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FACILE PREPARATION OF 2-ARYL-3-IODOPYRROLES WITH *N*-TOSYL 4-ARYL-3-BUTYN-1-YLAMINES, I_2, AND ^{t}BuOK

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Abstract – Treatment of *N*-tosyl 4-aryl-3-butyn-1-ylamines with I_2 and K_2CO_3, followed by the reaction with ^{t}BuOK under mild conditions gave 2-aryl-3-iodopyrroles in good yields. The present approach is a one-pot method for the preparation of 2-aryl-3-iodopyrroles from *N*-tosyl 4-aryl-3-butyn-1-ylamines, which could be easily prepared from aryl iodides, *N*-(3-butyn-1-yl)phthalimides, and *p*-toluenesulfonyl chloride.

INTRODUCTION

Pyrrole is one of the most important units in natural products and pharmaceuticals. In particular, 2-arylpyrrole derivatives show potent biological activities.[1] For example, compound **I** (Elopiprazole) is an antipsychotic drug, compound **II** has anticoccidial activity, and compound **III** (Bimetopyrol) has anti-inflammatory and analgesic properties, as shown in Figure 1.[1a]

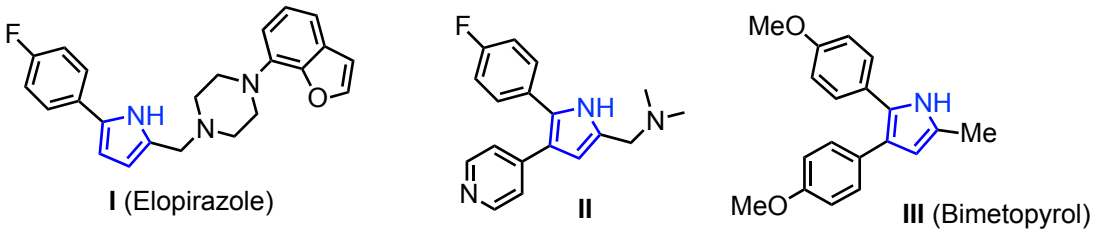


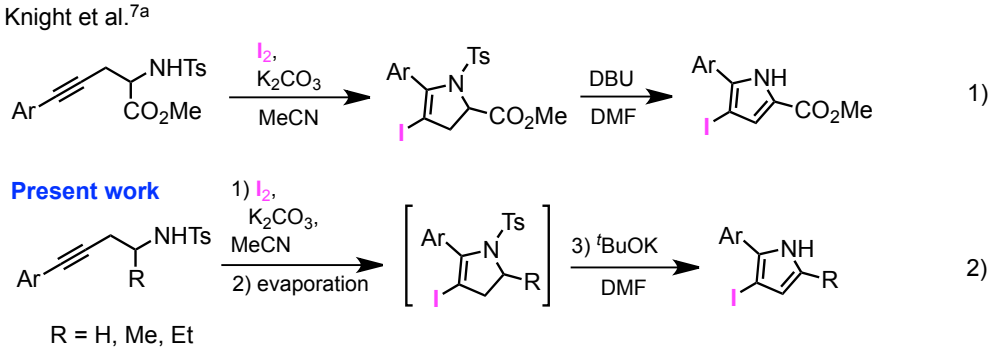
Figure 1. Biologically Active 2-Arylpyrrole Derivatives

In addition to classic methods for the preparation of the pyrrole unit, such as the Knorr pyrrole synthesis with α-aminoketones and β-keto esters [2a] and the Paal-Knorr pyrrole synthesis with 1,4-diketones and primary amines,[2b,2c] synthetic studies of the pyrrole unit have been carried out actively.[3] Recent reports for the construction of the pyrrole unit with transition metals are as follows:[4] the preparation of disubstituted pyrroles with vinyl azides and α-arylacetaldehydes in the presence of $NiCl_2$ or $Cu(OAc)_2$;[4a] the preparation of polysubstituted pyrroles with ketones, primary amines, and ethylene glycol in the

presence of $Ru_3(CO)_{12}$;[4b] the preparation of 2,3-disubstituted pyrroles with vinylogous diazoesters and nitriles in the presence of $AgSbF_6$;[4c] the preparation of 2,3,5-trisubstituted pyrroles with *N*-acetyl vinylamines and alkynes in the presence of $[RuCl_2(p\text{-cymene})]_2$ and $AgSbF_6$;[4d] the preparation of 2,3,5-trisubstituted pyrroles with 1,3-enynes and nitriles in the presence of $Cu(OAc)_2$ and SEGPHOS;[4e] the preparation of pentasubstituted 3-(trifluoromethyl)pyrroles with 2-nitro-1,3-enynes, anilines, and Togni reagent in the presence of $[Cp^*RuCl_2]_2$ and $Cu(OAc)_2$;[4f] and the preparation of 1,3,5-trisubstituted pyrroles with 1,3-dicarbonyl compounds and acrylate esters in the presence of $Cu(OAc)_2$.[4g]

On the other hand, recent reports for the construction of the pyrrole unit without transition metals are as follows:[5] the preparation of *N*-Ts 2,3,4-trisubstituted pyrroles with *N*-(4-pentynyl) *p*-toluenesulfonamides and (diacetoxyiodo)benzene;[5a] the preparation of 2,3,4,5-tetrasubstituted pyrroles with *2H*-azirines and alkynes in the presence of acridinium perchlorate under blue LED irradiation;[5b] the preparation of 3-iodo-4-nitropyrroles with 2-nitro-1,3-enynes, primary amines, and molecular iodine (I_2);[5c] the preparation of 2,3,5-trisubstituted pyrroles with diynones and primary amines;[5d] the preparation of 1,2,4-triarylpyrroles with acetophenones, anilines, and KI;[5e] the preparation of 2,3,5-trisubstituted pyrroles with tosylhydrazones and β-enamino esters under visible light irradiation;[5f] and the preparation of 2,5-disubstituted pyrroles with secondary alcohols, 2-aminoalcohols, and ^{t}BuOK.[5g]

Among those methods, the synthetic use of I_2 is very attractive and important because it is a low-toxicity inorganic reagent and not a transition metal. Recently, I_2 has been used in functional group transformation and iodocyclization.[6] In particular, preparation of the pyrrole unit with 3-alkynylamine derivatives and I_2 through iodocyclization via *5-endo-dig* mode is very attractive and useful[7] because the reaction can be carried out simply and the transformation of the iodine atom of the formed iodopyrroles into other functional groups could proceed smoothly. Previously, Knight *et al.*[7a] reported that the treatment of *N*-tosyl 4-aryl-1-(ethoxycarbonyl)-3-butyn-1-ylamines with I_2 in the presence of K_2CO_3, followed by the reaction with DBU in DMF in two steps gave 2-aryl-3-iodo-5-(methoxycarbonyl)pyrroles smoothly, as shown in eq. 1 of Scheme 1.



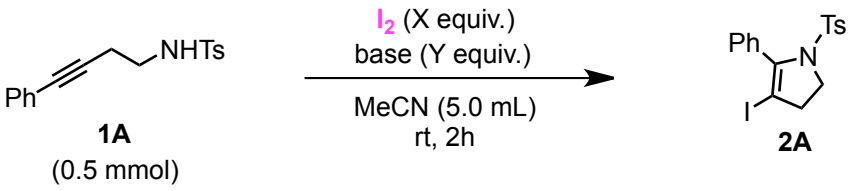
Scheme 1. Iodocyclization and β-Elimination to 2-Aryl-3-iodopyrroles

However, to the best of our knowledge, studies of the iodocyclization of *N*-tosyl 4-aryl-3-butyn-1-ylamines with I_2 to form 2-aryl-3-iodopyrroles in one pot have not been carried out in detail, as shown in eq. 2. As part of our synthetic studies of the nitrogen-containing heteroaromatics, such as quinolines, isoquinolines, phenanthridines, and oxazoles, with I_2 and related iodine reagents,[8] we would like to report herein a one-pot transformation of *N*-tosyl 4-aryl-3-butyn-1-ylamines with I_2 into 2-aryl-3-iodopyrroles through the iodocyclization via *5-endo-dig* mode and the subsequent *β*-elimination of the *N*-tosyl group.

RESULTS AND DISCUSSION

First, reaction of *N*-tosyl 4-phenyl-3-butyn-1-ylamine **1A** (0.5 mmol) with $NaHCO_3$ (1.1 equiv.) in acetonitrile (5.0 mL) at room temperature for 2 h did not occur and **1A** was recovered in 99% yield, as shown in Table 1 (entry 1). The treatment of **1A** with I_2 (1.1 equiv.) and $NaHCO_3$ under the same conditions gave dihydropyrrole **2A** in 46% yield, together with **1A** in 48% yield (entry 2). On the other hand, reactions with *N*-iodosuccinimide (NIS, 1.1 equiv.) and with (diacetoxyiodo)benzene (DIB, 1.1 equiv.) instead of I_2 under the same conditions did not generate dihydropyrrole **2A** smoothly, and **1A** was recovered in high yields, respectively (entries 3, 4). When **1A** was treated with I_2 (2.0 equiv., 3.0 equiv., and 3.5 equiv.) and $NaHCO_3$ (2.0 equiv., 3.0 equiv., and 3.5 equiv.) under the same conditions, dihydropyrrole **2A** was obtained in 75% yield together with **1A** in 16% yield, in 91% yield, and in 87% yield, respectively (entries 5~7). Thus, entry 6 using 3.0 equiv. each of I_2 and $NaHCO_3$ showed the best result. When DMF and dichloromethane (DCM) were used instead of acetonitrile under the same conditions as those of entry 6, the yield of dihydropyrrole **2A** was markedly decreased (entries 8, 9). When the *N*-tosyl group in **1A** was changed to *N*-$SO_2C_6H_4Cl$-*p* and *N*-$SO_2C_2H_5$ groups, the yields of dihydropyrroles **2A** bearing *N*-$SO_2C_6H_4Cl$-*p* and *N*-$SO_2C_2H_5$ groups were slightly decreased to 85% and 84%, respectively (entries 10, 11). Thus, the *N*-tosyl group in **1A** showed the best reactivity to form dihydropyrrole **2A** in good yield (entry 6). Moreover, the same reaction of **1A** with I_2 (3.0 equiv.) but without $NaHCO_3$; with I_2 (3.0 equiv.) and K_2CO_3 (3.0 equiv.); and I_2 (3.0 equiv.) and with Na_2CO_3 (3.0 equiv.) under the same conditions as those of entry 6 gave dihydropyrrole **2A** in 39%, 93%, and 93% yields, respectively (entries 12~14). Thus, the use of K_2CO_3 and Na_2CO_3 as the base showed the best results, as indicated in the previous report that used K_2CO_3 as the base.[7a]

Table 1. Optimal Condition for Preparation of 3-Iodo-2-phenyl-1-tosyl-4,5-dihydropyrrole **2A** from **1A**



Entry	X (equiv.)	Base	Y (equiv.)	Yield (%)
1	--	$NaHCO_3$	1.1	0 (99)[a]
2	1.1	$NaHCO_3$	1.1	46 (48)[a]
3[b]	1.1	$NaHCO_3$	1.1	5 (91)[a]
4[c]	1.1	$NaHCO_3$	1.1	0 (97)[a]
5	2.0	$NaHCO_3$	2.0	75 (16)[a]
6	3.0	$NaHCO_3$	3.0	91
7	3.5	$NaHCO_3$	3.5	87
8[d]	3.0	$NaHCO_3$	3.0	34 (14)[a]
9[e]	3.0	$NaHCO_3$	3.0	12 (10)[a]
10[f]	3.0	$NaHCO_3$	3.0	85
11[g]	3.0	$NaHCO_3$	3.0	84
12	3.0	--	--	39
13	**3.0**	**K_2CO_3**	**3.0**	**93**
14	**3.0**	**Na_2CO_3**	**3.0**	**93**
15	3.0	Cs_2CO_3	3.0	73
16	3.0	K_3PO_4	3.0	90
17	3.0	$MeCO_2K$	3.0	85
18	3.0	Et_3N	3.0	0 (93)[a]

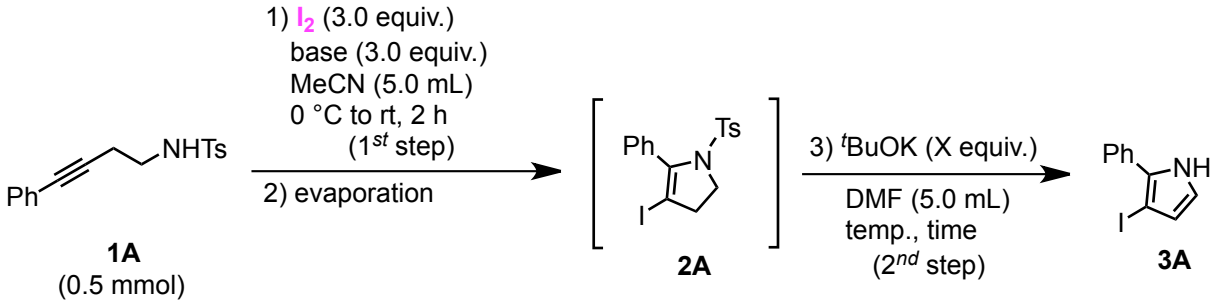
[a] Recovered yield of compound **1A**.
[b] Instead of I_2, NIS (1.1 equiv.) was used.
[c] Instead of I_2, DIB (1.1 equiv.) was used.
[d] Instead of MeCN, DMF (5.0 mL) was used.
[e] Instead of MeCN, DCM (5.0 mL) was used.
[f] Instead of *N*-Ts-*p* group in **1A**, *N*-$SO_2C_6H_4Cl$-*p* group was used.
[g] Instead of *N*-Ts-*p* group in **1A**, *N*-SO_2Et group was used.

However, the same reactions with Cs_2CO_3, K_3PO_4, and $MeCO_2K$ as the base gave slightly reduced yields of dihydropyrrole **2A**, whereas the same reaction with Et_3N as the base did not generate dihydropyrrole **2A** at all (entries 15~18).

Then, based on those results, the one-pot preparation of 3-iodo-2-phenylpyrrole **3A** with *N*-tosyl 4-phenyl-3-butyn-1-ylamine **1A** was studied. Treatment of **1A** (0.5 mmol) with I_2 (3.0 equiv.) and K_2CO_3 (3.0 equiv.) in acetonitrile (5.0 mL) at room temperature for 2 h (1st step), followed by removal of the solvent and the reaction with DBU (7.5 equiv.)[7a] in DMF at room temperature did not generate pyrrole **3A** at all and instead, dihydropyrrole **2A** was obtained in 93% yield, as shown in Table 2 (entry 1). Moreover, when the 2nd reaction step was carried out at 50 °C under the same procedure and conditions, pyrrole **3A** was not formed at all again (entry 2). Thus, DBU is not an effective base for the 2nd reaction

step. Then, ^{t}BuOK was used as a strong base in the 2nd reaction step. Treatment of **1A** (0.5 mmol) with I_2 and K_2CO_3 in acetonitrile at room temperature for 2 h (1st step), followed by removal of the solvent and the reaction with ^{t}BuOK (6.0 equiv., 7.5 equiv., and 8.0 equiv.) in DMF (5.0 mL) at room temperature for 16 h gave 3-iodo-2-phenylpyrrole **3A** in 27%, 66%, and 59% yields, respectively (entries 3~5). Moreover, treatment of **1A** with I_2 and K_2CO_3 in acetonitrile at room temperature for 2 h, followed by removal of the solvent and the reaction with ^{t}BuOK (7.5 equiv.) in DMF (5.0 mL) at room temperature and at 0 °C for 6 h gave 3-iodo-2-phenylpyrrole **3A** in 75% and 88% yields, respectively (entries 6, 7).

