JOC The Journal of Organic Chemistry

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Palladium-Catalyzed Deaminative Phenanthridinone Synthesis from Aniline via C−H Bond Activation

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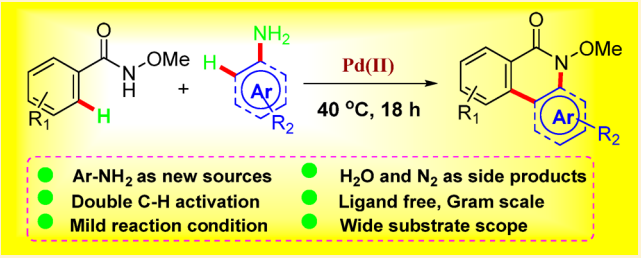
Supporting Information

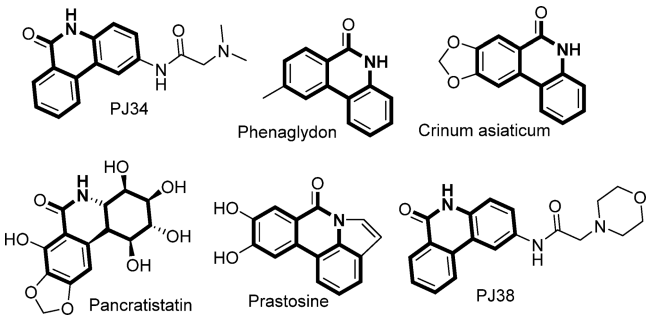
ABSTRACT: This work reports palladium-catalyzed phenanthridinone synthesis using the coupling of aniline and amide by formation of C−C and C−N bonds in a one-pot fashion via dual C−H bond activation. It involves simultaneous cleavage of four bonds and the formation of two new bonds. The present protocol is ligand-free, takes place under mild reaction conditions, and is environmentally benign as nitrogen gas and water are the only side products. This transformation demonstrates a broad range of aniline and amide substrates with different functional groups and has been scaled up to gram level.



INTRODUCTION

Phenanthridinone is an important building block that is found in various biologically active molecules and natural products.[1] Interestingly, these are also important scaffolds in anticancer drugs and treatment of nerve diseases (Scheme 1).[2] Despite several methods for the synthesis of phenanthridinone derivatives,[3] versatile and flexible methodologies to construct phenanthridinones are still desirable.

Scheme 1. Examples of Molecules Containing a Phenanthridinone Skeleton



The methodology involving C−H activation has gained great prominence in organic synthesis.[4] It is very important to use inexpensive and readily available starting materials to enhance sustainability through nonreactive C−H bond activation.[5] Usually, C−H bond activation has been brought about successfully by transition-metal-based catalytic systems.[6]

The most developed strategy is to obtain selective C−H bond activation by the use of a neighboring directing group (DG) that precomplexes with the metal and directs to the desired position.[7] With the help of C−H bond activation, construction of C−C and C−N bonds has been achieved.[8] Analogous to C−H bond activation and coupling reactions, the activation of functional groups has also been achieved.[9] Such a combination of C−H bond activation and functional group activation has a great advantage in the form of reducing synthetic steps in pharmaceutical and drug synthesis, thus making the process cost-effective. Recently, several groups have employed aryldiazonium salts as aryl surrogates for the construction of C−C and C−N bonds.[10] The $C-N_2^+$ bond is a weak bond having a dissociation energy (~130 kJ mol^{-1}) that allows the oxidative addition to palladium under mild conditions.[11] However, compared to externally prepared diazonium salts, the in situ prepared diazonium salts avoid waste and handling of large quantities of solvents required for the purification of the crystalline form. The important advantage of aromatic amine/arene diazonium salts is that they have been established in classical methods for functional group transformations. Furthermore, in situ synthesis of diazonium salts has been applied widely in various named reactions such as Suzuki coupling, Heck coupling, and Sonogashira coupling reactions having aniline as an aryl source.[12] Moreover, Beller's group and Wu's group have reported carbonylative Sonogashira coupling reactions for the synthesis of alkynones from aniline.[13]

This work develops a deaminative C−C bond coupling along with *ortho*-C−H bond activation of aniline. The literature survey shows that in situ generated diazonium salt has been employed only in deaminative coupling reactions. To the best of our knowledge, there is no report on the deaminative C−C coupling with the *ortho*-C−H bond activation of aniline for the synthesis of phenanthridinone.

Received: February 22, 2016
Published: April 18, 2016

DOI: 10.1021/acs.joc.6b00378
J. Org. Chem. 2016, 81, 4103−4111

Scheme 2. Synthetic Approach for Phenanthridinones

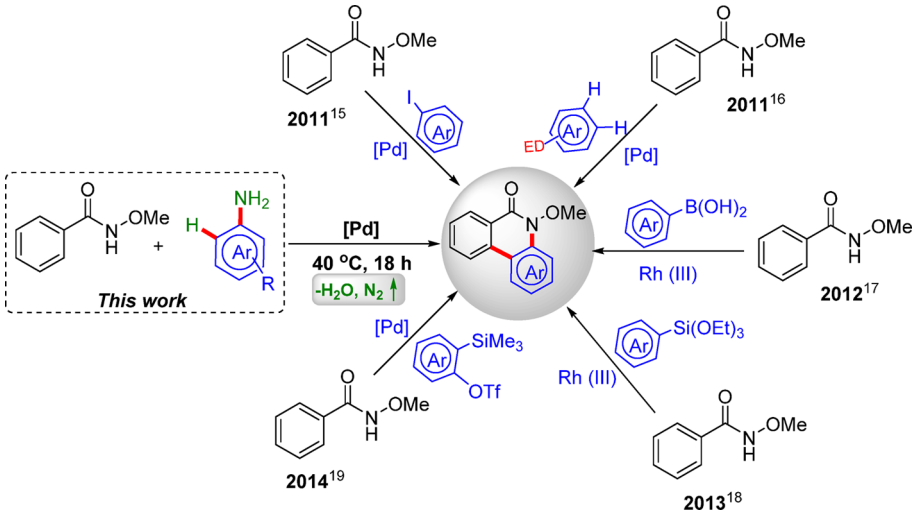
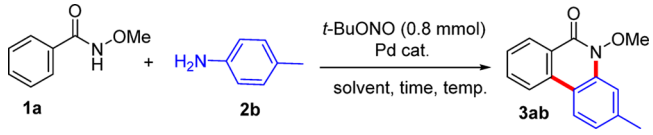


Table 1. Optimization of Reaction Conditions[a]



entry	catalyst (mol %)	oxidant (equiv)	solvent	time (h)	T (°C)	yield (%)[b]
1	$Pd(OAc)_2$ (5)	$K_2S_2O_8$ (1)	AcOH	24	40	58
2	$PdCl_2$ (5)	$K_2S_2O_8$ (1)	AcOH	24	40	23
3	$Pd(Ph_3P)_4$ (5)	$K_2S_2O_8$ (1)	AcOH	24	40	trace
4	$PdCl_2(CH_3CN)_2$ (5)	$K_2S_2O_8$ (1)	AcOH	24	40	trace
5		$K_2S_2O_8$ (1)	AcOH	24	40	0
6	$Pd(OAc)_2$ (5)	$K_2S_2O_8$ (2)	AcOH	24	40	61
7	$Pd(OAc)_2$ (10)	$K_2S_2O_8$ (1)	AcOH	24	40	57
8	$Pd(OAc)_2$ (5)	AgOAc (1)	AcOH	24	40	64
9	$Pd(OAc)_2$ (5)	AgOTf (1)	AcOH	24	40	27
10	$Pd(OAc)_2$ (5)	Ag_2O (1)	AcOH	24	40	90
11	$Pd(OAc)_2$ (5)	Ag_2CO_3 (1)	AcOH	24	40	81
12	$Pd(OAc)_2$ (5)	$AgNO_3$ (1)	AcOH	24	40	trace
13	$Pd(OAc)_2$ (5)	Ag_2O (1)	HCOOH	24	40	0
14	$Pd(OAc)_2$ (5)	Ag_2O (1)	CF_3COOH	24	40	0
15	$Pd(OAc)_2$ (5)	Ag_2O (1)	$MeSO_3H$	24	40	0
16	**$Pd(OAc)_2$ (5)**	**Ag_2O (1)**	**AcOH**	**18**	**40**	**90**
17	$Pd(OAc)_2$ (5)	Ag_2O (1)	AcOH	17	40	89
18	$Pd(OAc)_2$ (5)	Ag_2O (1)	AcOH	18	50	76
19	$Pd(OAc)_2$ (5)	Ag_2O (1)	AcOH	18	32 (rt)	61
20	$Pd(OAc)_2$ (7)	Ag_2O (1)	AcOH	18	40	90
21	$Pd(OAc)_2$ (3)	Ag_2O (1)	AcOH	18	40	71
22	$Pd(OAc)_2$ (5)	Ag_2O (0.5)	AcOH	18	40	61
23	$Pd(OAc)_2$ (5)	Ag_2O (1.5)	AcOH	18	40	90

