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Catalytic Formation of Ketones from Unactivated Esters through Rhodium Chelation-Assisted C−O Bond Activation

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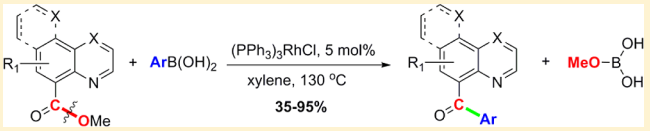
Supporting Information

ABSTRACT: A new method for building aryl aryl ketones containing heterocyclic rings through chelation-assisted C−O bond activation catalyzed by a rhodium complex has been developed. In this reaction, methyl quinoline-8-carboxylate, methyl quinoxaline-5-carboxylate, and their derivatives were reacted with an excess amount of a substituted phenyl boronic acid in the presence of a rhodium(I) complex to give substituted phenyl(quinolin-8-yl)methanone, phenylquinoxalin-5-ylmethanone, and their derivatives in medium to high yields. The current method offers a highly favorable synthetic pathway to efficiently build related drugs with an 8-benzoylquinoline core structure. This method may prove especially valuable for medicinal chemists for the late-stage introduction of versatile ketone moieties into complex scaffolds for diversity-oriented synthetic strategies.



INTRODUCTION

Ketones are important basic building blocks in the construction of organic molecules with important applications. Many synthetic methods for the formation of aryl aryl, alkyl aryl, and alkyl alkyl ketones have been developed on the basis of transition-metal-catalyzed C−C bond formation.[1] Traditionally, the formation of ketones can be achieved by transition-metal-catalyzed coupling reactions of activated carboxylic acid derivatives with various transmetalating reagents,[2] including organocompounds of tin,[2a] boron,[2b] antimony,[2c] gold,[2d] mercury,[2e] bismuth,[2f] zinc,[2g] and magnesium.[2h] Carbonylative coupling of an aryl iodide with an organometallic species of borane,[3a] silane,[3b] tin,[3c] or aluminum is another method that is commonly used for building ketone molecules. Numerous reports on ketone formation by these two methods are available, and these approaches have been thoroughly examined. More recently, a polarity-reversed disconnection strategy has also been used for ketone formation. To date, several reports have described the cross-coupling of acyl anion equivalents with appropriate electrophiles to generate ketones. The majority of these protocols involve the direct arylation of aldehydes or activated derivatives, such as imines or hydrazones with aryl halides[4] or organometallic species,[5] or utilize vinyl ethers or their metalated analogues, thus yielding the alkyl aryl ketone upon acidic hydrolysis of the reaction product.[6] The cross-coupling of acylstannanes, -silanes, and -zirconocenes with allylic halides and esters affords β- and γ-unsaturated ketones in high yields.[7,8] Acylstannane or -zirconocene reagents have also been used in the cross-coupling halobenzenes, generating ketone products in low yields.[8] Acyltin and -zirconocene reagents couple with acyl chlorides, producing unsymmetrical α,α-diketones.[8,9] The diaryl ketone can be prepared by the palladium-catalyzed cross-coupling of acylsilanes and aryl bromide.[10] We have described a new method to generate aryl ketones by cross coupling of an alkyl or aryl ketone with arylboronic acid through rhodium-chelated C−C activations.[11]

Esters are stable compounds with high functional group tolerance. Ester compounds do not have the toxicity problems associated with tin and are more accessible and easier to handle than the corresponding acylating reagents. Several reports on the C−O activation of the esters have been published,[12,13] and numerous recent research studies have focused on biaryl compound synthesis through coupling reactions via the C−O activation of esters (Scheme 1, path a).[13] However, the use of esters in cross-coupling reactions to generate ketones is rare (Scheme 1, path b).[14] To date, only a few reports have described the cross-coupling of esters with appropriate electrophiles to generate ketones.[14a−c] For example, aryl trifluoroacetates were also found to yield ketone products by coupling reactions with boronic acids.[14a] For inactivated esters, the coupling reaction requires a chelating group to direct the metal toward C−O bond activation. For example, alkyl esters of pyridin-2-ylmethanol were found to undergo cross-coupling reactions with arylboronic acids to give high yields of alkyl aryl ketone products using ruthenium catalysts.[14b] When aryl esters of pyridin-2-ol were used as cross partners with arylboronic acids, the reaction gave aryl aryl ketones in high yields.[14c] These reactions pave the way for using esters as key building blocks for ketone construction. However, valuable activating or chelating groups in all of these reactions act as the leaving group, significantly decreasing the atomic efficiency of these reactions. Hence, the development of new methods to activate the esters to and increase the efficiency of these reactions remains a strong need. If the directing group is situated on the frame of the acidic portion of the reacting molecule, the directing group will be retained and formed as a part of the product and the atomic efficiency of the reaction will increase. However, this type

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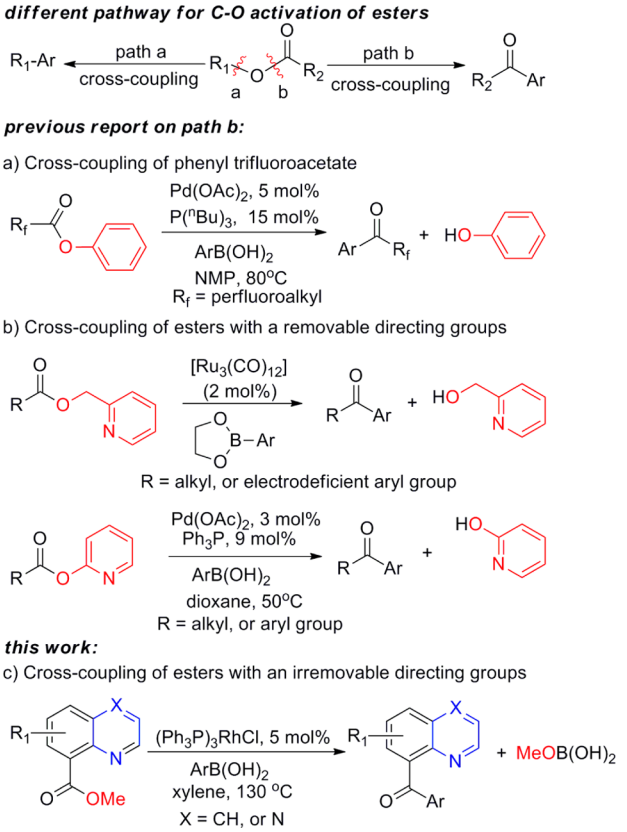
Scheme 1. Synthesis of Ketones by Cross-Coupling Reactions of Esters and Arylboronic Acids



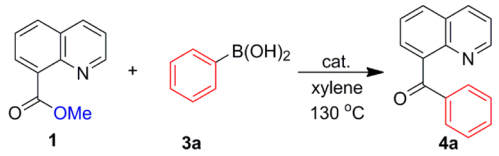
of C−O bond activation is rare. Only one report indicating that the C−O bond could be activated through a directing group properly positioned on the aryl acid portions of the reactants in the intermolecular oxyacylation reaction of alkenes is available.[15] In this study, we propose that aryl esters could undergo transmetalation reactions with transmetalating reagents such as boronic acids after the chelation-assisted activation of the C−O bond by transition metals to yield aryl ketones after an elimination reaction.

RESULTS AND DISCUSSION

To achieve this reaction, methyl quinoline-8-carboxylate (**1a**) and phenylboronic acid (**3a**) were initially used as cross-coupling partners to optimize the reaction conditions (Table 1). The reaction gave a 95% yield of the desired product **4a** when $(Ph_3P)_3RhCl$ (known as Wilkinson's catalyst) was used as the catalyst at 130 °C for 15 h. The addition of phosphine cleavage reagents,[16] such as CuCl or CuI, decreased the yield of the product. Bases commonly used in other cross-coupling reactions of arylboronic acid,[17] such as K_2CO_3, Cs_2CO_3, and K_3PO_4, were also found to decrease the reactions. Although $Pd(OAc)_2$ was found to be an active catalyst in the cross-coupled reaction of pyridin-2-yl benzoate with arylboronic acids,[15] the reaction gave very low yields when it was used as a catalyst in the coupling reaction of **1a** and **3a**. Ru and Ni complexes were completely inert for this reaction. These results clearly show the unique reactivity of the rhodium metal center for this type of C−O bond activation.

After optimizing the reaction conditions, the reactions of **1a** with various arylboronic acids containing electron-donating or electron-withdrawing groups were explored using similar

Table 1. Optimization of Reaction Conditions[a]



entry	catalyst	additive	yield (%)
1	$(Ph_3P)_3RhCl$		95
2	$(Ph_3P)_3RhCl$	CuCl	62
3	$(Ph_3P)_3RhCl$	CuI	55
4	$(Ph_3P)_3RhCl$	$CuCl_2$	10
5	$(Ph_3P)_3RhCl$	$Cu(OAc)_2$	53
6	$(Ph_3P)_3RhCl$	K_3PO_4	15
7	$(Ph_3P)_3RhCl$	K_2CO_3	75
8	$(Ph_3P)_3RhCl$	Cs_2CO_3	30
9	[Rh(COD)Cl]2		35
10[b]	$Pd(OAc)_2$		20
11[b]	$Pd(OAc)_2$	PPh_3	10
12[b]	$PdCl_2$		<5
13[b]	$PdCl_2$	PPh_3	<5
14	$Ru(PPh_3)_3Cl_2$		no reaction
15	$[Ru(COD)Cl_2]_2$		no reaction
16	$RuH_2(CO)(PPh_3)_2$		no reaction
17	$Ni(dppe)Cl_2$		no reaction

[a]Reaction conditions: **1** (0.10 mmol), **3a** (0.20 mmol), catalyst (5 mol %), xylene (0.50 mL), 130 °C, 15 h. [b]48 h.

reaction conditions, the results of which are shown in Table 2. When **1a** reacted with arylboronic acids with electron-donating groups, the corresponding products **4b−h** were obtained in high yields (72%−85%). The reaction of **1a** with 3,4-dimethoxyphenylboronic acid or 3,4,5-trimethoxyphenylboronic acid gave the desired product **4i** (53%) or **4j** (40%) in moderate yield because boronic acids possess strong electron-donating groups that are prone to oxidation under the reaction conditions. Both α- and β-naphthalene boronic acids exhibited excellent reactivity under similar reaction conditions and gave the desired products **4k** and **4l** in 87% and 91% yields, respectively, indicating that these reactions are not considerably inhibited by the steric hindrance of arylboronic acid. This result is very different from the previously reported exchange reaction of alkyl or aryl group in ketones in which the yields are significantly influenced by the steric hindrance properties of the arylboronic acids. Arylboronic acids with halide substituents remained intact in these coupling reactions. For example, arylboronic acids with a −Cl, −F, or −Br substituent at the 4-position reacted with **1a** to give **4m**, **4n**, and **4o** in 65%, 67%, and 69% yields, respectively. Arylboronic acids with a strong electron-withdrawing group at the 4-position, such as −COOEt, $-NO_2$, or $-CF_3$, gave products **4p**, **4q**, and **4r** in 82% 92%, and 88% yields, respectively. In addition, (3,4-difluorophenyl)boronic acid and (3,5-bis(trifluoromethyl)-phenyl)boronic acid also reacted smoothly with **1a** to give the desired products **4s** and **4t** in 95% and 92% yields, respectively. This indicates that strong electron-withdrawing groups in the arylboronic acids also had no effect in this reaction. However, when mesitylboronic acid, a more sterically hindered substrate, was reacted with **1a**, no product was obtained. Noting that methyl quinoxaline-5-carboxylate (**2a**) with an N atom at a suitable position may also act as a directing group, we attempted the coupling reactions of **2a** with arylboronic acids. Cross-coupling reactions of **2a** with a variety of arylboronic acids gave the desired ketone products in moderate to high yields (45%−

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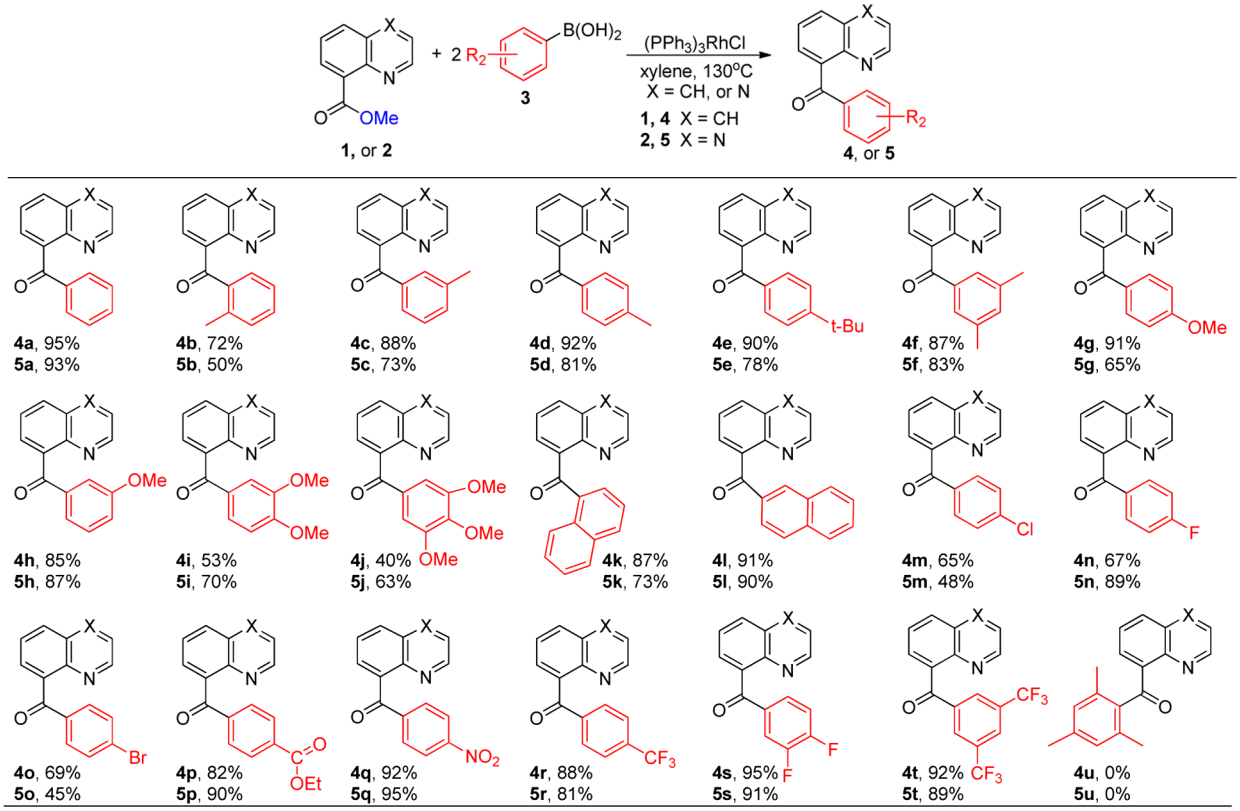
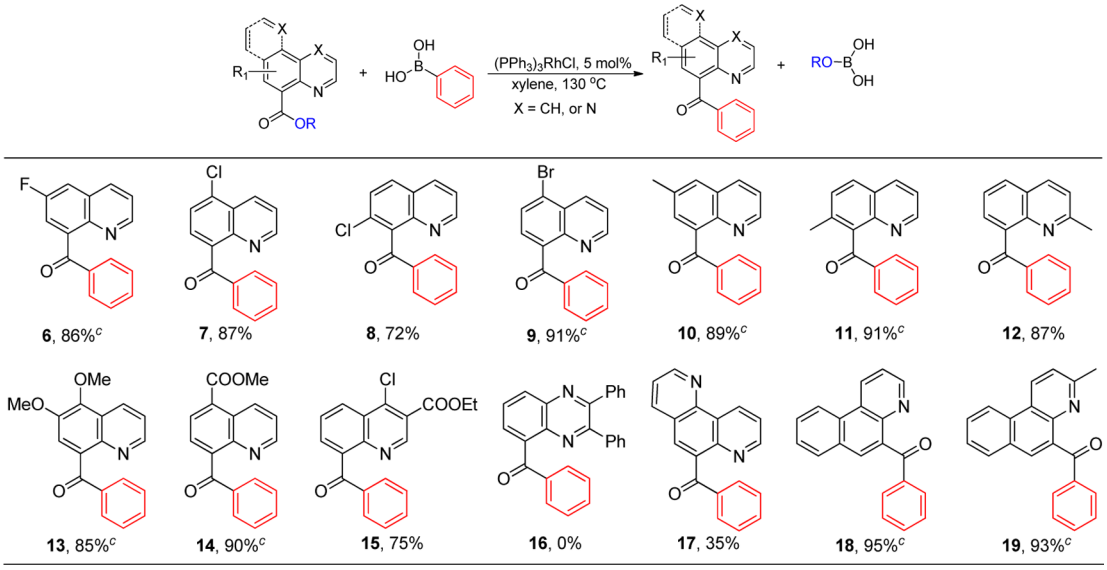
Table 2. Catalytic Coupling of Methyl Quinoline-8-carboxylate (1a) and Methyl Quinoxaline-5-carboxylate (2a) with Various Arylboronic Acids[a]



[a]Reaction conditions: **1a** or **2a** (0.10 mmol), substituted phenylboronic acid (0.20 mmol), $Rh(PPh_3)_3Cl$ (0.005 mmol), and xylene (0.5 mL), 130 °C, 15 h; [b]yields are given based on **1a** or **2a**.

Table 3. Catalytic Coupling of Quinoline-5- and Quinoxaline-5-carboxylate Derivatives with Phenylboronic Acids[a]



[a]Reaction conditions: quinoline-8-carboxylate and quinoxaline-5-carboxylate derivates (0.10 mmol), phenylboronic acid (0.20 mmol), $Rh(PPh_3)_3Cl$ (0.005 mmol), and xylene (0.5 mL), 130 °C, 15 h. [b]Yields are given based on quinoline-8-carboxylate derivates or quinoxaline-5-carboxylate derivatives. [c]Phenyl esters were used as substrates.

95%) under similar reaction conditions. Similar to the reaction with **1a**, the reactions of **2a** with arylboronic acids were not considerably influenced by steric or electron effects of arylboronic acids, indicating that this reaction is tolerant to many functional groups. These reaction characteristics could allow a variety of compounds having different substitutions to be prepared via coupling reactions.