Table 2. Optimal Condition for One-pot Preparation of 3-Iodo-2-phenylpyrrole **3A** from **1A**



	(1st step)	(2nd step)			
Entry	Base	Base (equiv.)	Temp.	Time	Yield (%)
1	K_2CO_3	DBU (7.5)	rt	16	0 (93)[a]
2	K_2CO_3	DBU (7.5)	50 °C	16	0 (91)[a]
3	K_2CO_3	^{t}BuOK (6.0)	rt	16	27 (66)[a]
4	K_2CO_3	^{t}BuOK (7.5)	rt	16	66
5	K_2CO_3	^{t}BuOK (8.0)	rt	16	59
6	K_2CO_3	^{t}BuOK (7.5)	rt	6	75
7	K_2CO_3	^{t}BuOK (7.5)	0 °C	6	88
8	**K_2CO_3**	**^{t}BuOK (7.5)**	**0 °C**	**3**	**93**
9	Na_2CO_3	^{t}BuOK (7.5)	0 °C	3	90

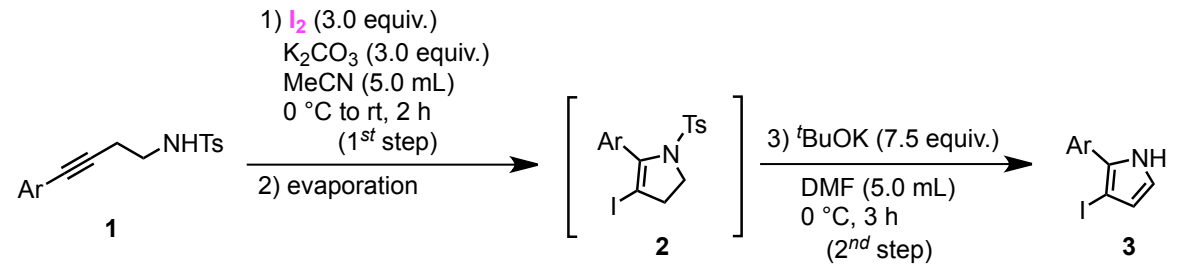
[a] Yield of compound **2A**.

Under the same procedure and conditions, when the 2nd reaction step was carried out at 0 °C for 3 h, pyrrole **3A** was obtained in 93% yield (entry 8). Na_2CO_3 instead of K_2CO_3 could be used under the same procedure and conditions to give pyrrole **3A** in 90% yield (entry 9). Thus, treatment of **1A** (0.5 mmol) with I_2 (3.0 equiv.) and K_2CO_3 (3.0 equiv.) in acetonitrile (5.0 mL) at room temperature for 2 h (1st step), followed by removal of the solvent and the reaction with ^{t}BuOK (7.5 equiv.) in DMF (5.0 mL) at 0 °C for 3 h (2nd step) gave pyrrole **3A** in the best yield (entry 8).

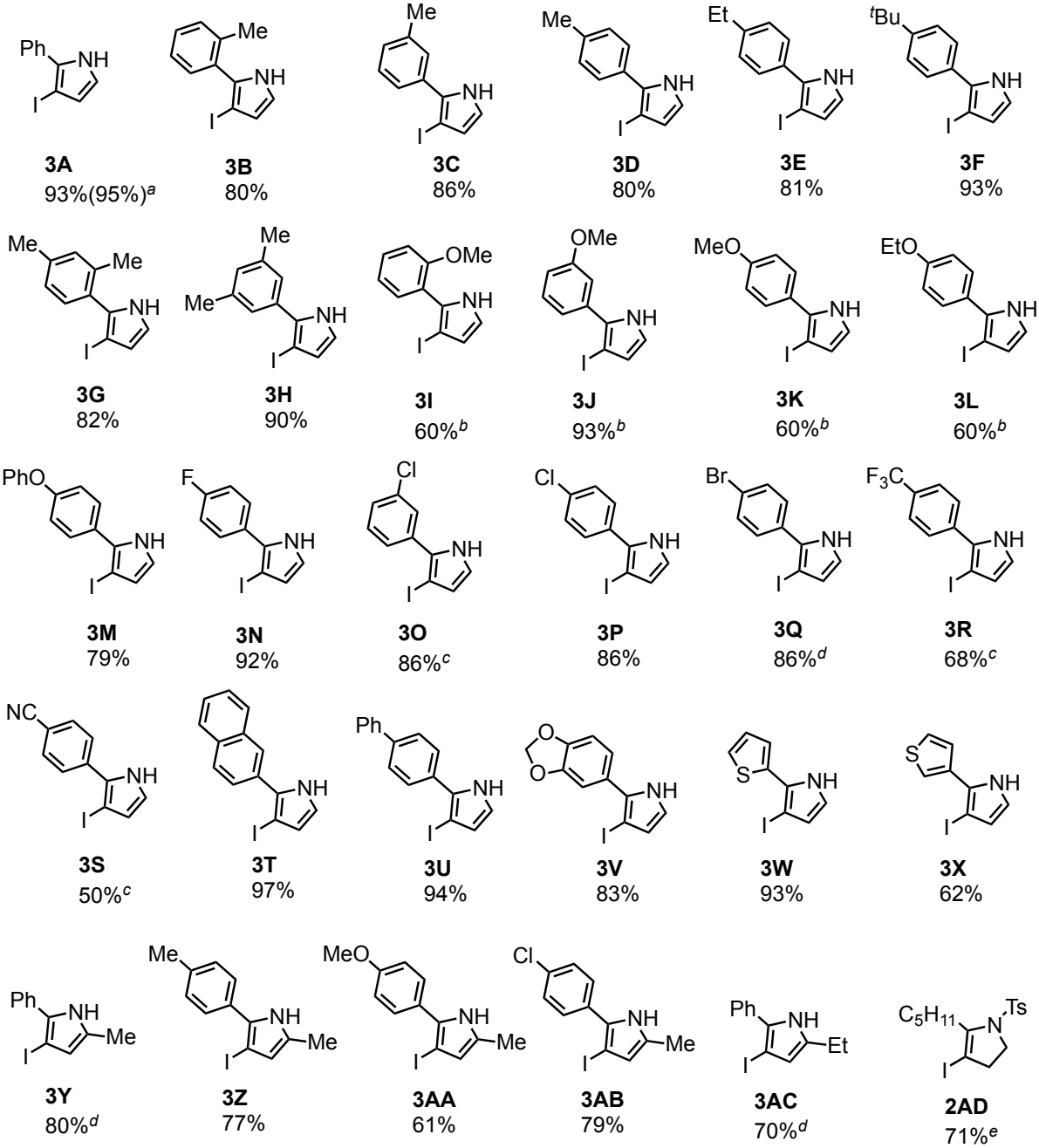
As a gram-scale experiment, treatment of **1A** (3.5 mmol) under the same procedure and conditions gave pyrrole **3A** in 95% yield, as shown in Scheme 2. Based on those results obtained in Table 2, the synthetic

generality for the one-pot preparation of 2-aryl-3-iodopyrroles from *N*-tosyl 4-aryl-3-butyn-1-ylamines was studied. Treatment of *N*-tosyl 4-aryl-3-butyn-1-ylamines **1** (0.5 mmol) bearing *o*-methylphenyl (**B**), *m*-methylphenyl (**C**), *p*-methylphenyl (**D**), *p*-ethylphenyl (**E**), *p*-*tert*-butylphenyl (**F**), 2,4-dimethylphenyl (**G**), 3,5-dimethylphenyl (**H**), *o*-methoxyphenyl (**I**), *m*-methoxyphenyl (**J**), *p*-methoxyphenyl (**K**), *p*-ethoxyphenyl (**L**), and *p*-phenoxyphenyl (**M**) with I_2 (3.0 equiv.) and K_2CO_3 (3.0 equiv.) in acetonitrile (5.0 mL) at room temperature for 2 h (1st step), followed by removal of the solvent and the reaction with ^{t}BuOK (7.5 equiv.) in DMF (5.0 mL) at 0 °C for 3 h (2nd step) gave 2-aryl-3-iodopyrroles **3B**~**3M** in good yields, respectively (Scheme 2). The same treatment of *N*-tosyl 4-aryl-3-butyn-1-ylamines **1N**~**1S** bearing fluoro, chloro, bromo, trifluoromethyl, and cyano groups on the aromatic ring also generated 2-aryl-3-iodopyrroles **3N**~**3S** in good to moderate yields, respectively. Moreover, *N*-tosyl 4-aryl-3-butyn-1-ylamines bearing naphthalen-2-yl (**T**), *p*-biphenyl (**U**), 1,3-benzodioxol-5-yl (**V**), thiophen-2-yl (**W**), and thiophen-3-yl (**X**) as the aryl group also gave the corresponding 2-aryl-3-iodopyrroles **3T**~**3X** in good yields, respectively, under the same procedure and conditions. Then, for the preparation of 5-alkyl-2-aryl-3-iodopyrroles **3**, *N*-tosyl 5-aryl-4-pentyn-2-ylamines **1Y**, **1Z**, **1AA**, and **1AB**, and *N*-tosyl 6-phenyl-5-hexyn-3-ylamine **1AC** were treated under the same procedure and conditions to form 2-aryl-3-iodo-5-methylpyrroles **3Y**~**3AB** and 5-ethyl-3-iodo-2-phenylpyrrole **3AC** in good yields, respectively. In contrast, treatment of *N*-tosyl 3-nonyn-1-ylamine **1AD**, *i.e.*, *N*-tosyl 4-alkyl-3-butyn-1-ylamine, with I_2 and K_2CO_3 in acetonitrile at room temperature for 2 h (1st step) gave 3-iodo-2-pentyl-1-tosyl-4,5-dihydropyrrole **2AD** in 71% yield. However, 3-iodo-2-pentylpyrrole was not obtained at all by the reaction with ^{t}BuOK. This reason probably comes from that 3-iodo-2-pentyl-1-tosyl-4,5-dihydropyrrole **2AD** is not so stable at 0 °C and decomposes slowly without formation of 3-iodo-2-pentylpyrrole. Thus the present method is not suitable for the preparation of 2-alkyl-3-iodopyrroles.

Once 2-aryl-3-iodopyrroles were obtained, they could be smoothly transformed into 2-arylpyrrole derivatives. 2-Phenylpyrrole **4A** was obtained in 99% yield by the reduction of 3-iodo-2-phenylpyrrole **3A** with Zn in ethanol under refluxing conditions, as shown in Scheme 3.



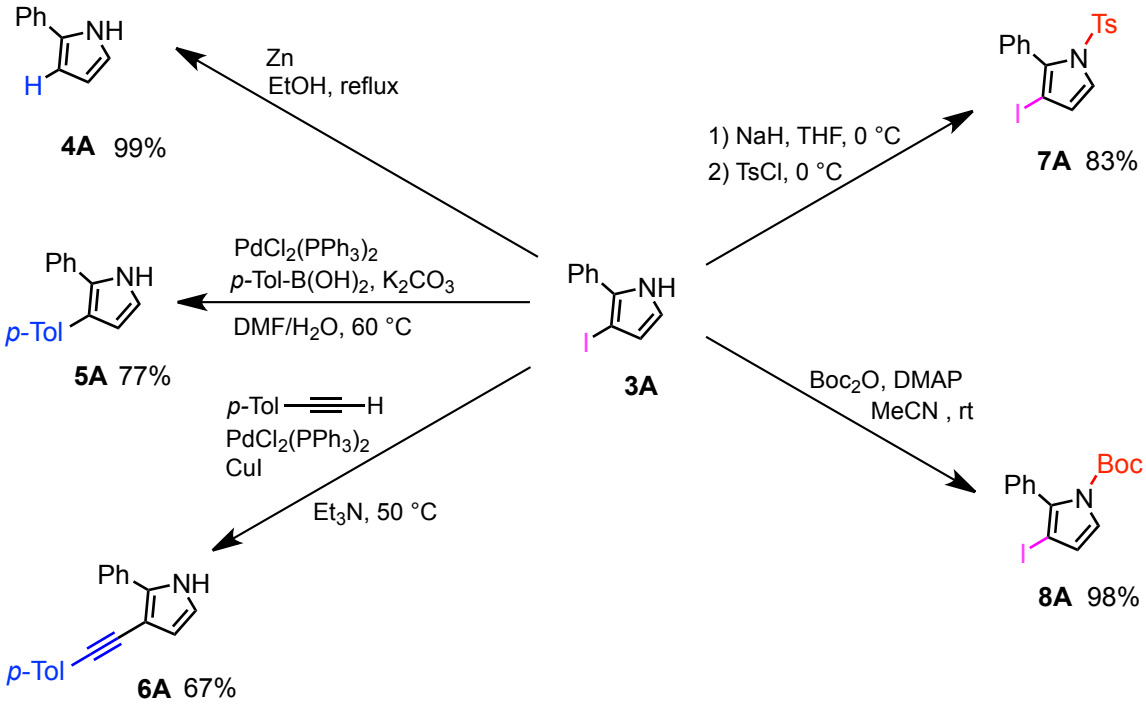
Products, Yields



[a] Reaction was carried out with substrate **1A** (3.5 mmol).
[b] 1st reaction step was carried out at 0 °C.
[c] 1st reaction step was carried out for 24 h.
[d] 1st reaction step was carried out for 6 h.
[e] Only 1st reaction step was carried out.

