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Synthesis of Lactams via Ir-Catalyzed C-H Amidation Involving Ir-nitrene Intermediates

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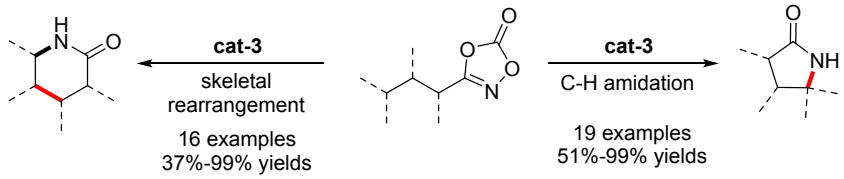
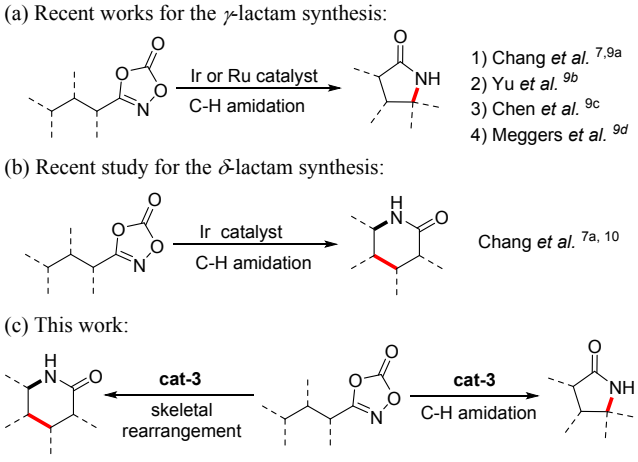
Supporting Information Placeholder



ABSTRACT: We have developed a divergent strategy for the synthesis of five- and six-membered lactams via either an amidation of sp^3 C-H bonds or electrophilic substitution of arenes via Ir-nitrene intermediates. With the employment of a readily available iridium catalyst in dichloromethane or hexafluoro-2-propanol, a wide range of lactams were synthesized in good to excellent yields with high selectivity.

INTRODUCTION

The five- and six-membered lactam rings are found not only in various natural products with diverse biological activities,[1] but also in a number of synthetic bioactive compounds and clinical drugs.[2] Previously, numerous methods were developed for the construction of N-substituted lactam motif due to its high utility.[3] One of the most versatile strategies is direct transformation of aliphatic C-H bonds into valuable C-N bonds.[4] Since the initial report of intramolecular nitrene C-H insertions mediated by transition-metal complexes a few decades ago,[5] numerous methods have been reported for the C-H amidation reaction.[6] However, most of these reactions afforded carbamates or sulfamates. Direct formation of cyclic amides or lactams through C-H amidation remained elusive until recently,[7] because free nitrenes derived from amides can easily undergo Curtius-type rearrangement to form isocyanates (Scheme 1a). Using dioxazolone[8] as the nitrene precursor and a series of carefully designed Ir-complexes as the catalysts, the formation of lactams via Ir-catalyzed C-H amidation reaction was realized by Chang and Baik in 2018 as one of the major breakthroughs in the area of C-H functionalization.[7a] Moreover, several groups reported the formation of chiral γ-lactams via enantioselective intramolecular C-H amidation in 2019 (Scheme **1a**). [9] The formation of δ-lactams using the same strategy was also achieved by Chang with different iridium catalysts (Scheme **1b**).[7a,10]



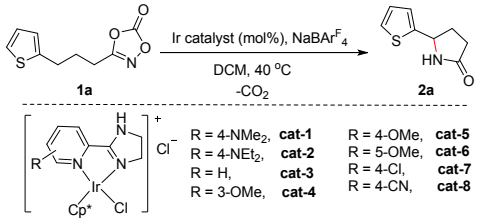
Scheme 1. Dioxazolones as the nitrene precursors.

In the present study, we devoted to further explore the employment of our recently developed readily available Ir-catalysts[11] for the synthesis of various lactams via either C-H insertion to sp^3 C-H bonds or electrophilic substitution of electron-rich arenes (Scheme **1c**).

RESULTS AND DISCUSSION

We first examined the reactivity of different catalysts in the C-H amidation reaction. We selected 3-[3-(thiophen-2-yl)propyl]-1,4,2-dioxazol-5-one (**1a**) as the model substrate. When 0.5 mol% of **cat-3** was used as catalyst with equal equivalent of sodium tetrakis(3,5-bis(trifluoromethyl)phenyl)borate ($NaBAr^F_4$) in dichloromethane, only trace amount of the product was detected (Table 1, entry 1). After increasing the catalyst loading, moderate to good yields were obtained (Table 1, entries 2,3). When the ratio of $NaBAr^F_4$ additive to Ir catalyst was increased to 2:1, the yield was improved from 67% to 89% (Table 1, entry 4).

Table 1. Optimization of Ir-catalyzed C-H amidation. [a]



Ir-catalysts

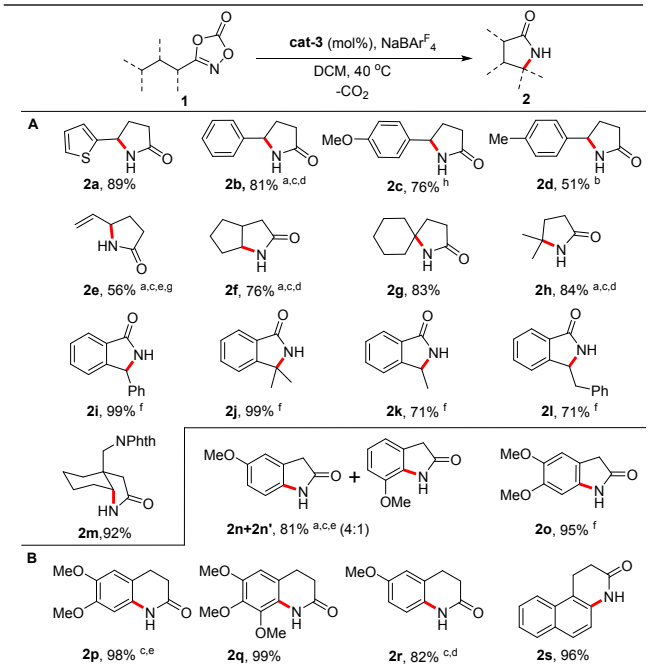
Entry	Catalyst (mol%)	$NaBAr^F_4$ (mol%)	Solvent	Yield [b] (%)
1	cat-3 (0.5)	0.5	DCM	8
2	cat-3 (1)	1	DCM	43
3[c]	cat-3 (2)	2	DCM	67
4[c]	cat-3 (2)	4	DCM	89
5[c]	cat-3 (5)	10	DCM	88
6[c]	cat-1 (2)	4	DCM	59
7[c]	cat-2 (2)	4	DCM	61
8[c]	cat-4 (2)	4	DCM	31
9[c]	cat-5 (2)	4	DCM	38
10[c]	cat-6 (2)	4	DCM	46
11[c]	cat-7 (2)	4	DCM	39
12[c]	cat-8 (2)	4	DCM	52
13	cat-3 (2)	4	MeOH	11
14	cat-3 (2)	4	dioxane	10
15	cat-3 (2)	4	THF	12
16	cat-3 (2)	4	MeCN	24
17	cat-3 (2)	4	EtOAc	34
18[d]	cat-3 (2)	4	DCE	68

[a] The reactions were performed on a 0.2 mmol scale for 12 h. [b] The yield was determined and calculated by ^{1}H NMR with 1,3,5-trimethoxybenzene as internal standard. [c] The reaction time was 20 h. [d] DCE was abbreviation of 1,2-dichloroethane.

We then examined the effect of different R-substituent on the pyridine ring of our catalysts. 4-Dialkylamino-substituted catalysts **cat-1** and **cat-2** delivered 59% and 61% yields, respectively (Table 1, entries 6,7). The 3-, 4-, and 5-methoxy-substituted catalysts **cat-4**, **cat-5**, and **cat-6** gave lower yields (31%, 38%, and 46% respectively, as shown in entries 8-10). 4-Chloro substituted **cat-7** gave 39% yield while the more electron withdrawing cyano substituted **cat-8** delivered 52% yield (Table 1, entries 11,12). Of all the catalysts we screened, **cat-3** exhibited the best activity for the C-H amidation reaction. The starting material for the ligand of this catalyst is also the least expensive comparing to other ligands. Other solvents did not provide any improvement over dichloromethane.

After the optimization of the reaction conditions, a wide range of substrates were examined for this C-H amidation (Table **2**). Dioxazolones, used as substrates in this reaction, were easily prepared from commercially available carboxylic acids following literature procedures.[7a, 12] Thiophene **2a** was obtained in 89% isolated yield. Benzylic substrates also gave good yields (**2b, 2c**), while *para*-methyl-substituted benzylic product **2d** was prepared in only 51% yield. Allylic lactam (**2e**) was also obtained in good yield. Cyclopentyl **2f**, which had nonactivated secondary C-H bonds, was also successfully synthesized. Insertion to tertiary C-H bonds yielded products **2g** and **2h**. When *ortho*-substituted benzamides were employed, *3*-subsitituted isoindolinones (**2i**, **2j**, **2k**, **2l**) were prepared in good to excellent yields. Treatment of *N*-phthalimide-protected gabapentin derivative with our catalyst also gave the corresponding lactam **2m** in 92% yield.