The substitution group on the quinoline or quinoxaline ring also affects the yields of the catalytic reactions (Table 3). For example, the reaction of methyl 6-fluoro- or 5-chloroquinoline-8-

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carboxylate with phenylboronic acid gave the products **6** and **7** in 86% and 87% yield, respectively, slightly lower than the yield of **1a** under similar reaction conditions. When methyl 7-chloroquinoline-8-carboxylate, which has a chlorine substitution adjacent to the carboxyl group on the quinoline ring, was used to couple with phenylboronic acid, the desired product **8** was obtained in 72% yield, lower than that of methyl 5-chloroquinoline-8-carboxylate. The reaction of methyl 5-bromoquinoline-8 carboxylate, which contains a Br substituent on the 5-position of the quinoline ring, gave a 91% yield of product **9**. These results clearly reveal that halide substituents on the quinoline ring remain intact during the coupling reactions,[1,18] which may allow further modification of the products by coupling reactions. Methyl substitution at the 6- and 2-positions of methyl quinoline-8-carboxylate had little effect on the reaction; the corresponding products of **10** and **12** were obtained in 89% and 87% yields, respectively. When 7-methylquinoline-8 carboxylate was used as the substrate for the coupling reaction, the desired product **11** was surprisingly obtained in 91% yield. Methyl 5,6-dimethoxyquinoline-8-carboxylate, having two strong electron-donating groups substituted on the quinoline ring, was used to react with phenylboronic acid, with the desired product **13** obtained in 85% yield, indicating that a high electron density on the quinoline ring is not conducive to the coupling reaction. The reaction of dimethyl quinoline-5,8-dicarboxylate, which contains two ester group substitutions on the 5- and 8-positions of the quinoline ring, gave the desired product **14** in 90% yield. Interestingly, the ester group at the 5-position was maintained during the reaction, indicating the high selectivity of this reaction; that is, only the ester group close to the directing atom can be activated to undergo the coupling reaction. For instance, dimethyl 4-chloroquinoline-3,8-dicarboxylate can couple with phenylboronic acid to give product **15** in 75% yield, with both chlorine and the ester group at the 3-position remaining intact during the reaction. The reaction of methyl 2,3-diphenylquinoxaline-5- carboxylate with phenylboronic acid gave no product. The highly steric effects of the phenyl group at the 2-position may prevent the coordination of the Rh-metal center with the N atom, thus disabling the reaction. Methyl 1,7-phenanthroline-6-carboxylate also reacted with phenylboronic acid to give the desired product **17** in low yield (35%); a side reaction, the coupling product obtained via C−H activation, was also observed. However, both methyl benzo[*f*]quinoline- 5-carboxylate and methyl 3-methylbenzo[*f*]-quinoline-5-carboxylate, which have an N atom at the appropriate position as a directing group, reacted with phenylboronic acid to give the desired products **18** and **19** in 95% and 93% yields, respectively. These results clearly show that the direct exchange of a methoxy group to an aryl group can be achieved in carboxylate compounds having an N-directing group and that this reaction can occur with many different arylboronic acids under optimized reaction conditions.

Based on the current results and previous literature,[15] we propose a catalytic reaction mechanism as shown in Figure 1. After the ligand exchange reaction of $(PPh_3)_3RhCl$ with the quinoline substrate, the Rh^I metal becomes closer to the C−O bond through the chelation of the N-directing group. Insertion of the Rh^I metal into the C−O bond affords a five-membered cycloacylrhodium(III) intermediate **A**.[19] Transmetalation of intermediate **A** with arylboronic acid then gives the rhodium intermediate **B**, in which the Rh-metal center bears a phenyl group. Finally, reductive elimination of **B** gives the product **4** and

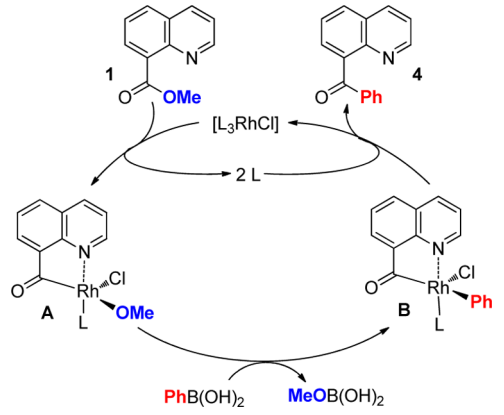

Figure 1. Proposed mechanism for the coupling reaction of methyl quinoline-8-carboxylate with arylboronic acids catalyzed by Rh-$(PPh_3)_3Cl$.

the Rh^I complex after the coordination of the two phosphine ligands.

Quinoline and quinoxaline derivatives are important building blocks in the construction of organic molecules having special properties. 8-Benzoylquinoline has been frequently used as a core structure for the design of modern pharmaceuticals and related compounds (Scheme 2),[20] such as tubulin polymerization inhibitors (**4j**),[20a,b] cannabinoid receptor ligands (**20**),[20c] drugs for the treatment of bone metabolic disorders (**21**, **22**),[20d] and antiulcer agents (**24a−c**).[20e] The current method offers a possible synthetic pathway to efficiently build similar compounds from readily available materials. The method may prove especially valuable for medicinal chemists for the late-stage introduction of versatile ketone moieties into complex scaffolds for diversity-oriented synthetic strategies.

For example, commencing with methyl 2-aminobenzoate (**25**), an inexpensive, readily commercially available compound, the reaction with diethyl 2-(ethoxymethylene)malonate (**26**) gives diethyl 2-(((2-(methoxycarbonyl)phenyl)amino)-methylene)malonate (**27**) in 90% yield (Scheme 3).[21a] After compound **27** is heated in diphenyl ether, the ring-closed product of 3-ethyl 8-methyl 4-oxo-1,4-dihydroquinoline-3,8-dicarboxylate (**28**) is obtained in 85% yield.[21a] When treated with excess amount of $POCl_3$, compound **28** is converted to 3-ethyl 8-methyl 4-chloroquinoline-3,8-dicarboxylate (**29**) in 98% yield.[21a] Substitution of Cl in **29** by *o*-toluidine in 1,4-dioxane at 100 °C gives 3-ethyl 8-methyl 4-(*o*-tolylamino)quinoline-3,8-dicarboxylate (**30**) in 89% yield.[21b] The following cross-coupling reaction of **30** with phenylboronic acid gives product **24** (92%; 61% in total based on **25**). When *p*-tolylboronic acid, (4-fluorophenyl)-boronic acid, and (4-chlorophenyl)boronic acid are used to couple with **30** under the Rh catalyst, **24a** (95%; 63% in total based on **25**), **24b** (92%; 61% yield overall based on **25**), and **24c** (91%; 61% in total based on **25**), respectively, are obtained in high yield. Compounds **24a−c** have been proven to be antiulcer agents.[20e] The reported synthesis of these compounds began with ethyl 8-formyl-4-(o-tolylamino)quinoline-3-carboxylate which is not a commercially available compound and requires multistep synthesis.[20e] After reaction with the corresponding *p*-tolylmagnesium bromide, (4-fluorophenyl)magnesium bromide, or (4-chlorophenyl)magnesium bromide and then subjecting the resulting alcohol compound to oxidation by MnO_2 in chloroform, the desired products of **24a**, **24b**, or **24c** were obtained in 13%, 17%, or 12% yields, respectively.[20e] Compared with this

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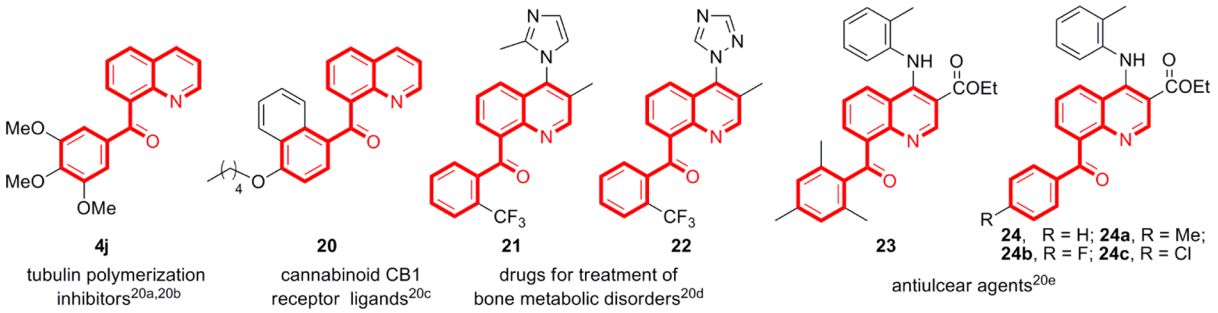
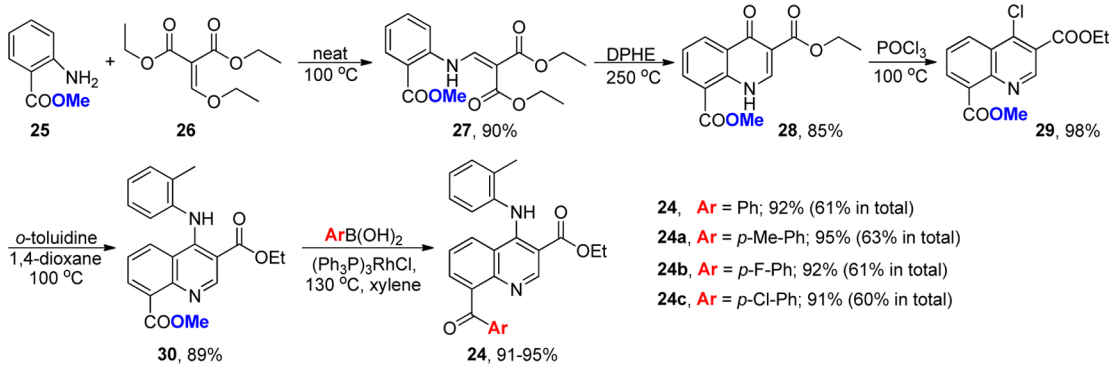
Scheme 2. Modern Pharmaceuticals and Related Compounds with an 8-Benzoylquinoline Core Structure



Scheme 3. Examples of the Use of $(PPh_3)_3RhCl$-Catalyzed Cross-Coupling Reactions of Esters and Arylboronic Acids in the Synthesis of Drugs Containing an 8-Benzoylquinoline Core Structure



previously reported method, the current procedure gives the corresponding products in higher yields and from more readily available materials. Therefore, this new method has huge advantages over the traditional method for the synthesis of such compounds.

CONCLUSION

A new approach for ketone synthesis by the chelation-assisted rhodium-catalyzed cross-coupling reaction of ester and arylboronic acids was described. A variety of ketone derivatives having different substituted quinolinone and quinoxaline groups were obtained in moderate to high yields. In all of these reactions, the directing group was maintained in the reaction and formed as an important functional part of the products, significantly increasing the atomic efficiency of the entire reaction. Further efforts to expand the scope of this reaction are currently underway in our laboratories.

EXPERIMENTAL SECTION

General Information. ^{1}H NMR, ^{19}F NMR, and ^{13}C NMR were obtained on 400 or 600 MHz spectrometer with $CDCl_3$ as solvent. The chemical shifts are reported in ppm relative to $CHCl_3$ (δ = 7.26) for ^{1}H NMR and relative to the central $CDCl_3$ resonance (δ = 77.0) for ^{13}C NMR. For ^{19}F NMR, the (trifluoromethyl)benzene was used as an external standard. NMR data of known compounds are in agreement with literature values. HRMS were recorded on a mass spectrometer with ESI resource. Coupling constants (J) are reported in hertz. Infrared spectra were recorded on FT-IR spectrophotometer. Multiplicities are reported as follows: singlet (s), doublet (d), doublet of doublets (dd), triplet (t), quartet (q), and multiplet (m).

Materials and Methods. Unless otherwise noted, all reactions were performed under an atmosphere of dry N_2 with oven-dried glassware and anhydrous solvents. Xylene was dried from sodium/benzophenone under a N_2 atmosphere and distilled prior to use. Reactions were monitored by analytical thin-layer chromatography. The substrates were prepared according to the literature procedures. Other chemicals or reagents were obtained from commercial sources and used directly.

General Experimental Procedure for the Rh-Catalyzed Methyl Quinoline-8-carboxylate or Methyl Quinoxaline-5-carboxylate with Arylboronic Acids. To an oven-dried screwed vial were added substituted methyl quinoline-8-carboxylate or methyl quinoxaline-5-carboxylate (0.10 mmol), arylboronic acid (0.20 mmol), $Rh(PPh_3)_3Cl$ (4.6 mg, 0.005 mmol), and xylene (0.5 mL). The mixture was vigorously stirred at 130 °C under N_2 to the end of the reaction. Organic solvents were removed in vacuo, and the residue was purified by flash chromatography to give the desired products.

Phenyl(quinolin-8-yl)methanone (4a). Methyl quinoline-8-carboxylate (18.7 mg, 0.10 mmol) and phenylboronic acid (24.4 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a white solid (22.1 mg, 95%): mp 94–96 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.32–7.37 (m, 3H), 7.49 (t, J = 7.2 Hz, 1H), 7.56 (t, J = 7.6 Hz, 1H), 7.69 (d, J = 7.2 Hz, 1H), 7.82 (d, J = 7.6 Hz, 2H), 7.90 (d, J = 8.0 Hz, 1H), 8.14 (d, J = 8.0 Hz, 1H), 8.78 (dd, J = 4.0 Hz, 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.8, 150.7, 146.1, 139.4, 137.9, 136.0, 133.2, 130.1, 129.7, 128.3, 128.1, 125.8, 121.6; IR (KBr) ν 3060, 1665, 1557, 1495, 1448, 1319, 1278, 1210, 929, 795, 713, 691, 623 cm^{-1}; HRMS (ESI-TOF) m/z [M + Na]$^+$ calcd for $C_{16}H_{11}NO$ 256.0733, found 256.0739. Anal. Calcd for $C_{16}H_{11}NO$: C, 82.38; H, 4.75; N, 6.00. Found: C, 82.45; H, 4.81; N, 6.07.

Quinolin-8-yl(*o*-tolyl)methanone (4b). Methyl quinoline-8-carboxylate (18.7 mg, 0.10 mmol) and *o*-tolylboronic acid (27.2 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a white solid (17.8 mg, 72%): mp 86–88 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.68 (s, 3H), 7.09 (t, J = 7.8 Hz, 1H), 7.31 (t, J = 7.2 Hz, 2H), 7.31–7.41 (m, 2H), 7.59 (t, J = 7.2 Hz, 1H), 7.73 (dd, J = 7.2, 1.2 Hz, 1H), 7.94 (dd, J = 7.8, 1.2 Hz, 1H), 8.18 (dd, J = 8.4, 1.8 Hz, 1H), 8.85 (dd, J = 3.6, 1.2 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 199.8, 150.9, 140.6, 139.7, 138.0, 135.8, 132.1, 131.7, 129.9, 128.7, 128.2, 125.7, 125.2, 121.5, 21.6; IR (KBr) ν 2957, 1664, 1571, 1493, 1268, 1208, 913, 799, 741 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{17}H_{13}NO$

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248.1070, found 248.1073. Anal. Calcd for $C_{17}H_{13}NO$: C, 82.57; H, 5.30; N, 5.66. Found: C, 82.65; H, 5.33; N, 5.67.

(Quinolin-8-yl)(*m*-tolyl)methanone (4c). Methyl quinoline-8-carboxylate (18.7 mg, 0.10 mmol) and *m*-tolylboronic acid (27.2 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a white solid (21.7 mg, 88%): mp 96−98 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.35 (s, 3H), 7.27 (t, J = 7.6 Hz, 1H), 7.36 (d, J = 7.2 Hz, 1H), 7.41 (dd, J = 8.0, 4.0 Hz, 1H), 7.55 (d, J = 7.6 Hz, 1H), 7.62 (t, J = 7.6 Hz, 1H), 7.72 (d, J = 8.4 Hz, 2H), 7.95 (d, J = 8.0 Hz, 1H), 8.21 (d, J = 8.4 Hz, 1H), 8.84 (d, J = 2.0 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.9, 150.7, 146.1, 139.5, 138.0, 137.8, 135.9, 134.0, 130.2, 129.5, 128.2, 128.1, 128.0, 127.7, 125.7, 121.5, 21.2; Anal. Calcd for $C_{17}H_{13}NO$: C, 82.57; H, 5.30; N, 5.66. Found: C, 82.69; H, 5.38; N, 5.69; IR (KBr) ν 3047, 2923, 1669, 1599, 1494, 1318, 1280, 1183, 1146, 947, 801, 731, 629 cm^{-1}; HRMS (ESI-TOF) m/z [M + Na]$^+$ calcd for $C_{17}H_{13}NO$ 270.0889, found 270.0893.

(Quinolin-8-yl)(*p*-tolyl)methanone (4d). Methyl quinoline-8-carboxylate (18.7 mg, 0.10 mmol) and *p*-tolylboronic acid (27.2 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a white solid (22.7 mg, 92%): mp 112−114 °C ; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.40 (s, 3H), 7.20 (d, J = 7.6 Hz, 2H), 7.41 (dd, J = 8.0 Hz, 4.0 Hz, 1H), 7.62 (t, J = 7.6 Hz, 1H), 7.72 (m, 3H), 7.95 (d, J = 8.0 Hz, 1H), 8.21 (d, J = 8.0 Hz, 1H), 8.85 (dd, J = 4.0 Hz, 2.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.4, 150.7, 146.1, 144.0, 139.7, 135.9, 135.4, 130.3, 129.4, 129.0, 128.2, 128.0, 125.8, 121.5, 21.6; IR (KBr) ν 3050, 2923, 1665, 1595, 1494, 1407, 1320, 1278, 1216, 1178, 929, 796, 739, 604 cm^{-1}; HRMS (ESI-TOF) m/z [M + Na]$^+$ calcd for $C_{17}H_{13}NO$ 270.0889, found 270.0890. Anal. Calcd for $C_{17}H_{13}NO$: C, 82.57; H, 5.30; N, 5.66. Found: C, 82.61; H, 5.33; N, 5.65.

(4-*tert*-Butylphenyl)(quinolin-8-yl)methanone (4e). Methyl quinoline-8-carboxylate (18.7 mg, 0.10 mmol) and (4-*tert*-butylphenyl)-boronic acid (35.6 mg, 0.20 mmol) was used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a white solid (26.0 mg, 90%): mp 98−100 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.34 (s, 9H), 7.41−7.45 (m, 3H), 7.63 (t, J = 8.0 Hz, 1H), 7.72 (dd, J = 7.2 Hz, 1.2 Hz, 1H), 7.80 (d, J = 8.4 Hz, 2H), 7.96 (dd, J = 8.0 Hz, 0.8 Hz, 1H), 8.22 (dd, J = 8.0 Hz, 1.2 Hz, 1H), 8.87 (dd, J = 4.0 Hz, 1.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.4, 157.0, 150.8, 146.1, 139.7, 135.9, 135.2, 130.2, 129.4, 128.2, 127.9, 125.8, 125.3, 121.5, 35.1, 31.0; IR (KBr) ν 3053, 2962, 2868, 1670, 1600, 1573, 1494, 1319, 1278, 1183, 1109, 930, 795 cm^{-1}; HRMS (ESI-TOF) m/z [M + Na]$^+$ calcd for $C_{20}H_{19}NO$ 312.1359, found 312.1367. Anal. Calcd for $C_{20}H_{19}NO$: C, 83.01; H, 6.62; N, 4.84. Found: C, 83.10; H, 6.71; N, 4.88.