[a]Reaction conditions: *N*-methoxybenzamide (**1a**, 0.5 mmol), *p*-toluidine (**2b**, 0.7 mmol), Pd source, oxidant, solvent (5 mL), time, temp. [b]GC yield, rt = room temperature.

Traditionally, preparation of phenanthridinones needs more synthetic steps, and the overall yields observed are lower.[14] In 2011, the group of Li and other groups reported palladium-catalyzed coupling of *ortho*-X/H (X = I) benzamides with aromatic halides.[15] This reported protocol has some disadvantages, such as high temperature and longer reaction time. In the same year, Chen's group reported electron-rich arenes for the phenanthridinone synthesis.[16] The same group also reported Rh(III)-catalyzed boronic acid coupling for phenanthridinone synthesis.[17] Subsequently, phenanthridinones were also synthesized by coupling of benzamides with aryltriethoxysilanes in the presence of a Rh(III) catalyst.[18] This work also suffers from the use of expensive starting materials and Rh(III) catalyst. Recently, Jeganmohan's group reported an alternate protocol for the synthesis of phenanthridinones by coupling of benzamide with an externally prepared benzyne-generating source (Scheme 2).[19]

DOI: 10.1021/acs.joc.6b00378
J. Org. Chem. 2016, 81, 4103−4111

Considering the importance of phenanthridinones,[1,2] herein we report deaminative C−C and C−N bond coupling via *ortho*-C−H bond activation of aniline to give phenanthridinones under mild reaction conditions. This developed methodology has a number of advantages: (i) it consists of three steps in a one-pot reaction, involving four bond cleavages and two bond formations simultaneously; (ii) it does not require isolation of diazonium crystalline salts; (iii) diazonium salt is generated in situ during the progress of the reaction; (iv) only nontoxic byproducts such as N_2, H_2O, and *t*-BuOH are generated; (v) the catalytic system is ligand-free; and (vi) the reaction could be completed at mild reaction temperature. The results of our studies are described herein.

RESULTS AND DISCUSSION

To optimize the reaction conditions, *N*-methoxybenzamide **1a** and *p*-toluidine **2b** were chosen as model substrates for the phenanthridinone synthesis. A series of experiments were carried out to study the effect of various reaction parameters such as Pd catalyst precursors, oxidants, solvents, time, and temperature. The results are displayed in Table 1. Initially, $Pd(OAc)_2$ (5 mol %), *p*-toluidine **2b** (0.7 mmol), *N*-methoxybenzamide **1a** (0.50 mmol), and $K_2S_2O_8$ (1 mmol) were added to a solution of 5 mL of acetic acid under a nitrogen atmosphere. The system was degassed four to five times by a vacuum pump. To the resulting suspension was added 0.8 mmol of *t*-BuONO (*tert*-butyl nitrite) by syringe. The mixture was heated at 40 °C for 12 h to obtain a 58% yield of product **3ab** (Table 1, entry 1). Next, various palladium precursors such as $PdCl_2$, $Pd(Ph_3P)_4$, and $PdCl_2(CH_3CN)_2$ catalysts were screened. $Pd(OAc)_2$ was found to be the best catalyst because it provided a good yield of the desired product **3ab** and other Pd catalysts provide moderate to poor yields (Table 1, entries 2−4). No formation of product **3ab** was observed when the reaction was performed in the absence of a Pd catalyst (Table 1, entry 5). Increasing the amount of oxidant ($K_2S_2O_8$) to 2 equiv did not show any significant effect on the yield of **3ab** (Table 1, entry 6). With our desire to increase the yield of product **3ab**, the catalyst loading was increased up to 10 mol %. Unfortunately, no significant change in the yield of product **3ab** was noted (Table 1, entry 7). In the next set of experiments, other Ag-containing oxidants such as AgOAc, AgOTf, Ag_2O, Ag_2CO_3, and $AgNO_3$ were screened, and we were delighted to observe that Ag_2O provided a very good yield of **3ab** (Table 1, entries 8−12).

Moreover, when the reaction was performed in CF_3COOH and HCOOH, no formation of product **3ab** was observed (Table 1, entries 13 and 14). Also, no product was observed when the reaction was performed in $MeSO_3H$ (Table 1, entry 15). Next, the reaction time was studied (Table 1, entries 16 and 17).

The reaction time can be reduced to 18 h, providing 90% yield of **3ab** (Table 1, entry 16). Further, decreasing the reaction duration to 17 h resulted in a considerable decrease in the yield of the desired product **3ab** (Table 1, entry 17). Increasing the reaction temperature above 40 °C or decreasing the reaction temperature below 40 °C led to a significant decrease in the yield of **3ab** (Table 1, entries 18 and 19). The increase in $Pd(OAc)_2$ loading to 7 mol % did not show any effect on the yield of **3ab** (Table 1, entry 20). However, the decrease in the $Pd(OAc)_2$ loading led to a drastic decrease in the yield of **3ab** (Table 1, entry 21). One equivalent of Ag_2O was found to be effective for this transformation, and further decreasing the amount of Ag_2O to 0.5 equiv provided a lower yield of **3ab** (Table 1, entry 22). On the other hand, no significant change in the yield of **3ab** was found when the reaction was performed with 1.5 equiv of Ag_2O (Table 1, entry 23).

Hence, we have established the optimized reaction conditions, and this developed methodology was explored for the scope and limitation of the substrates. As shown in Table 2, all the examined substrates provided good to excellent yields. The effect of electron-donating and electron-withdrawing groups on *N*-methoxybenzamide was studied. It was found that electron-donating groups, such as −Me, −OMe, and -*t*-butyl, produced corresponding products **3bb**−**3fb** in good to excellent yields (Table 2, entries 1−5). The *para*-substituted *N*-methoxybenzamides **1b**−**1d** provided excellent yields of **3bb**−**3db**, whereas *meta*-substituted *N*-methoxybenzamide **1e** offered a good yield of **3eb** regioselectively. Hindered *ortho*-methyl-*N*-methoxybenzamide furnished a lower yield of product **3fb**. Interestingly, *β*- and *α*-*N*-methoxybenzamide could also be transformed into corresponding products **3gb** and **3hb** selectively (Table 2, entries 6 and 7). Next, *N*-methoxybenzamide bearing weakly electron-withdrawing groups, such as −F, −Cl, and −Br, at the *para* position were explored and furnished respective products **3ib**−**3kb** in good to excellent yields (Table 2, entries 8−10).

The *meta*-chloro-substituted *N*-methoxybenzamide provided an excellent yield of **3lb**, and *ortho*-chloro-*N*-methoxybenzamide provided a low yield of **3mb**; this may be due to steric hindrance (Table 2, entries 11 and 12). The *N*-methoxy-4-nitrobenzamide was also tolerated to give **3nb** in 57% yield (Table 2, entry 13). To our delight, the amide containing an external double bond could also be transformed into the corresponding product **3ob** (Table 2, entry 14).