Table 2. Scope of intramolecular C-H amidation

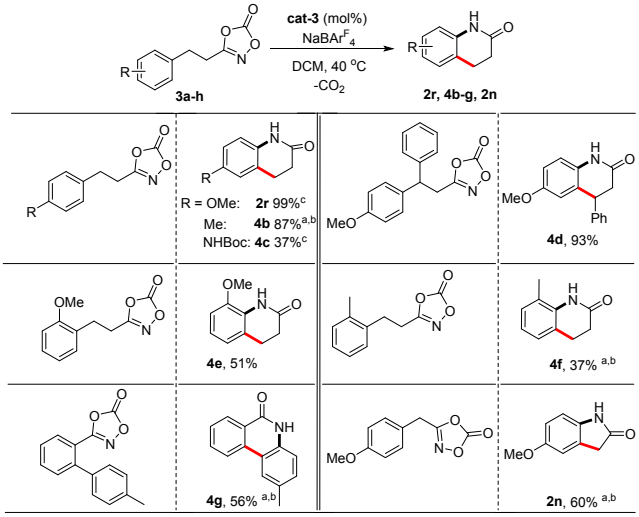


(**A**) Functionalization of aliphatic sp^3 C-H bonds. (**B**) Functionalization of aromatic sp^2 C-H bonds. Unless otherwise indicated, the reaction conditions were: 2 mol% of **cat-3**, 4 mol% of $NaBAr^F_4$ and dichloromethane at 40 °C for 12 h. [a] 5 mol% catalyst was used. [b] 10 mol% catalyst was used. [c] Hexafluoro-2-propanol (HFIP) was used as solvent. [d] Run at 50 °C. [e] Run at 60 °C. [f] Reaction time was 4 h. [g] Reaction time was 24 h. [h] Reaction time was 36 h.

As shown in Table **2B**, five- and six-membered lactams bearing an aniline moiety could also be prepared using our catalyst **cat-3**. *Meta*-substituted phenylacetyl substrate gave a mixture of isomeric desired products (**2n**, **2n'**) in a total of 81% yield with 4:1 regioselectivity. 3, 4-Dimethoxy-substituted dioxazolones generated lactams **2o** and **2p** in excellent yields, respectively. Dihydroquinolinone **2q** was also synthesized from the corresponding 3, 4, 5-trimethoxy-substituted substrate in 99% yield. It is worth to mention that the *meta*-methoxy substituted dihydroquinolinone **2r** was obtained as the major isomer with a regioselectivity of more than 20:1, presumably because the cyclization to the *ortho*-position is sterically too congested. When naphthylethyl dioxazolone was used as substrate, tricyclic dihydroquinolinone product **2s** was obtained successfully.

When we examined the *para*-methoxy substituted hydrocinnamyl substrates under the amidation conditions, unexpected rearrangement products were obtained. We then examined the scope of this rearrangement reaction as shown in Table **3**. *Para*-methoxy substituted dioxazolone gave the corresponding product **2r** in 99% yield. When the substitute was replaced by methyl group, **4b** was obtained in 87% yield. However, the reaction with Boc protected amino substituent gave a relatively low yield (**4c**). The cyclization reaction occurred efficiently with high regioselectivity on the more electron-rich methoxy substituted phenyl to give **4d** in 93% yield. The rearrangement product was also found for *ortho*-substituted substrates. Reaction of an *ortho*-methoxy-substituted phenylethyl dioxazolone proceeded in moderate yield (**4e**). However, when the substitute was replaced by a methyl group, the product **4f** was generated in a relatively low yield. Tricyclic product **4g** was also prepared in a moderate yield. In addition, five-membered-ring cyclization reaction also proceeded smoothly to generate product **2n** in satisfactory yield.

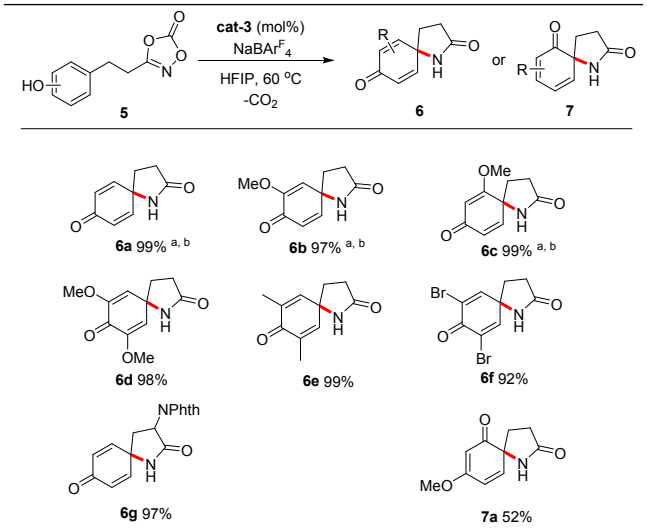
Table 3. Scope of benzo-fused *δ*-lactams via skeletal rearrangement



Unless otherwise indicated, the reaction conditions were: 2 mol% of catalyst, 4 mol% of NaBAr$^F_4$ and dichloromethane at 40 °C for 12 h. [a] Hexafluoro-2-propanol was used as solvent. [b] Run at 50 °C. [c] Reaction time was 2 h.

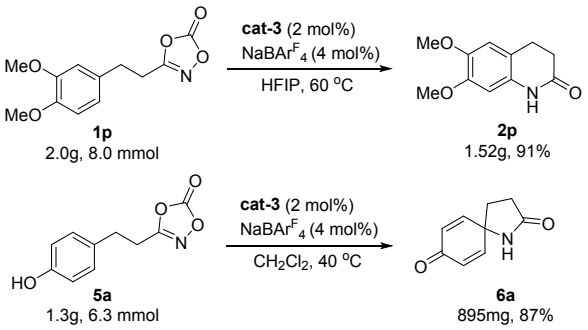
To further investigate the mechanism of the skeletal rearrangement, a range of phenol-based dioxazolones were examined under the reaction conditions, as shown in Table **4**.

Table 4. Scope of dearomative spirocyclization reaction



Unless otherwise indicated, the reaction conditions were: 2 mol% of catalyst, 4 mol% of NaBAr$^F_4$ and HFIP at 60 °C for 12 h. [a] Dichloromethane was used as solvent. [b] Run at 40 °C.

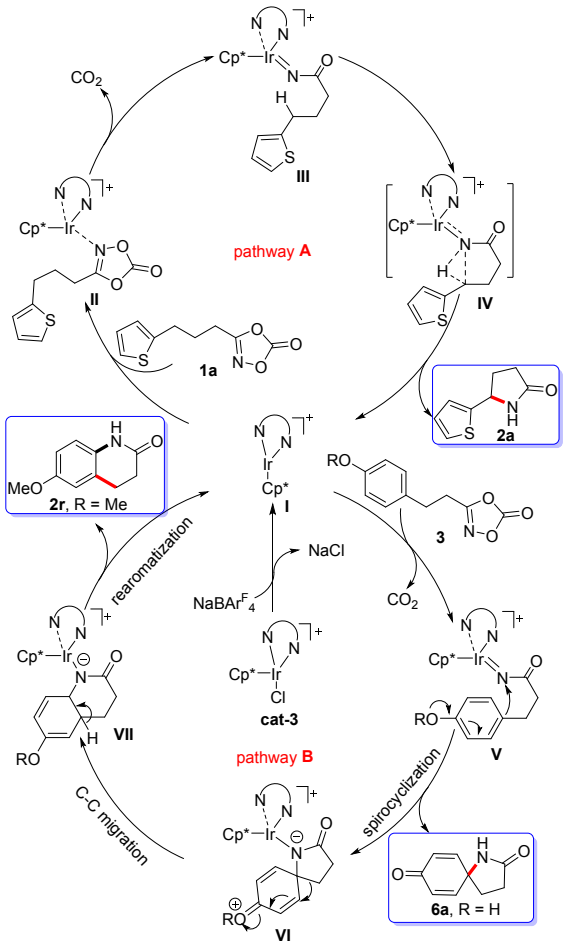
To our delight, when *para*-hydroxy substituted dioxazolone was used as substrate, the *aza*-spirodienone product **6a** was isolated in 99% yield. It appeared that the spirocyclization reaction occurred first, and it was followed by a C-C migration to form the rearrangement products. Chang's group reported similar reactions using their Ir-catalysts.[10] Other phenol-based dioxazolones having additional substituents also proceeded well. *Ortho*- and *meta*-substituted hydroxy phenol substrates generated the corresponding products **6b** and **6c** in excellent yield respectively. Derivatives bearing multiple substituents also underwent the dearomative spirocyclization reaction smoothly (**6d**, **6e**, **6f**). *N*-phthalimide-protected tyrosine afforded lactam **6g** in 97% yield. It needs to be emphasized that *ortho*-hydroxy substituted dioxazolone under the same reaction condition generated spirolactam **7a** in moderate yield.



Scheme 2. Gram-scale synthesis of lactams

Furthermore, this reaction was scalable, as demonstrated in the gram-scale experiments. For example, 2 g of dioxazolone **1p** and 1.3 g of **5a** were facilely converted to the corresponding lactams **2p** and **6a** in excellent yields (91% and 87% respectively) as shown in Scheme **2**, enhancing the synthetic utility of this method.

A plausible mechanism including two different pathways for the iridium catalyzed C-H amidation was proposed in Scheme **3**. In pathway **A**, an Ir-catalyzed insertion of Ir-nitrene into sp^3 C-H bond was proposed. Coordination of Ir-catalyst to dioxazolone in **1a** will induce the formation of Ir-nitrene **III**, releasing a molecule of carbon dioxide. Insertion of Ir-nitrene to C-H bond through **IV** would yield product **2a**. In pathway **B**, an electrophilic aromatic substitution mechanism was proposed for the amidation of sp^2 C-H bond. When *para*- or *ortho*-hydroxy substituted phenol dioxazolones were used, cyclization of intermediate **V** and the removal of the proton on the phenolic oxygen can generate the spirolactam **6a** directly. Otherwise, cyclization of intermediate **V** will afford the spirocyclic amido intermediate **VI**, which can then undergo 1,2-migration and rearomatization to yield the ring expanded rearrangement product **2r**.



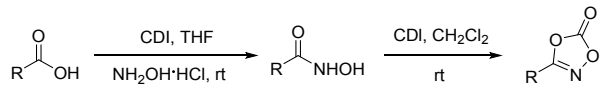
Scheme 3. Proposed mechanism of C-H amidation

In summary, we have successfully synthesized a series of five- and six-membered lactams using an iridium-complex we developed previously via amidation of sp^3 or sp^2 C-H bonds. A wide range of five- and six-membered lactams were successfully prepared in good to excellent yields with the employment of up to 2 mol% iridium catalyst. Using dioxazolones as the nitrene precursor, five-membered lactams were synthesized via insertion of the Ir-nitrene intermediate to sp^3 C-H bonds. Electrophilic substitution occurred for substrates with an electron-rich aryl substituent on the γ- or δ-position of the dioxazolones. Further studies concerning the development of an enantioselective variant for the preparation of chiral γ-lactams are currently underway in the laboratory.