(3,5-Dimethylphenyl)(quinolin-8-yl)methanone (4f). Methyl quinoline-8-carboxylate (18.7 mg, 0.10 mmol) and (3,5-dimethylphenyl)boronic acid (30 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a yellow solid (22.7 mg, 87%): mp 95−97 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.29 (s, 6H), 7.19 (s, 1H), 7.42 (dd, J = 8.4 Hz, 4.0 Hz, 1H), 7.45 (s, 2H), 7.62 (t, J = 8.0 Hz, 1H), 7.70 (dd, J = 6.8 Hz, 1.2 Hz, 1H), 7.95 (dd, J = 8.0 Hz, 1.6 Hz, 1H), 8.21 (dd, J = 8.0 Hz, 1.6 Hz, 1H), 8.86 (dd, J = 4.4 Hz, 1.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.1, 150.8, 146.2, 139.8, 137.96, 137.90, 135.9, 135.0, 129.4, 128.2, 127.9, 125.7, 121.5, 21.1; IR (KBr) ν 1714, 1485, 1416, 1269, 1209, 1154, 1017, 910, 867, 732 cm^{-1}; HRMS (ESI-TOF) m/z [M + Na]$^+$ calcd for $C_{18}H_{15}NO$ 284.1046, found 284.1050. Anal. Calcd for $C_{18}H_{15}NO$: C, 82.73; H, 5.79; N, 5.36. Found: C, 82.76; H, 5.88; N, 5.39.

(4-Methoxyphenyl)(quinolin-8-yl)methanone (4g). Methyl quinoline-8-carboxylate (18.7 mg, 0.10 mmol) and (4-methoxyphenyl)-boronic acid (30.4 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/8) as a white solid (23.9 mg, 91%): mp 113−114 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.83 (s, 3H), 6.87 (d, J = 8.8 Hz, 2H), 7.40 (dd, J = 8.4 Hz, 4.4 Hz, 1H), 7.60 (t, J = 8.0 Hz, 1H), 7.70 (dd, J = 6.8 Hz, 1.2 Hz, 1H), 7.81 (d, J = 8.8 Hz, 2H), 7.94 (dd, J = 8.4 Hz, 1.2 Hz, 1H), 8.20 (dd, J = 8.4 Hz, 1.6 Hz, 1H), 8.85 (dd, J = 4.0 Hz, 1.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.3, 163.7, 150.8, 146.1, 139.7, 135.9, 132.5, 131.0, 129.3, 128.2, 127.9, 125.8, 121.5, 113.6, 55.4; IR (KBr) ν 3073, 1659, 1595, 1495, 1260, 1170, 1025, 929, 797 cm^{-1}; HRMS (ESI-TOF) m/z [M + Na]$^+$ calcd for $C_{17}H_{13}NO_2$ 286.0838, found 286.0842. Anal. Calcd for $C_{17}H_{13}NO_2$: C, 77.55; H, 4.98; N, 5.32. Found: C, 77.59; H, 4.98; N, 5.41;

(3-Methoxyphenyl)(quinolin-8-yl)methanone (4h). Methyl quinoline-8-carboxylate (18.7 mg, 0.10 mmol) and (3-methoxyphenyl)-boronic acid (30.4 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/8) as a yellow viscous liquid (22.4 mg, 85%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.82 (s, 3H), 7.09−7.10 (m, 1H), 7.25 (s, 2H), 7.40 (dd, J = 8.0, 4.0 Hz, 1H), 7.53 (s, 1H), 7.61 (t, J = 7.2 Hz, 1H), 7.72 (d, J = 6.8 Hz, 1H), 7.94 (d, J = 8.0 Hz, 1H), 8.20 (d, J = 8.0 Hz, 1H), 8.84 (d, J = 2.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.6, 159.7, 150.8, 146.1, 139.4, 139.2, 135.9, 129.6, 129.2, 128.2, 128.1, 125.8, 123.6, 121.6, 119.9, 113.7, 55.4; IR (KBr) ν 1670, 1579, 1436, 1318, 1280, 1040, 800, 739, 721 cm^{-1}; HRMS (ESI-TOF) m/z [M + Na]$^+$ calcd for $C_{17}H_{13}NO_2$ 286.0838, found 286.0845. Anal. Calcd for $C_{17}H_{13}NO_2$: C, 77.55; H, 4.98; N, 5.32. Found: C, 77.67; H, 5.01; N, 5.32;

(3,4-Dimethoxyphenyl)(quinolin-8-yl)methanone (4i). Methyl quinoline-8-carboxylate (18.7 mg, 0.10 mmol) and (3,4-dimethoxyphenyl)boronic acid (36.4 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/2) as a yellow solid (15.5 mg, 53%): mp 130−132 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.88 (s, 3H), 3.92 (s, 3H), 6.73 (d, J = 8.4 Hz, 1H), 7.14 (dd, J = 8.4 Hz, 1.6 Hz, 1H), 7.40 (dd, J = 8.4 Hz, 4.4 Hz, 1H), 7.60 (t, J = 8.4 Hz, 1H), 7.69−7.72 (m, 2H), 7.92 (dd, J = 8.4 Hz, 1.2 Hz, 1H), 8.19 (dd, J = 8.4 Hz, 1.6 Hz, 1H), 8.85 (dd, J = 4.0 Hz, 1.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.3, 153.6, 150.8, 149.1, 146.2, 139.6, 135.9, 131.1, 129.3, 128.1, 127.9, 126.4, 125.7, 121.5, 111.2, 109.8, 56.0, 55.9; IR (KBr) ν 1660, 1592, 1515, 1463, 1417, 1271, 1138, 1022, 802 cm^{-1}; HRMS (ESI-TOF) m/z [M + Na]$^+$ calcd for $C_{18}H_{15}NO_3$ 316.0944, found 316.0947. Anal. Calcd for $C_{18}H_{15}NO_3$: C, 73.71; H, 5.15; N, 4.78. Found: C, 73.87; H, 5.26; N, 4.79.

Quinolin-8-yl(3,4,5-trimethoxyphenyl)methanone (4j). Methyl quinoline-8-carboxylate (18.7 mg, 0.10 mmol) and (3,4,5-trimethoxyphenyl)boronic acid (42.4 mg, 0.20 mmol) was used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/2) as a yellow solid (12.9 mg, 40%): mp 158−160 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.77 (s, 6H), 3.93 (s, 3H), 7.14 (s, 2H), 7.46 (dd, J = 8.4, 4.4 Hz, 1H), 7.65 (t, J = 7.2 Hz, 1H), 7.75 (d, J = 7.2 Hz, 1H), 7.98 (d, J = 8.0 Hz, 1H), 8.25 (dd, J = 8.4, 1.2 Hz, 1H), 8.91 (dd, J = 4.0, 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.4, 152.8, 150.8, 146.0, 143.0, 139.1, 136.0, 132.7, 129.6, 128.1, 128.0, 125.7, 121.6, 108.0, 60.8, 56.1; IR (KBr) ν 3063, 2938, 2836, 1655, 1583, 1502, 1461, 1413, 1335, 1232, 1129, 1001, 803, 733 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{19}H_{17}NO_4$ 324.1230, found 324.1235. Anal. Calcd for $C_{19}H_{17}NO_4$: C, 70.58; H, 5.30; N, 4.33. Found: C, 70.68; H, 5.37; N, 4.35;

Naphthalen-1-yl(quinolin-8-yl)methanone (4k). Methyl quinoline-8-carboxylate (18.7 mg, 0.10 mmol) and naphthalen-1-ylboronic acid (34.4 mg, 0.20 mmol) was used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a white solid (24.6 mg, 87%): mp 136−138 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.32 (t, J = 7.8 Hz, 1H), 7.39 (dd, J = 8.4 Hz, 4.2 Hz, 1H), 7.55−7.63 (m, 3H), 7.67 (t, J = 7.8 Hz, 1H), 7.82 (d, J = 7.2 Hz, 1H), 7.91 (d, J = 7.8 Hz, 1H), 7.96−8.00 (m, 2H), 8.21 (d, J = 7.8 Hz, 1H), 8.80 (d, J = 2.4 Hz, 1H), 9.14 (d, J = 9.0 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ199.7, 150.9, 146.2, 140.7, 135.9, 135.5, 133.9, 133.3, 132.5, 131.1, 130.1, 129.0, 128.3, 128.2, 126.5, 126.4, 125.7, 124.1, 121.5; IR (KBr) v1658, 1572, 1508, 1494, 1255, 1221, 1103, 911, 742 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{20}H_{13}NO$ 284.1070, found 284.1073. Anal. Calcd for $C_{20}H_{13}NO$: C, 84.78; H, 4.62; N, 4.94. Found: C, 84.78; H, 4.66; N, 4.94.

(Naphthalen-2-yl)(quinolin-8-yl)methanone (4l). Methyl quinoline-8-carboxylate (18.7 mg, 0.10 mmol) and naphthalen-2-ylboronic acid (34.4 mg, 0.20 mmol) were used for the preparation of the title

compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a white solid (25.7 mg, 91%): mp 137−139 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.42 (dd, J = 8.4 Hz, 4.4 Hz, 1H), 7.47 (t, J = 8.0 Hz, 1H), 7.57 (t, J = 6.8 Hz, 1H), 7.67 (t, J = 8.0 Hz, 1H), 7.76−7.82 (m, 2H), 7.87 (t, J = 8.8 Hz, 2H), 8.00 (dd, J = 8.0 Hz, 1.2 Hz, 1H), 8.07 (dd, J = 8.8 Hz, 1.6 Hz, 1H), 8.19 (s, 1H), 8.24 (dd, J = 8.4 Hz, 1.6 Hz, 1H), 8.82 (dd, J = 4.4 Hz, 1.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.8, 150.8, 146.3, 139.5, 135.9, 135.7, 135.3, 132.7, 132.4, 129.7, 128.4, 128.3, 128.2, 128.1, 127.7, 126.5, 125.8, 125.1, 121.6; IR (KBr) ν 3057, 1664, 1574, 1495, 1286, 1185, 1120, 800, 756 cm^{-1}; HRMS (ESI-TOF) m/z [M + Na]$^+$ calcd for $C_{20}H_{13}NO$ 306.0889, found 306.0895. Anal. Calcd for $C_{20}H_{13}NO$: C, 84.78; H, 4.62; N, 4.94. Found: C, 84.84; H, 4.65; N, 4.93;

(4-Chlorophenyl)(quinolin-8-yl)methanone (4m). Methyl quinoline-8-carboxylate (18.7 mg, 0.10 mmol) and (4-chlorophenyl)-boronic acid (31.2 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a yellow solid (17.3 mg, 65%): mp 148−150 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.37 (d, J = 8.4 Hz, 2H), 7.42 (dd, J = 8.4 Hz, 4.4 Hz, 1H), 7.63 (t, J = 7.2 Hz, 1H), 7.73−7.76 (m, 3H), 7.97 (d, J = 8.0 Hz, 1H), 8.22 (dd, J = 8.4 Hz, 1.6 Hz, 1H), 8.82 (dd, J = 4.0 Hz, 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.6, 150.7, 146.0, 139.5, 138.8, 136.3, 135.9, 131.4, 129.9, 128.5, 128.3, 128.1, 125.8, 121.6; IR (KBr) ν 3088, 3058, 1659, 1585, 1497, 1401, 1319, 1279, 1212, 1092, 928, 855, 790, 745 cm^{-1}; HRMS (ESI-TOF) m/z [M + Na]$^+$ calcd for $C_{16}H_{10}ClNO$ 290.0343, found 290.0344. Anal. Calcd for $C_{16}H_{10}ClNO$: C, 71.78; H, 3.77; N, 5.23. Found: C, 71.83; H, 3.77; N, 5.26.

(4-Fluorophenyl)(quinolin-8-yl)methanone (4n). Methyl quinoline-8-carboxylate (18.7 mg, 0.10 mmol) and (4-fluorophenyl)-boronic acid (28.0 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a yellow solid (16.8 mg, 67%): mp 116−118 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.07 (t, J = 8.4 Hz, 2H), 7.42 (dd, J = 8.0, 4.0 Hz, 1H), 7.63 (t, J = 8.0 Hz, 1H), 7.73 (d, J = 6.8 Hz, 1H), 7.83−7.87 (m, 2H), 7.97 (d, J = 8.0 Hz, 1H), 8.22 (d, J = 8.4 Hz, 1H), 8.83 (dd, J = 4.0 Hz, 2.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.3, 165.8 (d, $^1J_{C-F}$ = 253.6 Hz), 150.8, 146.0, 139.0, 136.0, 134.3, 132.9 (d, $^3J_{C-F}$ = 9.3 Hz), 129.8, 128.2, 125.9, 121.7, 115.5 (d, $^2J_{C-F}$ = 21.8 Hz); ^{19}F NMR (376 MHz, $CDCl_3$) δ −104.9; IR (KBr) ν 3069, 1669, 1596, 1496, 1410, 1278, 1226, 1151, 930, 853, 827, 792, 742, 602 cm^{-1}; HRMS (ESI-TOF) m/z [M + Na]$^+$ calcd for $C_{16}H_{10}FNO$ 274.0639, found 274.0643. Anal. Calcd for $C_{16}H_{10}FNO$: C, 76.48; H, 4.01; N, 5.57. Found: C, 76.52; H, 4.02; N, 5.61.

(4-Bromophenyl)(quinolin-8-yl)methanone (4o). Methyl quinoline-8-carboxylate (18.7 mg, 0.10 mmol) and (4-bromophenyl)-boronic acid (40.0 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a white viscous liquid (21.4 mg, 69%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.43 (dd, J = 8.4 Hz, 4.0 Hz, 1H), 7.52 (t, J = 8.4 Hz, 2H), 7.62−7.79 (m, 4H), 7.98 (d, J = 8.0 Hz, 1H), 8.22 (d, J = 8.0 Hz, 1H), 8.83 (d, J = 2.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.8, 150.8, 146.0, 137.6, 136.8, 136.0, 131.6, 131.5, 131.4, 130.0, 128.4, 128.2, 125.9, 121.7; IR (KBr) ν 3059, 1668, 1596, 1495, 1320, 1278, 1213, 1177, 929, 797, 712 cm^{-1}; HRMS (ESI-TOF) m/z [M + Na]$^+$ calcd for $C_{16}H_{10}BrNO$ 333.9838, found 333.9840. Anal. Calcd for $C_{16}H_{10}BrNO$: C, 61.56; H, 3.23; N, 4.49. Found: C, 61.64; H, 3.28; N, 4.50.

Ethyl 4-(Quinoline-8-carbonyl)benzoate (4p). Methyl quinoline-8-carboxylate (18.7 mg, 0.10 mmol) and (4-(ethoxycarbonyl)-phenyl)boronic acid (38.8 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/8) as a white solid (25.0 mg, 82%): mp 220−222 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.41 (t, J = 7.2 Hz, 3H), 4.41 (q, J = 7.2 Hz, 2H), 7.44 (dd, J = 8.4, 4.0 Hz, 1H), 7.67 (t, J = 7.6 Hz, 1H), 7.80 (d, J = 6.8 Hz, 1H), 7.87 (d, J = 8.4 Hz, 2H), 8.02 (d, J = 8.0 Hz, 1H), 8.08 (d, J = 8.4 Hz, 2H), 8.24 (dd, J = 8.4, 1.2 Hz, 1H), 8.82 (dd, J = 4.0, 1.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.4, 165.8, 150.8, 146.1, 141.2, 138.8, 136.0, 134.1, 130.2, 129.8, 129.4, 128.6, 128.2, 125.9, 121.7, 61.3, 14.2; IR (KBr) ν 3052, 2981, 2926, 2851, 1717, 1673, 1574, 1495, 1406, 1367, 1272, 1209, 1104, 1018, 930, 797, 728 cm^{-1}; HRMS (ESI-TOF) m/z [M + Na]$^+$ calcd for $C_{19}H_{15}NO_3$ 328.0944, found 328.0946. Anal. Calcd for $C_{19}H_{15}NO_3$: C, 74.74; H, 4.95; N, 4.59. Found: C, 74.76; H, 4.99; N, 4.59.

(4-Nitrophenyl)(quinolin-8-yl)methanone (4q). Methyl quinoline-8-carboxylate (18.7 mg, 0.10 mmol) and (4-nitrophenyl)boronic acid (33.4 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/8) as a yellow solid (25.6 mg, 92%): mp 193−195 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.44 (dd, J = 8.4, 4.0 Hz, 1H), 7.69 (t, J = 7.6 Hz, 1H), 7.85 (d, J = 6.8 Hz, 1H), 7.93 (d, J = 8.4 Hz, 2H), 8.04 (d, J = 8.0 Hz, 1H), 8.23−8.25 (m, 3H), 8.76 (d, J = 2.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.4, 150.8, 150.1, 145.9, 142.8, 138.0, 136.1, 130.8, 130.7, 129.1, 128.2, 126.1, 123.4, 121.8; IR (KBr) ν 1666, 1519, 1384, 1345, 1275, 1014, 796, 749 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{16}H_{10}N_2O_3$ 279.0764, found 279.0768. Anal. Calcd for $C_{16}H_{10}N_2O_3$: C, 69.06; H, 3.62; N, 10.07. Found: C, 69.08; H, 3.62; N, 10.09.