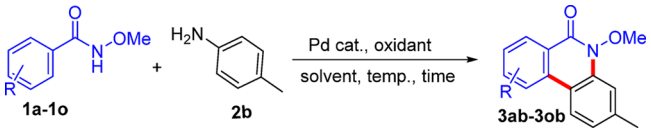
Having showed the viability of the mild catalytic system in efficient phenanthridinone synthesis from amide, we turned our attention to other aniline substrates (Table 3). In general, **2a** reacts with **1a** to give **3aa** in 89% yield (Table 3, entry 1). It was observed that the reactions of aniline having electron-donating substituents such as $-CH_3$ and $-OCH_3$ offer good yields of **3ac**−**3ae** (Table 3, entries 2−4). A weak electron-withdrawing group, such as chloro, furnished a good yield of product **3af** (Table 3, entry 5). Aniline having a $-NO_2$ group such as **2g** and **2h** was studied. Only **2g** could be converted into the desired product **3ag**; however, **3h** could not be transformed into the desired product **3ah** (Table 3, entries 6 and 7). Unfortunately, heteroatom-containing aniline, such as **2i** and **2j**, did not give the corresponding products **3ai** and **3aj** (Table 3, entries 8 and 9).

After the substrate study of various *N*-methoxy amides and aromatic amines, we moved toward the screening of N-substituted amides (Scheme 3). Benzamide, *N*-hydroxybenzamide, and *N*-alkyl/*N*-arylbenzamide were inactive for the synthesis of phenanthridinone products **3pa**, **3qa**, **3ra**, and **3sa**. Further, the reactivity of *N*-methoxy-*N*-methylbenzamide **1t** was tested, and no conversion of **3ta** was observed at standard reaction conditions. However, in the presence of $MeSO_3H$ solvent and AgOTf oxidant, the formation of product **3ta** was observed with a 21% yield.

In order to understand the chemoselectivity and mechanism of this transformation, some control experiments were conducted. Notably, no formation of product **3ab** was observed when *N*-methyltoluidine **2b′** and *N*,*N*-dimethyltoludine **2b″** were employed (Scheme 4). This is possible because there is no

DOI: 10.1021/acs.joc.6b00378
J. Org. Chem. 2016, 81, 4103−4111

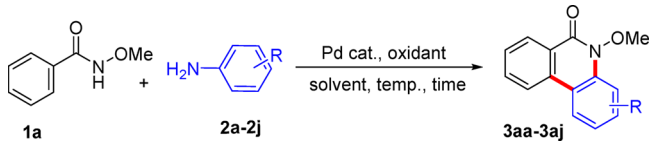
Table 2. Palladium-Catalyzed Phenanthridinone Synthesis from *p*-Toluidine with Various *N*-Methoxybenzamides[a]



entry	amide	aniline	product	yield (%)[b]
1	1b	2b	3bb	91
2	1c	2b	3cb	87
3	1d	2b	3db	87
4	1e	2b	3eb	86
5	1f	2b	3fb	71
6	1g	2b	3gb	86
7	1h	2b	3hb	89
8	1i	2b	3ib	87
9	1j	2b	3jb	81
10	1k	2b	3kb	78
11	1l	2b	3lb	83
12	1m	2b	3mb	63
13	1n	2b	3nb	57
14	1o	2b	3ob	73

[a]Reaction conditions: amide (**1a**−**1o**) (0.5 mmol), *p*-toluidine (**2b**, 0.7 mmol), *t*-BuONO (0.8 mmol), $Pd(OAc)_2$ (5.0 mol %), Ag_2O (1.0 mmol), AcOH (5 mL) at 40 °C for 18 h. [b]Isolated yield.

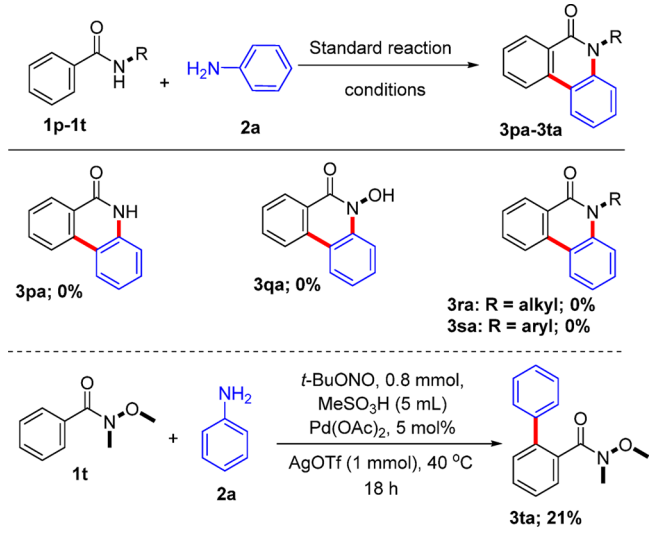
Table 3. Palladium-Catalyzed Phenanthridinone Synthesis with Various Aniline Derivatives[a]



entry	amide	aniline	product	yield (%)[b]
1	1a	2a	3aa	89
2	1a	2c	3ac	85
3	1a	2d	3ad	90
4	1a	2e	3ae	73
5	1a	3af	3af	76
6	1a	2g	3ag	53
7	1a	2h	3ah	00
8	1a	2i	3ai	00
9	1a	2j	3aj	00

[a]Reaction conditions: *N*-methoxybenzamide (**1a**) (0.5 mmol), aniline derivatives (**2a**−**2j**) (0.7 mmol), *t*-BuONO (0.8 mmol), $Pd(OAc)_2$ (5.0 mol %), Ag_2O (1.0 mmol), AcOH (5 mL) at 40 °C for 18 h. [b]Isolated yield.

Scheme 3. Reaction of N-Substituted Benzamide Derivatives



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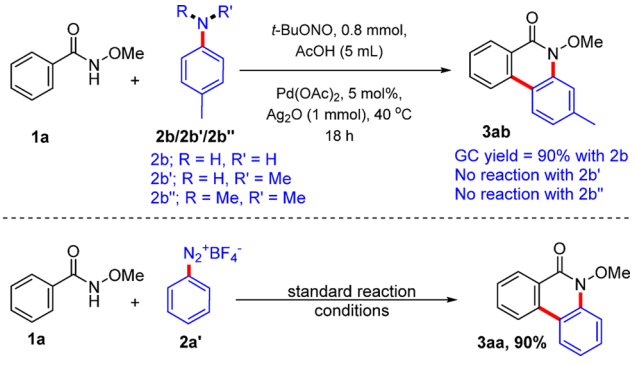
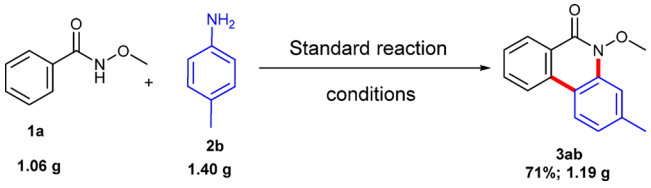
Scheme 4. Controlled Experiments



generation of azo salts with **2b**′ and **2b**″ under the given reaction conditions. The excellent yield of product **3aa** was observed in the presence of externally prepared diazonium salt.

To demonstrate the synthetic utility of this developed protocol, gram scale phenanthridinone synthesis was carried out by employing *p*-toluidine **2b** (9.4 mmol, 1.40 mg) and 1.06 g (7 mmol) of *N*-methoxybenzamide **1a** under the standard reaction condition (Scheme 5). This transformation proceeded smoothly to afford 1.19 g (71%) of product **3ab**.