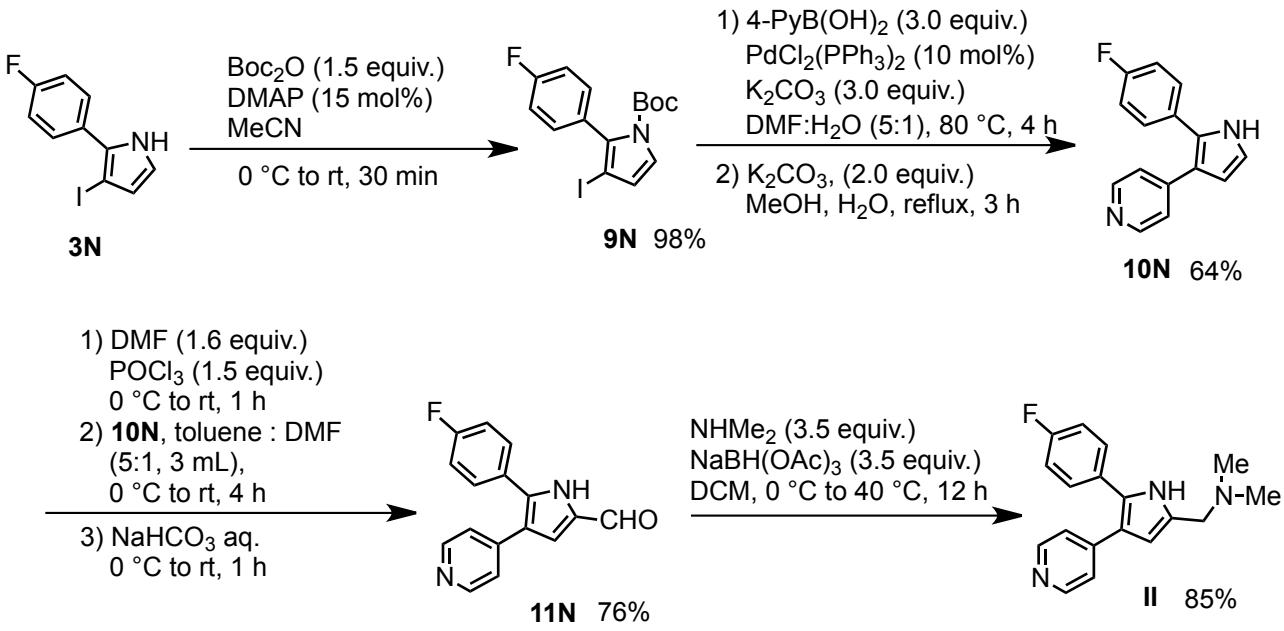
Scheme 2. One-pot Preparation of 2-Aryl-3-iodopyrroles **3** from Sulfonamides **1**

The Pd-catalyzed coupling reactions of **3A** with 4-methylphenylboronic acid and K_2CO_3 in a mixture of DMF and water at 60 °C and with 4-ethynyltoluene in the presence of CuI in Et_3N at 50 °C gave 3-(4'-methylphenyl)-2-phenylpyrrole **5A** in 77% yield and 3-(4'-methylphenyl)ethynyl-2-phenylpyrrole **6A** in 67% yield, respectively. For the *N*-protection of pyrrole **3A**, treatment of **3A** with NaH in THF, followed by the reaction with TsCl at 0 °C gave 3-iodo-2-phenyl-1-tosylpyrrole **7A** in 83% yield, and treatment of **3A** with Boc_2O in the presence of DMAP in acetonitrile at room temperature gave 1-butoxycarbonyl-3-iodo-2-phenylpyrrole **8A** in 98% yield.



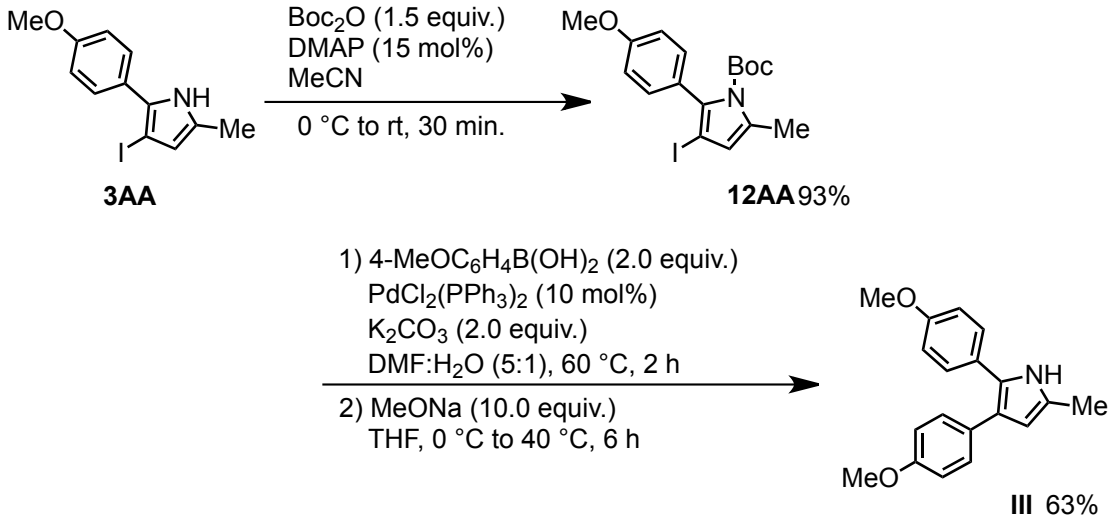
Scheme 3. Derivatization of 3-Iodo-2-phenylpyrrole **3A**

Finally, compound **II**, which is a biologically potent inhibitor of *Eimeria tenella* PKG, shown in Figure 1, was prepared.[1a,9] Treatment of 2-(4'-fluorophenyl)-3-iodopyrrole (**3N**) with Boc_2O in the presence of DMAP gave 1-butoxycarbonyl-2-(4'-fluorophenyl)-3-iodopyrrole **9N** in 98% yield, as shown in Scheme 4. The Pd-catalyzed coupling reaction of **9N** with 4-pyridylboronic acid and K_2CO_3, followed by the deprotection of the Boc group with K_2CO_3 in methanol gave 2-(4'-fluorophenyl)-3-(pyridin-4"-yl)pyrrole **10N** in 64% yield. The Vilsmeier-Haack reaction of **10N** with $POCl_3$ and DMF gave 5-(4'-fluorophenyl)-4-(pyridin-4"-yl)pyrrole-2-carbaldehyde **11N** in 76% yield. The reductive amination of **11N** with Me_2NH and $NaBH(OAc)_3$ generated 5-(*N*,*N*-dimethylamino)methyl-2-(4'-fluorophenyl)-3-(pyridin-4"-yl)pyrrole **II** in 85% yield. Totally, the preparation of pyrrole **II** with the present method would be more effective than the previous method because of short steps with good yield.[9]



Scheme 4. Synthesis of Biologically Active Pyrrole **II**

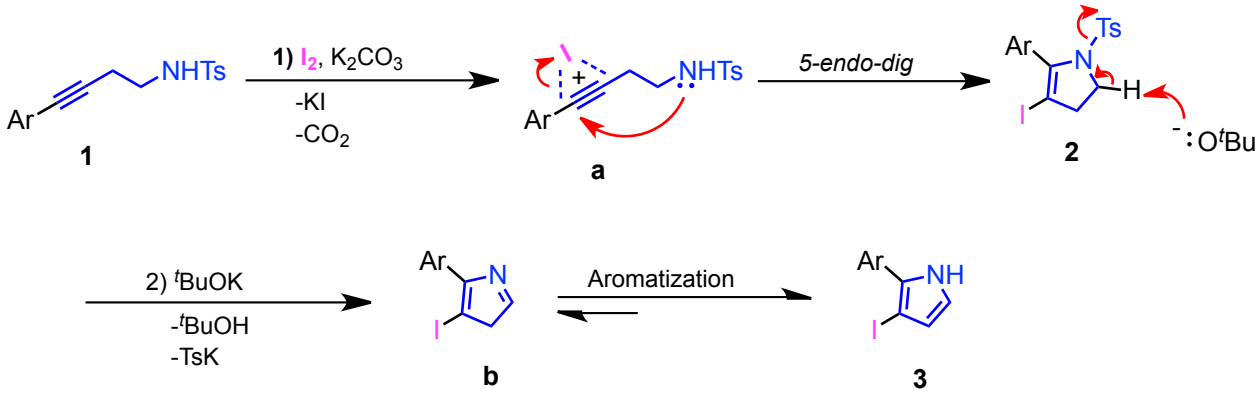
Moreover, compound **III** (Bimetopyrol) possessing anti-inflammatory and analgesic properties, as shown in Figure 1, was also prepared.[1a,10] Treatment of 3-iodo-2-(4'-methoxyphenyl)-5-methylpyrrole (**3AA**) with Boc_2O and DMAP gave 1-butoxycarbonyl-3-iodo-2-(4'-methoxyphenyl)-5-methylpyrrole (**12AA)** in 93% yield. The Pd-catalyzed coupling reaction of **12AA** with 4-methoxyphenylboronic acid and K_2CO_3 in a mixture of DMF and water at 60 °C, followed by the *N*-deprotection with MeONa gave pyrrole **III** in 63% yield, as shown in Scheme 5.



Scheme 5. Synthesis of Biologically Active Pyrrole **III**

A possible reaction pathway for the present one-pot preparation of 2-aryl-3-iodopyrroles **3** from *N*-tosyl 4-aryl-3-butyn-1-ylamines **1** is shown in Scheme 6. I_2 reacts with the triple bond of **1** to form iodonium

species **a.** The nitrogen atom of the tosylamide group in **a** attacks the carbon atom via *5-endo-dig* mode to form 2-aryl-3-iodo-1-tosyl-4,5-dihydropyrrole **2** (1st step). Addition of ^{t}BuOK induces the E2 elimination of dihydropyrrole **2** to form 2-aryl-3-iodopyrrole **3** and *p*-toluenesulfinate anion (2nd step).



Scheme 6. Possible Reaction Pathway

CONCLUSION

Various 2-aryl-3-iodopyrroles could be obtained in good yields by the treatment of *N*-tosyl 4-aryl-3-butyn-1-ylamines with I_2 in the presence of K_2CO_3, followed by the removal of the solvent and the reaction with ^{t}BuOK. The present method is applicable to the one-pot preparation of 2-aryl-3-iodopyrroles from *N*-tosyl 4-aryl-3-butyn-1-ylamines under mild reaction conditions and transition-metal-free conditions. The obtained 2-aryl-3-iodopyrroles could be further transformed into other pyrrole derivatives and biologically active pyrrole derivatives smoothly due to bearing their C-I bonds.

EXPERIMENTAL

^{1}H-NMR and ^{13}C-NMR spectra were obtained with JEOL-JNM-ECX400 and JEOL-JNM-ECS400 spectrometers. Chemical shifts were recorded as follows: chemical shift in ppm from internal tetramethylsilane (TMS) on the d scale, multiplicity (s = singlet; d = doublet; t = triplet; q = quartet; m = multiplet; br = broad), coupling constant (Hz) and integration. High-resolution mass spectra (HRMS) were recorded by a Thermo Fisher Scientific Exactive Orbitrap mass spectrometer. IR spectra were measured with a JASCO FT/IR-4100 spectrometer. Melting points were determined with a Yamato Melting Point Apparatus Model MP-21. Silica gel $60F_{254}$ (Merck) was used for TLC and Silica gel 60N (63~210 mesh, Kanto Kagaku Co.) was used for short column chromatography.

Typical Procedure for Preparation of *N*-Ts 4-Aryl-3-butyn-1-ylamines 1A-1L, 1N-1Q, 1W, and 1Y-1AD

To a solution of 3-butyn-1-ol (10.0 mmol, 700.9 mg), triphenylphosphine (13.0 mmol, 3409.0 mg), and

phthalimide (13.0 mmol, 1912.0 mg) in THF (20.0 mL) was added diisopropyl azodicarboxylate (DIAD, 13.0 mmol, 2.6 mL) at 0 °C, and the mixture was stirred for 12 h at room temperature under argon atmosphere. Then, sat. Na_2SO_3 aq. solution (15.0 mL) was added to the mixture, and the product was extracted with $CHCl_3$ (15.0 mL × 3). Then, the organic layer was dried over Na_2SO_4. After filtration and removal of the solvent under reduced pressure, the residue was purified by silica-gel column chromatography (eluent: *n*-hexane:EtOAc = 4:1) to give *N*-(3-butyn-1-yl)phthalimide (1713.0 mg, 86%). To a solution of *N*-(3-butyn-1-yl)phthalimide (8.0 mmol, 1594.0 mg), $PdCl_2(PPh_3)_2$ (0.40 mmol, 280.8 mg), and CuI (0.40 mmol, 76.2 mg) in Et_3N (30.0 mL) was added iodobenzene (10.4 mmol, 1.32 mL). The obtained mixture was stirred for 12 h at 30 °C under argon atmosphere. Sat. NH_4Cl aq. solution (15.0 mL) was added to the mixture, and the product was extracted with $CHCl_3$ (15.0 mL × 3). The organic layer was dried over Na_2SO_4. After filtration and removal of the solvent under reduced pressure, the residue was purified by silica-gel column chromatography (eluent: *n*-hexane:EtOAc = 4:1) to give *N*-(4-phenyl-3-butyn-1-yl)phthalimide (2158.0 mg, 98%). To the mixture of *N*-(4-phenyl-3-butyn-1-yl)phthalimide in MeOH (40.0 mL) was added hydrazine monohydrate (14.4 mmol, 0.7 mL). The obtained mixture was stirred for 6 h at 50 °C under argon atmosphere. H_2O (15.0 mL) was added to the mixture, and the product was extracted with $CHCl_3$ (15.0 mL × 3). The organic layer was dried over Na_2SO_4 and filtered. After removal of the solvent under reduced pressure, *p*-toluenesulfonyl chloride (8.0 mmol, 1525.0 mg) was added to the mixture in CH_2Cl_2 (8.0 mL) and pyridine (3.2 mL) at 0 °C. The obtained mixture was stirred for 12 h at room temperature under argon atmosphere. Sat. NH_4Cl aq. solution (15.0 mL) was added to the mixture, and the product was extracted with $CHCl_3$ (15.0 mL × 3). Then, the organic layer was dried over Na_2SO_4. After filtration and removal of the solvent under reduced pressure, the organic layer was purified by silica-gel column chromatography (eluent: *n*-hexane:EtOAc = 3:1) to give *N*-tosyl 4-phenyl-3-butyn-1-ylamine **1A** (2084.0 mg, 87%).

Other *N*-Ts 4-aryl-3-butyn-1-ylamines **1B-1L, 1N-1Q, 1W,** and **1Y-1AD** were obtained in 43–73% yields by the same procedure.

***N*-Tosyl 4-Phenyl-3-butyn-1-ylamine (1A):** white solid; mp: 86-87 °C; IR (neat): 3289, 1596, 1489, 1313, 1159 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.43 (s, 3H), 2.58 (t, 2H, *J* = 6.6 Hz), 3.20 (q, 2H, *J* = 6.6 Hz), 4.74 (t, 1H, *J* = 6.0 Hz), 7.28-7.31 (m, 5H), 7.34-7.36 (m, 2H), 7.78 (d, 2H, *J* = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 20.7, 21.5, 41.9, 82.7, 85.5, 122.9, 127.0, 128.1, 128.2, 129.7, 131.6, 136.9, 143.5; HRMS (ESI): Calcd for $C_{17}H_{18}O_2NS$ $[M+H]^+$ = 300.1053, Found = 300.1054.

***N*-Tosyl 4-(2'-Methylphenyl)-3-butyn-1-ylamine (1B):** white solid; mp: 84-85 °C; IR (neat): 3277, 1597, 1484, 1322, 1159 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.36 (s, 3H), 2.42 (s, 3H), 2.62 (t, 2H, *J* = 6.5 Hz), 3.21 (q, 2H, *J* = 6.5 Hz), 4.75-4.80 (m, 1H), 7.11 (td, 1H, *J* = 6.7, 2.2 Hz), 7.17-7.23 (m, 2H), 7.29-7.32 (m, 3H), 7.77 (d, 2H, *J* = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 20.6, 20.7, 21.4, 42.0, 81.5,

89.4, 122.6, 125.4, 126.9, 128.0, 129.3, 129.7, 131.8, 136.8, 139.9, 143.4; HRMS (ESI): Calcd for $C_{18}H_{20}O_2NS$ $[M+H]^+$ = 314.1209, Found = 314.1209.

