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REGIOSELECTIVE REACTION OF 2-INDOLYLCYANOCUPRATES WITH ELECTROPHILES

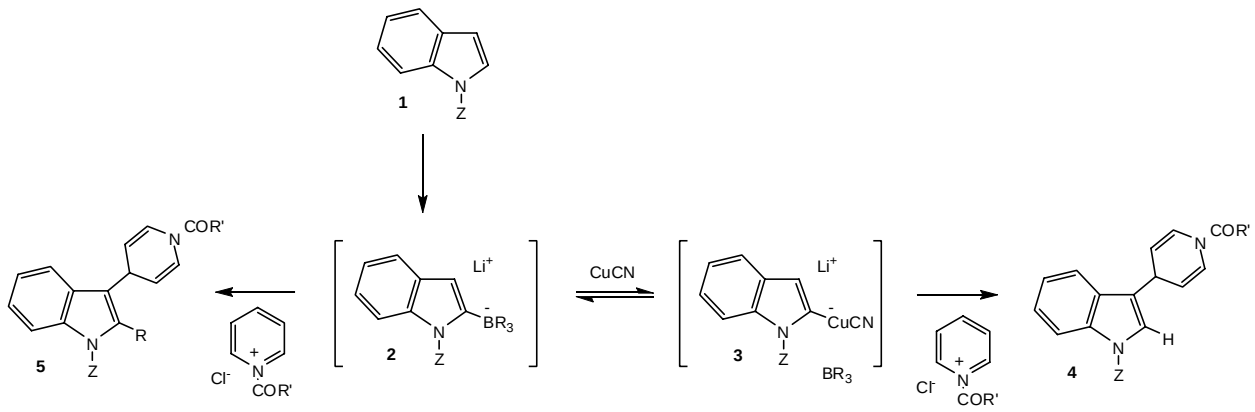
Minoru Ishikura,[a]* Reina Uemura,[a] Koji Yamada,[a] and Reiko Yanada[b]

[a] Faculty of Pharmaceutical Sciences, Health Sciences University of Hokkaido, Ishikari-Tobetsu, Hokkaido 061-0293, Japan. E-mail: ishikura@hoku-iryo-u.ac.jp
[b] Faculty of Pharmaceutical Sciences, Hiroshima International University, 5-1-1 Hirokoshingai, Kure, Hiroshima 737-0112, Japan

Abstract – The reaction of 2-indolylcyanocuprate with electrophiles was found to give rise to 2- and 3-substituted indoles in regioselective manner.

The widespread acceptance of organometallic reagents is largely attributable to their ability to effect chemical transformations difficult to attain with any other reagents. Among them, organocopper reagents have been routinely used in organic synthesis, including their use as a versatile C-C bond formation tool, because of their ease of preparation and their high chemical lability.[1]

During our investigation devoted to the development of the synthetic applicability of indolylborate (**2**) readily available from indole (**1**) *in situ*,[2] the reaction of indolylborate (**2**) with *N*-acylpyridinium salt in the presence of Cu^+ ion was found to give rise to 3-pyridylindole (**4**), in contrast to the sole formation of 2-alkyl-3-pyridylindole (**5**) without Cu^+ ion (Scheme 1).[3] This result was explained by the reaction of *N*-acylpyridinium salt with indolylcopper (**3**) generated *in situ* by way of a facile transmetallation from boron to copper.

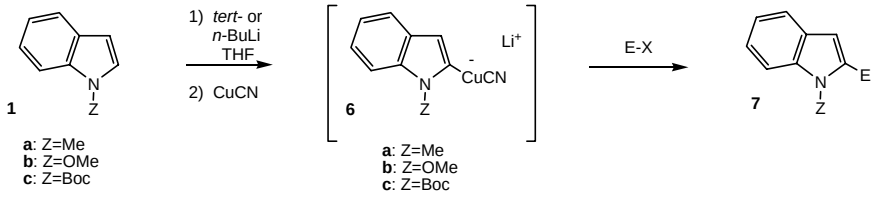


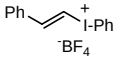
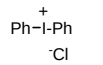
Scheme 1