Scheme 5. Gram Scale Phenanthridinone Synthesis

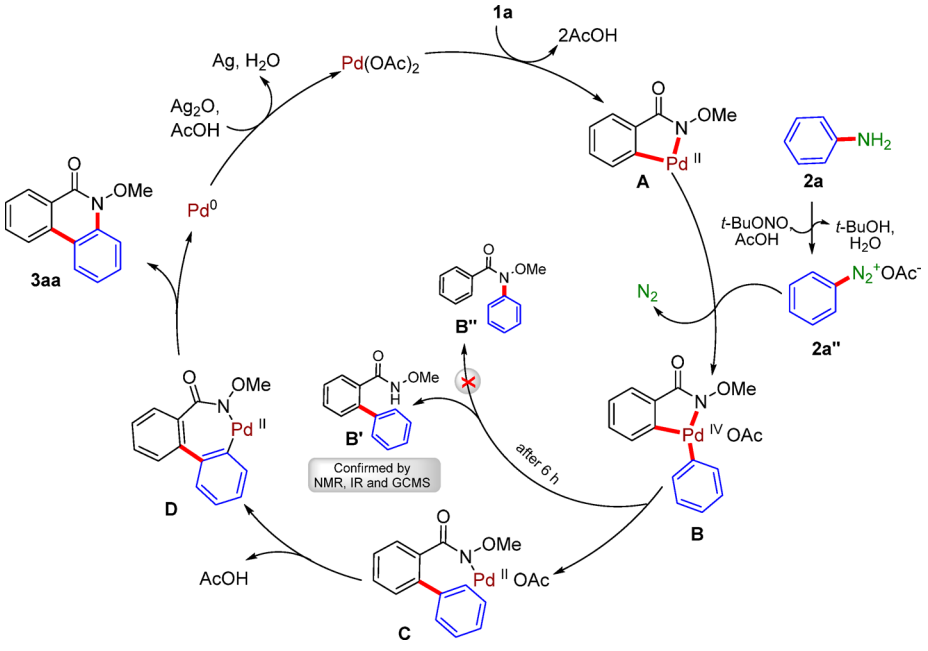


On the basis of known Pd(II)/Ag(I)-catalyzed directing-group-assisted C−H bond activation reactions[20] and obtained results, a plausible mechanism for the reaction of **1a** with **2a** to give **3aa** has been proposed in Scheme 6. The arylation of *N*-methoxybenzamide using aniline most likely proceeds through a pathway similar to the *para*-selective arylation of amides with aryl halide.[21] The initial step involves the coordination of **1a** to a Pd^{II} species and is followed by an *ortho*-C−H bond activation to form a five-membered palladacycle **A**[15,16,19,20c,22] and the release of protons. Parallel in situ diazotization of the aniline **2a** takes place in the presence of *t*-BuONO and acid to form a diazonium salt **2a**″ with the release of water and *t*-BuOH. The oxidative addition of diazonium salt[10−13,23] in palladacycle **A** with simultaneous expulsion of nitrogen forms intermediate **B** with Pd^{IV}.

Reductive elimination of **B** gives *ortho*-arylated amide intermediate **C**.[16] The reaction goes through intermediate **C** and was observed by stopping the reaction after 6 h, and **B**′ was isolated and characterized by IR and NMR. In the IR spectrum, the band at 3221 cm^{-1} corresponds to the N−H stretch of **1a**, whereas the band at 3195 cm^{-1} corresponds to the N−H stretch of the isolated intermediate **B**′. This was also confirmed by ^1H NMR, in which a broad singlet of N−H was observed at δ 8.17 ppm. Hence, it can be concluded that the reaction proceeds through the *ortho*-arylated intermediate **B**′, which is subsequently followed by C−N coupling and not through C−N coupling intermediate **B**″, followed by *ortho*-arylation. Subsequently, the release of a proton gives the seven-membered palladacycle **D**.[15,16] The C−N bond-forming reductive elimination from **D** affords **3ab** and Pd^0, which is oxidized by Ag_2O to regenerate a Pd^{II} catalyst for the next catalytic cycle.

In conclusion, we have shown for the first time the synthesis of phenanthridinone from *N*-methoxybenzamide and aniline as novel surrogates using $Pd(OAc)_2$ as an efficient catalyst. The developed methodology is ligand-free and proceeds via *ortho*-C−H bond activation of *N*-methoxybenzamide under mild reaction conditions. The elimination of the purification step of the in situ generated diazonium salt and formation of only nontoxic byproducts such as N_2, H_2O, and *t*-BuOH make this protocol greener. Interestingly, it involves simultaneous four-bond cleavage and two-bond formation, that is, three steps in one pot. A series of phenanthridinones were synthesized

Scheme 6. Plausible Reaction Mechanism



DOI: 10.1021/acs.joc.6b00378
J. Org. Chem. 2016, 81, 4103−4111

containing electron-withdrawing and electron-donating groups in good to excellent yields. The use of inexpensive and easily available aniline has made this protocol potentially viable for commercial and academic applications. This reaction can also be scaled up to gram level.

EXPERIMENTAL SECTION

All reactions were carried out in oven-dried glassware. All derivatives of aniline, palladium, and silver precursor were purchased from commercial sources. Analytical TLC was performed with silica gel plates (0.25 mm thickness). Column chromatography was performed with silica gel (40−200 mesh). NMR spectra were recorded with ^{1}H NMR at 500 MHz and ^{13}C NMR at 125 MHz spectrometers. The chemical shifts are reported in parts per million relative to tetramethylsilane as an internal standard and the coupling constant J in hertz. The reaction was monitored by GC, and the products were analyzed by GC-MS and IR. HRMS were recorded on a micromass ESI TOF (time-of-flight) mass spectrometer.

General Procedure for the Synthesis of *N*-Methoxybenzamides. Following a modified procedure by Glorious et al.[24] in a 50 mL single-neck round-bottom flask, *O*-methylhydroxylamine (301.0 mg, 3.6 mmol, 1.2 equiv) and K_2CO_3 (829.0 mg, 6.0 mmol, 2.0 equiv) were combined in a 2:1 mixture of EtOAc (24 mL) and H_2O (12 mL). The flask was capped with a rubber cap, and the mixture was cooled in an ice bath. The acid chloride (1.0 mmol, 1.0 equiv) was added dropwise, and the mixture was stirred at room temperature for 16−18 h. The reaction mixture was then diluted with EtOAc and washed twice with water and brine. Consequently, the ethyl acetate layer was washed with 5% aqueous solution of 25−30 mL of sodium bicarbonate. The organic layers were dried over Na_2SO_4, filtered, and concentrated. The pure products were obtained without any further purification, and it was confirmed by GC-MS.

Experimental Procedure for Phenanthridinone Synthesis from *p*-Toluidine. In a 15 mL Schlenk tube, a solution of 5 mL of acetic acid, $Pd(OAc)_2$ (5 mol %, 11.2 mg), *p*-toluidine **2b** (0.7 mmol, 0.74 mg), *N*-methoxybenzamide **1a** (0.50 mmol, 76 mg), and Ag_2O (1 mmol, 223 mg) was added under a nitrogen atmosphere. The system was degassed four to five times by a vacuum pump. To the resulting suspension was added *tert*-butyl nitrite (0.8 mmol, 85 mg) by syringe. The reaction mixture was stirred at 40 °C, the total time indicated in Table 1. After completion of the reaction, the reaction mixture was cooled to room temperature. All volatiles were removed under vacuum. The product was extracted with 20 mL of ethyl acetate, the organic layer dried over Na_2SO_4, and the solvent removed under vacuum. The colorless solid phenanthridinone product **3ab** was purified by column chromatography (silica gel, 40−200 mesh).

5-Methoxy-3-methylphenanthridin-6(5*H*)-one (3ab).[16] The typical procedure was applied to *N*-methoxybenzamide **1a** (0.50 mmol, 76 mg) and *p*-toluidine **2b** (0.70 mmol, 74 mg). Silica gel chromatography (eluent: petroleum ether/ethyl acetate = 4/1) of the product **3ab** afforded a colorless solid (106 mg, 89% yield): ^{1}H NMR (500 MHz, $CDCl_3$) δ_H/ppm 8.55 (d, J = 8.1 Hz, 1H), 8.24 (d, J = 8.1 Hz, 1H), 8.15 (d, J = 8.1 Hz, 1H), 7.82−7.73 (m, 1H), 7.57 (t, J = 7.6 Hz, 1H), 7.49 (s, 1H), 7.18 (d, J = 8.3 Hz, 1H), 4.15 (s, 3H), 2.54 (s, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ_C/ppm 157.5, 140.6, 135.7, 133.1, 132.6, 128.5, 127.6, 125.9, 124.4, 123.1, 121.7, 116.2, 112.7, 62.7, 21.9; GCMS (EI, 70 eV) m/z (%) 239.00 (0.06), 209.05 (40), 165.05 (44.18), 111.60 (5.73); IR (ATR) ν (cm^{-1}) 2920, 1644, and 1607.

