hz, 1H), 3.90 (s, 3H); $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 159.7, 158.9, 149.3, 142.0, 141.4, 135.1, 132.3, 131.9, 129.6, 129.5, 128.1, 127.6, 126.9, 125.4, 120.9, 115.7, 113.3, 55.4; HRMS (ESI): Exact mass calcd for $C_{18}H_{15}NO$ $[M+H]^+$, 262.1236; Found: 262.1238.

2-([1,1'-biphenyl]-2-yl)-3-methylpyridine (9e) [16]

Yield: 36% (17.7 mg), Yellow oil, R_f = 0.40 (petroleum ether/ethyl acetate = 8:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.51 (d, *J* = 4.5 Hz, 1H), 7.50-7.40 (m, 4H), 7.33-7.30 (m, 1H), 7.19-7.10 (m, 6H), 1.77 (s, 3H); $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 159.5, 146.5, 141.1, 140.7, 139.4, 137.5, 131.7, 129.9, 129.7, 129.3, 128.4, 127.8, 127.4, 126.6, 122.1, 18.8; HRMS (ESI): Exact mass calcd for $C_{18}H_{15}N$ $[M+H]^+$, 246.1277; Found: 246.1282.

2-(4'-methyl-[1,1'-biphenyl]-2-yl)pyridine (9f) [16]

Yield: 40% (19.6 mg), Pale yellow oil, R_f = 0.40 (petroleum ether/ethyl acetate = 8:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.66 (d, *J* = 5.1 Hz, 1H), 7.72-7.69 (m, 1H), 7.49-7.38 (m, 4H), 7.15-7.07 (m, 5H), 6.92 (d, *J* = 8.4 Hz, 1H), 2.34 (s, 3H); $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 149.4, 140.6, 139.4, 138.4, 136.4, 135.2, 130.5, 130.5, 129.6, 129.5, 128.8, 128.5, 128.4, 127.4, 125.4, 121.3, 21.1; HRMS (ESI): Exact mass calcd for $C_{18}H_{15}N$ $[M+H]^+$, 246.1277; Found: 246.1286.

2-(4'-(trifluoromethyl)-[1,1'-biphenyl]-2-yl)pyridine (9g) [16]

Yield: 39% (23.3 mg), Pale yellow oil, R_f = 0.40 (petroleum ether/ethyl acetate = 8:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.64-8.62 (m, 1H), 7.73-7.70 (m, 1H), 7.54-7.43 (m, 6H), 7.28 (t, *J* = 5.7 Hz, 2H), 7.18-7.13 (m, 1H), 6.95 (d, *J* = 7.8 Hz, 1H); $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 158.8, 149.5, 145.1, 139.6, 139.2, 135.6, 130.6, 130.4, 129.9, 128.7, 128.3, 125.2, 125.0, 125.0, 121.7; HRMS (ESI): Exact mass calcd for $C_{18}H_{12}F_3N$ [M+H]+, 300.0995; Found: 300.0999.

10-phenylbenzo[h]quinoline (9h) [16]

Yield: 40% (20.4 mg), Yellow oil, R_f = 0.40 (petroleum ether/ethyl acetate = 8:1); ^1H NMR (300 MHz, $CDCl_3$): δ 8.46-8.43 (m, 1H), 8.11 (d, *J* = 8.1 Hz, 1H), 7.95 (d, *J* = 8.1 Hz, 1H), 7.88 (d, *J* = 8.7 Hz, 1H), 7.73-7.68 (m, 2H), 7.57 (d, *J* = 7.2 Hz, 1H), 7.43-7.32 (m, 6H); $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 146.9, 146.8, 146.4, 141.7, 135.2, 135.0, 131.5, 129.0, 128.3, 127.9, 127.4, 127.2, 127.0, 125.9, 125.7, 121.1, 29.7; HRMS (ESI): Exact mass calcd for $C_{19}H_{13}N$ $[M+H]^+$, 256.1121; Found: 256.1124.

Genaral procedure: Synthetic applications

Path A: A oven-dried 15 mL Schlenk tube was charged with **7a** (0.2 mmol), SiO_2 (0.6 mmol) in a mixture of PE (1 mL) and EA (0.05 mL), which was stirred at room temperature for 5 h. After the reaction was complete (as determined by TLC analysis), the reaction was cooled to room temperature and 10 mL of water was added. Then, the mixture was extracted with ethyl acetate (10 mL × 3). The combined organic layers were washed with saturated brine and dried by anhydrous Na_2SO_4. The solvent was evaporated under reduced pressure, and the residue was purified on a silica gel column (petroleum ether/ethyl acetate = 2:1) to afford the corresponding product **8a**.