Quinolin-8-yl(4-(trifluoromethyl)phenyl)methanone (4r). Methyl quinoline-8-carboxylate (18.7 mg, 0.10 mmol) and (4-(trifluoromethyl)phenyl)boronic acid (38.0 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a white solid (26.5 mg, 88%): mp 107−109 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.43 (dd, J = 8.0 Hz, 4.0 Hz, 1H), 7.64−7.67 (m, 3H), 7.78 (d, J = 7.2 Hz, 1H), 7.91 (d, J = 8.0 Hz, 2H), 8.01 (d, J = 8.0 Hz, 1H), 8.23 (d, J = 8.4 Hz, 1H), 8.80 (dd, J = 4.0 Hz, 2.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.9, 150.8, 146.0, 140.7, 138.5, 136.0, 134.3, 134.0, 130.3, 130.2, 128.7, 128.2, 126.0, 125.4, 125.3, 125.0, 122.3, 121.7; ^{19}F NMR (376 MHz, $CDCl_3$) δ −63.0; IR (KBr) ν 3047, 1672, 1577, 1495, 1408, 1279, 1119, 1065, 913, 839, 798 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{17}H_{10}F_3NO$ 302.0787, found 302.0790. Anal. Calcd for $C_{17}H_{10}F_3NO$: C, 67.78; H, 3.35; N, 4.65. Found: C, 67.85; H, 3.38; N, 4.67.

(3,4-Difluorophenyl)(quinolin-8-yl)methanone (4s). Methyl quinoline-8-carboxylate (18.7 mg, 0.10 mmol) and (3,4-difluorophenyl)boronic acid (31.6 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a white solid (25.6 mg, 95%): mp 100−102 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.16 (q, J = 8.4 Hz, 1H), 7.43 (dd, J = 8.4 Hz, 4.2 Hz, 1H), 7.52−7.54 (m, 1H), 7.64 (t, J = 7.2 Hz, 1H), 7.67−7.75 (m, 2H), 7.98 (d, J = 8.4 Hz, 1H), 8.22 (d, J = 8.4 Hz, 1H), 8.82 (dd, J = 3.6 Hz, 1.2 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 195.4, 153.6 (dd, $^1J_{C-F}$ = 255.5 Hz, 12.5 Hz), 150.8, 150.2 (dd, $^1J_{C-F}$ = 249.2 Hz, 12.9 Hz), 145.9, 138.3, 136.1, 130.2, 128.4, 128.2, 127.3 (d, $^3J_{C-F}$ = 3.5 Hz), 127.2 (d, $^3J_{C-F}$ = 3.3 Hz), 125.9, 121.7, 119.0 (d, $^2J_{C-F}$ = 17.5 Hz), 117.2 (d, $^2J_{C-F}$ = 18.0 Hz); IR (KBr) ν 1673, 1608, 1512, 1428, 1288, 1179, 1108, 794, 768, 742 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{16}H_9F_2NO$ 270.0725, found 270.0730. Anal. Calcd for $C_{16}H_9F_2NO$: C, 71.37; H, 3.37; N, 5.20. Found: C, 71.43; H, 3.39; N, 5.20.

(3,5-Bis(trifluoromethyl)phenyl)(quinolin-8-yl)methanone (4t). Methyl quinoline-8- carboxylate (18.7 mg, 0.10 mmol) and (3,5-bis(trifluoromethyl)phenyl)boronic acid (51.6 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a yellow solid (33.9 mg, 92%): mp 118−120 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.45 (dd, J = 8.4 Hz, 4.2 Hz, 1H), 7.70 (t, J = 8.4 Hz, 1H), 7.87 (dd, J = 7.2 Hz, 1.2 Hz, 1H), 8.04 (s, 1H), 8.07 (dd, J = 8.4 Hz, 1.2 Hz, 1H), 8.21 (s, 2H), 8.26 (dd, J = 8.4 Hz, 1.2 Hz, 1H), 8.76 (dd, J = 2.8 Hz, 1.2 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 195.2, 150.8, 145.8, 139.7, 137.2, 136.2, 131.9, 131.7, 129.8, 129.5, 128.2, 126.2, 126.0, 123.8, 122.0; IR (KBr) ν 3086, 1674, 1280, 1184, 1118, 913, 793, 740, 705, 682 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{18}H_9F_6NO$ 370.0661, found 370.0665. Anal. Calcd for $C_{18}H_9F_6NO$: C, 58.55; H, 2.46; N, 3.79. Found: C, 58.56; H, 2.48; N, 3.79;

Phenyl(quinoxalin-5-yl)methanone (5a). Methyl quinoxaline-5-carboxylate (18.8 mg, 0.10 mmol) and phenylboronic acid (24.4 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a white solid (21.7 mg, 93%): mp 106−108 °C; ^{1}H NMR (400 MHz,

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$CDCl_3$) δ 7.43 (t, J = 7.2 Hz, 2H), 7.58 (t, J = 7.2 Hz, 1H), 7.81−7.84 (m, 3H), 7.87 (t, J = 7.2 Hz, 1H), 8.27 (dd, J = 8.4 Hz, 1.2 Hz, 1H), 8.78 (d, J = 1.8 Hz, 1H), 8.87 (d, J = 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.4, 145.4, 145.1, 142.5, 141.1, 139.5, 137.6, 133.4, 131.5, 130.1, 129.3, 129.0, 128.4; IR (KBr) ν 3061, 1671, 1596, 1487, 1274, 936, 870, 775, 712 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{15}H_{10}N_2O$ 235.0866, found 235.0868. Anal. Calcd for $C_{15}H_{10}N_2O$: C, 76.91; H, 4.30; N, 11.96. Found: C, 77.12; H, 4.37; N, 11.97.

Quinoxalin-5-yl(*o*-tolyl)methanone (5b). Methyl quinoxaline-5-carboxylate (18.8 mg, 0.10 mmol) and *o*-tolylboronic acid (27.2 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a white solid (12.4 mg, 50%): mp 93−95 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.67 (s, 3H), 7.10 (t, J = 7.2 Hz, 1H), 7.26 (d, J = 8.4 Hz, 1H), 7.32 (d, J = 7.6 Hz, 1H), 7.39 (t, J = 7.2 Hz, 1H), 7.83 (m, 2H), 8.24 (m, 1H), 8.78 (s, 1H), 8.85 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.4, 145.3, 145.2, 141.1, 140.6, 139.6, 137.8, 132.0, 131.9, 131.8, 129.5, 129.2, 125.3, 21.5; IR (KBr) ν 2961, 1656, 1572, 1486, 1306, 1267, 934, 913, 744 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{16}H_{12}N_2O$ 249.1022, found 249.1025. Anal. Calcd for $C_{16}H_{12}N_2O$: C, 77.40; H, 4.87; N, 11.28. Found: C, 77.53; H, 4.87; N, 11.32.

Quinoxalin-5-yl(*m*-tolyl)methanone (5c). Methyl quinoxaline-5-carboxylate (18.8 mg, 0.10 mmol) and *m*-tolylboronic acid (27.2 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a white solid (18.1 mg, 73%): mp 99−101 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.36 (s, 3H), 7.29 (t, J = 7.2 Hz, 1H), 7.38 (d, J = 7.8 Hz, 1H), 7.54 (d, J = 7.8 Hz, 1H), 7.70 (s, 1H), 7.81 (dd, J = 7.2 Hz, 1.2 Hz, 1H), 7.86 (t, J = 7.2 Hz, 1H), 8.25 (dd, J = 8.4 Hz, 1.2 Hz, 1H), 8.78 (d, J = 1.8 Hz, 1H), 8.86 (d, J = 1.2 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 196.7, 145.4, 145.2, 142.5, 141.1, 139.6, 138.3, 137.5, 134.3, 131.3, 130.3, 129.3, 128.8, 128.3, 128.7, 21.2; IR (KBr) ν 3049, 2922, 2861, 1669, 1602, 1583, 1486, 1299, 1277, 1167, 1139, 1086, 1053, 952, 842, 771 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{16}H_{12}N_2O$ 249.1022, found 249.1028. Anal. Calcd for $C_{16}H_{12}N_2O$: C, 77.40; H, 4.87; N, 11.28. Found: C, 77.54; H, 4.91; N, 11.32.

Quinoxalin-5-yl(*p*-tolyl)methanone (5d). Methyl quinoxaline-5-carboxylate (18.8 mg, 0.10 mmol) and p-tolylboronic acid (27.2 mg, 0.20 mmol) was used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a white solid (20.1 mg, 81%): mp 160−162 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.41 (s, 3H), 7.22 (d, J = 8.0 Hz, 2H), 7.71 (d, J = 8.0 Hz, 2H), 7.80−7.88 (m, 2H), 8.25 (d, J = 7.6 Hz, 1H), 8.78 (s, 1H), 8.86 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.1, 145.4, 145.1, 144.5, 142.5, 141.1, 139.7, 135.1, 131.3, 130.3, 129.3, 129.1, 128.8, 21.7; IR (KBr) ν 1663, 1603, 1485, 1401, 1275, 1174, 934, 769, 742 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{16}H_{12}N_2O$ 249.1022, found 249.1027. Anal. Calcd for $C_{16}H_{12}N_2O$: C, 77.40; H, 4.87; N, 11.28. Found: C, 77.41; H, 4.89; N, 11.29.

(4-(tert-Butyl)phenyl)(quinoxalin-5-yl)methanone (5e). Methyl quinoxaline-5-carboxylate (18.8 mg, 0.10 mmol) and (4-*tert*-butylphenyl)boronic acid (35.6 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a yellow solid (22.6 mg, 78%): mp 124−126 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 1.32 (s, 9H), 7.44 (d, J = 8.4 Hz, 2H), 7.75 (d, J = 8.0 Hz, 2H), 7.80 (dd, J = 7.2 Hz, 1.2 Hz, 1H), 7.85 (t, J = 7.2 Hz, 1H), 8.24 (dd, J = 8.4 Hz, 1.2 Hz, 1H), 8.78 (d, J = 1.8 Hz, 1H), 8.86 (d, J = 1.8 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 196.0, 157.4, 145.4, 145.2, 142.4, 141.0, 139.7, 134.8, 131.2, 130.1, 129.2, 128.7, 125.4, 35.1, 31.0; IR (KBr) ν 2962, 2904, 2868, 1670, 1603, 1486, 1297, 1275, 1182, 1109, 1052, 936, 855, 764, 728, 706 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{19}H_{18}N_2O$ 291.1492, found 291.1495. Anal. Calcd for $C_{19}H_{18}N_2O$: C, 78.59; H, 6.25; N, 9.65. Found: C, 78.63; H, 6.28; N, 9.65;

(3,5-Dimethylphenyl)(quinoxalin-5-yl)methanone (5f). Methyl quinoxaline-5-carboxylate (18.8 mg, 0.10 mmol) and (3,5-dimethylphenyl)boronic acid (30 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a white solid (21.7 mg, 83%): mp 160−162 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.30 (s, 6H), 7.22 (s, 1H), 7.42 (s, 2H), 7.79 (d, J = 6.6 Hz, 1H), 7.86 (t, J = 7.2 Hz, 1H), 8.26 (d, J = 8.4 Hz, 1H), 8.79 (d, J = 1.2 Hz, 1H), 8.87 (d, J = 1.2 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 196.8, 145.4, 145.2, 142.5, 141.1, 139.8, 138.1, 137.5, 135.3, 131.2, 129.3, 128.7, 127.9, 21.1; IR (KBr) ν 2954, 1667, 1596, 1486, 1384, 1310, 1173, 960, 913, 872, 769, 745 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{17}H_{14}N_2O$ 263.1179, found 263.1181. Anal. Calcd for $C_{17}H_{14}N_2O$: C, 77.84; H, 5.38; N, 10.68. Found: C, 77.91; H, 5.40; N, 10.72;

(4-Methoxyphenyl)(quinoxalin-5-yl)methanone (5g). Methyl quinoxaline-5-carboxylate (18.8 mg, 0.10 mmol) and (4-methoxyphenyl)boronic acid (30.4 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/8) as a white solid (17.1 mg, 65%): mp 120−122 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 3.85 (s, 3H), 6.89 (d, J = 8.0 Hz, 2H), 7.78−7.86 (m, 4H), 8.24 (dd, J = 8.4, 1.2 Hz, 1H), 8.78 (d, J = 1.2 Hz, 1H), 8.86 (d, J = 1.8 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 194.9, 163.9, 145.4, 145.1, 142.5, 141.0, 139.8, 133.2, 132.5, 131.1, 129.3, 128.7, 113.7, 55.4; IR (KBr) ν 1658, 1596, 1459, 1260, 1166, 1025, 913, 746 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{16}H_{12}N_2O_2$ 265.0972, found 265.0975. Anal. Calcd for $C_{16}H_{12}N_2O_2$: C, 72.72; H, 4.58; N, 10.60. Found: C, 72.75; H, 4.63; N, 10.67.

(3-Methoxyphenyl)(quinoxalin-5-yl)methanone (5h). Methyl quinoxaline-5-carboxylate (18.8 mg, 0.10 mmol) and (3-methoxyphenyl)boronic acid (30.4 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/8) as a white solid (22.9 mg, 87%): mp 121−123 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 3.84 (s, 3H), 7.13 (dd, J = 8.4 Hz, 1.8 Hz, 1H), 7.22 (d, J = 7.8 Hz, 1H), 7.29 (t, J = 7.8 Hz, 1H), 7.50−7.51 (m, 1H), 7.82 (dd, J = 7.2 Hz, 1.2 Hz, 1H), 7.86 (t, J = 7.2 Hz, 1H), 8.26 (dd, J = 8.4 Hz, 1.2 Hz, 1H), 8.78 (d, J = 1.8 Hz, 1H), 9.37 (d, J = 1.8 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 196.3, 159.8, 145.5, 145.2, 142.5, 141.1, 139.4, 138.8, 131.4, 129.4, 129.3, 128.9, 123.6, 120.2, 113.6, 55.4; IR (KBr) ν 1669, 1594, 1486, 1277, 1042, 913, 745 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{16}H_{12}N_2O_2$ 265.0972, found 265.0978. Anal. Calcd for $C_{16}H_{12}N_2O_2$: C, 72.72; H, 4.58; N, 10.60. Found: C, 72.79; H, 4.58; N, 10.63.

(3,4-Dimethoxyphenyl)(quinoxalin-5-yl)methanone (5i). Methyl quinoxaline-5-carboxylate (18.8 mg, 0.10 mmol) and (3,4-dimethoxyphenyl)boronic acid (36.4 mg, 0.20 mmol) was used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/2) as a white solid (20.6 mg, 70%): mp 162−164 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 3.91 (s, 3H), 3.94 (s, 3H), 6.76 (d, J = 8.4 Hz, 1H), 7.12 (dd, J = 8.4 Hz, 1.2 Hz, 1H), 7.70 (d, J = 1.2 Hz, 1H), 7.81 (m, 1H), 7.86 (t, J = 7.2 Hz, 1H), 8.24 (d, J = 8.4 Hz, 1H), 8.80 (d, J = 1.2 Hz, 1H), 8.86 (d, J = 1.8 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 195.0, 153.8, 149.2, 145.4, 145.2, 142.5, 141.1, 139.6, 131.1, 130.7, 129.2, 128.6, 126.6, 110.8, 109.7, 56.1, 56.0; IR (KBr) ν 1659, 1583, 1512, 1271, 1135, 967, 913, 826, 747 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{17}H_{14}N_2O_3$ 295.1077, found 295.1081. Anal. Calcd for $C_{17}H_{14}N_2O_3$: C, 69.38; H, 4.79; N, 9.52. Found: C, 69.45; H, 4.81; N, 9.56.

Quinoxalin-5-yl(3,4,5-trimethoxyphenyl)methanone (5j). Methyl quinoxaline-5-carboxylate (18.8 mg, 0.10 mmol) and (3,4,5-trimethoxyphenyl)boronic acid (42.4 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/2) as a yellow solid (20.4 mg, 63%): mp 163−165 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 3.76 (s, 3H), 3.92 (s, 3H), 7.09 (s, 2H), 7.81−7.88 (m, 2H), 8.26 (d, J = 7.8 Hz, 1H), 8.82 (s, 1H), 8.88 (s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 195.2, 153.0, 145.5, 145.3, 142.5, 141.1, 139.3, 132.5, 131.4, 129.2, 128.8, 108.0, 60.9, 56.3; IR (KBr) ν 1667, 1581, 1486, 1413, 1332, 1229, 1127, 913, 744 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ Calcd for $C_{18}H_{16}N_2O_4$ 325.1183, found 325.1186. Anal. Calcd for $C_{18}H_{16}N_2O_4$: C, 66.66; H, 4.97; N, 8.64. Found: C, 66.73; H, 4.99; N, 8.69.

Naphthalen-1-yl(quinoxalin-5-yl)methanone (5k). Methyl quinoxaline-5-carboxylate (18.8 mg, 0.10 mmol) and naphthalen-1-ylboronic acid (34.4 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a white solid (20.7 mg, 73%): mp 153−155

°C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.34 (t, J = 7.2 Hz, 1H), 7.51−7.69 (m, 3H), 7.85−7.94 (m, 3H), 8.01 (d, J = 8.4 Hz, 1H), 8.27 (dd, J = 8.4 Hz, 1.2 Hz, 1H), 8.72 (d, J = 1.2 Hz, 1H), 8.84 (d, J = 1.2 Hz, 1H), 9.06 (d, J = 8.0 Hz, 1H),; ^{13}C NMR (150 MHz, $CDCl_3$) δ 198.3, 145.3, 145.2, 142.6, 141.3, 140.8, 135.3, 133.9, 133.6, 132.5, 131.9, 130.9, 129.8, 129.2, 128.4, 126.6, 126.3, 124.1; IR (KBr) ν 1660, 1508, 1486, 1399, 1276, 914, 776, 744 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{19}H_{12}N_2O$ 285.1022, found 285.1028. Anal. Calcd for $C_{19}H_{12}N_2O$: C, 80.27; H, 4.25; N, 9.85. Found: C, 80.31; H, 4.27; N, 9.88;

Naphthalen-2-yl(quinoxalin-5-yl)methanone (5l). Methyl quinoxaline-5-carboxylate (18.8 mg, 0.10 mmol) and naphthalen-2-ylboronic acid (34.4 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a white solid (25.6 mg, 90%): mp 191−193 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.49 (t, J = 8.0 Hz, 1H), 7.59 (t, J = 8.0 Hz, 1H), 7.78 (d, J = 8.0 Hz, 1H), 7.87−7.92 (m, 4H), 8.05 (d, J = 8.4 Hz, 1H), 8.15 (s, 1H), 8.30−8.32 (m, 1H), 8.76 (s, 1H), 8.88 (s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 196.5, 145.5, 145.2, 142.5, 141.2, 139.5, 135.8, 135.0, 132.9, 132.3, 131.5, 129.6, 129.3, 129.1, 128.7, 128.4, 127.8, 126.7, 124.8; IR (KBr) ν 3058, 1661, 1486, 1400, 1352, 1299, 1278, 1177, 1122, 914, 867, 827, 757 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{19}H_{12}N_2O$ 285.1022, found 285.1025. Anal. Calcd for $C_{19}H_{12}N_2O$: C, 80.27; H, 4.25; N, 9.85. Found: C, 80.35; H, 4.29; N, 9.86.