5-Methoxy-3,9-dimethylphenanthridin-6(5*H*)-one (3bb).[16] The typical procedure was applied to *N*-methoxy-4-methylbenzamide **1b** (0.50 mmol, 83 mg) and *p*-toluidine **2b** (0.70 mmol, 74 mg). Silica gel chromatography (eluent: petroleum ether/ethyl acetate = 4/1) of the product **3bb** afforded a colorless solid (115 mg, 91% yield): ^{1}H NMR (500 MHz, $CDCl_3$) δ_H/ppm 8.42 (d, J = 8.1 Hz, 1H), 8.13 (d, J = 8.3 Hz, 1H), 8.01 (s, 1H), 7.47 (s, 1H), 7.38 (d, J = 8.0 Hz, 1H), 7.15 (d, J = 8.0 Hz, 1H), 4.13 (s, 3H), 2.56 (s, 3H), 2.53 (s, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ_C/ppm 157.5, 143.1, 140.4, 135.8, 133.1, 129.0, 128.4, 124.3, 123.5, 123.1, 121.7, 116.1, 112.7, 62.7, 22.1, 21.9; GCMS (EI, 70 eV) m/z (%) 253.10 (53.94), 194.10 (55.29), 165.10 (14.91), 96.60 (13.21); IR (ATR) ν (cm^{-1}) 2920, 1651, and 1614.

5,9-Dimethoxy-3-methylphenanthridin-6(5*H*)-one (3cb).[16] The typical procedure was applied to *N*-4-dimethoxybenzamide **1c** (0.50 mmol, 91 mg) and *p*-toluidine **2b** (0.70 mmol, 74 mg). Silica gel chromatography (eluent: petroleum ether/ethyl acetate =4/1) of the product **3cb** afforded a colorless solid (117 mg, 87% yield): ^{1}H NMR (500 MHz, $CDCl_3$) δ_H/ppm 8.46 (d, J = 8.9 Hz, 1H), 8.06 (d, J = 8.3 Hz, 1H), 7.58 (s, 1H), 7.46 (s, 1H), 7.13 (t, J = 9.1 Hz, 2H), 4.12 (s, 3H), 3.98 (s, 3H), 2.53 (s, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ_C/ppm 163.1, 157.3, 140.7, 136.1, 135.0, 130.6, 124.6, 123.1, 119.4, 115.5, 112.7, 104.6, 62.7, 55.6, 21.9; GCMS (EI, 70 eV) m/z (%) 269.05 (42.93), 239.05 (40), 201.05 (34.93), 167.05 (20.00), 103.60 (6.88); IR (ATR) ν (cm^{-1}) 2939, 1657, and 1612.

9-(*tert*-Butyl)-5-methoxy-3-methylphenanthridin-6(5*H*)-one (3db).[16] The typical procedure was applied to 4-(*tert*-butyl)-*N*-methoxybenzamide **1d** (0.50 mmol, 104 mg) and *p*-toluidine **2b** (0.70 mmol, 74 mg). Silica gel chromatography (eluent: petroleum ether/ethyl acetate = 4/1) of the product **3db** afforded a colorless solid (128 mg, 87% yield): ^{1}H NMR (500 MHz, $CDCl_3$) δ_H/ppm 8.52−8.40 (m, 1H), 8.24−8.17 (m, 2H), 7.67−7.60 (m, 1H), 7.48 (s, 1H), 7.17 (dd, J = 8.1, 0.5 Hz, 1H), 4.13 (s, 3H), 2.53 (s, 3H), 1.45 (s, 9H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ_C/ppm 157.4, 156.1, 140.3, 135.8, 132.8, 128.3, 125.6, 124.3, 123.5, 123.0, 117.8, 116.5, 112.7, 62.5, 35.5, 31.2, 21.9; GCMS (EI, 70 eV) m/z (%) 295.10 (54.21), 265.10 (50.50), 250.05 (40), 221.10 (24.44), 111.10 (24.67), 96.60 (18.62); IR (ATR) ν (cm^{-1}) 2956, 1662, and 1613.

5-Methoxy-3,8-dimethylphenanthridin-6(5*H*)-one (3eb).[16] The typical procedure was applied to *N*-methoxy-3-methylbenzamide **1e** (0.50 mmol, 83 mg) and *p*-toluidine **2b** (0.70 mmol, 74 mg). Silica gel chromatography (eluent: petroleum ether/ethyl acetate = 4/1) of the product **3eb** afforded a colorless solid (108 mg, 86% yield): ^{1}H NMR (500 MHz, $CDCl_3$) δ_H/ppm 8.34 (s, 1H), 8.12 (t, J = 8.0 Hz, 2H), 7.58 (d, J = 7.8 Hz, 1H), 7.48 (s, 1H), 7.16 (d, J = 8.1 Hz, 1H), 4.14 (d, J = 1.0 Hz, 3H), 2.53 (s, 3H), 2.52 (s. 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ_C/ppm 157.5, 140.0, 137.8, 135.4, 133.9, 130.7, 128.2, 125.7, 124.4, 122.9, 121.7, 116.3, 112.6, 62.6, 21.9, 21.3; GCMS (EI, 70 eV) m/z (%) 253.05 (66.89), 223.00 (40), 194.05 (88.16), 96.60 (17.12); IR (ATR) ν (cm^{-1}) 2918, 1646, and 1613.

5-Methoxy-3,7-dimethylphenanthridin-6(5*H*)-one (3fb).[16] The typical procedure was applied to *N*-methoxy-2-methylbenzamide **1f** (0.50 mmol, 83 mg) and *p*-toluidine **2b** (0.70 mmol, 74 mg). Silica gel chromatography (eluent: petroleum ether/ethyl acetate = 4/1) of the product **3fb** afforded a colorless solid (89 mg, 71% yield): ^{1}H NMR (500 MHz, $CDCl_3$) δ_H/ppm 7.86 (s, 1H), 7.33 (d, J = 7.4 Hz, 2H), 7.20−7.16 (m, 3H), 3.47 (s, 3H), 2.42 (s, 3H), 2.37 (s, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ_C/ppm 157.5, 140.0, 137.8, 135.4, 133.9, 130.6, 128.1, 125.7, 124.3, 122.9, 121.7, 116.3, 112.6, 62.6, 21.9, 21.3; GCMS (EI, 70 eV) m/z (%) 25.00 (0.12), 223.05 (40), 194.05 (37.06), 165.05 (27.02), 96.60 (22.35); IR (ATR) ν (cm^{-1}) 2918, 1646, and 1613.

5-Methoxy-3-methylbenzo[*j*]phenanthridin-6(5*H*)-one (3gb). The typical procedure was applied to *N*-methoxy-2-naphthamide **1g** (0.50 mmol, 40 mg) and *p*-toluidine **2b** (0.70 mmol, 74 mg). Silica gel chromatography (eluent: petroleum ether/ethyl acetate =4/1) of the product **3gb** afforded a colorless solid (124 mg, 86% yield): ^{1}H NMR (500 MHz, $CDCl_3$) δ_H/ppm 9.11 (s, 1H), 8.66 (s, 1H), 8.28 (d, J = 8.1 Hz, 1H), 8.08−8.01 (m, 2H), 7.65−7.55 (m, 2H), 7.47 (s, 1H), 7.19 (d, J = 8.0 Hz, 1H), 4.17 (s, 3H), 2.54 (s, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ_C/ppm 157.9, 140.3, 135.6, 135.1, 131.9, 129.8, 129.3, 129.1, 128.5, 120.0, 126.6, 124.5, 124.0, 123.3, 120.6, 116.5, 113.0, 62.7, 21.9; GCMS (EI, 70 eV) m/z (%) 289.10 (3.55), 281.00 (30.29), 207 (64.35), 73.05 (71.51), 43.95 (40); HRMS (H^+) calcd for $C_{19}H_{16}NO_2$ 290.1176, found 290.1169; IR (ATR) ν (cm^{-1}) 2922, 1660, and 1614.