EXPERIMENTAL SECTION

General information. All reactions in non-aqueous media were conducted under atmospheric conditions in glassware that had been oven dried prior to use unless noted otherwise. Oxygen and moisture-sensitive reactions were carried out under argon atmosphere. All commercially available reagents were used without further purification unless otherwise noted. Thin layer chromatography was performed using precoated silica gel plates (QC3724, F254). Flash column chromatography was performed with silica gel (Sillicycle, 50- 75μm). ^1H and ^{13}C Nuclear magnetic resonance spectra (NMR) were obtained on a Bruker 400 MHz or 500 MHz recorded in ppm (δ) downfield of TMS ($\delta = 0$) in $CDCl_3$. Signal splitting patterns were described as singlet (s), doublet (d), triplet (t), quartet (q), quintet (quint), or multiplet (m), with coupling constants (J) in Hertz.

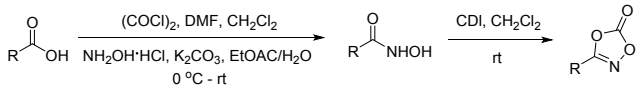
General procedure A for the preparation of 3-substituted-1,4,2-dioxazol-5-ones.



To a solution of carboxylic acid (10 mmol) in dry tetrahydrofuran (THF, 20 mL) was added 1,1'-Carbonyldiimidazole (CDI, 15 mmol, 1.5 equiv). The reaction mixture was stirred for 1 h before hydroxylamine hydrochloride (20 mmol, 2.0 equiv) was added. The resulting mixture was stirred overnight. The mixture was diluted with 5% aq. $KHSO_4$ (20 mL) and extracted with ethyl acetate. The combined organic phase was washed with brine (20 mL) and dried over anhydrous Na_2SO_4. The extract was filtered and concentrated to give the residue which was used directly for the next step.

To a solution of unpurified hydroxamic acids (5 mmol) in dry dichloromethane (20 mL) was added CDI (5.5 mmol, 1.1 equiv). The mixture was stirred for 5 min to 1 h until the reaction was complete. 2 N HCl solution (10 mL) was added and extracted with CH_2Cl_2. The combined organic phase was collected and dried over Na_2SO_4. The extract was filtered, concentrated and purified by silica gel column chromatography (eluent: petroleum ether/ethyl acetate = 10:1) to give 3-substituted-1,4,2-dioxazol-5-ones.

General procedure B for the preparation of 3-substituted-1,4,2-dioxazol-5-ones.

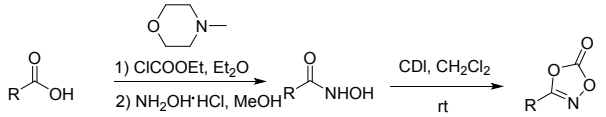


To a solution of the carboxylic acid (2.0 mmol) in dichloromethane (20 mL) was added Oxalyl chloride (4.0 mmol) and DMF (2 drops) at 0 °C. The mixture was allowed to stir at room temperature for 2.5 ~ 4 h, then the reaction mixture was concentrated, and the crude product was used directly for the next reaction.

Hydroxylamine hydrochloride (1.2 equiv) was added to a biphasic mixture of K_2CO_3 (2.0 equiv) in a 2:1 mixture of EtOAc (10 mL) and H_2O (5 mL). The resulting solution was cooled to 0 °C followed by dropwise addition of the unpurified acid chloride dissolved in a minimum amount of EtOAc under air. The reaction was warmed to room temperature and stirred for additional 12 h. The phases were separated and the aqueous phase was extracted twice with EtOAc. The combined organic layer was collected and dried over Na_2SO_4. The extract was filtered and concentrated to give the residue which was used directly for the next step.

To a solution of unpurified hydroxamic acids (5 mmol) in dry dichloromethane (20 mL) was added CDI (5.5 mmol, 1.1 equiv). The mixture was stirred for 5 min to 1 h until the reaction was complete. 2 N HCl solution (10 mL) was added and extracted with CH_2Cl_2. The combined organic phase was collected and dried over Na_2SO_4. The extract was filtered, concentrated and purified by silica gel column chromatography (eluent: petroleum ether/ethyl acetate = 10:1) to give 3-substituted-1,4,2-dioxazol-5-ones.

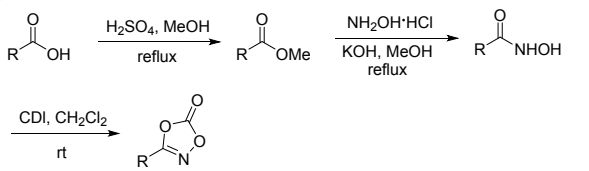
General procedure C for the preparation of 3-substituted-1,4,2-dioxazol-5-ones.



To a solution of the carboxylic acid (10 mmol) in diethylether (30 mL) was added ethylchloroformate (12 mmol, 1.2 eq) and *N*-methylmorpholine (13 mmol, 1.3 eq) at °C and the mixture was stirred for 10 min. The solid was filtered of and the filtrate was added to freshly prepared hydroxylamine (15 mmol, 1.5 eq) in methanol. The reaction mixture was stirred at room temperature for 15 min. The solvent was evaporated and the residue was purified by silica gel column chromatography to give the hydroxamic acid.

To a solution of hydroxamic acids (5 mmol) in dry dichloromethane (20 mL) was added CDI (5.5 mmol, 1.1 equiv). The mixture was stirred for 5 min to 1 h until the reaction was complete. 2 N HCl solution (10 mL) was added and extracted with CH_2Cl_2. The combined organic phase was collected and dried over Na_2SO_4. The extract was filtered, concentrated and purified by silica gel column chromatography (eluent: petroleum ether/ethyl acetate = 10:1) to give 3-substituted-1,4,2-dioxazol-5-ones.

General procedure D for the preparation of 3-substituted-1,4,2-dioxazol-5-ones.

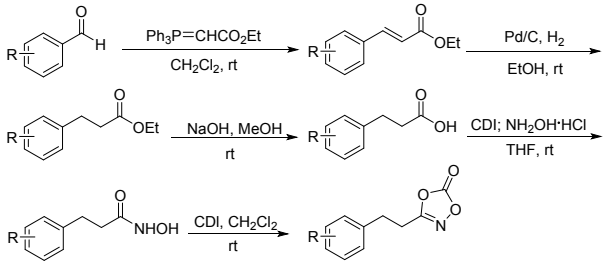


Carboxylic acid (20 mmol) was dissolved in methanol (40 mL) and sulfuric acid (conc., 0.4 mL) was added. The reaction mixture was heated to reflux for six hours until full conversion. Solid $KHCO_3$ was added to neutralize the solution. After filtration, the slightly yellow solution was evaporated to dryness. The residue was dissolved in ethyl acetate and washed with saturated sodium bicarbonate solution and saturated sodium chloride solution. The organic layer was dried and concentrated to give the methyl ester.

The methyl ester compounds (10 mmol) and hydroxylamine hydrochloride (30 mmol, 3 equiv) were suspended in methanol (50 mL) followed with the addition of potassium hydroxide (60 mmol, 6 equiv). The mixture was heated at reflux for 12 h. After the reaction was complete, the mixture was acidified with 1N HCl to pH 4 and then concentrated under reduced pressure to remove methanol. The resultant was dissolved in water and extracted with ethyl acetate. The combined organic phase was dried and concentrated, and the crude mixture was purified by silica gel column chromatography to obtain the hydroxamic acid.

To a solution of unpurified hydroxamic acids (5 mmol) in dry dichloromethane (20 mL) was added CDI (5.5 mmol, 1.1 equiv). The mixture was stirred for 5 min to 1 h until the reaction was complete. 2 N HCl solution (10 mL) was added and extracted with CH_2Cl_2. The combined organic phase was collected and dried over Na_2SO_4. The extract was filtered, concentrated and purified by silica gel column chromatography (eluent: petroleum ether/ethyl acetate = 10:1) to give 3-substituted-1,4,2-dioxazol-5-ones

General procedure E for the preparation of 3-substituted-1,4,2-dioxazol-5-ones.



To a solution of aldehyde (10 mmol) in 50 mL dichloromethane was added ethyl (triphenylphosphoranylidene) acetate (15 mmol) at 0 °C in several portions and the mixture was stirred at room temperature overnight. After the reaction was complete, the solvent was removed and the residue was purified on flash silica gel column to give the product.

To a solution of alkene (4 mmol) in 20 mLEtOH was added 5 wt. % Pd/C (10 mol %). Then the flask was vacuumed and refilled with hydrogen. The process was repeated for 3 times and the mixture was stirred at room temperature overnight. After the reaction was complete, the reaction mixture was filtered over a pad of celite and the filtrate was concentrated to give the crude product which was used directly for the next step.

To a solution of ethyl ester (2 mmol) in 20 mL methanol was added sodium hydroxide (5 mmol) in one portion. Then the mixture was stirred at room temperature overnight. After the reaction was complete, methanol was removed on the rotary evaporator and water was added. Then 1N HCl was added to pH 1-2 and extracted with ethyl acetate. The combined organic phase was collected and concentrated to give the crude product which was used for the next step without further purification.

To a solution of carboxylic acid (2 mmol) in dry tetrahydrofuran (THF, 15 mL) was added 1,1'-Carbonyldiimidazole (CDI, 3

mmol, 1.5 equiv). The reaction mixture was stirred for 1 h before hydroxylamine hydrochloride (20 mmol, 2 equiv) was added. The resulting mixture was stirred overnight. The mixture was diluted with 5% aq. $KHSO_4$ (20 mL) and extracted with ethyl acetate. The combined organic phase was washed with brine (20 mL) and dried over Na_2SO_4. The extract was filtered and concentrated to give the residue which was used directly for the next step.