***N*-Tosyl 4-(3'-Methylphenyl)-3-butyn-1-ylamine (1C):** white solid; mp: 73-74 °C; IR (neat): 3270, 1598, 1485, 1314, 1151 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.32 (s, 3H), 2.43 (s, 3H), 2.56 (t, 2H, *J* = 6.5 Hz), 3.19 (q, 2H, *J* = 6.3 Hz), 4.73 (t, 1H, *J* = 6.1 Hz), 7.11-7.14 (m, 1H), 7.16-7.21 (m, 3H), 7.31 (d, 2H, *J* = 8.5 Hz), 7.77 (d, 2H, *J* = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ =20.6, 21.1, 21.5, 41.9, 82.9, 85.1, 122.6, 127.0, 128.14, 128.6, 129.0, 129.7, 132.2, 136.9, 137.9, 143.5; HRMS (ESI): Calcd for $C_{18}H_{20}O_2NS$ $[M+H]^+$ = 314.1209, Found = 314.1210.

***N*-Tosyl 4-(4'-Methylphenyl)-3-butyn-1-ylamine (1D):** white solid; mp: 89-90 °C; IR (neat): 3278, 1596, 1508, 1315, 1151 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.35 (s, 3H), 2.43 (s, 3H), 2.56 (t, 2H, *J* = 6.3 Hz), 3.18 (q, 2H, *J* = 6.3 Hz), 4.73 (t, 1H, *J* = 6.3 Hz), 7.10 (d, 2H, *J* = 7.9 Hz), 7.24 (d, 2H, *J* = 8.3 Hz), 7.30 (d, 2H, *J* = 8.5 Hz), 7.77 (d, 2H, *J* = 8.1 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ =20.6, 21.4, 21.5, 41.9, 82.9, 84.7, 119.7, 127.1, 129.0, 129.7, 131.5, 136.9, 138.2, 143.5; HRMS (ESI): Calcd for $C_{18}H_{20}O_2NS$ $[M+H]^+$ = 314.1209, Found = 314.1209.

***N*-Tosyl 4-(4'-Ethylphenyl)-3-butyn-1-ylamine (1E):** white solid; mp: 76-77 °C; IR (neat): 3285, 1598, 1508, 1315, 1152 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 1.22 (t, 3H, *J* = 7.5 Hz), 2.42 (s, 3H), 2.56 (t, 2H, *J* = 6.5 Hz), 2.64 (q, 2H, *J* = 7.6 Hz), 3.18 (q, 2H, *J* = 6.5 Hz), 4.75 (t, 1H, *J* = 6.2 Hz), 7.13 (d, 2H, *J* = 8.3 Hz), 7.26-7.31 (m, 4H), 7.77 (d, 2H, *J* = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 15.3, 20.6, 21.5, 28.7, 41.9, 82.8, 84.7, 120.0, 127.0, 127.8, 129.7, 131.5, 136.9, 143.5, 144.4; HRMS (ESI): Calcd for $C_{19}H_{22}O_2NS$ $[M+H]^+$ = 328.1366, Found = 328.1365.

***N*-Tosyl 4-(4'-*tert*-Butylphenyl)-3-butyn-1-ylamine (1F):** white solid; mp: 101-102 °C; IR (neat): 3276, 1597, 1501, 1320, 1152 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 1.31 (s, 9H), 2.42 (s, 3H), 2.56 (t, 2H, *J* = 6.5 Hz), 3.18 (q, 2H, *J* = 6.5 Hz), 4.74 (t, 1H, *J* = 6.4 Hz), 7.27-7.33 (m, 6H), 7.77 (d, 2H, *J* = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 20.6, 21.5, 31.1, 34.7, 41.9, 82.8, 84.7, 119.8, 125.2, 127.0, 129.7, 131.3, 136.9, 143.5, 151.3; HRMS (ESI): Calcd for $C_{21}H_{26}O_2NS$ $[M+H]^+$ = 356.1679, Found = 356.1679.

***N*-Tosyl 4-(2',4'-Dimethylphenyl)-3-butyn-1-ylamine (1G):** white solid; mp: 75-76 °C; IR (neat): 3295, 1596, 1494, 1302, 1160 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.31 (s, 3H), 2.31 (s, 3H), 2.42 (s, 3H), 2.60 (t, 2H, *J* = 6.5 Hz), 3.19 (q, 2H, *J* = 6.3 Hz), 4.78 (t, 1H, *J* = 6.1 Hz), 6.92 (d, 1H, *J* = 7.9 Hz) 7.00 (s, 1H), 7.20 (d, 1H, *J* = 7.8 Hz), 7.30 (d, 2H, *J* = 7.9 Hz), 7.77 (d, 2H, *J* = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ =20.6, 20.7, 21.3, 21.5, 42.1, 81.8, 88.5, 119.6, 126.3, 127.0, 129.7, 130.2, 131.8, 136.9, 138.1, 139.8, 143.5; HRMS (ESI): Calcd for $C_{19}H_{22}O_2NS$ $[M+H]^+$ = 328.1366, Found = 328.1366.

***N*-Tosyl 4-(3',5'-Dimethylphenyl)-3-butyn-1-ylamine (1H):** white solid; mp: 76-77 °C; IR (neat): 3257, 1598, 1494, 1324, 1154 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.28 (s, 6H), 2.42 (s, 3H), 2.55 (t, 2H, *J* = 6.5 Hz), 3.18 (q, 2H, *J* = 6.3 Hz), 4.79 (m, 1H), 6.94 (s, 1H), 6.98 (s, 2H), 7.30 (d, 2H, *J* = 8.5 Hz) 7.77 (d,

2H, J = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 20.6, 21.0, 21.5, 41.9, 83.0, 84.7, 122.4, 127.0, 129.3, 129.7, 130.0, 136.9, 137.8, 143.5; HRMS (ESI): Calcd for $C_{19}H_{22}O_2NS$ $[M+H]^+$ = 328.1366, Found = 328.1366.

***N*-Tosyl 4-(2'-Methoxyphenyl)-3-butyn-1-ylamine (1I):** orange oil; IR (neat): 3280, 2836, 1597, 1492, 1327, 1258, 1155, 1092 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.41 (s, 3H), 2.52 (t, 2H, J = 6.3 Hz), 3.20 (q, 2H, J = 6.3 Hz), 3.96 (s, 3H), 5.37 (t, 1H, J = 6.3 Hz), 6.88-6.92 (m, 2H), 7.28-7.32 (m, 4H), 7.78 (d, 2H, J = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 20.5, 21.4, 41.6, 55.7, 80.0, 90.1, 110.4, 111.8, 120.4, 127.0, 129.6, 129.7, 132.6, 137.1, 143.4, 160.1; HRMS (ESI): Calcd for $C_{18}H_{20}O_3NS$ $[M+H]^+$ = 330.1158, Found = 330.1158.

***N*-Tosyl 4-(3'-Methoxyphenyl)-3-butyn-1-ylamine (1J):** orange oil; IR (neat): 3281, 2840, 1598, 1481, 1319, 1287, 1155, 1092 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.42 (s, 3H), 2.57 (t, 2H, J = 6.5 Hz), 3.19 (q, 2H, J = 6.5 Hz), 3.80 (s, 3H), 4.78 (t, 1H, J = 6.3 Hz), 6.85-6.88 (m, 2H), 6.95 (d, 1H, J = 7.4 Hz), 7.20 (t, 1H, J = 7.6 Hz), 7.31 (d, 2H, J = 8.1 Hz), 7.78 (d, 2H, J = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 20.6, 21.4, 41.8, 55.1, 82.4, 85.5, 114.5, 116.4, 123.9, 124.0, 126.9, 129.2, 129.6, 136.8, 143.4, 159.1; HRMS (ESI): Calcd for $C_{18}H_{20}O_3NS$ $[M+H]^+$ = 330.1158, Found = 330.1159.

***N*-Tosyl 4-(4'-Methoxyphenyl)-3-butyn-1-ylamine (1K):** white solid; mp: 89-90 °C; IR (neat): 3278, 2845, 1604, 1506, 1314, 1241, 1151, 1078 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.43 (s, 3H), 2.55 (t, 2H, J = 6.5 Hz), 3.18 (q, 2H, J = 6.3 Hz), 3.81 (s, 3H), 4.74 (t, 1H, J = 6.1 Hz), 6.82 (d, 2H, J = 9.0 Hz), 7.28-7.32 (m, 4H), 7.77 (d, 2H, J = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 20.6, 21.5, 41.9, 55.2, 82.5, 83.9, 113.8, 114.9, 127.0, 129.7, 133.0, 136.9, 143.5, 159.3; HRMS (ESI): Calcd for $C_{18}H_{20}O_3NS$ $[M+H]^+$ = 330.1158, Found = 330.1155.

***N*-Tosyl 4-(4'-Ethoxyphenyl)-3-butyn-1-ylamine (1L):** white solid; mp: 89-90 °C; IR (neat): 3274, 2851, 1606, 1509, 1324, 1243, 1155, 1079 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 1.42 (t, 3H, J = 7.2 Hz), 2.43 (s, 3H), 2.55 (t, 2H, J = 6.5 Hz), 3.17 (q, 2H, J = 6.3 Hz), 4.03 (q, 2H, J = 7.0 Hz), 4.73-4.75 (m, 1H), 6.81 (d, 2H, J = 9.0 Hz), 7.28-7.31 (m, 4H), 7.77 (d, 2H, J = 8.3Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 14.7, 20.6, 21.5, 42.0, 63.4, 82.6, 83.8, 114.3, 114.7, 127.0, 129.7, 132.9, 136.9, 143.5, 158.8; HRMS (ESI): Calcd for $C_{19}H_{22}O_3NS$ $[M+H]^+$ = 344.1315, Found = 344.1313.

***N*-Tosyl 4-(4'-Fluorophenyl)-3-butyn-1-ylamine (1N):** white solid; mp: 109-110 °C; IR (neat): 3285, 1599, 1505, 1313, 1151, 1078 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.43 (s, 3H), 2.57 (t, 2H, J = 6.5 Hz), 3.19 (q, 2H, J = 6.3 Hz), 4.71 (t, 1H, J = 6.7 Hz), 6.97-7.01 (m, 2H), 7.30-7.35 (m, 4H), 7.77 (d, 2H, J = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 20.6, 21.5, 41.8, 81.6, 85.3, 115.4 (d, $J_{C\text{-}F}$ = 21.6 Hz), 119.0 (d, $J_{C\text{-}F}$ = 3.8 Hz), 127.0, 129.7, 133.4 (d, $J_{C\text{-}F}$ = 8.5 Hz), 136.9, 143.5, 162.2 (d, $J_{C\text{-}F}$ = 249.0 Hz); HRMS (ESI): Calcd for $C_{17}H_{17}O_2NFS$ $[M+H]^+$ = 318.0959, Found = 318.0958.

***N*-Tosyl 4-(3'-Chlorophenyl)-3-butyn-1-ylamine (1O):** white solid; mp: 83-84 °C; IR (neat): 3274,

1590, 1473, 1313, 1151, 789 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.43 (s, 3H), 2.58 (t, 2H, *J* = 6.5 Hz), 3.20 (q, 2H, *J* = 6.3 Hz), 4.71 (t, 1H, *J* = 5.8 Hz), 7.22-7.23 (m, 1H), 7.23 (s, 1H), 7.27-7.32 (m, 4H), 7.78 (d, 2H, *J* = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 20.7, 21.5, 41.8, 81.3, 87.0, 124.6, 127.0, 128.3, 129.4, 129.7 (2C), 131.5, 133.9, 136.8, 143.6; HRMS (ESI): Calcd for $C_{17}H_{17}O_2N^{35}ClS$ $[M+H]^+$ = 334.0663, Found = 334.0660.

***N*-Tosyl 4-(4'-Chlorophenyl)-3-butyn-1-ylamine (1P):** white solid; mp: 109-110 °C; IR (neat): 3276, 1596, 1488, 1314, 1151, 813 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.43 (s, 3H), 2.58 (t, 2H, *J* = 6.5 Hz), 3.19 (q, 2H, *J* = 6.5 Hz), 4.71 (t, 1H, *J* = 7.0 Hz), 7.26-7.27 (m, 4H), 7.31 (d, 2H, *J* = 8.1 Hz), 7.77 (d, 2H, *J* = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 20.8, 21.5, 41.8, 81.7, 86.6, 121.4, 127.0, 128.6, 129.8, 132.8, 134.1, 136.9, 143.6; HRMS (ESI): Calcd for $C_{17}H_{17}O_2N^{35}ClS$ $[M+H]^+$ = 334.0663, Found = 334.0662.

***N*-Tosyl 4-(4'-Bromophenyl)-3-butyn-1-ylamine (1Q):** white solid; mp: 118-119 °C; IR (neat): 3274, 1595, 1485, 1314, 1151, 661 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.43 (s, 3H), 2.57 (t, 2H, *J* = 6.5 Hz), 3.19 (q, 2H, *J* = 6.5 Hz), 4.71 (t, 1H, *J* = 6.4 Hz), 7.21 (d, 2H, *J* = 8.1 Hz), 7.31 (d, 2H, *J* = 8.1 Hz), 7.43 (d, 2H, *J* = 8.5 Hz), 7.77 (d, 2H, *J* = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 20.8, 21.5, 41.8, 81.8, 86.8, 121.8, 122.3, 127.1, 129.8, 131.5, 133.1, 136.9, 143.6; HRMS (ESI): Calcd for $C_{17}H_{17}O_2N^{79}BrS$ $[M+H]^+$ = 378.0158, Found = 378.0154, $C_{17}H_{17}O_2N^{81}BrS$ $[M+H]^+$ = 380.0137, Found = 380.0137.

***N*-Tosyl 4-(Thiophen-2'-yl)-3-butyn-1-ylamine (1W):** brown solid; mp: 76-77 °C; IR (neat): 3270, 2965, 1597, 1456, 1313, 1151, 1076, 690 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.43 (s, 3H), 2.60 (t, 2H, *J* = 6.5 Hz), 3.19 (q, 2H, *J* = 6.5 Hz), 4.73 (t, 1H, *J* = 6.3 Hz), 6.96 (dd, 1H, *J* = 5.2, 3.6 Hz), 7.13 (dd, 1H, *J* = 3.7, 1.0 Hz), 7.22 (dd, 1H, *J* = 5.2, 1.1 Hz), 7.31 (d, 2H, *J* = 8.1 Hz), 7.77 (d, 2H, *J* = 8.3, Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 21.0, 21.5, 41.7, 75.9, 89.6, 122.8, 126.7, 126.8, 127.0, 129.8, 131.7, 136.8, 143.6; HRMS (ESI): Calcd for $C_{15}H_{16}O_2NS_2$ $[M+H]^+$ = 306.0617, Found = 306.0617.

***N*-Tosyl 5-Phenyl-4-pentyn-2-ylamine (1Y):** orange oil; IR (neat): 3273, 1598, 1490, 1327, 1159 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 1.24 (d, 3H, *J* = 6.7 Hz), 2.41 (s, 3H), 2.50 (d, 2H, *J* = 4.9 Hz), 3.53-3.63 (m, 1H), 4.72 (d, 1H, *J* = 8.1 Hz), 7.28-7.31 (m, 5H), 7.33-7.36 (m, 2H), 7.78 (d, 2H, *J* = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 20.8, 21.5, 27.7, 48.4, 83.4, 84.8, 123.0, 127.0, 128.0, 128.2, 129.6, 131.6, 137.7, 143.3; HRMS (ESI): Calcd for $C_{18}H_{20}O_2NS$ $[M+H]^+$ = 314.1209, Found = 314.1209.