(4-Chlorophenyl)(quinoxalin-5-yl)methanone (5m). Methyl quinoxaline-5-carboxylate (18.8 mg, 0.10 mmol) and (4-chlorophenyl)-boronic acid (31.2 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a white solid (12.8 mg, 48%): mp 194−196 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40 (d, J = 5.6 Hz, 2H), 7.74 (d, J = 6.0 Hz, 2H), 7.84−7.89 (m, 2H), 8.28 (dd, J = 5.6 Hz, 0.8 Hz, 1H), 8.76 (d, J = 1.2 Hz, 1H), 8.88 (d, J = 0.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 195.3, 145.6, 145.2, 142.5, 141.0, 140.0, 138.9, 136.0, 131.8, 131.4, 129.4, 129.1, 128.8; IR (KBr) ν 1654, 1585, 1487, 1400, 1276, 1194, 1175, 1091, 1009, 933, 875, 750 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{15}H_9ClN_2O$ 269.0476, found 269.0480. Anal. Calcd for $C_{15}H_9ClN_2O$: C, 67.05; H, 3.38; N, 10.43. Found: C, 67.11; H, 3.40; N,10.46;

(4-Fluorophenyl)(quinoxalin-5-yl)methanone (5n). Methyl quinoxaline-5-carboxylate (18.8 mg, 0.10 mmol) and (4-fluorophenyl)-boronic acid (28.0 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a white solid (22.4 mg, 89%): mp 164−166 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.09 (t, J = 8.0 Hz, 2H), 7.82−7.84 (m, 3H), 7.87 (t, J = 7.2 Hz, 1H), 8.27 (dd, J = 8.4, 1.2 Hz, 1H), 8.77 (d, J = 1.2 Hz, 1H), 8.88 (d, J = 1.2 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 194.9, 166.8, 165.1, 145.6, 145.2, 142.5, 141.0, 139.1, 134.1, 132.8, 132.7, 131.6, 129.4, 129.0, 115.7, 115.5; IR (KBr) ν 1656, 1595, 1489, 1277, 1228, 1153, 1050, 1012, 936, 876, 849, 752 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{15}H_9FN_2O$ 253.0772, found 253.0774. Anal. Calcd for $C_{15}H_9FN_2O$: C, 71.42; H, 3.60; N, 11.11. Found: C, 71.49; H, 3.65; N,11.13.

(4-Bromophenyl)(quinoxalin-5-yl)methanone (5o). Methyl quinoxaline-5-carboxylate (18.8 mg, 0.10 mmol) and (4-bromophenyl)-boronic acid (40.0 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a white solid (14.0 mg, 45%): mp 202−204 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.57 (d, J = 8.4 Hz, 2H), 7.66 (d, J = 8.4 Hz, 2H), 7.83−7.89 (m, 2H), 8.29 (d, J = 8.4 Hz, 1H), 8.76 (s, 1H), 8.84 (s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 195.5, 145.6, 145.2, 142.5, 141.0, 138.8, 136.4, 131.9, 131.8, 131.5, 129.4, 129.2, 128.8; IR (KBr) ν 1658, 1581, 1485, 1274, 1066, 1008, 932, 860, 748 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{15}H_9BrN_2O$ 312.9971, found 312.9975. Anal. Calcd for $C_{15}H_9BrN_2O$: C, 57.53; H, 2.90; N, 8.95. Found: C, 57.61; H, 2.95; N, 8.97

Ethyl 4-(Quinoxaline-5-carbonyl)benzoate (5p). Methyl quinoxaline-5-carboxylate (18.8 mg, 0.10 mmol) and (4-(ethoxycarbonyl)-phenyl)boronic acid (38.8 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/8) as a white solid (27.5 mg, 90%): mp 141−142 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 1.39 (t, J = 7.2 Hz, 3H), 4.39 (q, J = 7.2 Hz, 2H), 7.82−7.90 (m, 4H), 8.08 (d, J = 8.4 Hz, 2H), 8.30 (d, J = 6.6 Hz, 1H), 8.73 (s, 1H), 8.87 (s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 196.1, 165.7, 145.6, 145.1, 142.5, 141.0, 140.9, 138.8, 134.4, 132.0, 129.8, 129.6, 129.5, 129.4, 61.4, 14.2; IR (KBr) ν 1715, 1673, 1573, 1486, 1405, 1271, 1104, 1016, 935, 868, 765 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{18}H_{14}N_2O_3$ 307.1077, found 307.1078. Anal. Calcd for $C_{18}H_{14}N_2O_3$: C, 70.58; H, 4.61; N, 9.15. Found: C, 70.63; H, 4.65; N, 9.17.

(4-Nitrophenyl)(quinoxalin-5-yl)methanone (5q). Methyl quinoxaline-5-carboxylate (18.8 mg, 0.10 mmol) and (4-nitrophenyl)-boronic acid (33.4 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/8) as a yellow solid (26.5 mg, 95%): mp 180−182 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.90−7.94 (m, 4H), 8.25 (d, J = 9.0 Hz, 2H), 8.33 (d, J = 7.8 Hz, 1.2 Hz, 1H), 8.70 (d, J = 1.2 Hz, 1H), 8.87 (d, J = 1.2 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 195.1, 150.2, 145.7, 145.1, 142.5, 142.4, 140.9, 137.9, 132.7, 130.6, 129.9,129.5, 123.5; IR (KBr) ν 1673, 1519, 1402, 1345, 1298, 1272, 933, 762, 723 cm^{-1}; HRMS (ESI-TOF) m/z [M + H] $^+$ calcd for $C_{15}H_9N_3O_3$ 280.0717, found 280.0720. Anal. Calcd for $C_{15}H_9N_3O_3$: C, 64.52; H, 3.25; N, 15.05. Found: C, 64.57; H, 3.28; N, 15.07.

Quinoxalin-5-yl(4-(trifluoromethyl)phenyl)methanone (5r). Methyl quinoxaline-5- carboxylate (18.8 mg, 0.10 mmol) and (4-(trifluoromethyl)phenyl)boronic acid (38.0 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a white solid (24.5 mg, 81%): mp 147−149 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.68 (d, J = 7.2 Hz, 2H), 7.89−7.90 (m, 4H), 8.31−8.32 (m, 1H), 8.74 (s, 1H), 8.89 (s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 195.6, 145.6, 145.2, 142.5, 141.0, 140.5, 138.6, 134.8, 134.6, 134.4, 134.2, 132.2, 130.2, 129.5, 129.4, 125.5, 124.5, 122.6; ^{19}F NMR (376 MHz, $CDCl_3$) δ −63.1; IR (KBr) ν 1675, 1487, 1409, 1325, 1273, 1167, 1127, 1067, 1015, 936, 860, 761 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{16}H_9F_3N_2O$ 303.0740, found 303.0742. Anal. Calcd for $C_{16}H_9F_3N_2O$: C, 63.58; H, 3.00; N, 9.27. Found: C, 63.61; H, 3.05; N, 9.28.

(3,4-Difluorophenyl)(quinoxalin-5-yl)methanone (5s). Methyl quinoxaline-5-carboxylate (18.8 mg, 0.10 mmol) and (3,4-difluorophenyl)boronic acid (31.6 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a white solid (24.6 mg, 91%): mp 122−124 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.16−7.21 (m, 1H), 7.50−7.52 (m, 1H), 7.66−7.70 (m, 1H), 7.84 (dd, J = 7.2 Hz, 1.2 Hz, 1H), 7.88 (t, J = 7.2 Hz, 1H), 8.30 (dd, J = 8.4 Hz, 1.2 Hz, 1H), 8.76 (d, J = 1.8 Hz, 1H), 8.89 (d, J = 1.2 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 194.1, 154.7, 154.6, 153.0, 152.9, 151.2, 151.1, 149.5, 149.4, 145.7, 145.2, 142.5, 140.9, 138.4, 134.8, 132.0, 129.4, 129.2, 127.3, 127.2, 119.0, 118.8, 117.4, 117.3; IR (KBr) ν 1661, 1609, 1512, 1488, 1307, 1284, 1211, 1140, 1012, 913, 747 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{15}H_8F_2N_2O$ 271.0677, found 271.0678. Anal. Calcd for $C_{15}H_8F_2N_2O$: C, 66.67; H, 2.98; N, 10.37. Found: C, 66.71; H, 2.99; N, 10.40.

(3,5-Bis(trifluoromethyl)phenyl)(quinoxalin-5-yl)methanone (5t). Methyl quinoxaline-5- carboxylate (18.8 mg, 0.10 mmol) and (3,5-bis(trifluoromethyl)phenyl)boronic acid (51.6 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a white solid (32.9 mg, 89%): mp 136−138 °C. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.93−7.97 (m, 2H), 8.07 (s, 1H), 8.19 (s, 2H), 8.38 (dd, J = 7.8, 1.8 Hz, 1H), 8.71 (d, J = 1.2 Hz, 1H), 8.92 (d, J = 1.8 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 193.9, 145.9, 145.1, 140.8, 139.5, 137.2, 133.1, 132.2, 132.0, 130.3, 129.7, 126.3, 123.7, 121.9; IR (KBr) ν 1676, 1282, 1183, 1123, 911, 745 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{17}H_8F_6N_2O$ 371.0614, found 371.0619. Anal. Calcd for $C_{17}H_8F_6N_2O$: C, 55.15; H, 2.18; N, 7.57. Found: C, 55.20; H, 2.23; N, 7.59.

(6-Fluoroquinolin-8-yl)(phenyl)methanone (6). Phenyl 6-fluoroquinoline-8-carboxylate (26.7 mg, 0.10 mmol) and phenylboronic acid (24.4 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/

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hexane = 1/15) as a white solid (21.6 mg, 86%): mp 150−152 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.41−7.44 (m, 3H), 7.53 (dd, J = 7.8 Hz, 1.8 Hz, 1H), 7.56−7.58 (m, 2H), 7.82 (d, J = 8.4 Hz, 2H), 8.17 (d, J = 8.4 Hz, 1H), 8.79 (d, J = 4.2 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 196.1, 160.3, 158.7, 150.0, 143.3, 142.1, 142.0, 137.2, 135.4, 135.3, 133.5, 130.1, 129.2, 129.1, 128.4, 122.2, 118.4, 118.3, 112.4, 112.3; ^{19}F NMR (564 MHz, $CDCl_3$) δ −112.8; IR (KBr) ν 3037, 1659, 1578, 1495, 1306, 1272, 1127, 906, 870, 786, 750, 702 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{16}H_{10}FNO$ 252.0819, found 252.0824. Anal. Calcd for $C_{16}H_{10}FNO$: C, 76.48; H, 4.01; N, 5.57. Found: C, 76.51; H, 4.02; N, 5.60.

(5-Chloroquinolin-8-yl)(phenyl)methanone (7). Methyl 5-chloroquinoline-8-carboxylate (22.1 mg, 0.10 mmol) and phenylboronic acid (24.4 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/15) as a white solid (23.2 mg, 87%): mp 95−97 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41 (t, J = 7.6 Hz, 2H), 7.51−7.58 (m, 2H), 7.67 (d, J = 7.6 Hz, 1H), 7.72 (d, J = 7.6 Hz, 1H), 7.81 (d, J = 7.6 Hz, 2H), 8.64 (d, J = 7.2 Hz, 1H), 8.86 (d, J = 3.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.8, 151.3, 146.7, 138.6, 137.6, 133.3, 133.1, 132.8, 130.1, 128.3, 127.9, 126.3, 126.0, 122.3; IR (KBr) ν 3068, 1674, 1597, 1315, 1263, 950, 915, 747 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{16}H_{10}ClNO$ 268.0524, found 268.0527. Anal. Calcd for $C_{16}H_{10}ClNO$: C, 71.78; H, 3.77; N, 5.23. Found: C, 71.81; H, 3.79; N, 5.23.

(7-Chloroquinolin-8-yl)(phenyl)methanone (8). Methyl 7-chloroquinoline-8-carboxylate (22.1 mg, 0.10 mmol) and phenylboronic acid (24.4 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/15) as a white solid (19.2 mg, 72%): mp 148−150 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.40−7.45 (m, 3H), 7.56−7.61 (m, 2H), 7.84−7.88 (m, 3H), 8.20 (d, J = 8.4 Hz, 1H), 8.83 (d, J = 2.4 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 195.2, 151.6, 146.9, 137.3, 136.7, 135.8, 133.7, 131.5, 129.7, 129.5, 128.6, 127.9, 126.6, 121.6; IR (KBr) ν 1669, 1579, 1484, 1264, 1123, 920, 885, 827, 778, 688, 638 cm^{-1}; HRMS (ESI-TOF) m/z [M + H] $^+$ calcd for $C_{16}H_{10}ClNO$ 268.0524, found 268.0528. Anal. Calcd for $C_{16}H_{10}ClNO$: C, 71.78; H, 3.77; N, 5.23. Found: C, 71.85; H, 3.79; N, 5.25.

(5-Bromoquinolin-8-yl)(phenyl)methanone (9). Phenyl 5-bromoquinoline-8-carboxylate (32.6 mg, 0.10 mmol) and phenylboronic acid (24.4 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/15) as a white solid (28.3 mg, 91%): mp 142−144 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41 (t, J = 8.0 Hz, 2H), 7.50−7.61 (m, 3H), 7.81 (d, J = 7.2 Hz, 2H), 7.92 (d, J = 7.6 Hz, 1H), 8.61 (dd, J = 8.4 Hz, 1.2 Hz, 1H), 8.84 (dd, J = 4.0 Hz, 1.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 196.8, 151.3, 146.7, 139.3, 137.6, 135.4, 133.3, 130.1, 129.7, 128.4, 128.3, 127.6, 123.7, 122.7; IR (KBr) ν 1657, 1563, 1491, 1461, 1384, 1318, 1261, 1191, 1176, 933, 835, 779, 715, 692 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{16}H_{10}BrNO$ 312.0019, found 312.0023. Anal. Calcd for $C_{16}H_{10}BrNO$: C, 61.56; H, 3.23; N, 4.49. Found: C, 61.67; H, 3.23; N, 4.51.

(6-Methylquinolin-8-yl)(phenyl)methanone (10). Phenyl 6-methylquinoline-8-carboxylate (26.3 mg, 0.10 mmol) and phenylboronic acid (24.4 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/15) as a yellow solid (22.0 mg, 89%): mp 103−105 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.58 (s, 3H), 7.35−7.42 (m, 3H), 7.53−7.57 (m, 2H), 7.71(d, J = 6.0 Hz, 1H), 8.83 (d, J = 7.6 Hz, 2H), 8.11 (d, J = 8.4 Hz, 1H), 8.76 (d, J = 2.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.9, 149.9, 144.7, 139.1, 137.8, 135.8, 135.3, 133.1, 130.4, 130.2, 128.5, 128.2, 121.5, 29.6; IR (KBr) ν 3060, 2921, 1669, 1273, 1216, 913, 750, 701 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{17}H_{13}NO$ 248.1070, found 248.1073. Anal. Calcd for $C_{17}H_{13}NO$: C, 82.57; H, 5.30; N, 5.66. Found: C, 82.58; H, 5.35; N, 5.69.

(7-Methylquinolin-8-yl)(phenyl)methanone (11). Phenyl 7-methylquinoline-8-carboxylate (26.3 mg, 0.10 mmol) and phenylboronic acid (24.4 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/15) as a white solid (22.5 mg, 91%): mp 130−132 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.38 (s, 3H), 7.32 (dd, J = 8.4 Hz, 4.2 Hz, 1H), 7.40 (t, J = 1.8 Hz, 2H), 7.45 (d, J = 8.4 Hz, 1H), 7.54 (d, J = 7.2 Hz, 1H), 7.81 (d, J = 8.4 Hz, 3H), 8.15 (dd, J = 8.4 Hz, 1.8 Hz, 1H), 8.75 (dd, J = 4.2 Hz, 1.2 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 199.4, 150.5, 146.5, 136.1, 135.5, 133.3, 129.6, 129.4, 129.3, 128.5, 128.1, 126.2, 120.7, 115.3, 19.5; IR (KBr) ν 2959, 1670, 1500, 1450, 1268, 914, 831, 729, 696, 624 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{17}H_{13}NO$ 248.1070, found 248.1072. Anal. Calcd for $C_{17}H_{13}NO$: C, 82.57; H, 5.30; N, 5.66. Found: C, 82.61; H, 5.35; N, 5.69.

(2-Methylquinolin-8-yl)(phenyl)methanone (12). Methyl 2-methylquinoline-8-carboxylate (20.1 mg, 0.10 mmol) and phenylboronic acid (24.4 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/15) as a white solid (21.5 mg, 87%): mp 104−106 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.44 (s, 3H), 7.18 (d, J = 8.4 Hz, 1H), 7.31 (t, J = 7.8 Hz, 2H), 7.45 (t, J = 7.8 Hz, 2H), 7.60 (dd, J = 7.2 Hz, 1.2 Hz, 1H), 7.72 (dd, J = 7.2 Hz, 1.2 Hz, 2H), 7.81 (dd, J = 7.8 Hz, 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.3, 159.6, 145.8, 138.7, 135.7, 132.8, 130.1, 129.4, 128.2, 128.1, 126.3, 124.8, 122.5, 25.4; IR (KBr) ν 1658, 1579, 1496, 1328, 1276, 1203, 932, 763, 719 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{17}H_{13}NO$ 248.1070, found 248.1074. Anal. Calcd for $C_{17}H_{13}NO$: C, 82.57; H, 5.30; N, 5.66. Found: C, 82.60; H, 5.35; N, 5.66.

(5,6-Dimethoxyquinolin-8-yl)(phenyl)methanone (13). Phenyl 5,6-dimethoxyquinoline-8- carboxylate (30.9 mg, 0.10 mmol) and phenylboronic acid (24.4 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a yellow solid (24.9 mg, 85%): mp 97−99 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.01 (s, 3H), 4.08 (s, 3H), 7.36 (dd, J = 5.6 Hz, 2.8 Hz, 1H), 7.41(t, J = 5.2 Hz, 2H), 7.54− 7.57 (m, 2H), 7.82 (d, J = 4.8 Hz, 2H), 8.48 (dd, J = 5.6 Hz, 1.2 Hz, 1H), 8.68 (dd, J = 2.8 Hz, 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.2, 149.0, 147.6, 143.7, 142.0, 138.0, 135.2, 133.1, 130.2, 130.0, 128.2, 123.9, 121.3, 117.6, 61.4, 57.0; IR (KBr) ν 2923, 1664, 1585, 1335, 1232, 1117, 1065, 785, 713 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{18}H_{15}NO_3$ 294.1125, found 294.112. Anal. Calcd for $C_{18}H_{15}NO_3$: C, 73.71; H, 5.15; N, 4.78. Found: C, 73.81; H, 5.19; N, 4.839.