To a solution of unpurified hydroxamic acids (1.5 mmol) in dry dichloromethane (20 mL) was added CDI (1.5 mmol, 1.0 equiv). The mixture was stirred for 5 min to 1 h until the reaction was complete. 1 N HCl solution (10 mL) was added and extracted with CH_2Cl_2. The combined organic phase was collected and dried over Na_2SO_4. The extract was filtered, concentrated and purified by silica gel column chromatography (eluent: petroleum ether/ethyl acetate = 10:1) to give 3-substituted-1,4,2-dioxazol-5-ones.

3-(3-(thiophen-2-yl)propyl)-1,4,2-dioxazol-5-one (1a).[7a] Prepared according to general procedure A; Eluent: petroleum ether/ethyl acetate = 10:1; Colorless oil (900 mg, 76%);^{1}H NMR (400 MHz, $CDCl_3$) δ 2.10 (quintet, J = 7.6 Hz, 2H), 2.66 (t, J = 7.6 Hz, 2H), 2.97 (t, J = 7.6 Hz, 2H), 6.82 (dd, J = 0.8, 3.4 Hz, 1H), 6.94 (dd, J = 3.4, 5.2 Hz, 1H), 7.16 (dd, J = 1.2, 5.2 Hz, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 23.8, 26.2, 28.6, 123.9, 125.2, 127.0, 142.3, 154.1, 166.3

3-(3-phenylpropyl)-1,4,2-dioxazol-5-one (1b).[7a] Prepared according to general procedure A; Eluent: petroleum ether/ethyl acetate = 10:1; Colorless oil (360 mg, 98 %); ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.03 (quintet, J = 7.4 Hz, 2H), 2.58 (t, J = 7.4 Hz, 2H), 2.71 (t, J = 7.4 Hz, 2H), 7.16 (d, J = 7.2 Hz, 2H), 7.21 (d, J = 7.2 Hz, 1H), 7.29 (t, J = 7.2 Hz, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 24.0, 25.9, 34.6, 126.5, 128.5, 128.7,140.0, 154.2, 166.6

3-(3-(4-methoxyphenyl)propyl)-1,4,2-dioxazol-5-one (1c).[7a] Prepared according to general procedure A; Eluent: petroleum ether/ethyl acetate = 10:1; Colorless oil (200 mg, 89 %); ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.02 (quintet, J = 7.4 Hz, 2H), 2.60 (t, J = 7.4 Hz, 2H), 2.68 (t, J = 7.4 Hz, 2H), 3.79 (s, 3H), 6.85 (d, J = 8.8 Hz, 2H), 7.09 (d, J = 8.8 Hz, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 24.0, 26.1, 33.7, 55.3, 114.1, 129.4, 131.8, 154.1, 158.3, 166.5

3-(3-(p-tolyl)propyl)-1,4,2-dioxazol-5-one (1d).[9b] Prepared according to general procedure A; Eluent: petroleum ether/ethyl acetate = 10:1; Colorless oil (180 mg, 64%); ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.04 (quant, J = 7.6 Hz, 2H), 2.33 (s, 3H), 2.60 (t, J = 7.6 Hz, 2H), 2.70 (t, J = 7.6 Hz, 2H), 7.06 (d, J = 8.0 Hz, 2H), 7.12 (d, J = 8.0 Hz, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 21.0, 24.0, 26.0, 34.1, 128.3, 129.3, 136.1, 136.7, 154.1, 166.5

3-(pent-4-en-1-yl)-1,4,2-dioxazol-5-one (1e).[9c] Prepared according to general procedure A; Eluent: petroleum ether/ethyl acetate = 10:1; Colorless oil (280 mg, 72 %); ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.84 (quintet, J = 7.2 Hz, 2H), 2.19 (q, J = 7.2 Hz, 2H), 2.64 (t, J =7.2 Hz, 2H), 5.02-5.12 (m, 2H), 5.71-5.82 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 23.5, 24.0, 32.5, 116.6, 136.4, 154.2, 166.6

3-(cyclopentylmethyl)-1,4,2-dioxazol-5-one (1f).[9c] Prepared according to general procedure A; Eluent: petroleum ether/ethyl acetate = 10:1; Colorless oil (379 mg, 92 %); ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.22-1.29 (m, 2H), 1.55-1.73 (m, 4H), 1.85-1.93 (m, 2H), 2.24 (quintet, J = 7.6 Hz, 1H), 2.62 (d, J = 7.6 Hz, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 24.9, 30.4, 32.3, 36.0, 154.3, 166.5

3-(2-cyclohexylethyl)-1,4,2-dioxazolidin-5-one (1g).[7a] Prepared according to general procedure A; Eluent: petroleum ether/ethyl acetate = 10:1; Colorless oil (500 mg, 46 %); ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.89-0.98 (m, 2H), 1.13-1.34 (m, 4H), 1.60 (q, J = 8.4 Hz, 2H), 1.66-1.75 (m, 5H), 2.64 (t, J = 7.8 Hz, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 22.3, 26.0, 26.3, 31.7, 32.7, 36.8, 154.2, 167.1

3-isopentyl-1,4,2-dioxazol-5-one (1h).[7a] Prepared according to general procedure A; Eluent: petroleum ether/ethyl acetate = 10:1; Colorless oil (350 mg, 59 %); ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.88 (d, J = 6.3 Hz, 6H), 1.51-1.63 (m, 3H), 2.56 (t, J = 7.6 Hz, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 20.9, 21.8, 26.4, 32.1, 153.2, 166.0

3-(2-benzylphenyl)-1,4,2-dioxazol-5-one (1i).[9d] Prepared according to general procedure B; Eluent: petroleum ether/ethyl acetate = 10:1; White solid (190 mg, 62 %); m.p. = 77-80 ^{o}C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.31 (s, 2H), 7.11 (d, J = 7.0 Hz, 2H), 7.21 (dt, J = 2.0, 7.2 Hz, 1H), 7.27 (t, J = 7.6 Hz, 3H), 7.37 (td, J =1.0, 7.8 Hz, 1H), 7.52 (td, J = 1.2, 7.6 Hz, 1H), 7.74 (dd, J = 1.2, 7.8 Hz, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 39.9, 119.3, 126.6, 127.1, 128.7, 129.1, 129.4, 132.0, 133.4, 138.9, 141.8, 153.6, 163.8

3-(2-isopropylphenyl)-1,4,2-dioxazol-5-one (1j).[7a] Prepared according to general procedure B; Eluent: petroleum ether/ethyl acetate = 10:1; White solid (55 mg, 73%); m.p. = 52-55 ^{o}C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.29 (d, J = 6.8 Hz, 6H), 3.60 (qui, J = 6.8 Hz, 1H), 7.35 (td, J = 1.4, 7.8 Hz, 1H), 7.54 (dd, J = 0.9, 7.8 Hz, 1H), 7.60 (td, J = 1.2, 8.0 Hz, 1H), 7.68 (dd, J = 1.2, 8.0 Hz, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 23.6, 30.3, 118.3, 126.4, 127.0, 129.3, 133.5, 150.0, 153.8, 164.1

3-(2-ethylphenyl)-1,4,2-dioxazol-5-one (1k).[7a] Prepared according to general procedure B; Eluent: petroleum ether/ethyl acetate = 10:1; Colorless oil (160 mg, 52 %); ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.27 (t, J = 7.6 Hz, 3H), 2.96 (q, J = 7.6 Hz, 2H), 7.36 (t, J = 7.8 Hz, 1H), 7.41 (d, J = 7.8 Hz, 1H), 7.56 (td, J = 1.2, 7.6 Hz, 1H), 7.74 (dd, J = 1.0, 7.8 Hz, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 14.9, 27.7, 118.6, 126.5, 129.1, 130.4, 133.4, 145.3, 153.8, 163.9

3-(2-phenethylphenyl)-1,4,2-dioxazol-5-one (1l). Prepared according to general procedure B; Eluent: petroleum ether/ethyl acetate = 10:1; White solid (190 mg, 29 %); m.p. = 88-91 ^{o}C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.87 (t, J = 7.6 Hz, 2H), 3.22 (t, J = 7.6 Hz, 2H), 7.16 (dd, J = 7.0, 17.8 Hz, 3H), 7.25 (t, J = 7.6 Hz, 2H), 7.33 (dd, J = 7.6, 17.8 Hz, 2H), 7.50 (td, J = 0.8, 7.6 Hz, 1H), 7.69 (d, J = 7.6 Hz, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 36.9, 37.3, 119.0, 126.3, 126.9, 128.5, 128.7, 129.2, 131.2, 133.3, 140.8, 142.7, 153.7, 163.8; HRMS (ESI) m/z calcd. for $C_{16}H_{13}NO_3Na$ [M+Na]: 290.0793, found: 290.0783.