6-Methoxy-8-methylbenzo[*i*]phenanthridin-5(6*H*)-one (3hb). The typical procedure was applied to *N*-methoxy-1-naphthamide **1h** (0.50 mmol, 40 mg) and *p*-toluidine **2b** (0.70 mmol, 74 mg). Silica gel chromatography (eluent: petroleum ether/

DOI: 10.1021/acs.joc.6b00378
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ethyl acetate =4/1) of the product **3hb** afforded a colorless solid (128 mg, 89% yield): ^{1}H NMR (500 MHz, $CDCl_3$) δ_H/ppm 10.22 (d, J = 8.8 Hz, 1H), 8.25−8.17 (m, 2H), 8.09−8.07 (m, 1H), 7.87 (d, J = 7.5 Hz, 1H), 7.73 (dd, J = 8.5, 7.1 Hz, 1H), 7.59 (t, J = 7.4 Hz, 1H), 7.48 (s, 1H), 7.14 (d, J = 8.1 Hz, 1H), 4.17 (s, 3H), 2.03 (s, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ_C/ppm 171.1, 158.2, 141.0, 135.9, 134.1, 133.9, 132.7, 132.3, 128.6, 128.2, 127.7, 126.7, 124.2, 123.8, 119.5, 119.3, 115.6, 112.1, 60.4, 21.0; GCMS (EI, 70 eV) m/z (%) 289.00 (0.3), 259.05 (100), 230.05 (19.75), 202.05 (8.57), 161.10 (8.34), 128.60 (17.16), 43.00 (9.84); HRMS (Na^+) calcd for $C_{19}H_{15}NNaO_2$ 312.1000, found 312.0995; IR (ATR) ν (cm^{-1}) 2913, 1645, and 1614.

9-Fluoro-5-methoxy-3-methylphenanthridin-6(5*H*)-one (3ib).[16] The typical procedure was applied to 4-fluoro-*N*-methoxybenzamide **1i** (0.50 mmol, 85 mg) and *p*-toluidine **2b** (0.70 mmol, 74 mg). Silica gel chromatography (eluent: petroleum ether/ethyl acetate = 4/1) of the product **3ib** afforded a colorless solid (112 mg, 87% yield): ^{1}H NMR (500 MHz, $CDCl_3$) δ_H/ppm 8.60−8.50 (m, 1H), 8.01 (d, J = 8.2 Hz, 1H), 7.83 (dd, J = 10.2, 1.9 Hz, 1H), 7.47 (s, 1H), 7.28−7.24 (m, 1H), 7.19−7.15 (m, 1H), 4.17−4.12 (m, 3H), 2.54 (s, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ_C/ppm 165.7 (d, J = 252.6 Hz), 156.8, 141.5, 136.1, 135.7 (d, J = 9.6 Hz), 131.6 (d, J = 10.0 Hz), 124.6, 123.4, 122.3 (d, J = 2.0 Hz), 116.0 (d, J = 115.87 Hz), 115.4 (J = 115.37 Hz), 107.7 (d, J = 23.4 Hz), 62.8, 21.9; GCMS (EI, 70 eV) m/z (%) 257.05 (52.42), 227.00 (40), 198.00 (54.40), 170.05 (12.03), 112.60 (9.15); IR (ATR) ν (cm^{-1}) 2923, 1658, and 1613.

9-Chloro-5-methoxy-3-methylphenanthridin-6(5*H*)-one (3jb).[16] The typical procedure was applied to 4-chloro-*N*-methoxybenzamide **1j** (0.50 mmol, 93 mg) and *p*-toluidine **2b** (0.70 mmol, 74 mg). Silica gel chromatography (eluent: petroleum ether/ethyl acetate = 4/1) of the product **3jb** afforded a colorless solid (110 mg, 81% yield): ^{1}H NMR (500 MHz, $CDCl_3$) δ_H/ppm 8.40 (d, J = 8.5 Hz, 1H), 8.08 (s, 1H), 7.95 (d, J = 8.2 Hz, 1H), 7.50−7.37 (m, 2H), 7.10 (d, J = 8.1 Hz, 1H), 4.11 (s, 3H), 2.49 (s, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ_C/ppm 156.7, 141.4, 139.3, 136.0, 134.4, 130.1, 127.9, 124.6, 124.1, 123.1, 121.6, 114.9, 112.7, 62.7, 21.9; GCMS (EI, 70 eV) m/z (%) 273.05 (51.63), 243 (40), 214.05 (44.01), 165.10 (20.01), 151.10 (14.51), 120.60 (10.38), 82.15 (10.75); IR (ATR) ν (cm^{-1}) 2923, 1661, and 1598.

9-Bromo-5-methoxy-3-methylphenanthridin-6(5*H*)-one (3kb).[16] The typical procedure was applied to 4-bromo-*N*-methoxybenzamide **1k** (0.50 mmol, 76 mg) and *p*-toluidine **2b** (0.70 mmol, 74 mg). Silica gel chromatography (eluent: petroleum ether/ethyl acetate = 4/1) of the product **3kb** afforded a colorless solid (123 mg, 78% yield): ^{1}H NMR (500 MHz, $CDCl_3$) δ_H/ppm 8.41−8.34 (m, 2H), 8.06 (d, J = 8.2 Hz, 1H), 7.67 (dd, J = 8.5, 1.3 Hz, 1H), 7.48 (s, 1H), 7.18 (d, J = 8.2 Hz, 1H), 4.14 (s, 3H), 2.54 (s, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ_C/ppm 156.9, 141.5, 136.1, 134.7, 130.8, 130.3, 128.0, 124.8, 124.7, 124.6, 123.3, 114.9, 112.8, 62.8, 21.9; GCMS (EI, 70 eV) m/z (%) 318.95 (44.38), 316.95 (44.22), 286.95 (40), 257.95 (34.68), 179.05 (46.79), 151.10 (23.41), 82.55 (17.83); IR (ATR) ν (cm^{-1}) 2920, 1662, and 1594.

8-Chloro-5-methoxy-3-methylphenanthridin-6(5*H*)-one (3lb). The typical procedure was applied to 3-chloro-*N*-methoxybenzamide **1l** (0.50 mmol, 93 mg) and *p*-toluidine **2b** (0.70 mmol, 74 mg). Silica gel chromatography (eluent: petroleum ether/ethyl acetate = 4/1) of the product **3lb** afforded a colorless solid (113 mg, 83% yield): ^{1}H NMR (500 MHz, $CDCl_3$) δ_H/ppm 8.52 (d, J = 2.3 Hz, 1H), 8.17 (d, J = 8.7 Hz, 1H), 8.09 (d, J = 8.2 Hz, 1H), 7.71 (d, J = 2.3 Hz, 1H), 7.49 (s, 1H), 7.18 (d, J = 7.2 Hz, 1H), 4.14 (s, 3H), 2.54 (s, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ_C/ppm 156.4, 141.0, 135.7, 133.8, 133.2, 132.9, 131.6, 128.0, 124.7, 123.4, 123.1, 115.5, 112.8, 77.2, 76.9, 76.7, 62.7, 21.9; GCMS (EI, 70 eV) m/z (%) 273.05 (53.26), 214.05 (43.16), 179.10 (20.06), 165.10 (20.65), 82.15 (10.48); HRMS (Na^+) calcd 296.0449 for $C_{15}H_{12}ClNNaO_2$, found 296.0441; IR (ATR) ν (cm^{-1}) 2918, 1656, and 1619.