Methyl 8-Benzoylquinoline-5-carboxylate (14). Dimethyl quinoline-5,8-dicarboxylate (24.5 mg, 0.10 mmol) and phenylboronic acid (24.4 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a white solid (26.2 mg, 90%): mp 137−139 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.04 (s, 3H), 7.41 (t, J = 7.6 Hz, 2H), 7.51−7.56 (m, 2H), 7.43 (d, J = 7.2 Hz, 1H), 7.79 (d, J = 7.2 Hz, 2H), 8.36 (d, J = 7.6 Hz, 1H), 8.84 (d, J = 2.8 Hz, 1H), 9.37 (dd, J = 8.8 Hz, 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.2, 166.4, 150.8, 146.2, 144.2, 137.2, 134.2, 133.4, 130.0, 128.4, 128.1, 127.0, 126.2, 122.8, 52.4; IR (KBr) ν 2952, 1718, 1673, 1597, 1501, 1449, 1276, 1199, 1118, 1050, 1009, 797, 713 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{18}H_{13}NO_3$ 292.0968, found 292.0975. Anal. Calcd for $C_{18}H_{13}NO_3$: C, 74.22; H, 4.50; N, 4.81. Found: C, 74.32; H, 4.56; N, 4.83.

Ethyl 8-Benzoyl-4-chloroquinoline-3-carboxylate (15). 3-Ethyl 8-methyl 4-chloroquinoline-3,8-dicarboxylate (29.3 mg, 0.10 mmol) and phenylboronic acid (24.4 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a yellow solid (25.4 mg, 75%): mp 274−276 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 1.42 (t, J = 7.2 Hz, 3H), 4.47 (q, J = 7.2 Hz, 2H), 7.41 (t, J = 7.8 Hz, 2H), 7.56 (t, J = 7.2 Hz, 1H), 7.77 (d, J = 8.4 Hz, 2H), 7.80 (t, J = 8.4 Hz, 1H), 7.88 (d, J = 7.2 Hz, 1H), 8.57 (d, J = 8.4 Hz, 1H), 9.10 (s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 196.7, 164.1, 150.3, 147.2, 143.3, 139.9, 137.6, 133.4, 130.5, 130.0, 128.4, 127.8, 127.1, 126.1, 123.5, 62.1, 14.1; IR (KBr) ν 3061, 2926, 2852, 1731, 1673, 1582, 1474, 1280, 1257, 1212, 1175, 1146, 1024, 781, 687 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{19}H_{14}ClNO_3$ 340.0735, found 340.0741. Anal. Calcd for $C_{19}H_{14}ClNO_3$: C, 67.16; H, 4.15; N, 4.12. Found: C, 67.19; H, 4.22; N, 4.15.

(1,7-Phenanthrolin-6-yl)(phenyl)methanone (17). Methyl 1,7-phenanthroline-6-carboxylate (23.8 mg, 0.10 mmol) and phenylboronic acid (24.4 mg, 0.20 mmol) were used for the preparation of the title

compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a yellow solid (9.9 mg, 35%): mp 213−215 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.42 (t, J = 7.8 Hz, 2H), 7.57 (t, J = 7.8 Hz, 1H), 7.64−7.66 (m, 2H), 7.88−7.90 (m, 2H), 8.00 (s, 1H), 8.29 (dd, J = 7.8 Hz, 1.2 Hz, 1H), 8.95 (dd, J = 4.2 Hz, 1.8 Hz, 1H), 9.11 (dd, J = 4.2 Hz, 1.8 Hz, 1H), 9.61 (dd, J = 8.4 Hz, 1.8 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 197.2, 151.3, 150.3, 147.7, 139.1, 137.6, 136.5, 133.4, 132.7, 130.1, 128.4, 127.8, 126.9, 125.2, 122.9, 122.4; IR (KBr) ν 3059, 1673, 1596, 1445, 1276, 921, 751 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{19}H_{12}N_2O$ 285.1022, found 285.1025. Anal. Calcd for $C_{19}H_{12}N_2O$: C, 80.27; H, 4.25; N, 9.85. Found: C, 80.35; H, 4.31; N, 9.86.

Benzo[*f*]quinolin-5-yl(phenyl)methanone (18). Phenyl benzo[f]quinoline-5-carboxylate (29.9 mg, 0.10 mmol) and phenylboronic acid (24.4 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a yellow solid (26.9 mg, 95%): mp 158−160 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41 (t, J = 7.6 Hz, 2H), 7.53−7.58 (m, 2H), 7.71 (t, J = 7.2 Hz, 1H), 7.78 (t, J = 7.2 Hz, 1H), 7.90 (d, J = 7.6 Hz, 2H), 7.97 (d, J = 8.0 Hz, 1H), 8.03 (s, 1H), 8.67 (d, J = 8.0 Hz, 1H), 8.86 (d, J = 3.2 Hz, 1H), 8.99 (d, J = 8.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.7, 149.7, 146.4, 138.1, 137.8, 133.1, 130.7, 130.5, 130.2, 130.1, 129.6, 129.3, 128.3, 128.1, 127.8, 125.4, 122.6, 121.7; IR (KBr) ν 3057, 1671, 1595, 1445, 1248, 915, 749 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{20}H_{13}NO$ 284.1070, found 284.1075. Anal. Calcd for $C_{20}H_{13}NO$: C, 84.78; H, 4.62; N, 4.94. Found: C, 84.83; H, 4.65; N, 4.97.

(3-Methylbenzo[*f*]quinolin-5-yl)(phenyl)methanone (19). Phenyl 3-methylbenzo[f]quinoline-5-carboxylate (31.3 mg, 0.10 mmol) and phenylboronic acid (24.4 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a yellow solid (27.6 mg, 93%): mp 138−140 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.55 (s, 3H), 7.38−7.43 (m, 3H), 7.54 (t, J = 7.2 Hz, 1H), 7.66 (t, J = 7.2 Hz, 1H), 7.75 (t, J = 8.0 Hz, 1H), 7.86 (d, J = 7.2 Hz, 2H), 7.96 (d, J = 8.0 Hz, 1H), 8.00 (s, 1H), 8.63 (d, J = 8.4 Hz, 1H), 8.85 (d, J = 8.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.1, 158.7, 146.1, 138.3, 137.9, 132.8, 130.6, 130.4, 130.1, 130.0, 129.4, 129.3, 128.1, 127.9, 127.2, 123.0, 122.3, 122.2, 24.9; IR (KBr) ν 2961, 1662, 1401, 1259, 1088, 1018, 796 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{21}H_{15}NO$ 298.1226, found 298.1233. Anal. Calcd for $C_{21}H_{15}NO$: C, 84.82; H, 5.08; N, 4.71. Found: C, 84.90; H, 5.11; N, 4.75.

Preparation of Substituted Quinoline-8-carboxylic Acid. A mixture of substituted anthranilic acids or methyl 2-aminobenzoate (7.5 mmol), nitrobenzene (4.5 mmol), anhydrous glycerol (27 mmol), and concentrated sulfuric acid (1.5 mL) was warmed gently until reaction began. After the initial vigorous reaction had subsided, the mixture was refluxed gently for 7 h, cooled, and poured onto ice. The solution was adjusted to a pH of 6−7 with NaOH solution and extracted with chloroform. The crude was recrystallized by ethanol to give the title compound.

Synthesis of Substituted Methyl or Phenyl Quinoline-8-carboxylate. *Procedure 1.* Concentrated sulfuric acid was added to the mixture of quinoline-8-carboxylic acid and methanol until the quinoline-8-carboxylic acid has completely dissolved. The mixture was refluxed to the end of the reaction. An aqueous NaOH solution was added until the solution was basified. After removal of the methanol in vacuum, the mixture was extracted with ethyl acetate. The combined organic layers were then dried over anhydrous Mg_2SO_4 and concentrated in vacuo. The crude compound was purified by flash chromatography to give the desired product.

Procedure 2. In a flame dried flask, the mixture of substituted quinoline-8-carboxylic acid (1.0 mmol), dicyclohexylcarbodiimide (DCC, 195.8 mg, 0.95 mmol), *N*,*N*-dimethyl-4-aminopyridine (DMAP, 36.6 mg, 0.3 mmol) and phenol (94 mg, 1.0 mmol), and dichloromethane (1.5 mL) was stirred overnight. The reaction mixture was diluted with CH_2Cl_2 and washed with saturated aqueous NH_4Cl followed by saturated aqueous $NaHCO_3$. The organic portion was dried over Na_2SO_4 and concentrated. The resulting crude product was further purified by flash chromatography to obtain the desired product .

*Methyl Quinoline-8-carboxylate (**1**).* Quinoline-8-carboxylic acid (1.73 g, 10 mmol) was used for the preparation of the title compound according to procedure 1 and purified by silica gel column chromatography (EtOAc/hexane = 1/8) as a white viscous liquid (1.12 g, 60%): ^{1}H NMR (600 MHz, $CDCl_3$) δ 4.06 (s, 3H), 7.46 (dd, J = 7.8, 3.6 Hz, 1H), 7.57 (d, J = 7.8 Hz, 1H), 7.95 (dd, J = 8.4, 1.2 Hz, 1H), 8.04 (dd, J = 7.2, 1.2 Hz, 1H), 8.20 (dd, J = 8.4, 1.8 Hz, 1H), 9.06 (dd, J = 4.2, 1.2 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 168.0, 151.2, 145.2, 135.9, 131.0, 130.1, 128.1, 125.3, 121.3, 52.3; IR (KBr) ν 3066, 2925, 1703, 1583, 1522, 1380, 1293, 1191, 1068, 956, 841, 806, 774 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{11}H_9NO_2$ 188.0706, found 188.0710. Anal. Calcd for $C_{11}H_9NO_2$: C, 70.58; H, 4.85; N, 7.48. Found: C, 70.64; H, 4.85; N, 7.51.

*Phenyl 6-Fluoroquinoline-8-carboxylate (**6′**).* 6-Fluoroquinoline-8-carboxylic acid (191 mg, 1.0 mmol) was used for the preparation of the title compound according to procedure 2 and purified by silica gel column chromatography (EtOAc/hexane = 1/8) as a yellow viscous liquid (200 mg, 75%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.29 (t, J = 7.2 Hz, 1H), 7.37−7.50 (m, 5H), 7.62 (dd, J = 8.4, 2.8 Hz, 1H), 8.01 (dd, J = 8.4 Hz, 2.8 Hz, 1H), 8.15 (dd, J = 8.4 Hz, 0.8 Hz, 1H), 9.04 (d, J = 2.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 164.6, 158.9 (d, $^1J_{C-F}$ = 248.2 Hz), 150.9, 150.8, 150.7, 142.8, 135.5 (d, $^3J_{C-F}$ = 5.1 Hz), 129.4, 129.3 (d, $^3J_{C-F}$ = 9.5 Hz), 126.0, 122.3, 121.6, 120.7 (d, $^2J_{C-F}$ = 27.6 Hz), 114.5 (d, $^2J_{C-F}$ = 20.9 Hz); ^{19}F NMR (376 MHz, $CDCl_3$) δ −112.9; IR (KBr) ν 1754, 1491, 1269, 1191, 1000, 737 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{16}H_{10}FNO_2$ 268.0768, found 268.0771. Anal. Calcd for $C_{16}H_{10}FNO_2$: C, 71.91; H, 3.77; N, 5.24. Found: C, 71.95; H, 3.78; N, 5.24.

*Methyl 5-Chloroquinoline-8-carboxylate (**7′**).* 5-Chloroquinoline-8-carboxylic acid (207 mg, 1.0 mmol) was used for the preparation of the title compound according to procedure 1 and purified by silica gel column chromatography (EtOAc/hexane = 1/8) as a white solid (176 mg, 80%): mp 43−45 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.04 (s, 3H), 7.56 (dd, J = 8.0, 4.0 Hz, 1H), 7.65 (d, J = 7.6 Hz, 1H), 7.95 (d, J = 7.6 Hz, 1H), 8.61 (d, J = 8.4 Hz, 1H), 9.09 (d, J = 2.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.4, 146.1, 134.8, 133.0, 130.1, 128.8, 126.5, 125.7, 122.3, 52.6; IR (KBr) ν 2952, 2851, 1732, 1568, 1495, 1434, 1311, 1265, 1194, 1177, 1137, 1029, 795 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{11}H_8ClNO_2$ 222.0316, found 222.0322. Anal. Calcd for $C_{11}H_8ClNO_2$: C, 59.61; H, 3.64; N, 6.32. Found: C, 59.72; H, 3.68; N, 6.32.

*Methyl 7-Chloroquinoline-8-carboxylate (**8′**).* 7-Chloroquinoline-8-carboxylic acid (207 mg, 1.0 mmol) was used for the preparation of the title compound according to procedure 1 and purified by silica gel column chromatography (EtOAc/hexane = 1/8) as a white solid (166 mg, 75%): mp 80−82 °C. ^{1}H NMR (600 MHz, $CDCl_3$) δ 4.10 (s, 3H), 7.44 (dd, J = 8.4, 4.2 Hz, 1H), 7.53 (d, J = 8.0 Hz, 1H), 7.80 (d, J = 8.0 Hz, 1H), 8.15 (d, J = 7.8 Hz, 1H), 8.95 (d, J = 3.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.9, 151.9, 145.8, 135.8, 132.9, 131.7, 129.7, 127.6, 126.4, 121.7, 52.9; IR (KBr) ν 2951, 1737, 1607, 1572, 1489, 1268, 1224, 1145, 1033, 860, 800, 736 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{11}H_8ClNO_2$ 222.0316, found 222.0318. Anal. Calcd for $C_{11}H_8ClNO_2$: C, 59.61; H, 3.64; N, 6.32. Found: C, 59.65; H, 3.64; N, 6.34.

*Phenyl 5-Bromoquinoline-8-carboxylate (**9′**).* 5-Bromoquinoline-8-carboxylic acid (251 mg, 1.0 mmol) was used for the preparation of the title compound according to procedure 2 and purified by silica gel column chromatography (EtOAc/hexane = 1/8) as a white viscous liquid (209 mg, 64%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.29 (t, J = 7.2 Hz, 1H), 7.38 (d, J = 7.6 Hz, 2H), 7.45 (t, J = 7.6 Hz, 2H), 7.59 (dd, J = 8.8 Hz, 4.4 Hz, 1H), 7.93 (d, J = 8.0 Hz, 1H), 8.08 (d, J = 8.0 Hz, 1H), 8.61 (dd, J = 8.4, 1.2 Hz, 1H), 9.10 (dd, J = 4.0, 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 165.4, 152.1, 151.0, 146.3, 135.6, 130.6, 129.5, 129.4, 127.9, 125.9, 122.8, 121.7; IR (KBr) ν 3071, 3041, 1752, 1565, 1491, 1306, 1252, 1191, 1168, 1129, 989, 919, 835, 797, 737, 689 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{16}H_{10}BrNO_2$ 327.9968, found 327.9970. Anal. Calcd for $C_{16}H_{10}BrNO_2$: C, 58.56; H, 3.07; N, 4.27. Found: C, 58.65; H, 3.12; N, 4.29.

*Phenyl 6-Methylquinoline-8-carboxylate (**10′**).* 6-Methylquinoline-8-carboxylic acid (187 mg, 1.0 mmol) was used for the preparation of the

title compound according to procedure 2 and purified by silica gel column chromatography (EtOAc/hexane = 1/8) as a white solid (213 mg, 81%): mp 77−79 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.55 (s, 3H), 7.22−7.26 (m, 1H), 7.36−7.43 (m, 5H), 7.71 (s, 1H), 8.07 (dd, J = 8.4 Hz, 1.2 Hz, 2H), 8.98 (dd, J = 4.2 Hz, 1.8 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 165.9, 151.1, 150.7, 144.4, 135.4, 132.9, 130.6, 130.3, 129.3, 128.5, 125.7, 121.8, 121.6, 21.3; IR (KBr) ν 3045, 2926, 1753, 1589, 1492, 1260, 1190, 1163, 1142, 1054, 995, 836, 779 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{17}H_{13}NO_2$ 264.1019, found 264.1025. Anal. Calcd for $C_{17}H_{13}NO_2$: C, 77.55; H, 4.98; N, 5.32. Found: C, 77.65; H, 5.01; N, 5.33.

*Phenyl 7-Methylquinoline-8-carboxylate (**11′**).* 7-Methylquinoline-8-carboxylic acid (187 mg, 1.0 mmol) was used for the preparation of the title compound according to procedure 2 and purified by silica gel column chromatography (EtOAc/hexane = 1/8) as a white solid (171 mg, 65%): mp 67−69 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.69 (s, 3H), 7.28−7.31 (m, 1H), 7.40 (dd, J = 8.4, 4.2 Hz, 1H), 7.43−7.49 (m, 5H), 7.81 (d, J = 8.4 Hz, 1H), 8.13 (d, J = 7.8 Hz, 1H), 8.97 (dd, J = 4.2, 1.8 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 167.9, 151.1, 151.0, 145.7, 136.2, 135.4, 132.1, 129.4, 128.8, 126.1, 125.9, 121.8, 121.0, 19.6; IR (KBr) ν 3043, 2927, 1751, 1595, 1490, 1265, 1239, 1190, 1160, 1142, 1124, 1052, 996, 833, 788, 689 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{17}H_{13}NO_2$ 264.1019, found 264.1022. Anal. Calcd for $C_{17}H_{13}NO_2$: C, 77.55; H, 4.98; N, 5.32. Found: C, 77.64; H, 4.98; N, 5.35.

*Methyl 2-Methylquinoline-8-carboxylate (**12′**).* 2-Methylquinoline-8-carboxylic acid (187 mg, 1.0 mmol) was used for the preparation of the title compound according to procedure 1 and purified by silica gel column chromatography (EtOAc/hexane = 1/8) as a yellow viscous liquid (122 mg, 61%): ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.71 (s, 3H), 4.01 (s, 3H), 7.21 (d, J = 8.4 Hz, 1H), 7.40 (t, J = 7.2 Hz, 1H), 7.78 (d, J = 8.4 Hz, 1H), 7.92 (d, J = 7.2 Hz, 1H), 7.94 (d, J = 8.4 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 168.2, 159.9, 144.8, 135.6, 130.9, 130.4, 129.5, 126.2, 124.2, 122.1, 52.0, 25.4; IR (KBr) ν 2950, 1731, 1600, 1569, 1498, 1428, 1373, 1328, 1275, 1198, 1141, 1039, 840, 804, 766, 748 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{12}H_{11}NO_2$ 202.0863, found 202.0870. Anal. Calcd for $C_{12}H_{11}NO_2$: C, 71.63; H, 5.51; N, 6.96. Found: C, 71.70; H, 5.53; N, 6.96.