Yield: 87% (41.4 mg), Mp 113-115 °C, Pale yellow solid, R_f = 0.40 (petroleum ether / ethyl acetate = 2:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.91 (d, *J* = 4.2 Hz, 1H), 8.60 (d, *J* = 8.4 Hz, 1H), 7.80 (d, *J* = 7.8 Hz, 1H), 7.59-7.55 (m, 1H), 7.49 (d, *J* = 7.8 Hz, 1H), 5.17 (s, 2H), 4.76 (br s, 1H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 149.7, 147.7, 138.3, 136.3, 130.1, 128.1, 127.8, 122.3, 121.3, 64.2; IR (KBr): *v* 3361, 3055, 2920, 2850, 1559, 1494, 1467, 1429, 1287, 1247, 1147, 1113, 876, 831, 778, 729; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{10}H_9BrNO$ 237.9862, Found 237.9872.

Path B: A oven-dried 15 mL Schlenk tube was charged with a mixture of **7e** (0.2 mmol), *t*-BuCl (0.24 mmol), [pmIm]Br (0.4 mmol) and was stirred in a 60 °C oil-bath for 4 h. After the reaction was complete (as determined by TLC analysis), the reaction was cooled to room temperature and 10 mL of water was added. Then, the mixture was extracted with ethyl acetate (10 mL × 3). The combined organic layers were washed with saturated brine and dried by anhydrous Na_2SO_4. The solvent was evaporated under reduced pressure, and the residue was purified on a silica gel column (petroleum ether/ethyl acetate = 8:1) to afford the targeted product **10**.

Yield: 78% (34.7 mg), Mp 99-100 °C, Pale yellow solid, R_f = 0.40 (petroleum ether / ethyl acetate = 8:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.11 (t, *J* = 3.9 Hz, 1H), 9.03 (d, *J* = 8.7 Hz, 1H), 8.35 (d, *J* = 7.8 Hz, 1H), 7.95 (d, *J* = 8.1 Hz, 1H), 7.72-7.68 (m, 1H), 5.25 (s, 2H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 151.1, 145.5, 143.7, 132.3, 128.5, 127.6, 124.3, 124.2, 121.3, 27.9; IR (KBr): *v* 3047, 2922, 2853, 1594, 1516, 1496, 1404, 1237, 1212, 1155, 1122, 873, 831, 791, 739; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{10}H_8ClN_2O_2$ 223.0269, Found 223.0269.

Path C: A oven-dried 15 mL Schlenk tube was charged with a mixture of **7e** (0.2 mmol), *t*-BuBr (0.24 mmol), [pmIm]Br (0.4 mmol) and was sonicated in an ultrasonic bath for 0.5 h. After the reaction was complete (as determined by TLC analysis), the reaction was cooled to room temperature and 10 mL of water was added. Then, the mixture was extracted with ethyl acetate (10 mL × 3). The combined organic layers were washed with saturated brine and dried by anhydrous Na_2SO_4. The solvent was evaporated under reduced pressure, and the residue was purified on a silica gel column (petroleum ether/ethyl acetate = 8:1) to afford the corresponding product **11**.

Yield: 95% (50.7 mg), Mp 106-107 °C, Pale yellow solid, R_f = 0.40 (petroleum ether / ethyl acetate =

8:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.12 (d, *J* = 2.1 Hz, 1H), 9.03 (d, *J* = 8.7 Hz, 1H), 8.36 (d, *J* = 7.8 Hz, 1H), 7.96 (d, *J* = 7.8 Hz, 1H), 7.73-7.69 (m, 1H), 5.26 (s, 2H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 151.1, 145.5, 143.7, 132.3, 128.5, 124.3, 124.2, 121.3, 27.9; IR (KBr): *v* 2965, 2920, 2853, 1591, 1511, 1496, 1404, 1250, 1217, 1160, 876, 831, 791, 714; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{10}H_8BrN_2O_2$ 266.9764, Found 266.9756.

Path D: A oven-dried 15 mL Schlenk tube was charged with a mixture of **7e** (0.2 mmol), *t*-BuI (0.24 mmol), [pmIm]Br (0.4 mmol) and was sonicated in an ultrasonic bath for 0.5 h. After the reaction was complete (as determined by TLC analysis), the reaction was cooled to room temperature and 10 mL of water was added. Then, the mixture was extracted with ethyl acetate (10 mL × 3). The combined organic layers were washed with saturated brine and dried by anhydrous Na_2SO_4. The solvent was evaporated under reduced pressure, and the residue was purified on a silica gel column (petroleum ether/ethyl acetate = 8:1) to afford the corresponding product **12**.