2-((1-((5-oxo-1,4,2-dioxazol-3-yl)methyl)cyclohexyl)methyl)isoindoline-1,3-dione (1m).[7a] Prepared according to general procedure A; Eluent: petroleum ether/ethyl acetate = 10:1; Colorless oil (260 mg, 24 %); ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.38-1.58 (m, 8H), 1.66-1.78 (m, 2H), 2.75 (s, 2H), 3.78 (s, 2H), 7.76 (d, J = 2.8 Hz, 2H), 7.84 (d, J = 2.8 Hz, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 21.3, 25.3, 31.9, 33.4, 38.6, 45.2, 123.4, 131.8, 134.3, 154.0, 165.2, 169.1

3-(3-methoxybenzyl)-1,4,2-dioxazol-5-one (1n).[7a] Prepared according to general procedure A; Eluent: petroleum ether/ethyl acetate = 10:1; Colorless oil (350 mg, 52 %); ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.80 (s, 3H), 3.87 (s, 2H), 6.81 (t, J = 2.0 Hz, 1H), 6.84-6.89 (m, 2H), 7.28 (t, J = 7.8 Hz, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 31.2, 55.3, 113.8, 114.8, 121.2, 130.3, 131.8, 154.0, 160.2, 165.3

3-(3,4-dimethoxybenzyl)-1,4,2-dioxazol-5-one (1o).[7a] Prepared according to general procedure A; Eluent: petroleum ether/ethyl acetate = 10:1; White solid (61 mg, 76 %); m.p. = 95-97 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.87 (s, 2H), 3.88 (s, 3H), 3.89 (s, 3H), 6.78 (s, 1H), 6.85 (s, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 30.9, 55.9, 56.0, 111.6, 111.9, 121.4, 122.6, 149.2, 149.5, 154.0, 165.5

3-(3,4-dimethoxyphenethyl)-1,4,2-dioxazol-5-one (1p).[7a] Prepared according to general procedure A; Eluent: petroleum ether/ethyl acetate = 10:1; White solid (530 mg, 59 %); m.p. = 60-62 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.92 (d, J = 6.4 Hz, 2H), 2.97 (d, J = 6.4 Hz, 2H), 3.87 (d, J = 2.8 Hz, 6H), 6.71-6.75 (m, 2H), 6.82 (d, J = 8.0 Hz, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 26.9, 30.1, 55.9, 56.0, 111.5, 111.6, 120.2, 130.5, 148.2, 149.2, 154.0, 165.9

3-(3,4,5-trimethoxyphenethyl)-1,4,2-dioxazol-5-one (1q). Prepared according to general procedure A; Eluent: petroleum ether/ethyl acetate = 10:1; White solid (450 mg, 64 %); m.p. = 99-102 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.96 (q, J =4.8 Hz, 4H), 3.83 (s, 3H), 3.85 (s, 6H), 6.41 (s, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 26.8, 30.9, 56.2, 60.9, 105.2, 133.7, 137.1, 153.5, 154.0, 165.8; HRMS (ESI) m/z calcd. for $C_{13}H_{16}NO_6$ [M+H]: 282.0978, found: 282.0969.

3-(3-methoxyphenethyl)-1,4,2-dioxazol-5-one (1r).[10] Prepared according to general procedure A; Eluent: petroleum ether/ethyl acetate = 10:1; Colorless oil (1.2 g, 87 %); ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.90 (ddd, J = 2.0, 6.8, 14.6 Hz, 2H), 2.98 (ddd, J = 2.0, 6.8, 14.6 Hz, 2H), 3.78 (s, 3H), 6.73 (t, J = 2.0 Hz, 1H), 6.79 (td, J = 2.4, 7.8 Hz, 2H), 7.23 (t, J = 7.8 Hz, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 26.5, 30.4, 55.2, 112.3, 114.1, 120.5, 130.0, 139.7, 154.1, 160.0, 166.0

3-(2-(naphthalen-1-yl)ethyl)-1,4,2-dioxazol-5-one (1s).[10] Prepared according to general procedure A; Eluent: petroleum ether/ethyl acetate = 10:1; White solid (570 mg, 75 %); m.p. = 68-70 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.99 (t, J = 8.0 Hz, 2H), 3.43 (t, J = 8.0 Hz, 2H), 7.30 (d, J = 6.8 Hz, 1H), 7.39 (d, J = 7.8 Hz, 1H), 7.41-7.56 (m, 2H), 7.76 (d, J = 8.0 Hz, 1H), 7.86 (d, J = 8.0 Hz, 1H), 7.91 (d, J = 8.0 Hz, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 25.9, 27.7, 122.7, 125.6, 126.0, 126.4, 126.7, 128.1, 129.2, 131.2, 134.0, 134.1, 154.1, 166.0

3-(4-methoxyphenethyl)-1,4,2-dioxazol-5-one (3a).[10] Prepared according to general procedure A; Eluent: petroleum ether/ethyl acetate = 10:1; Colorless oil (790 mg, 80 %); ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.90 (td, J = 1.2, 6.8 Hz, 2H), 2.98 (td, J = 1.2, 6.8 Hz, 2H), 3.79 (s, 3H), 6.86 (d, J = 8.6 Hz, 2H), 7.11 (d, J = 8.6 Hz, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 27.0, 29.7, 55.3, 114.3, 129.2, 130.0, 154.1, 158.7, 165.9

3-(4-methylphenethyl)-1,4,2-dioxazol-5-one (3b).[10] Prepared according to general procedure A; Eluent: petroleum ether/ethyl acetate = 10:1; Colorless oil (390 mg, 68 %); ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.31 (s, 3H), 2.86-2.90 (m, 2H), 2.95-2.99 (m, 2H), 7.07 (d, J = 8.0 Hz, 2H), 7.12 (d, J = 8.0 Hz, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 21.1, 26.8, 30.1, 128.1, 129.6, 135.1, 136.8, 154.1, 166.0

tert-butyl (4-(2-(5-oxo-1,4,2-dioxazol-3-yl)ethyl)phenyl)carbamate (3c). Prepared according to general procedure A; Eluent: petroleum ether/ethyl acetate = 10:1; White solid (330 mg, 77 %); m.p. = 108-110 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.51 (s, 9H), 2.89 (d, J = 7.2 Hz, 2H), 2.97 (d, J = 7.2 Hz, 2H), 6.65 (brs, 1H), 7.10 (d, J = 8.2 Hz, 2H), 7.32 (d, J = 8.2 Hz, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 26.7, 28.3, 29.8, 80.6, 119.0, 128.7, 132.5, 137.4, 152.8, 154.1, 165.9; HRMS (ESI) m/z calcd. for $C_{15}H_{19}N_2O_5$ [M+H]: 307.1294, found: 307.1289.

3-(2-(4-methoxyphenyl)-2-phenylethyl)-1,4,2-dioxazol-5-one (3d).[10] Prepared according to general procedure A; Eluent: petroleum ether/ethyl acetate = 10:1; Colorless oil (210 mg, 71 %); ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.25 (d, J = 8.0 Hz, 2H), 3.71 (s, 3H), 4.39 (t, J = 8.0 Hz, 1H,), 6.82 (d, J = 8.0 Hz, 2H), 7.12 (d, J = 8.0 Hz, 2H), 7.20 (d, J = 7.2 Hz, 3H), 7.28 (t, J = 7.2 Hz, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 31.3, 46.0, 55.3, 114.4, 127.3, 127.4, 128.6, 129.0, 133.4, 141.8, 154.0, 158.8, 165.2

3-(2-methoxyphenethyl)-1,4,2-dioxazol-5-one (3e).[10] Prepared according to general procedure A; Eluent: petroleum ether/ethyl acetate = 10:1; Colorless oil (486 mg, 88%); ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.87 (t, J = 7.2 Hz, 2H), 2.99 (t, J = 7.2 Hz, 2H), 3.80 (s, 3H), 6.84-6.90 (m, 2H), 7.10 (dd, J = 1.6, 7.2 Hz, 1H), 7.23 (td, J = 1.6, 8.0 Hz, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 25.1, 26.2, 55.2, 110.5, 120.8, 126.4, 128.6, 130.1, 154.4, 157.5, 166.5; HRMS (ESI) m/z calcd. for $C_{11}H_{12}NO_4$ [M+H]: 222.0766, found: 222.0756.

3-(2-methylphenethyl)-1,4,2-dioxazol-5-one (3f).[10] Prepared according to general procedure A; Eluent: petroleum ether/ethyl acetate = 10:1; White solid (460 mg, 58 %); m.p. = 81-83 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.34 (s, 3H), 2.90 (t, J = 8.0 Hz, 2H), 3.03 (t, J = 8.0 Hz, 2H), 7.12-7.21 (m, 4H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 19.2, 25.4, 28.0, 126.5, 127.4, 128.5, 130.8, 135.8, 136.2, 154.0, 166.0

3-(4'-methyl-[1,1'-biphenyl]-2-yl)-1,4,2-dioxazol-5-one (3g). Prepared according to general procedure B; Eluent: petroleum ether/ethyl acetate = 10:1; White solid (310 mg, 52 %); m.p. = 59-61 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.25 (s, 3H), 7.07 (q, J = 8.0 Hz, 4H), 7.33 (dd, J = 7.8, 12.0 Hz, 2H), 7.50 (t, J = 7.6 Hz, 1H), 7.62 (d, J = 7.6 Hz, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 21.3, 119.0, 127.7, 128.4, 129.4, 129.9, 131.5, 133.2, 136.1, 138.3, 143.0, 153.9, 164.8; HRMS (ESI) m/z calcd. for $C_{15}H_{12}NO_3$ [M+H]: 254.0817, found: 254.0807.

3-(4-methoxybenzyl)-1,4,2-dioxazol-5-one (3h).[7a] Prepared according to general procedure A; Eluent: petroleum ether/ethyl acetate = 10:1; Colorless oil (490 mg, 86 %); ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.78 (s, 3H), 3.84 (s, 2H), 6.88 (d, J = 8.4 Hz, 2H), 7.19 (d, J = 8.4 Hz, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 30.3, 55.3, 114.6, 122.3, 130.2, 154.1, 159.6, 165.7

3-(4-hydroxyphenethyl)-1,4,2-dioxazol-5-one (5a).[10] Prepared according to general procedure C; Eluent: petroleum ether/ethyl acetate = 10:1; White solid (350 mg,81%); m.p. = 75-77 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.88 (d, J = 7.4 Hz, 2H), 2.95 (d, J = 6.8 Hz, 2H), 5.05 (s, 1H), 6.78 (d, J = 8.4 Hz, 2H), 7.06 (d, J = 8.4 Hz, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 27.0, 29.7, 115.7, 129.5, 130.2, 154.1, 154.6, 165.9

3-(4-hydroxy-3-methoxyphenethyl)-1,4,2-dioxazol-5-one (5b).[10] Prepared according to general procedure D; Eluent: petroleum ether/ethyl acetate = 10:1; White solid (74 mg, 66%); m.p. = 93-95 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.87-2.95 (m, 4H), 3.86 (s, 3H), 5.68 (s, 1H), 6.68 (d, J = 6.6 Hz, 2H), 6.84 (d, J = 8.4 Hz, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 27.0, 30.2, 55.9, 110.8, 114.7, 120.9, 130.0, 144.7, 146.7, 154.1, 166.0

3-(4-hydroxy-2-methoxyphenethyl)-1,4,2-dioxazol-5-one (5c).[10] Prepared according to general procedure E; Eluent: petroleum ether/ethyl acetate = 10:1; White solid (59 mg, 17 %); m.p. = 95-97 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.79-2.87 (m, 2H), 2.88-2.95 (m, 2H), 3.75 (s, 3H), 5.61 (s, 1H), 6.34 (d, J = 8.0 Hz, 1H), 6.40 (s, 1H), 6.93 (d, J = 8.0 Hz, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 25.4, 25.7, 55.3, 99.1, 107.0, 118.5, 130.6, 154.6, 156.2, 158.5, 166.6

3-(4-hydroxy-3,5-dimethoxyphenethyl)-1,4,2-dioxazol-5-one (5d). Prepared according to general procedure E; Eluent: petroleum ether/ethyl acetate = 10:1; White solid (70 mg, 17 %); m.p. = 69-72 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.93 (s, 4H), 3.87 (s, 6H), 5.50 (s, 1H), 6.41 (s, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 27.0, 30.7, 56.4, 105.0, 129.1, 133.9, 147.3, 154.0, 165.9; HRMS (ESI) m/z calcd. for $C_{12}H_{14}NO_6$ [M+H]: 282.0978, found: 282.0969.