*Phenyl 5,6-Dimethoxyquinoline-8-carboxylate (**13′**).* 5,6-Dimethoxyquinoline-8-carboxylic acid (233 mg, 1.0 mmol) was used for the preparation of the title compound according to procedure 2 and purified by silica gel column chromatography (EtOAc/hexane = 1/5) as a white solid (225 mg, 73%): mp 80−82 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.07 (s, 3H), 4.10 (s, 3H), 7.28 (t, J = 7.2 Hz, 1H), 7.38 (d, J = 8.0 Hz, 2H), 7.42−7.47 (m, 3H), 8.15 (s, 1H), 8.53 (d, J = 8.4 Hz, 1H), 8.98 (d, J = 2.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 165.1, 151.1, 149.9, 146.8, 145.7, 142.1, 130.2, 129.3, 125.7, 124.2, 121.8, 121.3, 120.7, 61.3, 57.0; IR (KBr) ν 2938, 2851, 1750, 1593, 1494, 1338, 1192, 1113, 1068, 966, 793, 733 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{18}H_{15}NO_4$ 310.1074, found 310.1078. Anal. Calcd for $C_{18}H_{15}NO_4$: C, 69.89; H, 4.89; N, 4.53. Found: C, 69.93; H, 4.92; N, 4.55.

*Dimethyl Quinoline-5,8-dicarboxylate (**14′**).* 8-(Methoxycarbonyl)quinoline-5-carboxylic acid (231 mg, 1.0 mmol) was used for the preparation of the title compound according to procedure 1 and purified by silica gel column chromatography (EtOAc/hexane = 1/8) as a white solid (135 mg, 55%): mp 94−96 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.02 (s, 3H), 4.07 (s, 3H), 7.55 (dd, J = 8.8, 4.0 Hz, 1H), 7.93 (d, J = 7.2 Hz, 1H), 8.27 (d, J = 7.6 Hz, 1H), 9.05 (dd, J = 8.0, 1.6 Hz, 1H), 9.34 (dd, J = 8.8, 1.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ168.0, 166.2, 151.2, 145.3, 136.8, 134.3, 129.5, 129.1, 127.6, 127.1, 122.8, 52.8, 52.4; IR (KBr) ν 2953, 1720, 1503, 1434, 1279, 1174, 1136, 1032, 798, 762, 748 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{13}H_{11}NO_4$ 246.0761, found 246.0765. Anal. Calcd for $C_{13}H_{11}NO_4$: C, 63.67; H, 4.52; N, 5.71. Found: C, 63.73; H, 4.53; N, 5.74.

*Methyl 1,7-Phenanthroline-6-carboxylate (**17′**).* 1,7-Phenanthroline-6-carboxylic acid (224 mg, 1.0 mmol) was used for the preparation of the title compound according to procedure 1 and purified by silica gel column chromatography (EtOAc/hexane = 1/5) as a yellow viscous liquid (71 mg, yield: 30%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.09 (s, 3H), 7.61 (dd, J = 8.0, 4.0 Hz, 1H), 7.68 (dd, J = 8.4, 4.4 Hz, 1H), 8.25−8.28 (m, 2H), 9.06 (dd, J = 4.0, 1.2 Hz, 1H), 9.14 (dd, J = 4.0, 1.2 Hz, 1H), 9.58 (dd, J = 8.4, 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.8, 151.6, 150.8, 146.6, 146.5, 136.6, 132.8, 131.4, 130.4, 127.1, 124.6, 122.8, 122.3, 52.7; IR (CH_2Cl_2) ν 3054, 2988, 2952, 1732, 1428, 1265, 1029, 798, 740 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{14}H_{10}N_2O_2$ 239.0815, found 239.0819. Anal. Calcd for $C_{14}H_{10}N_2O_2$: C, 70.58; H, 4.23; N, 11.76. Found: C, 70.65; H, 4.29; N, 11.78.

*Phenyl Benzo[f]quinoline-5-carboxylate (**18′**).* Benzo[f]quinoline-5-carboxylic acid (223 mg, 1.0 mmol) was used for the preparation of the title compound according to procedure 2 and purified by silica gel column chromatography (EtOAc/hexane = 1/5) as a white solid (114 mg, 38%): mp 99−101 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.30 (t, J = 7.6 Hz, 1H), 7.43−7.49 (m, 4H), 7.60−7.62 (m, 1H), 7.70 (t, J = 7.2 Hz, 1H), 7.78 (t, J = 7.2 Hz, 1H), 8.01 (d, J = 7.8 Hz, 1H), 8.52 (s, 1H), 8.61 (d, J = 7.8 Hz, 1H), 8.95 (d, J = 8.4 Hz, 1H), 9.08 (d, J = 3.6 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 166.0, 151.1, 150.0, 145.2, 132.7, 130.9, 130.6, 129.8, 129.7, 129.3, 128.9, 127.8, 125.8, 125.6, 122.5, 121.8; IR (KBr) ν 3065, 1746, 1592, 1490, 1192, 1170, 977, 791, 751 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{20}H_{13}NO_2$ 300.1019, found 300.1021. Anal. Calcd for $C_{20}H_{13}NO_2$: C, 80.25; H, 4.38; N, 4.68. Found: C, 80.31; H, 4.39; N, 4.71.

*Phenyl 3-Methylbenzo[f]quinoline-5-carboxylate (**19′**).* 3-Methylbenzo[f]quinoline-5-carboxylic acid (237 mg, 1.0 mmol) was used for the preparation of the title compound according to procedure 2 and purified by silica gel column chromatography (EtOAc/hexane = 1/5) as a white solid (141 mg, 45%): mp 90−92 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.82 (s, 3H), 7.30 (t, J = 7.2 Hz, 1H), 7.45−7.51 (m, 5H), 7.68 (t, J = 7.2 Hz, 1H), 7.77 (t, J = 7.2 Hz, 1H), 8.02 (d, J = 7.8 Hz, 1H), 8.42 (s, 1H), 8.61 (d, J = 8.4 Hz, 1H), 8.86 (d, J = 9.0 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 167.0, 159.0, 151.4, 144.8, 131.6, 130.9, 130.7, 130.2, 129.7, 129.5, 129.4, 128.6, 127.2, 125.8, 123.3, 122.3, 121.9, 115.3, 25.1; IR (KBr) ν 3062, 2924, 1747, 1594, 1490, 1320, 1223, 1193, 1026, 800, 741, 690 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{21}H_{15}NO_2$ 314.1177, found 314.1176. Anal. Calcd for $C_{21}H_{15}NO_2$: C, 80.49; H, 4.82; N, 4.47. Found: C, 80.52; H, 4.85; N, 4.47.

Synthesis of Methyl Quinoxaline-5-carboxylate (2).[22] (1) 2-(Hydroxyimino)-*N*-(2-nitrophenyl)acetamide (**S1**): A solution of chloral hydrate (29 g, 175 mmol), hydroxylamine hydrochloride (69.4 g, 1000 mmol), and anhydrous sodium sulfate (21 g, 149 mmol) in water (800 mL) was heated to 65 °C. To this a suspension was added 2-nitroaniline (20 g, 150 mmol) in 2 molar aqueous HCl (20 mL). This mixture was stirred overnight at the same temperature, then cooled to room temperature. The precipitated product was collected by filtration, washed with water dried in a vacuum oven to give 25 g of the required product as a yellow solid. Yield: 83%.

(2) 7-Nitroindoline-2,3-dione (**S2**): 2-(Hydroxyimino)-*N*-(2-nitrophenyl)acetamide (15 g, 72 mol) was carefully added in small portions to a stirred solution of preheated (90 °C) concentrated sulfuric acid (45 mL) over a period of 30 min, and the resulting mixture was stirred for another 2 h at the same temperature. It was then cooled to room temperature and poured into crushed ice, and the precipitated products were collected by filtrations. The collected precipitated products were washed with water and dried in a vacuum oven to get a brick red powder. Yield: 91%.

(3) 2-Amino-3-nitrobenzoic acid (**S3**): To an ice-cold solution of 7-nitroindoline-2,3-dione (9 g, 47 mmol) in 2 M aqueous sodium hydroxide (50 mL) was added 30% hydrogen peroxide (9 mL) dropwise. The mixture was warmed to room temperature and stirred overnight. The mixture was carefully acidified by addition of a saturated citric acid solution. The solid precipitate was collected by filtration, washed with water, and dried in a vacuum oven to get 6 g of the required product as a yellow solid. Yield: 70%

(4) Methyl 2-amino-3-nitrobenzoate (**S4**): 2-Amino-3-nitrobenzoic acid (4 g, 21.98 mmol) was dissolved in a solution of HCl/methanol (4 M, 60 mL), and the mixture was refluxed for 12 h under nitrogen. After completion of the reaction, the mixture was concentrated under reduced pressure and then neutralized with saturated aq $NaHCO_3$. The aqueous layer was extracted with EtOAc, and the organic layer was combined and washed with brine, dried over anhydrous sodium sulfate, concentrated in

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vacuo to give a crude product that was purified by flash chromatography (EtOAc/hexane = 1/15). Yield: 50%.

(5) Methyl 2,3-diaminobenzoate (**S5**): To a solution of methyl 2-amino-3-nitrobenzoate (2 g, 10 mmol) in methanol was added a suspension of 10% Pd/C (300 mg) in methanol (5 mL) and the mixture hydrogenated with a hydrogen balloon over a period of 8 h. The reaction mixture was filtered, and the filtrate was concentrated under reduced pressure to afford the required compound as a brown solid (1.5 g, 88%).

(6) Methyl quinoxaline-5-carboxylate (**2**): The mixture of methyl 2,3-diaminobenzoate (2 mmol) and H_2O (10 mL) was heated to reflux, and sodium glyoxal bisulfite (2.1 mmol) was added dropwise to the reaction solution over 15 min. Then, the resulting solution was stirred for 0.5 h and until complete by TLC analysis. A 10% aq solution of sodium carbonate was added to the reaction mixture.The mixture was extracted with ethyl acetate. The combined organics were then dried over anhydrous Na_2SO_4 and concentrated in vacuo. The crude compound was purified by column chromatography (EtOAc/hexane = 1/10) to afford the final product as a white solid: yield 87%; mp 68−70 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.05 (s, 3H), 7.81 (t, J = 8.0 Hz, 1H), 8.16 (d, J = 7.2 Hz, 1H), 8.25 (d, J = 8.8 Hz, 1H), 8.90 (s, 1H), 8.99 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.8, 145.6, 145.2, 142.6, 140.6, 133.1, 128.9, 52.6; IR (KBr) ν 2962, 2849, 1732, 1490, 1302, 1278, 1038, 869, 840, 772, 750 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{10}H_8N_2O_2$ 189.0659, found 189.0662. Anal. Calcd for $C_{10}H_8N_2O_2$: C, 63.82; H, 4.28; N, 14.89. Found: C, 63.95; H, 4.35; N, 14.91.

*Methyl 2,3-Diphenylquinoxaline-5-carboxylate (**16′**).* The product was prepared using benzil as the reaction partner according to procedure 6 and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a white solid (289 mg, 85%): mp 127−129 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 4.06 (s, 3H), 7.31−7.39 (m, 6H), 7.58 (d, J = 7.2 Hz, 2H), 7.64 (d, J = 7.2 Hz, 2H), 7.77 (t, J = 7.8 Hz, 1H), 8.17 (d, J = 7.2 Hz, 1H), 8.29 (d, J = 8.4 Hz, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 167.0, 153.4, 153.3, 140.5, 138.9, 138.8, 138.5, 132.8, 131.2, 130.2, 129.7, 129.1, 129.0, 128.7, 128.3, 128.1, 52.4; IR (KBr) ν 3084, 1733, 1565, 1442, 1391, 1342, 1289, 1221, 1139, 1055, 1019, 769, 697 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{22}H_{16}N_2O_2$ 341.1285, found 341.1288. Anal. Calcd for $C_{22}H_{16}N_2O_2$: C, 77.63; H, 4.74; N, 8.23. Found: C, 77.71; H, 4.77; N, 8.27.

Synthesis of the 3-Ethyl 8-Methyl 4-(*o*-Tolylamino)quinoline-3,8-dicarboxylate. (1) **Diethyl 2-(((2-(methoxycarbonyl)phenyl)amino)methylene)malonate (27)**:[21a] The mixture of diethyl 2-(ethoxymethylene)malonate **26** (10.80 g, 0.05 mol) and methyl 2-aminobenzoate **25** (7.5 g, 0.05 mol) was stirred at 373 K in an open 50 mL round-bottom flask as long as no ethanol was produced (ca. 1−1.5 h). The yellow solution was cooled to room temperature. The product crystallized almost completely overnight. The crystals were collected by filtration, washed with a small amount of *n*-pentane, and dried in vacuum at room temperature. The filtrate was reduced in vacuo. The crystallization and washing procedure was repeated until no product precipitated. Yield: 90% (14.4 g).

(2) **3-Ethyl 8-methyl 4-oxo-1,4-dihydroquinoline-3,8-dicarboxylate (28)**:[21a] Diethyl 2-(((2-(methoxycarbonyl)phenyl)amino)-methylene)malonate **27** (6.1 g, 19 mmol) was dissolved in melted diphenyl ether (50 mL) and heated to ca. 523 K via a heating mantle. After 30 min, the solution was cooled down to room temperature. The product started to precipitate during cooling. For complete precipitation *n*-pentane (100 mL) was added. The solid product was collected by filtration, washed with *n*-pentane (20 mL) and acetone (20 mL), and dried in vacuum to give product **28**. Yield: 85% (4.44 g).

(3) **3-Ethyl 8-methyl 4-chloroquinoline-3,8-dicarboxylate (29)**:[21a] 3-Ethyl 8-methyl 4-oxo-1,4- dihydroquinoline-3,8-dicarboxylate **28** (2.48 g, 9 mmol) was furnished in a 50 mL three-neck round-bottom flask with reflux condenser. Phosphorus trichloride (2.34 g, 15 mmol) was added under an argon atmosphere, and the mixture was heated at 373 K. The solution was cooled after 15 min. Excess o$POCl_3$ was hydrolyzed at 273 K with H_2O (6 mL) and concentrated aqueous ammonia (20 mL). The mixture was extracted with dichloromethane (3 × 20 mL), and the organic phase was dried over $MgSO_4$. After removal of the solvent in vacuum the product was purified by flash chromatography (EtOAc/hexane = 1/8): yellow solid; yield 98% (2.58 g); mp 155−157 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 1.43 (t, J = 7.2 Hz, 3H), 4.04 (s, 3H), 4.49 (q, J = 7.2 Hz, 2H), 7.11 (t, J = 7.8 Hz, 1H), 8.10 (d, J = 7.2 Hz, 1H), 8.54 (d, J = 8.4 Hz, 1H), 9.29 (s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 167.5, 164.0, 150.9, 146.7, 143.4, 132.4, 132.2, 128.4, 127.3, 126.3, 123.4, 62.1, 52.7, 14.1; IR (KBr) ν 3079, 2955, 1731, 1616, 1519, 1437, 1371, 1285, 1204, 1076, 772 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{14}H_{12}ClNO_4$ 294.0528, found 294.0531. Anal. Calcd for $C_{14}H_{12}ClNO_4$: C, 57.25; H, 4.12; N, 4.77. Found: C, 57.32; H, 4.15; N, 4.78.

(4) **3-Ethyl 8-methyl 4-(*o*-tolylamino)quinoline-3,8-dicarboxylate (30)**:[21b] A solution of 3-ethyl 8-methyl 4-chloroquinoline-3,8-dicarboxylate **29** (3.72 g, 12.7 mmol) and 2-toluidine (1.47 g, 13.8 mmol) was heated in refluxing 1,4-dioxane (70 mL) for 2 h. The yellow solid which formed was removed by filtration of the hot suspension and taken up in CH_2Cl_2 (100 mL). The CH_2Cl_2 solution was washed with NaOH solution (3 × 25 mL), dried, and concentrated in vacuo to give a yellow solid, which was recrystallized to give the product **30** (4.11 g, 89%): mp 122−124 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 1.42 (t, J = 7.2 Hz, 3H), 2.38 (s, 3H), 4.03 (s, 3H), 4.42 (q, J = 7.2 Hz, 2H), 6.82 (d, J = 7.8 Hz, 1H), 7.04 (t, J = 7.2 Hz, 1H), 7.07−7.12 (m, 2H), 7.28 (d, J = 7.8 Hz, 1H), 7.62 (d, J = 8.0 Hz, 1H), 7.83 (d, J = 6.6 Hz, 1H), 9.36 (s, 1H), 10.42 (s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 168.4, 168.3, 153.2, 152.2, 148.1, 140.9, 132.4, 131.6, 131.1, 128.9, 126.7, 125.4, 123.2, 123.1, 119.7, 105.9, 61.1, 52.5, 18.2, 14.1; IR (KBr) ν 3233, 3173, 3055, 2982, 2950, 1736, 1677, 1578, 1514, 1461, 1268, 1209, 1171, 1108, 1027, 753, 712 cm^{-1}; HRMS (ESI-TOF) m/z [M + H] $^+$ Calcd for $C_{21}H_{20}N_2O_4$ 365.1496, found 365.1497. Anal. Calcd for $C_{21}H_{20}N_2O_4$: C, 69.22; H, 5.53; N, 7.69. Found: C, 69.28; H, 5.56; N, 7.70.

(5) **Ethyl 8-benzoyl-4-(*o*-tolylamino)quinoline-3-carboxylate (26a):** 3-Ethyl 8-methyl 4-(*o*-tolylamino)quinoline-3,8-dicarboxylate (36.4 mg, 0.10 mmol) and phenylboronic acid (24.4 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a yellow solid (37.7 mg, 92%): mp 133−135 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 1.39 (t, J = 7.2 Hz, 3H), 2.42 (s, 3H), 4.39 (q, J = 7.2 Hz, 2H), 6.92 (d, J = 7.8 Hz, 1H), 7.11 (t, J = 7.2 Hz, 1H), 7.14−7.18 (m, 2H), 7.33 (d, J = 7.2 Hz, 1H), 7.41 (d, J = 7.8 Hz, 2H), 7.55 (t, J = 7.2 Hz, 1H), 7.59−7.63 (m, 2H), 7.82 (d, J = 7.2 Hz, 2H), 9.16 (s, 1H), 10.49 (s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 197.8, 168.5, 153.2, 151.6, 148.7, 141.0, 139.7, 137.8, 133.1, 131.9, 131.2, 130.0, 129.5, 128.3, 127.7, 126.7, 125.6, 123.6, 123.5, 119.4, 105.7, 61.1, 18.2, 14.1; IR (KBr) ν 1674, 1577, 1514, 1447, 1373, 1269, 1207, 1171, 1025, 895, 789, 751, 716 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{26}H_{22}N_2O_3$ 411.1703, found 411.1706. Anal. Calcd for $C_{26}H_{22}N_2O_3$: C, 76.08; H, 5.40; N, 6.82. Found: C, 76.14; H, 5.45; N, 6.82.