***N*-Tosyl 5-(4'-Methylphenyl)-4-pentyn-2-ylamine (1Z):** yellow solid; mp: 91-92 °C; IR (neat): 3249, 1508, 1335, 1161 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 1.24 (d, 3H, *J* = 6.5 Hz), 2.35 (s, 3H), 2.41 (s, 3H), 2.48 (d, 2H, *J* = 5.2 Hz), 3.52-3.62 (m, 1H), 4.71 (d, 1H, *J* = 8.3 Hz), 7.10 (d, 2H, *J* = 8.3 Hz), 7.23-7.31 (m, 4H), 7.79 (d, 2H, *J* = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 20.8, 21.3, 21.4, 27.7, 48.4, 83.4, 84.0, 119.9, 126.9, 128.9, 129.6, 131.4, 137.7, 138.0, 143.2; HRMS (ESI): Calcd for $C_{19}H_{22}O_2NS$ $[M+H]^+$ = 328.1366, Found = 328.1364.

***N*-Tosyl 5-(4'-Methoxyphenyl)-4-pentyn-2-ylamine (1AA):** white solid; mp: 108-109 °C; IR (neat): 3278, 1604, 1508, 1332, 1238, 1145, 1089 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 1.24 (d, 3H, *J* = 6.5 Hz), 2.41 (s, 3H), 2.48 (d, 2H, *J* = 5.3 Hz), 3.51-3.61 (m, 1H), 3.82 (s, 3H), 4.69 (d, 1H, *J* = 8.1 Hz), 6.83 (d, 2H, *J* = 8.8 Hz), 7.28-7.31 (m, 4H), 7.78 (d, 2H, *J* = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 21.0, 21.5, 27.7, 48.4, 52.3, 83.1, 83.4, 113.8, 115.1, 127.0, 129.7, 133.0, 137.8, 143.3, 159.4; HRMS (ESI): Calcd for $C_{19}H_{22}O_3NS$ $[M+H]^+$ = 344.1315, Found = 344.1313.

***N*-Tosyl 5-(4'-Chlorophenyl)-4-pentyn-2-ylamine (1AB):** white solid; mp: 110-111 °C; IR (neat): 3254, 1599, 1487, 1361, 1161, 670 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 1.23 (d, 3H, *J* = 6.5 Hz), 2.41 (s, 3H), 2.51 (d, 2H, *J* = 5.3 Hz), 3.55-3.62 (m, 1H), 4.62 (d, 1H, *J* = 8.3 Hz), 7.27-7.31 (m, 6H), 7.78 (d, 2H, *J* = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 20.7, 21.4, 27.8, 48.3, 82.2, 86.1, 121.5, 126.9, 128.4, 129.6, 132.8, 133.8, 137.7, 143.3; HRMS (ESI): Calcd for $C_{18}H_{19}O_2N^{35}ClS$ $[M+H]^+$ = 348.0820, Found = 348.0813.

***N*-Tosyl 6-Phenyl-5-hexyn-3-ylamine (1AC):** white solid; mp: 88-89 °C; IR (neat): 3292, 1597, 1490, 1313, 1152 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 0.86 (t, 3H, *J* = 7.4 Hz), 1.58-1.68 (m, 2H), 2.41 (s, 3H), 2.48-2.51 (m, 2H), 3.31-3.39 (m, 1H), 4.64 (d, 1H, *J* = 9.2 Hz), 7.29-7.31 (m, 5H), 7.34-7.37 (m, 2H), 7.78 (d, 2H, *J* = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 10.1, 21.5, 25.4, 27.3, 53.7, 83.4, 84.7, 123.0, 127.0, 128.0, 128.2, 129.6, 131.6, 137.9, 143.3; HRMS (ESI): Calcd for $C_{19}H_{22}O_2NS$ $[M+H]^+$ = 328.1366, Found = 328.1364.

***N*-Tosyl 3-Nonyn-1-ylamine (1AD):** white solid; mp: 37-38 °C; IR (neat): 3272, 2929, 1598, 1495, 1317, 1152 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 0.90 (t, 3H, *J* = 7.2 Hz), 1.30-1.35 (m, 4H), 1.45 (quin, 2H, *J* = 7.2 Hz), 2.08-2.13 (m, 2H), 2.28-2.32 (m, 2H), 2.44 (s, 3H), 3.03-3.08 (m, 2H), 4.68 (t, 1H, *J* = 6.1 Hz), 7.32 (d, 2H, *J* = 8.1 Hz), 7.76 (d, 2H, *J* = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 13.9, 18.5, 19.8, 21.4, 22.1, 28.4, 31.0, 42.1, 75.6, 83.1, 127.0, 129.6, 136.9, 143.4; HRMS (ESI): Calcd for $C_{16}H_{24}O_2NS$ $[M+H]^+$ = 294.1522, Found = 294.1521.

Typical Procedure for Preparation of *N*-Tosyl 4-Aryl-3-butyn-1-ylamines 1M, 1R-1V, and 1X

To a solution of 3-butyn-1-ol (10.0 mmol, 700.9 mg), triphenylphosphine (13.0 mmol, 3409.0 mg) and phthalimide (13.0 mmol, 1912 mg) in THF (20.0 mL) was added diisopropyl azodicarboxylate (DIAD, 13.0 mmol, 2.6 mL) at 0 °C, and the mixture was stirred for 12 h at room temperature under argon atmosphere. Then, sat. Na_2SO_3 aq. solution (15.0 mL) was added to the mixture, and the product was extracted with $CHCl_3$ (15.0 mL × 3). The organic layer was dried over Na_2SO_4. After filtration and removal of the solvent under reduced pressure, the residue was purified by silica-gel column chromatography (eluent: *n*-hexane:EtOAc = 4:1) to give *N*-(3-butyn-1-yl)phthalimide (1713.0 mg, 86%). To a solution of *N*-(3-butyn-1-yl)phthalimide (8.0 mmol, 1594.0 mg), $PdCl_2(PPh_3)_2$ (0.40 mmol, 280.8 mg), and CuI (0.40 mmol, 76.2 mg) in Et_3N (30.0 mL) was added 4-bromodiphenyl ether (16.0 mmol,

1.32 mL). The obtained mixture was stirred for 12 h at 50 °C under argon atmosphere. Sat. NH_4Cl aq. solution (15.0 mL) was added to the mixture, and the product was extracted with $CHCl_3$ (15.0 mL × 3). The organic layer was dried over Na_2SO_4 and filtered. After removal of the solvent under reduced pressure, the residue was purified by silica-gel column chromatography (eluent: *n*-hexane:EtOAc = 4:1) to give *N*-[4-(4'-phenoxyphenyl)-3-butyn-1-yl]phthalimide (2880.0 mg, 98%). To the mixture of *N*-[(4'-phenoxyphenyl)-3-butyn-1-yl]phthalimide in MeOH (40.0 mL) was added hydrazine monohydrate (14.4 mmol, 0.7 mL). The obtained mixture was stirred for 6 h at 50 °C under argon atmosphere. H_2O (15.0 mL) was added to the mixture, and the product was extracted with $CHCl_3$ (15.0 mL × 3). The organic layer was dried over Na_2SO_4 and filtered. After removal of the solvent under reduced pressure, *p*-toluenesulfonyl chloride (8.0 mmol, 1525.0 mg) and pyridine (3.2 mL) were added to the mixture in CH_2Cl_2 (8.0 mL) at 0 °C. The obtained mixture was stirred for 12 h at room temperature under argon atmosphere. Sat. NH_4Cl aq. solution (15.0 mL) was added to the mixture, and the product was extracted with $CHCl_3$ (15.0 mL × 3). The organic layer was dried over Na_2SO_4 and filtered. After removal of the solvent under reduced pressure, the residue was purified by silica-gel column chromatography (eluent: *n*-hexane:EtOAc = 3:1) to give *N*-tosyl 4-(4'-phenoxyphenyl)-3-butyn-1-ylamine **1M** (1754.0 mg, 56%). Other *N*-tosyl 4-aryl-3-butyn-1-ylamines **1R-1V** and **1X** were obtained in 49–71% yields by the same procedure.

***N*-Tosyl 4-(4'-Phenoxyphenyl)-3-butyn-1-ylamine (1M):** white solid; mp: 96-97 °C; IR (neat): 3277, 1587, 1502, 1314, 1234, 1151, 1079 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.43 (s, 3H), 2.57 (t, 2H, *J* = 6.5 Hz), 3.19 (q, 2H, *J* = 6.5 Hz), 4.72-4.76 (m, 1H), 6.91 (d, 2H, *J* = 9.0 Hz), 7.00-7.03 (m, 2H) 7.14 (tt, 1H, *J* = 7.4, 1.1 Hz), 7.29-7.32 (m, 4H), 7.34-7.39 (m, 2H), 7.77 (d, 2H, *J* = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 20.7, 21.5, 41.9, 82.3, 84.8, 117.4, 118.3, 119.3, 123.8, 127.1, 129.7, 129.8, 133.2, 136.9, 143.5, 156.4, 157.4; HRMS (ESI): Calcd for $C_{23}H_{22}O_3NS$ $[M+H]^+$ = 392.1315, Found = 392.1314.

***N*-Tosyl 4-[4'-(Trifluoromethyl)phenyl]-3-butyn-1-ylamine (1R):** white solid; mp: 137-138 °C; IR (neat): 3279, 1614, 1493, 1313, 1184, 1151 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.43 (s, 3H), 2.62 (t, 2H, *J* = 6.5 Hz), 3.22 (q, 2H, *J* = 6.5 Hz), 4.72 (t, 1H, *J* = 5.8 Hz), 7.31 (d, 2H, *J* = 8.1 Hz), 7.45 (d, 2H, *J* = 8.1 Hz), 7.55 (d, 2H, *J* = 8.1 Hz), 7.78 (d, 2H, *J* = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 20.8, 21.5, 41.7, 81.4, 88.4, 123.8 (q, J_{C-F} = 272.5 Hz), 125.1 (q, J_{C-F} = 3.8 Hz), 126.8, 127.0, 129.7 (q, J_{C-F} = 32.9 Hz), 129.8, 131.9, 136.9, 143.6; HRMS (ESI): Calcd for $C_{18}H_{17}O_2NF_3S$ $[M+H]^+$ = 368.0927, Found = 368.0923.

***N*-Tosyl 4-(4'-Cyanophenyl)-3-butyn-1-ylamine (1S):** white solid; mp: 120-121 °C; IR (neat): 3237, 2230, 1603, 1499, 1328, 1158 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.43 (s, 3H), 2.63 (t, 2H, *J* = 6.5 Hz), 3.21 (q, 2H, *J* = 6.5 Hz), 4.84 (t, 1H, *J* = 6.3 Hz), 7.31 (d, 2H, *J* = 8.3 Hz), 7.43 (d, 2H, *J* = 8.3 Hz), 7.58 (d, 2H, *J* = 8.3 Hz), 7.78 (d, 2H, *J* = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 20.9, 21.4, 41.6, 81.1,

90.7, 111.1, 118.4, 126.9, 128.0, 129.7, 131.8, 132.1, 136.8, 143.5; HRMS (ESI): Calcd for $C_{18}H_{17}O_2N_2S$ $[M+H]^+$ = 325.1005, Found = 325.1002.

***N*-Tosyl 4-(Naphthalen-2'-yl)-3-butyn-1-ylamine (1T):** white solid; mp: 99-100 °C; IR (neat): 3271, 1595, 1495, 1315, 1153 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.42 (s, 3H), 2.63 (t, 2H, *J* = 6.5 Hz), 3.24 (q, 2H, *J* = 6.3 Hz), 4.79 (t, 1H, *J* = 6.1 Hz), 7.31 (d, 2H, *J* = 8.5 Hz), 7.39 (dd, 1H, *J* = 8.5, 1.6 Hz), 7.48-7.52 (m, 2H), 7.75-7.82 (m, 5H), 7.87 (s, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 20.8, 21.4, 41.9, 83.0, 85.9, 120.2, 126.5 (2C), 127.0, 127.6 (2C), 127.8, 128.4, 129.7, 131.4, 132.6, 132.8, 136.9, 143.5; HRMS (ESI): Calcd for $C_{21}H_{20}O_2NS$ $[M+H]^+$ = 350.1209, Found = 350.1205.

***N*-Tosyl 4-(4'-Biphenyl)-3-butyn-1-ylamine (1U):** white solid; mp: 127-128 °C; IR (neat): 3241, 1598, 1486, 1323, 1156 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.43 (s, 3H), 2.61 (t, 2H, *J* = 6.5 Hz), 3.21 (q, 2H, *J* = 6.5 Hz), 4.75 (t, 1H, *J* = 5.8 Hz), 7.32 (d, 2H, *J* = 7.9 Hz), 7.36 (t, 1H, *J* = 7.4 Hz), 7.41-7.47 (m, 4H), 7.52-7.60 (m, 4H), 7.79 (d, 2H, *J* = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 20.8, 21.5, 41.9, 82.7, 86.2, 121.7, 126.9, 127.0, 127.1, 127.6, 128.8, 129.8, 132.0, 136.9, 140.2, 140.9, 143.6; HRMS (ESI): Calcd for $C_{23}H_{22}O_2NS$ $[M+H]^+$ = 376.1366, Found = 376.1362.

***N*-Tosyl 4-(1',3'-Benzodioxol-5'-yl)-3-butyn-1-ylamine (1V):** white solid; mp: 119-120 °C; IR (neat): 3245, 2790, 1600, 1508, 1321, 1154, 933, 707 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.43 (s, 3H), 2.54 (t, 2H, *J* = 6.5 Hz), 3.17 (q, 2H, *J* = 6.3 Hz), 4.76 (t, 1H, *J* = 6.3 Hz), 5.97 (s, 2H), 6.73 (d, 1H, *J* = 8.1 Hz), 6.78 (s, 1H), 6.87 (dd, 1H, *J* = 8.1, 1.6 Hz), 7.31 (d, 2H, *J* = 7.9 Hz), 7.77 (d, 2H, *J* = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 20.6, 21.5, 41.9, 82.6, 83.7, 101.2, 108.3, 111.6, 116.1, 126.1, 127.0, 129.7, 136.9, 143.5, 147.3, 147.7; HRMS (ESI): Calcd for $C_{18}H_{18}O_4NS$ $[M+H]^+$ = 344.0951, Found = 344.0948.

***N*-Tosyl 4-(Thiophen-3'-yl)-3-butyn-1-ylamine (1X):** brown solid; mp: 82-83 °C; IR (neat): 3269, 2965, 1597, 1519, 1313, 1150, 1077, 670 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.43 (s, 3H), 2.56 (t, 2H, *J* = 6.5 Hz), 3.18 (q, 2H, *J* = 6.3 Hz), 4.74 (t, 1H, *J* = 6.3 Hz), 7.03 (dd, 1H, *J* = 5.1, 1.0 Hz), 7.24-7.26 (m, 1H), 7.31 (d, 2H, *J* = 8.3 Hz), 7.36 (s, 1H), 7.77 (d, 2H, *J* = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ =20.7, 21.5, 41.8, 77.8, 85.1, 121.8, 125.2, 127.0, 128.5, 129.7, 129.8, 136.8, 143.5; HRMS (ESI): Calcd for $C_{15}H_{16}O_2NS_2$ $[M+H]^+$ = 306.0617, Found = 306.0613.