3-(4-hydroxy-3,5-dimethylphenethyl)-1,4,2-dioxazol-5-one (5e).[10] Prepared according to general procedure E; Eluent: petroleum ether/ethyl acetate = 10:1; White solid (120 mg, 34 %); m.p. = 96-98 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.21 (s, 6H), 2.86 (s, 4H), 4.76 (s, 1H), 6.79 (s, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 15.9, 27.0, 29.7, 123.6, 128.3, 129.6, 151.3, 154.2, 166.2

3-(3,5-dibromo-4-hydroxyphenethyl)-1,4,2-dioxazol-5-one (5f). Prepared according to general procedure A; Eluent: petroleum ether/ethyl acetate = 10:1; White solid (170 mg, 22 %); m.p. = 88-90 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.93 (s, 4H), 5.90 (s, 1H), 7.32 (s, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 26.5, 28.8, 110.1, 131.8, 132.6, 148.6, 153.8, 165.4; HRMS (ESI) m/z calcd. for $C_{10}H_7Br_2NO_4Na$ [M+Na]: 385.8640, found: 385.8639.

2-(2-(4-hydroxyphenyl)-1-(5-oxo-1,4,2-dioxazol-3-yl)ethyl) isoindoline-1,3-dione (5g).[10] Prepared according to general procedure A; Eluent: petroleum ether/ethyl acetate = 10:1; Colorless oil (70 mg, 66 %); ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.42-3.61 (m, 2H), 5.06 (brs, 1H), 5.53 (dd, J = 6.0, 10.0 Hz, 1H), 6.68 (d, J = 8.0 Hz, 2H), 7.05 (d, J = 8.0 Hz, 2H), 7.73-7.78 (m, 2H), 7.80-7.86 (m, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 33.0, 46.6, 115.8, 124.0, 126.3, 130.3, 131.0, 134.8, 153.3, 155.0, 163.7, 166.7

3-(2-hydroxy-4-methoxyphenethyl)-1,4,2-dioxazol-5-one (5h).[10] Prepared according to general procedure E; Eluent: petroleum ether/ethyl acetate = 10:1; White solid (120 mg, 37 %); m.p. = 70-73 °C;^{1}H NMR (400 MHz, $CDCl_3$) δ 2.87-2.96 (m, 4H), 3.73 (s, 3H), 5.90 (s, 1H), 6.32 (s, 1H), 6.42 (d, J = 8.4 Hz, 1H), 6.99 (d, J = 8.4 Hz, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 25.2, 25.3, 55.4, 102.2, 105.9, 117.3, 131.1, 154.6, 154.7, 159.7, 166.6

Preparation of the catalysts

Catalysts **cat-1**, **cat-1**, **cat-3**, **cat-4, cat-5, cat-6** and **cat-7** were prepared according to our previous publications. The procedure for preparation of **cat-8** is described as following.

Preparation of the ligand. To the solution of 2-formylisonicotinonitrile (150 mg, 1.1 mmol) in dichloromethane (20 mL) was dropwise added ethylenediamine (0.09 mL, 1.3 mmol). The mixture was stirred for 1 h, and then was cooled to 0 °C. N-Bromosuccinimide (240 mg, 1.3 mmol) was added and the mixture was stirred overnight. The reaction mixture was washed with 5% NaOH solution (10 mL) and then saturated $Na_2S_2O_3$ solution (10 mL). The organic phase was dried with Na_2SO_4, concentrated to give the ligand as brown solid (170 mg, 99%). This product was directly used in next step without further purification.

synthesis of cat-8. To a solution of ligand (150 mg, 0.87 mmol) in 10 ml DCM was added the powder of $[Cp^*IrCl_2]_2$ (330 mg, 0.4 mmol). The resultant orange solution was stirred overnight. DCM was removed under reduced pressure, and the resultant yellow solid was dissolved in minimum amount of DCM. Then a large amount of EtOAc slowly was added to precipitate an orange solid as desired product, which was isolated by reduced-pressure filtration and further dried under vacuum at room temperature to give **cat-8** as red power (460 mg, 93%).

Cat-8. Orange power (460 mg, 93%). m.p. > 350 °C; ^{1}H NMR (400 MHz, D_2O) δ 1.63 (s, 15H), 3.87 (s, 1H), 4.00 (t, J = 20.9 Hz, 2H), 4.70 (s,1H), 8.06 (dd, J = 1.6, 5.8 Hz, 1H), 8.27 (d, J = 1.0 Hz, 1H), 9.05 (d, J = 5.8 Hz, 1H); ^{13}C{^{1}H} NMR (100 MHz, D_2O) δ 8.1, 46.0, 52.4, 89.5, 114.9, 123.2, 127.4, 132.1, 147.4, 153.1, 168.2; HRMS (ESI) for $C_{19}H_{23}ClIrN_4$ $(M)^+$, 535.1235 (Calc.), found 535.1220.

General Procedures of the Ir-catalyzed Intramolecular Amidation of Dioxazolones. To a 10 mL flask equipped with a magnetic stirring bar was added 1,4,2-dioxazol-5-one (0.1mmol-0.5mmol), **cat-3** (2 mol %), sodium tetrakis{3,5-bis(trifluoromethyl)phenyl} borate (4 mol %) and dichloromethane (3 mL). The reaction mixture was stirred in a pre-heated oil bath at 40 °C for 12 h. After the solvent was removed, the residue was purified by silica chromatography (eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1).

Procedures for the gram scale reaction of 1p to 2p

To a 100 mL flask equipped with a magnetic stirring bar was added 1,4,2-dioxazol-5-one **1p** (8.0 mmol), **cat-3** (2 mol %), sodium tetrakis{3,5-bis(trifluoromethyl)phenyl} borate (4 mol %) and HFIP (50mL). The reaction mixture was stirred in a pre-heated oil bath at 60 °C for 24 h until the reaction was complete. After the solvent was removed, the residue was purified by silica chromatography (eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1) to give **2p** as white solid (1.52g, 7.3 mmol), the yield was 91%.

Procedures for the gram scale reaction of 5a to 6a

To a 100 mL flask equipped with a magnetic stirring bar was added 1,4,2-dioxazol-5-one **5a** (6.3 mmol), **cat-3** (2 mol %), sodium tetrakis{3,5-bis(trifluoromethyl)phenyl} borate (4 mol %) and dichloromethane (50mL). The reaction mixture was stirred in a pre-heated oil bath at 40 °C for 24 h until the reaction was complete. After the solvent was removed, the residue was purified by silica chromatography (eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1) to give **6a** as white solid (895 mg, 5.5 mmol), the yield was 87%.

5-(thiophen-2-yl)pyrrolidin-2-one (2a).[7a] Eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1; Light yellow solid (35 mg, 89%); m.p. = 100-103 °C; ^{1}H NMR (400 MHz,

$CDCl_3$) δ 2.07-2.17 (m, 1H), 2.34-2.44 (m, 1H), 2.46-2.54 (m, 1H), 2.56-2.64 (m, 1H), 5.02 (t, J = 6.6 Hz, 1H), 6.62 (s, 1H), 6.93-7.02 (m, 2H), 7.24 (d, J = 4.0 Hz, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 30.2, 31.2, 54.0, 124.1, 124.8, 127.0, 146.5, 178.1

5-phenylpyrrolidin-2-one (2b).[7a] Eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1; White solid (26 mg, 81%); m.p. = 98-101 °C; ^1H NMR (400 MHz, $CDCl_3$) δ 1.91-2.00 (m, 1H), 2.35-2.49 (m, 2H), 2.50-2.59 (m, 1H), 4.75 (t, J = 7.0 Hz, 1H), 6.64 (brs, 1H), 7.23 -7.30 (m, 3H), 7.34-7.38 (m, 2H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 31.4, 31.3, 58.1, 125.6, 127.9, 128.9, 142.5, 178.8

5-(4-methoxyphenyl)pyrrolidin-2-one (2c).[7a] Eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1; White solid (61 mg, 76 %); m.p. = 118-120 °C;^1H NMR (400 MHz, $CDCl_3$) δ 1.87-1.95 (m, 1H), 2.32-2.46 (m, 2H), 2.47-2.58 (m, 1H), 3.79 (s, 3H), 4.69 (t, J = 7.0 Hz, 1H), 6.79 (s, 1H), 6.88 (d, J = 8.0 Hz, 2H), 7.21 (d, J = 8.0 Hz, 2H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 30.6, 31.4, 55.3, 57.7, 114.2, 126.9, 134.6, 159.2, 178.8

5-(p-tolyl)pyrrolidin-2-one (2d).[9b] Eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1; White solid (26 mg, 51%); m.p. = 112-115 °C; ^1H NMR (400 MHz, $CDCl_3$) δ 1.93-2.00 (m, 1H), 2.35 (s, 3H), 2.39-2.47 (m, 2H), 2.51-2.58 (m, 1H), 4.72 (t, J = 7.0 Hz, 1H), 5.90 (brs, 1H), 7.18 (s, 4H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 21.1, 30.4, 31.4, 57.9, 125.6, 129.5, 137.6, 139.5, 178.6.