Yield: 71% (44.6 mg), Mp 126-127 °C, Pale yellow solid, R_f = 0.40 (petroleum ether / ethyl acetate = 8:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.13 (d, *J* = 2.4 Hz, 1H), 9.06 (d, *J* = 8.7 Hz, 1H), 8.31 (d, *J* = 7.8 Hz, 1H), 7.92 (d, *J* = 8.1 Hz, 1H), 7.72-7.68 (m, 1H), 5.21 (s, 2H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 150.6, 145.9, 145.2, 132.2, 127.6, 124.6, 124.4, 121.6, 0.87; IR (KBr): *v* 3037, 2922, 2853, 1561, 1511, 1494, 1402, 1235, 1165, 876, 851, 833, 793; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{10}H_8IN_2O_2$ 314.9625, Found 314.9627.

Path E: A oven-dried 15 mL Schlenk tube was charged with a mixture of **7e** (0.2 mmol), $AgNO_3$ (0.4 mmol) in *t*-AmOH (1 mL) and was stirred in a 120 °C oil-bath for 6 h. After the reaction was complete (as determined by TLC analysis), the reaction was cooled to room temperature and 10 mL of water was added. Then, the mixture was extracted with ethyl acetate (10 mL × 3). The combined organic layers were washed with saturated brine and dried by anhydrous Na_2SO_4. The solvent was evaporated under reduced pressure, and the residue was purified on a silica gel column (petroleum ether/ethyl acetate = 8:1) to afford the corresponding product **13**.

Yield: 51% (23.8 mg), Yellow oil, R_f = 0.40 (petroleum ether / ethyl acetate = 8:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.05 (d, *J* = 9.0 Hz, 2H), 8.40 (d, *J* = 8.1 Hz, 1H), 7.88 (d, *J* = 7.8 Hz, 1H), 7.75-7.71 (m, 1H), 6.28 (s, 2H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 151.2, 145.6, 138.7, 132.3, 126.1, 124.4, 124.1, 121.1, 70.2; IR (KBr): *v* 3104, 2913, 2850, 1594, 1516, 1499, 1402, 1277, 1232, 1190, 1157, 858, 833, 806, 778, 736; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{10}H_8N_3O_4$ 234.0509, Found 234.0511.

Path F: To a solution of sodium azide (0.30 mmol) in water (1 mL) in a two necked round bottom flask equipped with a stirring bar and reflux condenser was added a solution of **7e** (0.20 mmol) in THF (0.2 mL) and the mixture was heated to reflux in an oil-bath for 3 h. After the reaction was complete (as determined by TLC analysis), the reaction was cooled to room temperature and 10 mL of water was

added. Then, the mixture was extracted with ethyl acetate (10 mL × 3). The combined organic layers were washed with saturated brine and dried by anhydrous Na_2SO_4. The solvent was evaporated under reduced pressure, and the residue was purified on a silica gel column (petroleum ether/ethyl acetate = 8:1) to afford the corresponding product **14**.

Yield: 94% (43.1 mg), Mp 93-94 °C, Yellow solid, R_f = 0.40 (petroleum ether / ethyl acetate = 8:1); ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.05 (t, *J* = 5.1 Hz, 2H), 8.40 (d, *J* = 8.1 Hz, 1H), 7.88 (d, *J* = 7.8 Hz, 1H), 7.72-7.68 (m, 1H), 5.19 (s, 2H); ^{13}C{^{1}H} NMR (75 MHz, $CDCl_3$): δ 150.9, 145.8, 145.2, 142.1, 132.3, 126.3, 124.4, 124.2, 121.1, 51.1; IR (KBr): *v* 3047, 2922, 2853, 1594, 1519, 1501, 1432, 1282, 1195, 1162, 1130, 878, 846, 803, 776; HRMS (ESI-TOF) m/z: $[M+H]^+$ Calcd for $C_{10}H_8N_5O_2$ 230.0673, Found 230.0676.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.xxxxxx.

^{1}H and ^{13}C spectra for **3a-3m**, **4a-4l**, **6a-6f**, **7a-7r**, **8a-8g**, **9a-9h**, **10-14** and ^{31}P spectra for **3a-3m**, **4a-4l** (pdf)

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Notes

The authors declare no competing financial interests.

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