7-Chloro-5-methoxy-3-methylphenanthridin-6(5*H*)-one (3mb).[16] The typical procedure was applied to 2-chloro-*N*-methoxybenzamide **1m** (0.50 mmol, 93 mg) and *p*-toluidine **2b** (0.70 mmol, 74 mg). Silica gel chromatography (eluent: petroleum ether/ethyl acetate = 4/1) of the product **3mb** afforded a colorless solid (86 mg, 63% yield): ^{1}H NMR (500 MHz, $CDCl_3$) δ_H/ppm 7.99 (s, 1H), 7.39 (d, J = 4.9 Hz, 1H), 7.35 (d, J = 8.0 Hz, 2H), 7.31−7.27 (m, 1H), 7.22 (d, J = 7.8 Hz, 1H), 3.60 (s, 3H), 2.38 (s, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ_C/ppm 164.4, 142.3, 138.2, 135.6, 132.5, 131.8, 130.8, 129.2, 128.5, 128.3, 128.3, 126.6, 125.7, 64.1, 21.2; GCMS (EI, 70 eV) m/z (%) 273.05 (46.39), 243.05 (40), 214.05 (42.76), 179.10 (19.69), 120.60 (8.39), 82.15 (9.00); IR (ATR) ν (cm^{-1}) 2922 and 1658.

5-Methoxy-3-methyl-9-nitrophenanthridin-6(5*H*)-one (3nb). The typical procedure was applied to *N*-methoxy-4-nitrobenzamide **1n** (0.50 mmol, 98 mg) and *p*-toluidine **2b** (0.70 mmol, 74 mg). Silica gel chromatography (eluent: petroleum ether/ethyl acetate = 4/1) of the product **3nb** afforded a colorless solid (81 mg, 57% yield): ^{1}H NMR (500 MHz, $CDCl_3$) δ_H/ppm 9.09 (s, 1H), 8.71 (d, J = 8.8 Hz, 1H), 8.32 (d, J = 8.8 Hz, 1H), 8.21 (d, J = 8.2 Hz, 1H), 7.53 (s, 1H), 7.27 (d, J = 5.6 Hz, 1H), 4.17 (s, 3H), 2.57 (s, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ_C/ppm 156.0, 150.5, 142.5, 136.4, 134.3, 130.6, 129.8, 125.2, 123.6, 121.2, 117.5, 115.0, 113.1, 62.9, 22.0; GCMS (EI, 70 eV) m/z (%) 284.00 (47.87), 254.00 (40), 208.00 (59.98), 103.05 (64.82), 57.05 (66.86); HRMS (H^+) calcd 285.0870 for $C_{15}H_{13}N_2O_4$, found 285.0876; IR (ATR) ν (cm^{-1}) 2916, 1666, and 1602.

1-Methoxy-7-methyl-4-phenylquinolin-2(1*H*)-one (3ob). The typical procedure was applied to *N*-methoxycinnamamide **1o** (0.50 mmol, 89 mg) and *p*-toluidine **2b** (0.70 mmol, 74 mg). Silica gel chromatography (eluent: petroleum ether/ethyl acetate = 4/1) of the product **3ob** afforded a colorless oil (97 mg, 73% yield): ^{1}H NMR (500 MHz, $CDCl_3$) δ_H/ppm 7.69 (d, J = 8.3 Hz, 1H), 7.62−7.57 (m, 2H), 7.50−7.34 (m, 2H), 7.19 (t, J = 7.6 Hz, 2H), 6.97 (s, 1H), 6.67 (s, 1H), 4.14 (s, 3H), 2.43 (s, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ_C/ppm 157.4, 150.8, 138.9, 138.0, 133.7, 131.1, 129.3, 128.7, 127.7, 125.4, 122.6, 121.7, 119.8, 112.0, 112.0, 62.9, 21.3; GCMS (EI, 70 eV) m/z (%) 265.15 (42.68), 235.10 (40), 206.10 (25.28), 178.10 (14.57), 102.20 (17.96); HRMS (H^+) calcd 266.1176 for $C_{17}H_{16}NO_2$, found 266.1173; IR (ATR) ν (cm^{-1}) 2934, 1648, and 1588.

5-Methoxyphenanthridin-6(5*H*)-one (3aa).[15a] The typical procedure was applied to *N*-methoxybenzamide **1a** (0.50 mmol, 76 mg) and aniline **2a** (0.70 mmol, 65 mg). Silica gel chromatography (eluent: petroleum ether/ethyl acetate = 4/1) of the product **3aa** afforded a colorless solid (40 mg, 89% yield): ^{1}H NMR (500 MHz, $CDCl_3$) δ_H/ppm 8.57 (dd, J = 8.0, 0.9 Hz, 1H), 8.28 (dd, J = 8.0, 3.8 Hz, 2H), 7.82−7.76 (m, 1H), 7.69 (d, J = 8.3 Hz, 1H), 7.60 (td, J = 8.1, 1.0 Hz, 2H), 7.40−7.32 (m, 1H), 4.15 (s, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ_C/ppm 157.3, 135.8, 132.9, 132.6, 129.9, 128.5, 128.1, 126.4, 123.2, 123.2, 121.9, 118.6, 112.6, 62.7; GCMS (EI, 70 eV) m/z (%) 225.00 (57.20), 195 (40), 180.00 (34.45), 166.05 (55.58), 140.10 (23.07), 82.60 (12.43); IR (ATR) ν (cm^{-1}) 2922, 1651, and 1660.

3,5-Dimethoxyphenanthridin-6(5*H*)-one (3ac).[16] The typical procedure was applied to *N*-methoxybenzamide **1a** (0.50 mmol, 76 mg) and 4-methoxyaniline **2c** (0.70 mmol, 85 mg). Silica gel chromatography (eluent: petroleum ether/ethyl acetate = 4/1) of the product **3ac** afforded a colorless solid (108 mg, 85% yield): ^{1}H NMR (500 MHz, $CDCl_3$) δ_H/ppm 8.52−8.42 (m, 1H), 8.08 (t, J = 8.2 Hz, 2H), 7.74−7.64 (m, 1H), 7.47 (dd, J = 7.9, 7.2 Hz, 1H), 7.15−7.05 (m, 1H), 6.86 (dd, J = 9.0, 2.0 Hz, 1H), 4.11 (s, 3H), 3.91 (s, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ_C/ppm 161.3, 157.6, 137.2, 133.1, 132.6, 128.4, 126.9, 124.9, 124.7, 121.3, 111.9, 110.6, 96.7, 62.6, 55.6; GCMS (EI, 70 eV) m/z (%) 255.00 (40), 225.00 (82.00), 196.00 (81.99), 153.05 (40.65), 127.10 (12.48); IR (ATR) ν (cm^{-1}) 2937, 1659, and 1605.

5-Methoxy-2,3-dimethylphenanthridin-6(5*H*)-one (3ad).[16] The typical procedure was applied to *N*-methoxybenzamide **1a** (0.50 mmol, 76 mg) and 3,4-dimethylaniline **2d** (0.70 mmol, 85 mg). Silica gel chromatography (eluent: petroleum ether/ethyl acetate = 4/1) of the product **3ad** afforded a colorless solid (114 mg, 90% yield): ^{1}H NMR (500 MHz, $CDCl_3$) δ_H/ppm 8.52 (d, J = 8.1 Hz, 1H), 8.21 (d, J = 8.1 Hz, 1H), 7.97 (s, 1H), 7.77−7.70 (m, 1H), 7.54 (dd, J = 8.0, 7.2 Hz, 1H), 7.42 (s, 1H), 4.13 (s, 3H), 2.42 (s, 3H), 2.39 (s, 3H); ^{13}C{^{1}H} NMR (125 MHz, $CDCl_3$) δ_C/ppm 157.2, 139.5, 133.9, 133.0, 132.4, 131.8, 128.4, 127.4, 126.0, 123.7, 121.6, 116.3, 113.2, 62.6, 20.4,

DOI: 10.1021/acs.joc.6b00378
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19.6; GCMS (EI, 70 eV) m/z (%) 253.10 (79.72), 223.05 (86.21), 194.05 (40), 165.10 (17.67), 126.65 (10.86), 89.10 (12.16); IR (ATR) ν (cm^{-1}) 2914, 1641, and 1607.