(6) **Ethyl 8-(4-methylbenzoyl)-4-(o-tolylamino)quinoline-3-carboxylate (26b):** 3-ethyl 8-methyl 4-(*o*-tolylamino)quinoline-3,8-dicarboxylate (36.4 mg, 0.10 mmol) and p-tolylboronic acid (27.2 mg, 0.20 mmol) was used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a yellow solid (40.3 mg, 95%): mp 180−182 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 1.38 (t, J = 7.2 Hz, 3H), 2.40 (s, 3H), 2.42 (s, 3H), 4.39 (q, J = 7.2 Hz, 2H), 6.92 (d, J = 7.8 Hz, 1H), 7.10 (t, J = 7.2 Hz, 1H), 7.13−7.17 (m, 2H), 7.21 (d, J = 7.8 Hz, 2H), 7.32 (d, J = 7.2 Hz, 1H), 7.57−7.61 (m, 2H), 7.72 (d, J = 8.4 Hz, 2H), 9.17 (s, 1H), 10.4 (s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 197.4, 168.5, 153.1, 151.6, 148.7, 143.9, 141.0, 140.0, 135.4, 131.8, 131.2, 130.2, 129.4, 129.0, 127.6, 126.7, 125.6, 123.6, 123.5, 119.4, 115.1, 105.7, 61.1, 21.7, 18.2; IR (KBr) ν 3234, 3052, 3027, 2979, 2925, 2856, 1673, 1605, 1577, 1514, 1461, 1268, 1208, 1171, 1029, 895, 789, 752 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{27}H_{24}N_2O_3$ 425.1860, found 425.1862. Anal. Calcd for $C_{27}H_{24}N_2O_3$: C, 76.39; H, 5.70; N, 6.60. Found: C, 76.44; H, 5.72; N, 6.65.

(7) **Ethyl 8-(4-fluorobenzoyl)-4-(o-tolylamino)quinoline-3-carboxylate (26c):** 3-Ethyl 8-methyl 4-(*o*-tolylamino)quinoline-3,8-dicarboxylate (36.4 mg, 0.10 mmol) and (4-fluorophenyl)boronic acid (28.0 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a yellow solid (39.4 mg, 92%): mp 171−173 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 1.39 (t, J = 7.2 Hz, 3H), 2.42 (s, 3H), 4.39 (q, J = 7.2 Hz, 2H), 6.93 (d, J = 7.8 Hz, 1H), 7.06−7.18 (m, 5H), 7.33 (d,

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J = 7.2 Hz, 1H), 7.59−7.63 (m, 2H), 7.82−7.84 (m, 2H), 9.15 (s, 1H), 10.5 (s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 196.3, 168.4, 166.6, 164.9, 153.2, 151.7, 148.6, 140.9, 139.4, 134.3, 132.7, 132.6, 131.9, 131.2, 129.5, 127.9, 126.8, 125.7, 123.7, 123.5, 119.4, 115.5, 115.3, 105.6, 61.1, 18.2, 14.1; ^{19}F NMR (376 MHz, $CDCl_3$) δ −105.0; IR (KBr) ν 3230, 3171, 3061, 2980, 2961, 2927, 2851, 1674, 1595, 1513, 1461, 1283, 1208, 1172, 1150, 1029, 896, 852, 789, 754 cm^{-1}; HRMS (ESI-TOF) m/z [M + H]$^+$ calcd for $C_{26}H_{21}FN_2O_3$ 429.1609, found 429.1612. Anal. Calcd for $C_{26}H_{21}FN_2O_3$: C, 72.88; H, 4.94; N, 6.54. Found: C, 72.93; H, 4.98; N, 6.55.

(8) **Ethyl 8-(4-chlorobenzoyl)-4-(*o*-tolylamino)quinoline-3-carboxylate (26d):** 3-Ethyl 8-methyl 4-(*o*-tolylamino)quinoline-3,8-dicarboxylate (36.4 mg, 0.10 mmol) and (4-chlorophenyl)boronic acid (31.2 mg, 0.20 mmol) were used for the preparation of the title compound and purified by silica gel column chromatography (EtOAc/hexane = 1/10) as a yellow solid (40.4 mg, 91%): mp 170−172 °C; ^{1}H NMR (600 MHz, $CDCl_3$) δ 1.39 (t, J = 7.2 Hz, 3H), 2.42 (s, 3H), 4.39 (q, J = 7.2 Hz, 2H), 6.93 (d, J = 7.8 Hz, 1H), 7.10−7.18 (m, 3H), 7.32 (d, J = 7.8 Hz, 1H), 7.37 (d, J = 8.4 Hz, 2H), 7.59−7.63 (m, 2H), 7.73 (d, J = 8.4 Hz, 2H), 9.14 (s, 1H), 10.5 (s, 1H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 196.7, 168.4, 153.2, 151.7, 148.6, 140.9, 139.5, 139.2, 136.3, 131.9, 131.3, 131.2, 129.7, 128.6, 128.0, 126.8, 125.7, 123.7, 123.6, 119.4, 105.6, 61.2, 18.2, 14.1; IR (KBr) ν 3232, 3057, 2979, 2918, 2850, 1674, 1577, 1514, 1461, 1398, 1374, 1269, 1209, 1172, 1090, 1029, 895, 848, 785, 752 cm^{-1}; HRMS (ESI-TOF) m/z [M + H] $^+$ Calcd for $C_{26}H_{21}ClN_2O_3$ 445.1313, found 445.1317. Anal. Calcd for $C_{26}H_{21}ClN_2O_3$: C, 70.19; H, 4.76; N, 6.30. Found: C, 70.25; H, 4.79; N, 6.32.

■ ASSOCIATED CONTENT

Supporting Information

^{1}H, ^{13}C, and ^{19}F NMR spectra for all of the substrates and products. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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■ REFERENCES

(1) (a) Jana, R.; Pathak, T. P.; Sigman, M. S. *Chem. Rev.* **2011**, *111*, 1417−1492. (b) *Metal-Catalyzed Cross-Coupling Reactions*, 2nd ed.; de Meijere, A., Diederich, F., Eds.; Wiley-VCH: Weinheim, 2004; Vols. *1*−*2*. (c) Tsuji, J. *Palladium Reagents and Catalysts: New Perspectives for the 21st Century*; Wiley-VCH: Weinheim, 2004. (d) *Handbook of Organopalladium Chemistry for Organic Synthesis*; Negishi, E., Ed.; Wiley-Interscience: New York, 2002; Vols. *1*−*2*.

(2) (a) Villalobos, J. M.; Srogl, J.; Liebeskind, L. S. *J. Am. Chem. Soc.* **2007**, *129*, 15734−15735. (b) Goossen, L. J.; Ghosh, K. *Angew. Chem., Int. Ed.* **2001**, *40*, 3458−3460. (c) Luzikova, E. V.; Bumagin, N. A. *Russ. Chem. Bull.* **1997**, *46*, 1961. (d) Zhang, L. -J.; Huang, Y. -Z.; Jiang, H.; Jun, D.; Liao, Y. *J. Org. Chem.* **1992**, *57*, 774−777. (e) Barton, D. H. R.; Ozbalik, N.; Ramesh, M. *Tetrahedron* **1988**, *44*, 5661−5668. (f) Fiandanese, V.; Marchese, G.; Martina, V.; Ronzini, L. *Tetrahedron Lett.* **1984**, *25*, 4805−4808. (g) Labadie, J. W.; Stille, J. K. *J. Am. Chem. Soc.* **1983**, *105*, 6129−6137. (h) Negishi, E.; Bagheri, V.; Chatterjee, S.; Luo, F. T.; Miller, J. A.; Stoll, A. T. *Tetrahedron Lett.* **1983**, *24*, 5181−5184.

(3) (a) Ishiyama, T.; Kizaki, H.; Hayashi, T.; Suzuki, A.; Miyaura, N. *J. Org. Chem.* **1998**, *63*, 4726−4731. (b) Hatanaka, Y.; Fukushima, S.; Hiyama, T. *Tetrahedron* **1992**, *48*, 2113−2126. (c) Echavarren, A. M.; Stille, J. K. *J. Am. Chem. Soc.* **1988**, *110*, 1557−1565.

(4) (a) Liu, Y.; Yao, B.; Deng, C.-L.; Tang, R.-Y.; Zhang, X.-G.; Li, J.-H. *Org. Lett.* **2011**, *13*, 2184−2187. (b) Colbon, P.; Ruan, J.; Purdie, M.; Xiao, J. *Org. Lett.* **2010**, *12*, 3670−3673. (c) Álvarez-Bercedo, P.; Flores-Gaspar, A.; Correa, A.; Martin, R. *J. Am. Chem. Soc.* **2010**, *132*, 466−467. (d) Wang, S.; Xie, K.; Tan, Z.; An, X.; Zhou, X.; Guo, C.-C.; Peng, Z. *Chem. Commun.* **2009**, 6469−6471. (e) Ruan, J.; Saidi, O.; Iggo, J. A.; Xiao, J. *J. Am. Chem. Soc.* **2008**, *130*, 10510−10511. (f) Takemiya, A.; Hartwig, J. F. *J. Am. Chem. Soc.* **2006**, *128*, 14800−14801.

(5) (a) Ko, S.; Kang, B.; Chang, S. *Angew. Chem., Int. Ed.* **2005**, *44*, 455−457. (b) Pucheault, M.; Darses, S.; Genet, J.-P. *J. Am. Chem. Soc.* **2004**, *126*, 15356−15357.

(6) (a) Katz, J. D.; Lapointe, B. T.; Dinsmore, C. J. *J. Org. Chem.* **2009**, *74*, 8866−8869. (b) Arvela, R. K.; Pasquini, S.; Larhed, M. *J. Org. Chem.* **2007**, *72*, 6390−6396. (c) Harris, P. A.; Cheung, M.; Hunter, R. N., III; Brown, M. L.; Veal, J. M.; Nolte, R. T.; Wang, L.; Liu, W.; Crosby, R. M.; Johnson, J. H.; Epperly, A. H.; Kumar, R.; Luttrell, D. K.; Stafford, J. A. *J. Med. Chem.* **2005**, *48*, 1610−1619.

(7) (a) Obora, Y.; Nakanishi, M.; Tokunaga, M.; Tsuji, Y. *J. Org. Chem.* **2002**, *67*, 5835−5837. (b) Hanzawa, Y.; Narita, K.; Yabe, M.; Taguchi, T. *Tetrahedron* **2002**, *58*, 10429−10435. (c) Obora, Y.; Ogawa, Y.; Imai, Y.; Kawamura, T.; Tsuji, Y. *J. Am. Chem. Soc.* **2001**, *123*, 10489−10493.

(8) (a) Hanzawa, Y.; Tabuchi, N.; Taguchi, T. *Tetrahedron Lett.* **1998**, *39*, 6249−6252. (b) Kosugi, M.; Naka, H.; Harada, S.; Sano, H.; Migita, T. *Chem. Lett.* **1987**, 1371.

(9) Verlhac, J.-B.; Chanson, E.; Jousseaume, B.; Quintard, J.-P. *Tetrahedron Lett.* **1985**, *26*, 6075−6078.

(10) Schmink, J. R.; Krska, S. W. *J. Am. Chem. Soc.* **2011**, *133*, 19574−19577.

(11) Wang, J.-J.; Chen, W.-Q.; Zuo, S.-J.; Liu, L.; Zhang, X.-R.; Wang, J.-H. *Angew. Chem., Int. Ed.* **2012**, *51*, 12334−12338.

(12) (a) Gooßen, L. J.; Rodríguez, N.; Gooßen, K. *Angew. Chem., Int. Ed.* **2008**, *47*, 3100−3120. (b) Kokubo, K.; Miura, M.; Nomura, M. *Organometallics* **1995**, *14*, 4521−4524. (c) Grotjahn, D. B.; Joubran, C. *Organometallics* **1995**, *14*, 5171−5177. (d) Yamamoto, T.; Ishizu, J.; Kohara, T.; Komiya, S.; Yamamoto, A. *J. Am. Chem. Soc.* **1980**, *102*, 3758−3764.

(13) (a) Muto, K.; Yamaguchi, J.; Itam, K. *J. Am. Chem. Soc.* **2012**, *134*, 169−172. (b) Li, B.-J.; Yu, D.-G.; Sun, C.-L.; Shi, Z.-J. *Chem.—Eur. J.* **2011**, *17*, 1728−1759. (c) Huang, K.; Yu, D.-G.; Zheng, S.-F.; Wu, Z.-H.; Shi, Z.-J. *Chem.—Eur. J.* **2011**, *17*, 786−791. (d) Yu, D.-G.; Li, B.-J.; Shi, Z.-J. *Acc. Chem. Res.* **2010**, *43*, 1486−1495. (e) Xu, L.; Li, B.-J.; Wu, Z.-H.; Lu, X.-Y.; Guan, B.-T.; Wang, B.-Q.; Zhao, K.-Q.; Shi, Z.-J. *Org. Lett.* **2010**, *12*, 884−887. (f) Li, B.-J.; Xu, L.; Wu, Z.-H.; Guan, B.-T.; Sun, C.-L.; Wang, B.-Q.; Shi, Z.-J. *J. Am. Chem. Soc.* **2009**, *131*, 14656−14657. (g) Yu, J. -Y.; Kuwano, R. *Angew. Chem., Int. Ed.* **2009**, *48*, 7217−7220. (h) Guan, B.; Wang, Y.; Li, B.; Yu, D.; Shi, Z.-J. *J. Am. Chem. Soc.* **2008**, *130*, 14468−14470.

(14) (a) Kakino, R.; Shimizu, I.; Yamamoto, A. *Bull. Chem. Soc. Jpn.* **2001**, *74*, 371−376. (b) Tatamidani, H.; Yokota, K.; Kakiuchi, F.; Chantani, N. *J. Org. Chem.* **2004**, *69*, 5615−5621. (c) Tatamidani, H.; Kakiuchi, F.; Chatani, N. *Org. Lett.* **2004**, *6*, 3597−3599. (d) Ooguri, A.; Nakai, K.; Kurahashi, T.; Matsubara, S. *J. Am. Chem. Soc.* **2009**, *131*, 13194−13195.

(15) Hoang, G. T.; Reddy, V. J.; Nguyen, H. H. K.; Douglas, C. J. *Angew. Chem., Int. Ed.* **2011**, *50*, 1882−1884.

(16) Lipshutz, B. H.; Frieman, B.; Birkedal, H. *Org. Lett.* **2004**, *6*, 2305−2308.

(17) (a) Yamamoto, E.; Izumi, K.; Horita, Y.; Ito, H. *J. Am. Chem. Soc.* **2012**, *134*, 19997−20000. (b) Wang, H.; Grohmann, C.; Nimphius, C.; Glorius, F. *J. Am. Chem. Soc.* **2012**, *134*, 19592−19595. (c) Li, H.; Sun, C.-L.; Yu, M.; Yu, D.-G.; Li, B.-J.; Shi, Z.-J. *Chem.—Eur. J.* **2011**, *16*, 3593−3597. (d) Hoshiya, N.; Shimoda, M.; Yioshikawa, H.; Yamashita, Y.; Shuto, S.; Arisawa, M. *J. Am. Chem. Soc.* **2010**, *132*, 7270−7272. (e) Suzuki, A. *J. Organomet. Chem.* **1999**, *576*, 147−168.

(18) Lei, Z.-Q.; Li, H.; Li, Y.; Zhang, X.-S.; Chen, K.; Wang, X.; Sun, J.; Shi, Z.-J. *Angew. Chem., Int. Ed.* **2012**, *51*, 2690−2694.

(19) (a) Dowerah, D.; Radonovich, L. J.; Woolsey, N. F. *Organometallics* **1990**, *9*, 614−620. (b) Suggs, J. W.; Jun, C.-H. *J. Am. Chem. Soc.* **1986**, *108*, 4679−4681. (c) Suggs, J. W.; Jun, C. -H. *J. Am. Chem. Soc.* **1984**, *106*, 3054−3056. (d) Omae, I. *Chem. Rev.* **1979**, *79*, 287−321.
(20) (a) Zarghi, A.; Ghodsi, R. *Bioorg. Med. Chem.* **2010**, *18*, 5855−5860. (b) Nien, C.-Y.; Chen, Y.-C.; Kuo, C.-C.; Hsieh, H.-P.; Chang, C.-Y.; Wu, J.-S.; Wu, S.-Y.; Liou, J.-P.; Chang, J.-Y. *J. Med. Chem.* **2010**, *53*, 2309−2313. (c) Thomas, B. C.; James, C. A.; Karol, D. E.; Ulrich, S. PCT Int. Appl. 2002042248A2, 2002. (d) Teruo, O.; Shigeki, S.; Takayuki, I.; Yasuji, U.; Tatsuya, Y.; Noriko, Y. Jpn. Kokai Tokkyo Koho, JP10291988A, 1998. (e) Yasuo, O.; Juji, N.; Haruki, T.; Naokatsu, S.; Hiroshi, K.; Shunei, Y.; Akio, I. Jpn. Kokai Tokkyo Koho, JP07173138A, 1995.
(21) (a) Klein, N.; Senkovska, I.; Baburin, I. A.; Grünker, R.; Stoeck, U.; Schlichtenmayer, M.; Streppel, B.; Mueller, U.; Leoni, S.; Hirscher, M.; Kaskel, S. *Chem.—Eur. J.* **2011**, *17*, 13007−13016. (b) Atkins, R. J.; Breen, G. F.; Crawford, L. P.; Grinter, T. J.; Harris, M. A.; Hayes, J. F.; Moores, C. J.; Saunders, R. N.; Share, A. C.; Walsgrove, T. C.; Wicks, C. *Org. Process Res. Dev.* **1997**, *1*, 185−197.
(22) Rao, T. S. S.; Hosahalli, S.; Reddy, K. S.; Vijay, S.; Reddy, S.; Chakrapani, B.; Raviraj, K.; Matthias, S.; Michael, A. PCT Int. Appl. 2010115736A2, 2010.