Typical Procedure for Preparation of 3-Iodo-2-phenyl-1-tosyl-4,5-dihydropyrrole 2A

To a solution of *N*-tosyl 4-phenyl-3-butyn-1-ylamine **1A** (0.5 mmol, 149.7 mg) and K_2CO_3 (1.5 mmol, 207.3 mg) in MeCN (5.0 mL) was added I_2 (1.5 mmol, 380.8 mg) at 0 °C, and the mixture was stirred for 2 h at room temperature under argon atmosphere. Then, sat. Na_2SO_3 aq. solution (15.0 mL) was added to the mixture, and the product was extracted with $CHCl_3$ (15.0 mL × 3). The organic layer was dried over Na_2SO_4. After filtration and removal of the solvent under reduced pressure, the residue was purified by silica-gel column chromatography (eluent: *n*-hexane:EtOAc = 4:1) to give 3-iodo-2-phenyl-1-tosyl-4,5-dihydropyrrole **2A** (197.8 mg, 93%).

3-Iodo-2-phenyl-1-tosyl-4,5-dihydropyrrole (2A): Yield: 197.8 mg (93%); yellow solid; mp: 145-146 °C; IR (neat): 1596, 1493, 1350, 1158 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.45 (s, 3H), 2.49 (t, 2H, *J* = 8.5 Hz), 4.03 (t, 2H, *J* = 8.5 Hz), 7.28 (d, 2H, *J* = 7.9 Hz), 7.38-7.41 (m, 3H), 7.52-7.54 (m, 4H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 21.6, 40.1, 50.9, 79.7, 127.6, 127.8, 129.1, 129.5, 129.8, 132.2, 133.9, 144.1, 144.4; HRMS (ESI): Calcd for $C_{17}H_{17}O_2NIS$ $[M+H]^+$ = 426.0019, Found = 426.0015.

3-Iodo-2-*n*-pentyl-1-tosyl-4,5-dihydropyrrole (2AD): Yield: 149.0 mg (71%); orange oil; IR (neat): 2954, 1631, 1494, 1350, 1161 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 0.91 (t, 3H, *J* = 7.0 Hz), 1.31-1.39 (m, 4H), 1.63 (quin, 2H, *J* = 7.2 Hz), 2.30 (t, 2H, *J* = 8.3 Hz), 2.44 (s, 3H), 2.65 (t, 2H, *J* = 7.6 Hz), 3.78 (t, 2H, *J* = 8.5 Hz), 7.31 (d, 2H, *J* = 8.1 Hz), 7.64 (d, 2H, *J* = 8.3 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 14.0, 21.6, 23.4, 27.1, 29.9, 31.3, 38.0, 50.4, 77.7, 127.3, 129.7, 134.0, 144.0, 145.8; HRMS (APCI): Calcd for $C_{16}H_{23}O_2NIS$ $[M+H]^+$ = 420.0489, Found = 420.0486.

Typical Procedure for Preparation of 2-Aryl-3-iodopyrroles 3

To a solution of *N*-tosyl 4-phenyl-3-butyn-1-ylamine **1A** (0.5 mmol, 149.7 mg) and K_2CO_3 (1.5 mmol, 207.3 mg) in MeCN (5.0 mL) was added I_2 (1.5 mmol, 380.8 mg) at 0 °C, and the mixture was stirred for 2 h at room temperature under argon atmosphere. After removal of the solvent under reduced pressure, the residue was dissolved in DMF (5.0 mL). ^{t}BuOK (3.75 mmol, 420.8 mg) was added to the solution at 0 °C, and the mixture was stirred for 3 h at 0 °C under argon atmosphere. Sat. NH_4Cl aq. solution (15.0 mL) was added to the mixture, and the product was extracted with Et_2O (15.0 mL × 3). The organic layer was dried over Na_2SO_4. After filtration and removal of the solvent under reduced pressure, the residue was purified by silica-gel column chromatography (eluent: *n*-hexane:EtOAc = 4:1) to give 3-iodo-2-phenylpyrrole **3A** (125.1 mg, 93%). Compound **3A** and other 2-aryl-3-iodopyrroles **3** were stored at -78 °C.

3-Iodo-2-phenylpyrrole (3A): Yield: 125.1 mg (93%); yellow solid; mp: 52-53 °C; IR (neat): 3354, 3130, 1600, 1488 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 6.43-6.44 (m, 1H), 6.84-6.86 (m, 1H), 7.33 (tt, 1H, *J* = 7.4, 2.0 Hz), 7.43 (tt, 2H, *J* = 8.1, 1.6 Hz), 7.62 (d, 2H, *J* = 8.2 Hz), 8.36 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 60.3, 118.5, 120.0, 127.3, 127.5, 128.6, 132.4, 132.6; HRMS (ESI): Calcd for $C_{10}H_8NI$ M^+ = 268.9696, Found = 268.9692.

3-Iodo-2-(2'-methylphenyl)pyrrole (3B): Yield: 113.4 mg (80%); orange oil; IR (neat): 3403, 3125, 1601, 1487 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.26 (s, 3H), 6.40-6.42 (m, 1H), 6.82-6.83 (m, 1H), 7.22-7.24 (m, 1H), 7.27-7.32 (m, 3H), 8.19 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 20.2, 62.9, 116.5, 119.2, 125.5, 128.7, 130.2, 131.1, 132.3, 133.6, 137.8; HRMS (ESI): Calcd for $C_{11}H_{10}NI$ M^+ = 282.9852, Found = 282.9848.

3-Iodo-2-(3'-methylphenyl)pyrrole (3C): Yield: 121.7 mg (86%); orange oil; IR (neat): 3406, 1604, 1585 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.41 (s, 3H), 6.42-6.43 (m, 1H), 6.83-6.84 (m, 1H), 7.15 (d,

1H, *J* = 7.4 Hz), 7.32 (t, 1H, *J* = 8.1 Hz), 7.42 (s, 1H), 7.43 (d, 1H, *J* = 7.4 Hz), 8.37 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ =21.5, 60.1, 118.4, 119.9, 124.5, 127.9, 128.2, 128.5, 132.3, 132.7, 138.2; HRMS (ESI): Calcd for $C_{11}H_{10}NI$ M^+ = 282.9852, Found = 282.9849.

3-Iodo-2-(4'-methylphenyl)pyrrole (**3D**)**:** Yield: 113.8 mg (80%); orange solid; mp: 65-66 °C; IR (neat): 3406, 1550, 1504 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.39 (s, 3H), 6.41-6.43 (m, 1H), 6.82-6.83 (m, 1H), 7.24 (d, 2H, *J* = 7.9 Hz), 7.51 (d, 2H, *J* = 8.3 Hz), 8.35 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 21.2, 59.9, 118.3, 119.7, 127.3, 129.3, 129.6, 132.8, 137.4; HRMS (ESI): Calcd for $C_{11}H_{10}NI$ M^+ = 282.9852, Found = 282.9848.

2-(4'-Ethylphenyl)-3-iodopyrrole (**3E**)**:** Yield: 119.9 mg (81%); brown solid; mp: 58-59 °C; IR (neat): 3404, 1598, 1505 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 1.27 (t, 3H, *J* = 7.6 Hz), 2.69 (q, 2H, *J* = 7.6 Hz), 6.41-6.43 (m, 1H), 6.82-6.83 (m, 1H), 7.26 (d, 2H, *J* = 8.3 Hz), 7.53 (d, 2H, *J* = 8.3 Hz), 8.34 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 15.4, 28.6, 59.9, 118.3, 119.7, 127.3, 128.1, 129.7, 132.7, 143.6; HRMS (ESI): Calcd for $C_{12}H_{12}NI$ M^+ = 297.0009, Found = 297.0004.

2-(4'-*tert*-Butylphenyl)-3-iodopyrrole (**3F**)**:** Yield: 151.5 mg (93%); orange solid; mp: 87-88 °C; IR (neat): 3351, 1565, 1498 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 1.35 (s, 9H), 6.42-6.43 (m, 1H), 6.82-6.84 (m, 1H), 7.45 (d, 2H, *J* = 8.5 Hz), 7.56 (d, 2H, *J* = 8.8 Hz), 8.36 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 31.3, 34.6, 59.8, 118.3, 119.8, 125.5, 126.9, 129.5, 132.6, 150.4; HRMS (ESI): Calcd for $C_{14}H_{16}NI$ M^+ = 325.0322, Found = 325.0319.

2-(2',4'-Dimethylphenyl)-3-iodopyrrole (**3G**)**:** Yield: 122.0 mg (82%); orange oil; IR (neat): 3406, 1614, 1495 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.22 (s, 3H), 2.37 (s, 3H), 6.39-6.40 (m, 1H), 6.80-6.82 (m, 1H), 7.06 (d, 1H, *J* = 8.1 Hz), 7.11 (s, 1H), 7.19 (d, 1H, *J* = 7.6 Hz), 8.16 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 20.1, 21.2, 62.9, 116.4, 119.1, 126.3, 129.4, 131.0 (2C), 133.6, 137.6, 138.5; HRMS (ESI): Calcd for $C_{12}H_{12}NI$ M^+ = 297.0009, Found = 297.0005.

2-(3',5'-Dimethylphenyl)-3-iodopyrrole (**3H**)**:** Yield: 133.8 mg (90%); purple solid; mp: 79-80 °C; IR (neat): 3373, 1602, 1473 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.37 (s, 6H), 6.41-6.42 (m, 1H), 6.81-6.83 (m, 1H), 6.97 (s, 1H), 7.23 (s, 2H), 8.34 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 21.3, 60.0, 118.3, 119.7, 125.1, 129.2, 132.2, 132.8, 138.1; HRMS (ESI): Calcd for $C_{12}H_{12}NI$ M^+ = 297.0009, Found = 297.0004.

3-Iodo-2-(2'-methoxyphenyl)pyrrole (**3I**)**:** Yield: 90.3 mg (60%); purple solid; mp: 83-84 °C; IR (neat): 3374, 2834, 1577, 1488, 1294, 1115 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 3.87 (s, 3H), 6.42-6.44 (m, 1H), 6.85-6.87 (m, 1H), 6.98 (d, 1H, *J* = 8.3 Hz), 7.06 (td, 1H, *J* = 7.4, 1.1 Hz), 7.28-7.33 (m, 1H), 7.89 (dd, 1H, *J* = 7.6, 1.8 Hz), 9.16 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 55.6, 60.8, 111.3, 117.8, 119.3, 120.5, 120.7, 128.7, 129.0, 130.6, 156.0; HRMS (ESI): Calcd for $C_{11}H_{10}ONI$ M^+ = 298.9802, Found = 298.9795.

3-Iodo-2-(3'-methoxyphenyl)pyrrole (3J): Yield: 139.3 mg (93%); purple solid; mp: 64-65 °C; IR (neat): 3363, 2835, 1601, 1472, 1219, 1020 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 3.86 (s, 3H), 6.43-6.44 (m, 1H), 6.83-6.85 (m, 1H), 6.88 (d, 1H, *J* = 8.3 Hz), 7.16 (d, 1H, *J* = 7.6 Hz), 7.22 (s, 1H), 7.34 (d, 1H, *J* = 8.1 Hz), 8.40 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 55.3, 60.4, 112.8, 113.2, 118.5, 119.4, 120.1, 129.7, 132.3, 133.6, 159.5; HRMS (ESI): Calcd for $C_{11}H_{10}ONI$ M^+ = 298.9802, Found = 298.9799.

3-Iodo-2-(4'-methoxyphenyl)pyrrole (3K): Yield: 90.3 mg (60%); colorless oil; IR (neat): 3387, 2833, 1609, 1503, 1243, 1020 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 3.85 (s, 3H), 6.40-6.41 (m, 1H), 6.80-6.82 (m, 1H), 6.97 (d, 2H, *J* = 8.8 Hz), 7.53 (d, 2H, *J* = 8.8 Hz), 8.30 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 55.3, 59.7, 113.9, 118.0, 119.5, 125.0, 128.8, 132.7, 159.0; HRMS (ESI): Calcd for $C_{11}H_{10}ONI$ M^+ = 298.9802, Found = 298.9803.

2-(4'-Ethoxyphenyl)-3-iodopyrrole (3L): Yield: 93.9 mg (60%); purple solid; mp: 64-65 °C; IR (neat): 3421, 2830, 1607, 1504, 1242, 1043 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 1.44 (t, 3H, *J* = 7.2 Hz), 4.07 (q, 2H, *J* = 7.0 Hz), 6.40-6.41 (m, 1H), 6.80-6.82 (m, 1H), 6.95 (d, 2H, *J* = 9.0 Hz), 7.52 (d, 2H, *J* = 9.0 Hz), 8.29 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 15.0, 59.8, 63.6, 114.6, 118.2, 119.6, 125.0, 128.9, 132.9, 158.5; HRMS (ESI): Calcd for $C_{12}H_{12}ONI$ M^+ = 312.9958, Found = 312.9955.

3-Iodo-2-(4'-phenoxyphenyl)pyrrole (3M): Yield: 143.0 mg (79%); orange oil; IR (neat): 3413, 1588, 1487, 1231, 1094 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 6.42-6.43 (m, 1H), 6.83-6.84 (m, 1H), 7.03-7.08 (m, 4H), 7.14 (t, 1H, *J* = 7.4 Hz), 7.37 (d, 2H, *J* = 8.0 Hz), 7.57 (d, 2H, *J* = 9.0 Hz), 8.34 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 60.1, 118.3, 118.5, 119.3, 119.8, 123.6, 127.3, 128.8, 129.8, 132.2, 156.6, 156.8; HRMS (ESI): Calcd for $C_{16}H_{12}ONI$ M^+ = 360.9958, Found = 360.9951.

2-(4'-Fluorophenyl)-3-iodopyrrole (3N): Yield: 131.6 mg (92%); yellow oil; IR (neat): 3367, 1605, 1500, 1094 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 6.42-6.43 (m, 1H), 6.83-6.85 (m, 1H), 7.12 (t, 2H, *J* = 8.5 Hz), 7.55-7.60 (m, 2H), 8.35 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 60.5, 115.6 (d, $J_{C\text{-}F}$ = 21.6 Hz), 118.3, 120.0, 128.5 (d, $J_{C\text{-}F}$ = 2.8 Hz), 129.2 (d, $J_{C\text{-}F}$ = 7.5 Hz), 131.9, 162.1 (d, $J_{C\text{-}F}$ = 248.1 Hz); HRMS (ESI): Calcd for $C_{10}H_7NFI$ M^+ = 286.9602, Found = 286.9594.

2-(3'-Chlorophenyl)-3-iodopyrrole (3O): Yield: 131.1 mg (86%); brown solid; mp: 52-53 °C; IR (neat): 3400, 1598, 1478, 756 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 6.44-6.45 (m, 1H), 6.85-6.87 (m, 1H), 7.30 (d, 1H, *J* = 8.1 Hz), 7.36 (t, 1H, *J* = 7.6 Hz) 7.53 (d, 2H, *J* = 7.6 Hz), 7.60 (s, 1H), 8.39 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 61.1, 118.8, 120.6, 125.4, 127.1, 127.4, 129.9, 131.1, 134.0, 134.4; HRMS (ESI): Calcd for $C_{10}H_7N^{35}ClI$ M^+ = 302.9306, Found = 302.9298.