5-Methoxy-1,3-dimethylphenanthridin-6(5*H*)-one (3ae). The typical procedure was applied to *N*-methoxybenzamide **1a** (0.50 mmol, 76 mg) and 2,4-dimethylaniline **2e** (0.70 mmol, 85 mg). Silica gel chromatography (eluent: petroleum ether/ethyl acetate = 4/1) of the product **3ae** afforded a colorless solid (92 mg, 73% yield): ^{1}H NMR (500 MHz, $CDCl_3$) δ_H/ppm 8.55−8.51 (m, 1H), 8.28−8.24 (m, 1H), 8.01 (s, 1H), 7.78−7.74 (m, 1H), 7.58−7.56 (m, 1H), 7.46 (s, 1H), 4.14 (s, 3H), 2.45 (s, 3H), 2.41 (s, 3H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$) δ_C/ppm 157.3, 139.5, 135.7, 132.5, 132.4, 131.8, 128.5, 128.4, 127.4, 123.8, 122.2, 121.6, 113.3, 62.6, 20.4, 19.6; GCMS (EI, 70 eV) m/z (%) 253.05 (68.01), 223.00 (40), 194.05 (91.30), 165.05 (18.76), 76.00 (9.72); HRMS (Na^+) calcd 276.0995 for $C_{16}H_{15}NNaO_2$, found 276.1000; IR (ATR) ν (cm^{-1}) 2916, 1666, and 1554.

3-Chloro-5-methoxyphenanthridin-6(5*H*)-one (3af).[16] The typical procedure was applied to *N*-methoxybenzamide **1a** (0.50 mmol, 76 mg) and 4-chloroaniline **2f** (0.70 mmol, 89 mg). Silica gel chromatography (eluent: petroleum ether/ethyl acetate = 4/1) of the product **3af** afforded a colorless solid (98 mg, 76% yield): ^{1}H NMR (500 MHz, $CDCl_3$) δ_H/ppm 8.56 (d, J = 8.0 Hz, 1H), 8.23−8.18 (m, 2H), 7.80 (t, J = 7.2 Hz, 1H), 7.71−7.59 (m, 2H), 7.36−7.30 (m, 1H), 4.16 (s, 3H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$) δ_C/ppm 157.3, 139.3, 136.2, 132.9, 132.3, 131.14, 128.7, 128.4, 124.5, 123.5, 121.9, 114.0, 112.6, 62.9; GCMS (EI, 70 eV) m/z (%) 258.95 (22.02), 229.95 (69.43), 103.05 (40), 57.05 (88.14); IR (ATR) ν (cm^{-1}) 2916, 1663, and 1602.

5-Methoxy-3-nitrophenanthridin-6(5*H*)-one (3ag).[15a] The typical procedure was applied to *N*-methoxy-*N*-methylbenzamide **1a** (0.50 mmol, 76 mg) and 4-nitroaniline **2g** (0.70 mmol, 97 mg). Silica gel chromatography (eluent: petroleum ether/ethyl acetate = 4/1) of the product **3ag** afforded a colorless solid (71 mg, 53% yield): ^{1}H NMR (500 MHz, $CDCl_3$) δ_H/ppm 8.62 (d, J = 8.0 Hz, 1H), 8.53 (d, J = 2.3 Hz, 1H), 8.42 (d, J = 8.8 Hz, 1H), 8.33 (d, J = 8.2 Hz, 1H), 8.20 (dd, J = 8.8, 2.3 Hz, 1H), 7.90−7.87 (m, 1H), 7.75 (t, J = 7.6 Hz, 1H), 4.22 (s, 3H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$) δ_C/ppm 157.0, 148.5, 136.4, 133.3, 131.2, 130.1, 129.0, 127.3, 124.4, 123.5, 123.0, 117.63, 108.4, 63.3; GCMS (EI, 70 eV) m/z (%) 270.00 (31.36), 240.00 (40), 182.00 (57.54), 103.05 (88.18), 43.95 (70.54); IR (ATR) ν (cm^{-1}) 2917, 1661, and 1515.

***N*-Methoxy-*N*-methyl-[1,1′-biphenyl]-2-carboxamide (3ta).**[25] In a 15 mL Schlenk tube, a solution of 5 mL of methanesulfonic acid, $Pd(OAc)_2$ (5 mol %, 11.2 mg), aniline **2a** (0.7 mmol, 0.65 mg), *N*-methoxy-*N*-methylbenzamide **1t** (0.50 mmol, 83 mg), and AgOTf (1 mmol, 257 mg) was added under a nitrogen atmosphere. The system was degassed four to five times by a vacuum pump. To the resulting suspension was added *tert*-butyl nitrite (0.8 mmol, 85 mg) by syringe. The reaction mixture was stirred at 40 °C for 18 h. After completion of the reaction, the reaction mixture was cooled to room temperature. All volatiles were removed under vacuum. The product was extracted with 20 mL of ethyl acetate, the organic layer dried over Na_2SO_4, and the solvent removed under vacuum. The colorless solid phenanthridinone product **3ta** was purified by column chromatography (silica gel, 40−200 mesh, eluent: petroleum ether/ethyl acetate = 4/1, 25 mg, 21% yield): ^{1}H NMR (500 MHz, $CDCl_3$) δ_H/ppm 7.69−7.07 (m, 9H), 3.48 (br s, 1H), 3.24 (br s, 2H), 3.08 (br s, 2H), 2.65 (br s, 1H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$) δ_C/ppm 172.0, 167.1, 140.5, 139.5, 139.5, 134.9, 134.8, 129.6, 129.4, 128.4, 128.3, 127.7, 127.6, 127.4, 126.8, 61.1, 59.8, 35.8, 32.4, 29.7; GCMS (EI, 70 eV) m/z (%) 241.05 (1.73), 181.10 (40), 152.15 (40.35), 76.05 (7.34); IR (ATR) ν (cm^{-1}) 2932, 1645, and 1375.

***N*-Methoxy-[1,1′-biphenyl]-2-carboxamide (B′):**[18] ^{1}H NMR (500 MHz, $CDCl_3$) δ_H/ppm 8.17 (s, 1H), 7.57 (s, 1H), 7.48 (td, J = 7.6, 1.4 Hz, 1H), 7.39−7.35 (m 7H), 3.47 (s, 3H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$) δ_C/ppm 167.3, 140.1, 140.0, 139.7, 132.3, 130.6, 130.0, 129.0, 128.7, 127.9, 127.6, 63.7; GCMS (EI, 70 eV) m/z (%) 227.10 (1.10), 197.10 (39.43), 180.05 (100.00), 152.15 (55.01), 76.05 (23.17); IR (ATR) ν (cm^{-1}) 3221, 1639, 1508, 1310.

Typical Procedure for the Synthesis of 3ab on the Gram Scale. In 40 mL double-neck round-bottom flask, a solution of 20 mL of acetic acid, $Pd(OAc)_2$ (5 mol %), *p*-toluidine **2a** (9.7 mmol, 1.40 g), *N*-methoxybenzamide **1a** (7 mmol, 1.06 g), and Ag_2O (14 mmol, 3.12 g) was added under a nitrogen atmosphere. The system was degassed four to five times by a vacuum pump. To the resulting suspension was added *tert*-butyl nitrite (11.2 mmol, 1.5 mL) by syringe at room temperature. The reaction mixture temperature was 40 °C for up to 18 h. After completion of the reaction, the reaction mixture was cooled to room temperature. All volatiles were removed under vacuum. The product was extracted with 20 mL of ethyl acetate, the organic layer dried over Na_2SO_4, and the solvent removed under vacuum. The phenanthridinone product was purified by column chromatography (silica gel, 40−200 mesh).

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.6b00378.

Copies of ^{1}H and ^{13}C NMR spectra (PDF)

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Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

S.L.Y. is thankful to the Council of Scientific and Industrial Research (CSIR), New Delhi, India, for providing a Senior Research Fellowship (SRF). We are also thankful to the Department of Chemistry, IIT Mumbai, for providing HRMS analysis of products.

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