5-vinylpyrrolidin-2-one (2e).[9c] Eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1; Colorless oil (15 mg, 56 %); ^1H NMR (400 MHz, $CDCl_3$) δ 1.77-1.86 (m, 1H), 2.25-2.42 (m, 3H), 4.16 (q, J = 6.4 Hz, 1H), 5.13 (d, J = 10.2 Hz, 1H), 5.22 (d, J = 17.2 Hz, 1H), 5.75-5.85 (m, 1H), 6.12 (brs, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 28.0, 29.9, 56.7, 115.7, 138.7, 178.5

hexahydrocyclopenta[b]pyrrol-2(1H)-one (2f).[9c] Eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1; Colorless oil (27 mg, 76 %); ^1H NMR (400 MHz, $CDCl_3$) δ 1.49-1.55 (m, 1H), 1.60-1.73 (m, 4H), 1.74-1.82 (m, 1H), 2.05 (dd, J = 3.6, 17.6 Hz, 1H), 2.63 (dd, J = 10.2 Hz, 1H), 2.78-2.86 (m, 1H), 4.09-4.13 (m, 1H), 6.52 (brs, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 23.7, 34.3, 34.5, 37.2, 38.0, 59.3, 178.5

1-azaspiro[4.5]decan-2-one (2g).[7a] Eluent: petroleum ether /ethyl acetate/methanol = 10:10:1~5:5:1; White solid (51 mg, 83 %); m.p. = 120-122 °C; ^1H NMR (400 MHz, $CDCl_3$) δ1.42 (s, 2H), 1.47-1.62 (m, 8H), 1.89 (t, J = 8.0 Hz, 2H), 2.38 (t, J = 8.0 Hz, 2H), 7.07 (brs, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 23.0, 25.2, 30.0, 32.7, 38.3, 59.5, 177.5

5,5-dimethylpyrrolidin-2-one (2h).[7a] Eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1; Colorless oil (30 mg, 84 %); ^1H NMR (400 MHz, $CDCl_3$) δ 1.29 (s, 6H), 1.92 (t, J = 8.0 Hz, 2H), 2.42 (t, J = 8.0 Hz, 2H), 7.10 (brs, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 29.2, 30.7, 35.3, 56.6, 177.1

3-phenylisoindolin-1-one (2i).[9d] Eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1; White solid (29 mg, 99 %); m.p. = 209-212 °C;^1H NMR (400 MHz, DMSO-d_6) δ 5.73 (s, 1H), 7.30 (t, J = 8.0 Hz, 4H), 7.36 (t, J = 7.2 Hz, 2H), 7.48 (t, J = 7.2 Hz, 1H), 7.54 (t, J = 7.2 Hz, 1H), 7.72 (d, J = 7.2 Hz, 1H), 9.07 (brs, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, DMSO-d_6) δ 60.0, 123.3, 123.9, 127.0, 128.4, 128.6, 129.2, 131.8, 132.3, 140.1, 148.6, 170.1

3,3-dimethylisoindolin-1-one (2j).[7a] Eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1; White solid (39 mg, 99 %); m.p. = 152-154 °C; ^1H NMR (400 MHz, $CDCl_3$) δ 1.58 (s, 6H), 7.41 (d, J = 7.6 Hz, 1H), 7.44 (td, J = 0.4, 7.4 Hz, 1H), 7.56 (td, J = 0.8, 7.4 Hz, 1H), 7.83 (d, J = 7.6 Hz, 1H), 8.08 (brs, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 27.7, 59.2, 120.9, 123.8, 127.9, 130.8, 132.0, 153.2, 170.1

3-methylisoindolin-1-one (2k).[7a] Eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1; White solid (29 mg, 71 %); m.p. = 102-104 °C; ^1H NMR (400 MHz, $CDCl_3$) δ 1.52 (d, J = 6.8 Hz, 3H), 4.72 (q, J = 6.8 Hz, 1H), 7.46 (q, J = 7.4 Hz, 2H), 7.57(t, J = 7.4 Hz, 1H), 7.85 (d, J = 7.4 Hz, 1H), 8.18 (brs, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 20.2, 52.8, 122.2, 123.6, 128.0, 131.7, 131.9, 149.0, 171.3

3-benzylisoindolin-1-one (2l).[13] Eluent: petroleum ether/ethyl acetate/methanol, 10:10:1~5:5:1; White solid (22 mg, 71 %); m.p. = 128-130 °C;^1H NMR (400 MHz, $CDCl_3$) δ 2.79 (dd, J = 10.0, 12.4 Hz, 1H), 3.24 (dd, J = 4.2, 13.6 Hz, 1H), 4.80 (t, J = 7.4 Hz, 1H), 6.45 (brs, 1H), 7.20-2.25 (m, 2H), 7.30 (d, J = 6.6 Hz, 1H), 7.34 (d, J = 7.4 Hz, 3H), 7.48 (t, J = 7.4 Hz, 1H), 7.55 (t, J = 7.4 Hz, 1H), 7.84 (d, J = 7.4 Hz, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 41.4, 58.0, 122.7, 123.9, 127.2, 128.4, 128.9, 129.3, 131.8, 131.9, 137.0, 146.9, 170.4

2-(((3aR,7aR)-2-oxooctahydro-3aH-indol-3a-yl)methyl)isoindoline-1,3-dione (2m).[7a] Eluent: petroleum ether/ethyl acetate/methanol, 10:10:1~5:5:1; White solid (16 mg, 92%); m.p. = 173-176 °C; ^1H NMR (400 MHz, $CDCl_3$) δ 1.45-1.59 (m, 6H), 1.68-1.75 (m, 1H), 1.82-1.91 (m, 1H), 2.01 (d, J = 16.4 Hz, 1H), 2.49 (d, J = 16.4 Hz, 1H), 3.58 (s, 1H), 3.79 (s, 2H), 6.04 (s, 1H), 7.75 (d, J = 2.2 Hz, 2H), 7.86 (d, J = 2.2 Hz, 2H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 19.8, 21.1, 26.3, 30.7, 42.4, 42.9, 43.2, 55.4, 123.5, 131.8, 134.3, 168.9, 176.8

5-methoxyindolin-2-one (2n).[7a] Eluent: petroleum ether/ethyl acetate/methanol, 10:10:1~5:5:1; White solid (36 mg, 65 %); m.p. = 140-142 °C; ^1H NMR (400 MHz, $CDCl_3$) δ 3.52 (s, 2H), 3.78 (s, 3H), 6.77 (q, J = 8.2 Hz, 2H), 6.85 (s, 1H), 8.50 (brs, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 36.8, 55.8, 110.2, 111.7, 112.5, 126.7, 136.2, 155.7, 178.2

7-methoxyindolin-2-one (2n').[7a] Eluent: petroleum ether/ethyl acetate/methanol, 10:10:1~5:5:1; White solid (9 mg, 16 %); m.p. = 139-141 °C; ^1H NMR (400 MHz, $CDCl_3$) δ 3.56 (s, 2H), 3.88 (s, 3H), 6.83 (dd, J = 7.4, 17.2 Hz, 2H), 6.98 (t, J = 7.8 Hz, 1H), 8.08 (brs, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 36.8, 55.7, 110.2, 117.0, 122.8, 126.0, 131.3, 143.8, 176.6

5,6-dimethoxyindolin-2-one (2o).[7a] Eluent: petroleum ether/ethyl acetate/methanol, 10:10:1~5:5:1; White solid (22 mg, 95 %); m.p. = 170-173 °C; ^1H NMR (400 MHz, $CDCl_3$) δ 3.50 (s, 2H), 3.85 (s, 3H), 3.86 (s, 3H), 6.55 (s, 1H), 6.84 (s, 1H), 8.77 (brs, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 36.5, 56.3, 56.8, 95.7, 109.7, 115.9, 136.1, 145.0, 149.4, 178.4

6,7-dimethoxy-3,4-dihydroquinolin-2(1H)-one (2p).[7a] Eluent: petroleum ether/ethyl acetate/methanol, 10:10:1~5:5:1; White solid (19 mg, 98 %); m.p. = 123-125 °C; ^1H NMR (400 MHz, $CDCl_3$) δ 2.62 (t, J = 7.4 Hz, 2H), 2.89 (t, J = 7.4 Hz, 2H), 3.85 (s, 3H), 3.87 (s, 3H), 6.53 (s, 1H), 6.84(s, 1H), 8.46 (s, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 25.0, 30.9, 56.2, 56.4, 100.6, 111.7, 114.8, 130.8, 144.7, 148.4, 172.3

6,7,8-trimethoxy-3,4-dihydroquinolin-2(1H)-one (2q). Eluent: petroleum ether/ethyl acetate/methanol, 10:10:1~5:5:1;

White solid (50 mg, 99 %); m.p. = 118-120 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.61 (t, J = 7.4 Hz, 2H), 2.91 (t, J = 7.4 Hz, 2H), 3.83 (s, 3H), 3.86 (s, 3H), 3.92 (s, 3H), 6.48 (s, 1H), 7.75 (s, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 25.6, 30.8, 56.4, 61.0, 61.1, 106.9, 118.3, 124.2, 140.2, 140.9, 148.8, 170.0; HRMS (ESI) m/z calcd. for $C_{12}H_{16}NO_4$ [M+H]: 238.1079, found: 238.1070.

6-methoxy-3,4-dihydroquinolin-2(1H)-one (2r).[10] Eluent: petroleum ether/ethyl acetate/methanol, 10:10:1~5:5:1; White solid (39 mg, 82 %); m.p. = 125-127 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.62 (t, J = 8.0 Hz, 2H), 2.94 (t, J = 8.0 Hz, 2H), 3.78 (s, 3H), 6.69-6.72 (m, 2H), 6.76-6.79 (m, 1H), 9.13 (brs, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 25.7, 30.6, 55.6, 112.4, 113.8, 116.3, 125.0, 130.9, 155.6, 171.8

1,4-dihydrobenzo[f]quinolin-3(2H)-one (2s). Eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1; White solid (19 mg, 96 %); m.p. = 233-236 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.80 (t, J = 7.8 Hz, 2H), 3.35 (t, J = 7.8 Hz, 2H), 7.06 (d, J = 8.6 Hz, 1H), 7.39 (t, J = 7.2 Hz, 1H), 7.53 (t, J = 7.2 Hz, 1H), 7.71 (d, J = 8.6 Hz, 1H), 7.80 (d, J = 8.2 Hz, 1H), 7.89 (d, J = 8.2 Hz, 1H), 9.10 (s, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 21.1, 30.3, 116.1, 116.8, 122.6, 124.2, 127.0, 128.3, 128.8, 130.5, 131.5, 134.6, 171.9; HRMS (ESI) m/z calcd. for $C_{13}H_{12}NO$ [M+H]: 198.0919, found: 198.0910.