2-(4'-Chlorophenyl)-3-iodopyrrole (3P): Yield: 130.7 mg (86%); orange oil; IR (neat): 3420, 1598, 1489, 726 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 6.43-6.44 (m, 1H), 6.84-6.86 (m, 1H), 7.40 (d, 2H, *J* = 8.8 Hz), 7.55 (d, 2H, *J* = 8.8 Hz), 8.37 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 60.9, 118.6, 120.5,

128.5, 128.8, 130.8, 131.4, 133.3; HRMS (ESI): Calcd for $C_{10}H_7N^{35}ClI$ M^+ = 302.9306, Found = 302.9298.

2-(4'-Bromophenyl)-3-iodopyrrole (3Q): Yield: 149.9 mg (86%); orange oil; IR (neat): 3418, 1543, 1486 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 6.43-6.45 (m, 1H), 6.85-6.86 (m, 1H), 7.49 (d, 2H, *J* = 8.3 Hz), 7.56 (d, 2H, *J* = 8.3 Hz), 8.38 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 60.8, 118.7, 120.4, 121.4, 128.8, 131.2, 131.4, 131.7; HRMS (ESI): Calcd for $C_{10}H_7N^{79}BrI$ M^+ = 346.8801, Found = 346.8793, $C_{10}H_7N^{81}BrI$ M^+ = 348.8781, Found = 348.8773.

3-Iodo-2-[4'-(trifluoromethyl)phenyl]pyrrole (3R): Yield: 114.6 mg (68%); orange oil; IR (neat): 3409, 1617, 1507, 1321, 1165, 1109 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 6.47-6.48 (m, 1H), 6.89-6.90 (m, 1H), 7.68 (d, 2H, *J* = 8.8 Hz), 7.75 (d, 2H, *J* = 8.1 Hz), 8.45 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 61.7, 119.1, 121.0, 124.1 (q, $J_{C\text{-}F}$ = 271.5 Hz), 125.6 (q, $J_{C\text{-}F}$ = 3.8 Hz), 127.2, 129.1 (q, $J_{C\text{-}F}$ = 32.9 Hz), 131.0, 135.7; HRMS (ESI): Calcd for $C_{11}H_7NF_3I$ M^+ = 336.9570, Found = 336.9563.

2-(4'-Cyanophenyl)-3-iodopyrrole (3S): Yield: 74.1 mg (50%); yellow solid; mp: 109-110 °C; IR (neat): 3361, 2224, 1602, 1491 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 6.49-6.50 (m, 1H), 6.91-6.93 (m, 1H), 7.71 (d, 2H, *J* = 8.3 Hz), 7.77 (d, 2H, *J* = 8.3 Hz), 8.51 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 62.5, 110.3, 118.9, 119.6, 121.7, 127.2, 130.3, 132.4, 136.7; HRMS (ESI): Calcd for $C_{11}H_7N_2I$ M^+ = 293.9648, Found = 293.9641.

3-Iodo-2-(naphthalen-2'-yl)pyrrole (3T): Yield: 154.8 mg (97%); yellow solid; mp: 85-86 °C; IR (neat): 3421, 1598, 1501 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 6.48-6.49 (m, 1H), 6.89-6.90 (m, 1H), 7.47-7.53 (m, 2H), 7.77 (dd, 1H, *J* = 8.5, 1.8 Hz), 7.84-7.91 (m, 3H), 8.06 (s, 1H), 8.51 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 60.9, 118.8, 120.5, 125.5, 126.2, 126.3, 126.6, 127.9, 128.1, 128.4, 130.0, 132.6, 132.7, 133.4; HRMS (ESI): Calcd for $C_{14}H_{10}NI$ M^+ = 318.9852, Found = 318.9845.

2-(4'-Biphenyl)-3-iodopyrrole (3U): Yield: 161.9 mg (94%); orange solid; mp: 90-91 °C; IR (neat): 3398, 1543, 1508 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 6.45-6.47 (m, 1H), 6.86-6.88 (m, 1H), 7.37 (tt, 1H, *J* = 7.2, 2.0 Hz), 7.46 (t, 2H, *J* = 7.5 Hz), 7.62-7.66 (m, 3H), 7.67-7.72 (m, 3H), 8.42 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 60.5, 118.7, 120.2, 127.0, 127.3, 127.4, 127.5, 128.8, 131.3, 132.2, 140.1, 140.4; HRMS (ESI): Calcd for $C_{16}H_{12}NI$ M^+ = 345.0009, Found = 345.0005.

2-(1',3'-Benzodioxol-5'-yl)-3-iodopyrrole (3V): Yield: 130.0 mg (83%); orange oil; IR (neat): 3402, 2891, 1606, 1500, 932, 718 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 6.01 (s, 2H), 6.39-6.41 (m, 1H), 6.80-6.81 (m, 1H), 6.87 (d, 1H, *J* = 8.1 Hz), 7.03 (dd, 1H, *J* = 8.0, 1.7 Hz), 7.11 (s, 1H), 8.29 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 60.1, 101.2, 108.2, 108.4, 118.1, 119.6, 121.2, 126.4, 132.5, 147.0, 147.6; HRMS (ESI): Calcd for $C_{11}H_8O_2NI$ M^+ = 312.9594, Found = 312.9589.

3-Iodo-2-(thiophen-2'-yl)pyrrole (3W): Yield: 127.9 mg (93%); orange oil; IR (neat): 3406, 3098, 1653, 1562, 1425, 695 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 6.41-6.42 (m, 1H), 6.78-6.80 (m, 1H), 7.09 (dd,

1H, *J* = 5.2, 3.6 Hz), 7.28 (dd, 1H, *J* = 5.2, 1.1 Hz), 7.33 (dd, 1H, *J* = 3.7, 1.3 Hz), 8.39 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 61.5, 118.5, 120.1, 124.3, 124.4, 127.4, 127.7, 134.0; HRMS (ESI): Calcd for C_8H_6NIS M^+ = 274.9260, Found = 274.9253.

3-Iodo-2-(thiophen-3'-yl)pyrrole (3X): Yield: 85.7 mg (62%); orange oil; IR (neat): 3310, 3096, 1604, 1536, 1047, 755 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 6.40-6.42 (m, 1H), 6.78-6.79 (m, 1H), 7.38-7.43 (m, 2H), 7.59 (dd, 1H, *J* = 2.8, 1.6 Hz), 8.36 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 60.2, 118.2, 119.5, 121.0, 125.9, 126.1, 129.0, 132.9; HRMS (ESI): Calcd for C_8H_6NIS M^+ = 274.9260, Found = 274.9255.

3-Iodo-5-methyl-2-phenylpyrrole (3Y): Yield: 113.2 mg (80%); orange oil; IR (neat): 3407, 1602, 1517 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.31 (s, 3H), 6.10-6.11 (m, 1H), 7.29 (tt, 1H, *J* = 7.4, 1.1 Hz), 7.41 (t, 2H, *J* = 7.9 Hz), 7.60 (d, 2H, *J* = 7.2 Hz), 8.05 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 12.9, 60.1, 116.2, 126.9, 127.0, 128.5, 130.2, 131.2, 132.5; HRMS (ESI): Calcd for $C_{11}H_{10}NI$ M^+ = 282.9852, Found = 282.9846.

3-Iodo-5-methyl-2-(4'-methylphenyl)pyrrole (3Z): Yield: 114.7 mg (77%); yellow oil; IR (neat): 3413, 1577, 1525 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.30 (s, 3H), 2.37 (s, 3H), 6.08-6.09 (m, 1H), 7.22 (d, 2H, *J* = 7.9 Hz), 7.49 (d, 2H, *J* = 8.1 Hz), 8.01 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ =13.0, 21.2, 59.7, 115.9, 126.9, 129.2, 129.7, 129.9, 131.4, 136.9; HRMS (ESI): Calcd for $C_{12}H_{12}NI$ M^+ = 297.0009, Found = 297.0006.

3-Iodo-2-(4'-methoxyphenyl)-5-methylpyrrole (3AA): Yield: 95.7 mg (61%); orange oil; IR (neat): 3400, 2835, 1613, 1525, 1245, 1030 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.29 (s, 3H), 3.84 (s, 3H), 6.06-6.07 (m, 1H), 6.94 (d, 2H, *J* = 9.0 Hz), 7.51 (d, 2H, *J* = 9.0 Hz), 7.98 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 13.0, 55.3, 59.4, 113.9, 115.6, 125.3, 128.4, 129.6, 131.3, 158.7; HRMS (ESI): Calcd for $C_{12}H_{12}ONI$ M^+ = 312.9958, Found = 312.9953.

2-(4'-Chlorophenyl)-3-iodo-5-methylpyrrole (3AB): Yield: 126.1 mg (79%); yellow oil; IR (neat): 3421, 1601, 1492, 731 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.30 (s, 3H), 6.10-6.11 (m, 1H), 7.37 (d, 2H, *J* = 8.5 Hz), 7.53 (d, 2H, *J* = 8.8 Hz), 8.02 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 13.0, 60.7, 116.4, 128.1, 128.7, 130.1, 130.6, 131.0, 132.8; HRMS (ESI): Calcd for $C_{11}H_9N^{35}ClI$ M^+ = 316.9463, Found = 314.9465.

5-Ethyl-3-iodo-2-phenylpyrrole (3AC): Yield: 103.9 mg (70%); orange oil; IR (neat): 3407, 1602, 1517 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 1.27 (t, 3H, *J* = 7.6 Hz), 2.66 (q, 2H, *J* = 7.4 Hz), 6.13-6.14 (m, 1H), 7.29 (t, 1H, *J* = 7.6 Hz), 7.41 (t, 2H, *J* = 7.9 Hz), 7.61 (d, 2H, *J* = 7.2 Hz), 8.07 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 13.3, 20.8, 60.0, 114.7, 126.9, 127.0, 128.5, 131.0, 132.6, 136.6; HRMS (APCI): Calcd for $C_{12}H_{13}NI$ $[M+H]^+$ = 298.0087, Found = 298.0088.

Preparation of 2-Phenylpyrrole 4A

To a mixture of 3-iodo-2-phenylpyrrole (**3A**) (0.5 mmol, 134.6 mg) in EtOH (3.0 mL) was added Zn powder (5.0 mmol, 363.3 mg). The mixture was stirred for 16 h at refluxing temperature under argon atmosphere. The cooled mixture was filtered through Celite, and then the filtrate was concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (eluent: *n*-hexane/EtOAc = 5:1) to afford 2-phenylpyrrole (**4A**) (70.9 mg, 99%).

2-Phenylpyrrole (4A): Yield: 70.9 mg (99%); pink solid; mp: 119-120 °C; IR (neat): 3433, 1603, 1493 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 6.31 (dd, 1H, *J* = 6.1, 2.5 Hz), 6.52-6.54 (m, 1H), 6.87-6.88 (m, 1H), 7.21 (t, 1H, *J* = 7.4 Hz), 7.37 (t, 2H, *J* = 7.9 Hz), 7.48 (d, 2H, *J* = 8.3 Hz), 8.43 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 105.9, 110.1, 118.8, 123.8, 126.2, 128.9, 132.1, 132.7; HRMS (ESI): Calcd for $C_{10}H_9N$ M^+ = 143.0730, Found = 143.0727.

Preparation of 2-Phenyl-3-(4'-methylphenyl)pyrrole 5A

To a mixture of 3-iodo-2-phenylpyrrole (**3A**) (0.5 mmol, 134.6 mg) and 4-methylphenylboronic acid (1.0 mmol, 136.0 mg) in DMF (10.0 mL) was added $PdCl_2(PPh_3)_2$ (0.025 mmol, 17.5 mg). The mixture was stirred for 30 min at room temperature under argon atmosphere. Then, K_2CO_3 (1.0 mmol, 138.2 mg) in H_2O (2.0 mL) was added to the mixture, and the obtained mixture was stirred for 2 h at 60 °C. Sat. NH_4Cl aq. solution (15.0 mL) was added to the mixture, and the product was extracted with Et_2O (15.0 mL × 3). The organic layer was dried over Na_2SO_4. After filtration and removal of the solvent under reduced pressure, the residue was purified by silica-gel column chromatography (eluent: *n*-hexane/EtOAc = 4:1) to give 2-phenyl-3-(4'-methylphenyl)pyrrole **(5A)** (89.2 mg, 77%).

2-Phenyl-3-(4'-methylphenyl)pyrrole (5A): Yield: 89.2 mg (77%); pink solid; mp: 121-122 °C; IR (neat): 3398, 1602, 1517 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.34 (s, 3H), 6.40-6.41 (m, 1H), 6.87-6.89 (m, 1H), 7.08 (d, 2H, *J* = 7.9 Hz), 7.21-7.25 (m, 3H), 7.28-7.32 (m, 2H), 7.34-7.37 (m, 2H), 8.23 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 21.1, 111.0, 118.0, 121.9, 126.7, 127.4, 128.0, 128.3, 128.6, 129.0, 133.4, 133.6, 135.2; HRMS (ESI): Calcd for $C_{17}H_{15}N$ M^+ = 233.1199, Found = 233.1196.

Preparation of 2-Phenyl-3-(4'-methylphenyl)ethynylpyrrole 6A

To a mixture of 3-iodo-2-phenylpyrrole (**3A**) (0.5 mmol, 134.6 mg), CuI (0.02 mmol, 3.8 mg), and $PdCl_2(PPh_3)_2$ (0.01 mmol, 7.0 mg) in Et_3N (2.0 mL) was added 4-methylethynylbenzene (0.6 mmol, 76 μL). The obtained mixture was stirred for 12 h at 50 °C under argon atmosphere. Sat. NH_4Cl aq. solution (15.0 mL) was added to the mixture, and the product was extracted with $CHCl_3$ (15.0 mL × 3). The organic layer was dried over Na_2SO_4. After filtration and removal of the solvent under reduced pressure, the residue was purified by silica-gel column chromatography (eluent: *n*-hexane/EtOAc = 4:1) to give 2-phenyl-3-(4'-methylphenyl)ethynylpyrrole (**6A**) (86.5 mg, 67%).

2-Phenyl-3-(4'-methylphenyl)ethynylpyrrole (6A): Yield: 86.5 mg (67%); brown solid; mp: 96-97 °C; IR (neat): 3425, 2208, 1599, 1496 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.36 (s, 3H), 6.46-6.47 (m, 1H),

6.79-6.81 (m, 1H), 7.14 (d, 2H, J = 7.6 Hz), 7.30 (d, 1H, J = 7.4 Hz), 7.38-7.45 (m, 4H), 7.85 (d, 2H, J = 7.2 Hz), 8.36 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 21.6, 85.2, 90.4, 102.3, 114.0, 118.3, 121.3, 125.4, 127.1, 128.9, 129.1, 131.2, 132.1, 134.2, 137.6; HRMS (ESI): Calcd for $C_{19}H_{15}N$ M^+ = 257.1199, Found = 257.1197.

Preparation of 3-Iodo-2-phenyl-1-tosylpyrrole 7A

To a solution of 3-iodo-2-phenylpyrrole (**3A**) (0.5 mmol, 134.6 mg) in THF (5.0 mL) was added NaH (0.75 mmol, 55%, dispersion in paraffin liquid, 32.7 mg) at 0 °C under argon atmosphere. After 30 min, *p*-toluenesulfonyl chloride (0.53 mmol, 100.1 mg) was added to the mixture at 0 °C. The obtained mixture was stirred for 2 h at 0 °C under argon atmosphere. Sat. NH_4Cl aq. solution (15.0 mL) was added to the reaction mixture, and the product was extracted with $CHCl_3$ (15.0 mL × 3). The organic layer was dried over Na_2SO_4. After filtration and removal of the solvent under reduced pressure, the residue was purified by silica-gel column chromatography (eluent: *n*-hexane/EtOAc = 4:1) to give 3-iodo-2-phenyl-1-tosylpyrrole (**7A**) (174.8 mg, 83%).