6-methyl-3,4-dihydroquinolin-2(1H)-one (4b).[10] Eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1; White solid (45 mg, 87 %); m.p. = 126-128 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.29 (s, 3H), 2.62 (t, J = 8.0 Hz, 2H), 2.93 (t, J = 8.0 Hz, 2H), 6.72 (d, J = 8.4 Hz, 1H), 6.98 (s, 2H), 8.95 (brs, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 20.8, 25.4, 30.8, 115.4, 123.5, 127.9, 128.6, 132.6, 134.9, 172.0

tert-butyl (2-oxo-1,2,3,4-tetrahydroquinolin-6-yl)carbamate (4c). Eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1; White solid (19 mg, 37 %); m.p. = 187-189 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.51 (s, 9H), 2.60 (t, J = 8.0 Hz, 2H), 2.93 (t, J = 7.2 Hz, 2H), 6.66 (brs, 1H), 6.75 (d, J = 8.4 Hz, 1H), 7.02 (dd, J = 2.0, 10.4 Hz, 1H), 7.35 (s, 1H), 9.23 (brs, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 25.5, 28.4, 30.6, 80.6, 115.8, 118.0, 118.8, 124.4, 132.9, 133.7, 153.1, 172.0; HRMS (ESI) m/z calcd. for $C_{14}H_{19}N_2O_3$[M+H]: 263.1396, found: 263.1396.

6-methoxy-4-phenyl-3,4-dihydroquinolin-2(1H)-one (4d).[10] Eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1; White solid (16 mg, 93 %); m.p. = 150-153 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.84-2.95 (m, 2H), 3.69 (s, 3H), 4.25 (t, J = 7.2 Hz, 1H), 6.48 (s, 1H), 6.74 (d, J = 8.4 Hz, 1H), 6.80 (d, J = 8.4 Hz, 1H), 7.19 (d, J = 7.6 Hz, 2H), 7.27 (d, J = 8.4 Hz, 1H), 7.33 (t, J = 7.6 Hz, 2H), 8.65 (s, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 38.4, 42.3, 55.5, 112.8, 114.4, 116.5, 127.3, 127.8, 128.1, 129.0, 130.6, 141.3, 155.8, 170.4

8-methoxy-3,4-dihydroquinolin-2(1H)-one (4e). Eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1; White solid (39 mg, 51 %); m.p. = 55-58 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.61 (t, J = 8.0 Hz, 2H), 2.96 (t, J = 7.2 Hz, 2H), 3.86 (s, 3H), 6.76 (dd, J = 2.8, 8.4 Hz, 2H), 6.93 (t, J = 8.0 Hz, 1H), 7.83 (brs, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 25.4, 30.7, 55.8, 109.0, 119.9, 122.7, 124.0, 126.5, 145.8, 170.4; HRMS (ESI) for $C_{10}H_{12}NO_2$(M+H), 178.0868 (Calc.), found 178.0863.

8-methyl-3,4-dihydroquinolin-2(1H)-one (4f).[10] Eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1; White solid (9 mg, 37 %); m.p. = 113-115 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.22 (s, 3H), 2.63 (t, J = 7.2 Hz, 2H), 2.96 (t, J = 7.2 Hz, 2H), 6.91 (t, J = 7.4 Hz, 1H), 7.03 (d, J = 7.4 Hz, 2H), 7.37 (brs, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 16.6, 25.7, 30.8, 122.5, 122.7, 123.7, 125.8, 129.0, 135.5, 171.3

2-methylphenanthridin-6(5H)-one (4g).[14] Eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1; White solid (14 mg, 56 %); m.p. = 234-236 °C; ^{1}H NMR (400 MHz, MeOD-d_4) δ 2.41 (s, 3H), 7.28 (q, J = 8.4 Hz, 2H), 7.62 (t, J = 7.6 Hz, 1H), 7.83 (t, J = 8.0 Hz, 1H), 8.18 (s, 1H), 8.32 (d, J = 7.8 Hz, 1H), 8.47 (d, J = 8.0 Hz, 1H), 11.60 (s, 1H); ^{13}C{^{1}H} NMR (100 MHz, MeOD-d_4) δ 20.7, 116.0, 117.4, 122.5, 123.0, 125.7, 127.5, 127.7, 130.5, 131.2, 132.6, 134.2, 134.4, 160.7

1-azaspiro[4.5]deca-6,9-diene-2,8-dione (6a).[10] Eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1; White solid (36 mg, 99%); m.p. = 170-174 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.26 (t, J = 8.0 Hz, 2H), 2.56 (t, J = 8.0 Hz, 2H), 6.23 (d, J = 9.6 Hz, 2H), 6.84 (d, J = 9.6 Hz, 2H), 6.98 (s, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 29.5, 32.2, 57.5, 128.8, 149.4, 177.7, 184.4

7-methoxy-1-azaspiro[4.5]deca-6,9-diene-2,8-dione (6b).[10] Eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1; White solid (28 mg, 97%); m.p. = 219-221 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.31 (q, J = 7.2 Hz, 2H), 2.58 (t, J = 8.0 Hz, 2H), 3.70 (s, 3H), 5.73 (s, 1H), 6.24 (d, J= 9.8 Hz, 1H), 6.41 (s, 1H), 6.85 (dd, J = 1.8, 9.8 Hz, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 29.6, 33.4, 55.1, 59.1, 116.5, 127.7, 149.9, 150.7, 177.1, 179.9

6-methoxy-1-azaspiro[4.5]deca-6,9-diene-2,8-dione (6c).[10] Eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1; White solid (19 mg, 99 %); m.p. = 175-177 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.19-2.25 (m, 1H), 2.33-2.39 (m, 1H), 2.42-2.49 (m, 1H), 2.63-2.70 (m, 1H), 3.78 (s, 3H), 5.53 (s, 1H), 6.17 (d, J = 10.0 Hz, 1H), 6.27 (s, 1H), 6.58 (d, J = 10.0 Hz, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 29.8, 32.2, 56.1, 58.8, 101.4, 128.2, 145.9, 174.6, 178.6, 186.4

7,9-dimethoxy-1-azaspiro[4.5]deca-6,9-diene-2,8-dione (6d). Eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1; White solid (19 mg, 98 %); m.p. = 252-255 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.36 (t, J = 8.0 Hz, 2H), 2.60 (t, J = 8.0 Hz, 2H), 3.70 (s, 6H), 5.55 (s, 1H), 5.76 (s, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 29.7, 34.8, 55.5, 57.7, 117.0, 150.1, 175.6, 176.5; HRMS (ESI) m/z calcd. for $C_{11}H_{14}NO_4$ [M+H]: 224.0923, found: 224.0916.

7,9-dimethyl-1-azaspiro[4.5]deca-6,9-diene-2,8-dione (6e).[10] Eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1; White solid (39 mg, 99 %); m.p. = 178-182 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.90 (s, 6H), 2.21 (t, J = 8.0 Hz, 2H), 2.53 (t, J = 8.0 Hz, 2H), 6.16 (s, 1H), 6.59 (s, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 15.9, 29.6, 32.5, 57.5, 135.2, 144.4, 177.4, 185.9

7,9-dibromo-1-azaspiro[4.5]deca-6,9-diene-2,8-dione (6f). Eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1; White solid (8 mg, 92 %); m.p. = 219-221 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.39 (t, J = 8.0 Hz, 2H), 2.58 (t, J = 8.0 Hz, 2H), 5.93 (s, 1H), 7.31 (s, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 28.8, 31.8, 61.7, 122.7, 149.5, 171.4, 176.0; HRMS (ESI) m/z calcd. for $C_{19}H_8Br_2NO_2$ [M+H]: 319.8922, found: 319.8917.

3-(1,3-dioxoisoindolin-2-yl)-1-azaspiro[4.5]deca-6,9-diene-2,8-dione (6g).[10] Eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1; White solid (30 mg, 97 %); m.p. = 276-280 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.58 (t, J = 11.4 Hz, 1H), 2.74 (t, J = 11.4 Hz, 1H), 5.18 (t, J = 10.0 Hz, 1H), 6.27 (dd, J = 10.4, 15.0 Hz, 2H), 6.67 (s, 1H), 6.94 (d, J = 10.0 Hz, 1H), 7.12 (d, J = 10.0 Hz, 1H), 7.74-7.80 (m, 2H), 7.85-7.91 (m, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 35.7, 48.2, 54.5, 123.7, 128.7, 129.5, 131.7, 134.6, 148.3, 149.2, 167.3, 171.5, 184.1

8-methoxy-1-azaspiro[4.5]deca-7,9-diene-2,6-dione (7a).[10] Eluent: petroleum ether/ethyl acetate/methanol = 10:10:1~5:5:1; White solid (10 mg, 52 %); m.p. = 120-123 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.01-2.07 (m, 1H), 2.25-2.32 (m, 1H), 2.35-2.40 (m, 1H), 2.63-2.70 (m, 1H), 3.80 (s, 3H), 5.42 (d, J = 1.2 Hz, 1H), 5.89 (s, 1H), 6.13 (dd, J = 1.6, 10.0 Hz, 1H), 6.39 (d, J = 10.0 Hz, 1H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 28.3, 32.4, 56.2, 64.1, 97.7, 123.0, 143.3, 170.5, 179.2, 199.5

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website.
Experimental procedures, full characterization of products, and NMR spectra (PDF)

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The manuscript was written through contributions of all authors.

Notes

The authors declare no competing financial interest.

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