3-Iodo-2-phenyl-1-tosylpyrrole (**7A**)**:** Yield: 174.8 mg (83%); brown solid; mp: 82-83 °C; IR (neat): 1596, 1495, 1359, 1168 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.38 (s, 3H), 6.45 (d, 1H, J = 3.6 Hz), 7.07 (d, 2H, J = 7.2 Hz), 7.12 (d, 2H, J = 8.8 Hz), 7.20 (d, 2H, J = 8.3 Hz), 7.32 (t, 2H, J = 7.4 Hz), 7.41 (t, 1H, J = 7.4 Hz), 7.46 (d, 1H, J = 3.4 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 21.6, 72.6, 118.5, 123.8, 127.5, 129.0, 129.5 (2C), 130.3, 132.1, 135.0, 135.6, 145.1; HRMS (ESI): Calcd for $C_{17}H_{15}O_2NIS$ $[M+H]^+$ = 423.9863, Found = 423.9856.

Typical Procedure for *N*-Boc Protection of 3-Iodo-2-arylpyrroles 3

To a mixture of 3-iodo-2-phenylpyrrole (**3A**) (0.5 mmol, 134.6 mg) and di-*tert*-butyl dicarbonate (0.75 mmol, 0.17 mL) in MeCN (1.0 mL) was added 4-(dimethylamino)pyridine (0.075 mmol, 9.2 mg) at 0 °C. The obtained mixture was stirred for 30 min at room temperature under argon atmosphere. Sat. $NaHCO_3$ aq. solution (15.0 mL) was added to the mixture, and the product was extracted with $CHCl_3$ (15.0 mL × 3). The organic layer was dried over Na_2SO_4. After filtration and removal of the solvent under reduced pressure, the residue was purified by silica-gel column chromatography (eluent: *n*-hexane/EtOAc = 19:1) to give 1-(*tert*-butoxycarbonyl)-3-iodo-2-phenylpyrrole (**8A**) (181.3 mg, 98%).

1-(*tert*-Butoxycarbonyl)-3-iodo-2-phenylpyrrole (**8A**)**:** Yield: 181.3 mg (98%); white solid; mp: 73-74 °C; IR (neat): 1728, 1610, 1503, 1301, 1146 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 1.24 (s, 9H), 6.38 (d, 1H, J = 3.6 Hz), 7.26-7.28 (m, 2H), 7.35 (d, 1H, J = 3.4 Hz), 7.38-7.43 (m, 3H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 27.3, 71.5, 84.1, 117.8, 122.8, 127.7, 127.9, 130.4, 133.9, 135.3, 148.0; HRMS (ESI): Calcd for $C_{15}H_{16}O_2NI$ M^+ = 369.0220, Found = 369.0217.

1-(*tert*-Butoxycarbonyl)-2-(4'-fluorophenyl)-3-iodopyrrole (**9N**)**:** Yield: 189.7 mg (98%); white solid; mp: 87-88 °C; IR (neat): 1736, 1605, 1508, 1304, 1143 cm^{-1}; ^{1}H-NMR (400 MHz, DMSO-d_6): δ = 1.22 (s,

9H), 6.45 (d, 1H, J = 3.4 Hz), 7.24 (t, 2H, J = 9.0 Hz), 7.28-7.32 (m, 2H), 7.39 (d, 1H, J = 3.4 Hz); ^{13}C-NMR (100 MHz, DMSO-d_6): δ = 26.9, 72.7, 84.0, 114.6 (d, $J_{C\text{-}F}$ = 21.6 Hz), 117.6, 123.0, 129.8 (d, $J_{C\text{-}F}$ = 2.8 Hz), 132.4 (d, $J_{C\text{-}F}$ = 8.5 Hz), 133.7, 147.3, 161.8 (d, $J_{C\text{-}F}$ = 245.2 Hz); HRMS (APPI): Calcd for $C_{15}H_{15}O_2NFI$ M^+ = 387.0126, Found = 387.0129.

1-(*tert*-Butoxycarbonyl)-3-iodo-2-(4'-methoxyphenyl)-5-methylpyrrole (12AA): Yield: 192.2 mg (93%); white solid; mp: 108-109 °C; IR (neat): 2834, 1735, 1613, 1491, 1302, 1242, 1152, 1086 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 1.21 (s, 9H), 6.42 (s, 3H), 3.85 (s, 3H), 6.09-6.10 (m, 1H), 6.93 (d, 2H, J = 8.8 Hz), 7.18 (d, 2H, J = 8.8 Hz); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 15.2, 27.3, 55.3, 69.7, 83.8, 113.2, 117.4, 127.2, 131.2, 133.5, 134.9, 149.0, 159.0; HRMS (APCI): Calcd for $C_{17}H_{21}O_3NI$ $[M+H]^+$ = 414.0561, Found = 414.0558.

Preparation of 2-(4'-Fluorophenyl)-3-(pyridin-4"-yl)pyrrole 10N

To a mixture of pyridine-4-boronic acid (1.5 mmol, 184.3 mg) in DMF (10.0 mL) was added K_2CO_3 (1.5 mmol, 207.3 mg) in H_2O (2.0 mL). The mixture was stirred for 30 min at room temperature under argon atmosphere. Then, 1-(*tert*-butoxycarbonyl)-3-iodo-2-(4'-fluorophenyl)pyrrole (**9N**) (0.5 mmol, 193.6 mg) and $PdCl_2(PPh_3)_2$ (0.05 mmol, 35.1 mg) were added to the mixture, and the obtained mixture was stirred for 4 h at 80 °C. Sat. NH_4Cl aq. solution (15.0 mL) was added to the mixture, and the product was extracted with Et_2O (15.0 mL × 3). The organic layer was dried over Na_2SO_4. After filtration and removal of the solvent under reduced pressure, K_2CO_3 (1.0 mmol, 138.2 mg) and H_2O (2.0 mL) were added to the solution of the residue in MeOH (10.0 mL). The obtained mixture was stirred for 3 h at 65 °C under argon atmosphere. H_2O (15.0 mL) was added to the reaction mixture and the product was extracted with $CHCl_3$ (15.0 mL × 3). The organic layer was dried over Na_2SO_4 and filtered. After removal of the solvent under reduced pressure, the residue was purified by silica-gel column chromatography (eluent: *n*-hexane/EtOAc = 1:1) to give 2-(4'-fluorophenyl)-3-(pyridine-4"-yl)pyrrole (**10N**) (76.3 mg, 64%).

2-(4'-Fluorophenyl)-3-(pyridin-4"-yl)pyrrole (10N): Yield: 76.3 mg (64%); white solid; mp: 253 °C; IR (neat): 2990, 1602, 1508, 828 cm^{-1}; ^{1}H-NMR (400 MHz, DMSO-d_6): δ = 6.41-6.43 (m, 1H), 6.92-6.93 (m, 1H), 7.18 (d, 2H, J = 6.1 Hz), 7.21 (t, 2H, J = 8.3 Hz), 7.35-7.39 (m, 2H), 8.36 (d, 2H, J = 6.1 Hz), 11.41 (br, 1H); ^{13}C-NMR (100 MHz, DMSO-d_6): δ = 109.4, 115.5 (d, $J_{C\text{-}F}$ = 21.6 Hz), 118.0, 119.2, 121.9, 128.5, 129.3 (d, $J_{C\text{-}F}$ = 2.8 Hz), 130.1 (d, $J_{C\text{-}F}$ = 7.5 Hz), 144.1, 149.5, 161.3 (d, $J_{C\text{-}F}$ = 244.3 Hz); HRMS (ESI): Calcd for $C_{15}H_{12}N_2F$ $[M+H]^+$ = 239.0979, Found = 239.0974.

Preparation of 5-(4'-Fluorophenyl)-4-(pyridin-4"-yl)pyrrole-2-carbaldehyde 11N

To a mixture of DMF (0.8 mmol, 62 μL) in toluene (0.4 mL) was added $POCl_3$ (0.75 mmol, 68 μL) at 0 °C. The mixture was stirred for 1 h at room temperature under argon atmosphere. Then, toluene (2.1 mL), DMF (0.5 mL), and 2-(4'-fluorophenyl)-3-(pyridin-4"-yl)pyrrole (**10N**) (0.5 mmol, 119.2 mg) were added to the mixture, and the obtained mixture was stirred for 4 h at room temperature. Sat. $NaHCO_3$ aq.

solution (2.0 mL) was added to the reaction mixture, and the obtained mixture was stirred for 1 h at room temperature. H_2O (15.0 mL) was added to the mixture, and the product was extracted with $CHCl_3$ (15.0 mL × 3). The organic layer was dried over Na_2SO_4. After filtration and removal of the solvent under reduced pressure, the residue was purified by silica-gel column chromatography (eluent: *n*-hexane/EtOAc = 1:1) to give 5-(4'-fluorophenyl)-4-(pyridin-4"-yl)pyrrole-2-carbaldehyde (**11N**) (101.2 mg, 76%).

5-(4'-Fluorophenyl)-4-(pyridin-4"-yl)pyrrole-2-carbaldehyde (11N): Yield: 101.2 mg (76%); white solid; mp: 271-272 °C; IR (neat): 3101, 2848, 1662, 1601, 1509, 829 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 7.12 (t, 2H, *J* = 8.8 Hz), 7.17-7.20 (m, 3H), 7.35-7.40 (m, 2H), 8.52 (d, 2H, *J* = 6.1 Hz), 9.46 (br, 1H), 9.61 (s, 1H); ^{13}C-NMR (100 MHz, DMSO-*d*$_6$): δ = 115.6 (d, $J_{C\text{-}F}$ = 21.6 Hz), 120.7, 121.0, 122.3, 127.1 (d, $J_{C\text{-}F}$ = 2.8 Hz), 131.1 (d, $J_{C\text{-}F}$ = 8.5 Hz), 132.9, 136.3, 142.4, 149.7, 162.2 (d, $J_{C\text{-}F}$ = 246.2 Hz), 179.4; HRMS (ESI): Calcd for $C_{16}H_{12}ON_2F$ $[M+H]^+$ = 267.0928, Found = 267.0923.

Preparation of 5-(*N*,*N*-Dimethylamino)methyl-2-(4'-fluorophenyl)-3-(pyridin-4"-yl)pyrrole II

To a mixture of 5-(4'-fluorophenyl)-4-(pyridin-4"-yl)pyrrole-2-carbaldehyde (**11N**) (0.5 mmol, 133.2 mg) and dimethylamine (1.75 mmol, 2.0 M in MeOH, 1.88 mL) in DCM (1.0 mL) was added $NaBH(OAc)_3$ (1.75 mmol, 463.6 mg) at 0 °C. The mixture was stirred for 12 h at 40 °C under argon atmosphere. Sat. $NaHCO_3$ aq. solution (15.0 mL) was added to the mixture, and the product was extracted with $CHCl_3$ (15.0 mL × 3). The organic layer was dried over Na_2SO_4. After filtration and removal of the solvent under reduced pressure, the residue was washed with *n*-hexane to give 5-(*N*,*N*-dimethylamino)methyl-2-(4'-fluorophenyl)-3-(pyridin-4"-yl)pyrrole **II** (125.5 mg, 85%).

5-(*N*,*N*-Dimethylamino)methyl-2-(4'-fluorophenyl)-3-(pyridin-4"-yl)pyrrole II: Yield: 125.5 mg (85%); white solid; mp: 228 °C; IR (neat): 3105, 1595, 1512, 1219, 1031, 826 cm^{-1}; ^{1}H-NMR (400 MHz, DMSO-*d*$_6$): δ = 2.17 (s, 6H), 3.37 (s, 2H), 6.25 (s, 1H), 7.15 (d, 2H, *J* = 6.1 Hz), 7.20 (d, 2H, *J* = 8.8 Hz), 7.33-7.37 (m, 2H), 8.34 (d, 2H, *J* = 6.1 Hz), 11.25 (br, 1H); ^{13}C-NMR (100 MHz, DMSO-*d*$_6$): δ = 44.6, 55.3, 108.8, 115.3 (d, $J_{C\text{-}F}$ = 20.7 Hz), 117.6, 121.7, 128.0, 129.2 (d, $J_{C\text{-}F}$ = 2.8 Hz), 130.1 (d, $J_{C\text{-}F}$ = 8.5 Hz), 130.3, 144.1, 149.4, 161.2 (d, $J_{C\text{-}F}$ = 244.3 Hz); HRMS (ESI): Calcd for $C_{18}H_{19}N_3F$ $[M+H]^+$ = 296.1558, Found = 296.1553.

Preparation of 2,3-Bis(4'-methoxyphenyl)-5-methylpyrrole III

To a mixture of 4-methoxyphenylboronic acid (1.0 mmol, 152.0 mg) in DMF (10 mL) was added K_2CO_3 (1.0 mmol, 138.2 mg) in H_2O (2.0 mL). The mixture was stirred for 30 min at room temperature under argon atmosphere. 1-(*tert*-Butoxycarbonyl)-3-iodo-2-(4'-methoxyphenyl)pyrrole (**12AA**) (0.5 mmol, 206.7 mg) and $PdCl_2(PPh_3)_2$ (0.05 mmol, 35.1 mg) were added to the mixture, and the obtained mixture was stirred for 2 h at 60 °C. Sat. NH_4Cl aq. solution (15.0 mL) was added to the mixture, and the product was extracted with Et_2O (15.0 mL × 3). The organic layer was dried over Na_2SO_4. After filtration and removal of the solvent under reduced pressure, MeONa (5.0 mmol, 5.0 M in MeOH, 1.00 mL) was added

to the solution of the residue in THF (5.0 mL) at 0 °C. The obtained mixture was stirred for 6 h at 40 °C under argon atmosphere. H_2O (15.0 mL) was added to the reaction mixture and the product was extracted with $CHCl_3$ (15.0 mL × 3). The organic layer was dried over Na_2SO_4 and filtered. After removal of the solvent under reduced pressure, the residue was purified by silica-gel column chromatography (eluent: *n*-hexane/EtOAc = 4:1) to give 2,3-bis(4'-methoxyphenyl)-5-methylpyrrole **III** (92.4 mg, 63%).

2,3-Bis(4'-methoxyphenyl)-5-methylpyrrole III: Yield: 92.4 mg (63%); purple solid; mp: 115-116 °C; IR (neat): 3346, 2924, 2857, 1611, 1517, 1232, 1020 cm^{-1}; ^{1}H-NMR (400 MHz, $CDCl_3$): δ = 2.34 (s, 3H), 3.80 (s, 3H), 3.81 (s, 3H), 6.04-6.05 (m, 1H), 6.80-6.85 (m, 4H), 7.22-7.26 (m, 4H), 7.82 (br, 1H); ^{13}C-NMR (100 MHz, $CDCl_3$): δ = 13.0, 55.2 (2C), 108.5, 113.6, 114.0, 120.9, 126.2, 126.3, 127.5, 128.5, 129.3, 129.4; HRMS (ESI): Calcd for $C_{19}H_{19}O_2N$ M^+ = 293.1410, Found = 293.1408.

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