Thus, our attention has been turned to investigate the chemical lability of indolylcopper (**3**) as a synthetic intermediate. In this paper, we will describe the method by which indolylcyanocuprates (**6**), generated *in situ* from 2-lithioindoles and CuCN, regioselectively react with various electrophilic reagents to provide 2- or 3-substituted indoles, depending on the nature of electrophiles used.[4]

As substitution reaction of organic halides with organocopper reagents is one of the most popular reactions, our initial investigation began with the reaction of **6** with organic halides (E-X). In accordance with the well-known lability of allylic halides toward organocopper substitution reaction, simple treatment of **6** with allylic bromides smoothly afforded 2-allylindoles (**7a-i**). Of particular interest was the reaction of **6a** with 2,3-dibromopropene, in which **7d** was obtained in 38% yield along with 1,1'-dimethyl-1*H*-2,2'-bisindole[5] in 20% yield (Table 1). Vinyl and phenyl iodonium salts could also be adapted for the reaction with **6**, providing 2-substituted indoles (**7j**-**o**).

Table 1 Formation of 2-substituted indoles (**7**)

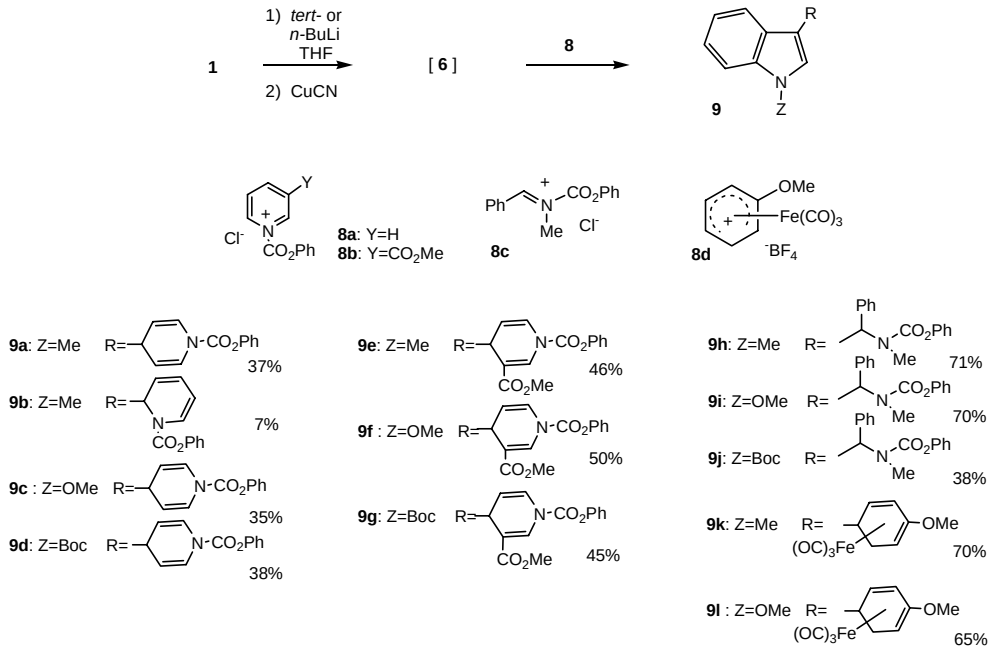


E-X	Z	Yield (%) of **7**[a]	E-X	Z	Yield (%) of **7**[a]
	Me	80 (**7a**: E=allyl)[b]		Me	65 (**7j**: E=(*E*)-2-phenylvinyl)[d]
	OMe	80 (**7b**: E=allyl)		OMe	60 (**7k**: E=(*E*)-2-phenylvinyl)[d]
	Boc	80 (**7c**: E=allyl)		Boc	55 (**7l**: E=(*E*)-2-phenylvinyl)[d]
	Me	38 (**7d**: E=2-bromoprop-2-en-1-yl)[c]		Me	54 (**7m**: E=phenyl)[d]
	OMe	70 (**7e**: E=2-bromoprop-2-en-1-yl)		OMe	50 (**7n**: E=phenyl)[d]
	Boc	74 (**7f**: E=2-bromoprop-2-en-1-yl)		Boc	45 (**7o**: E=phenyl)[d]
	Me	78 (**7g**: E=cyclohex-2-en-1-yl)			
	OMe	77 (**7h**: E=cyclohex-2-en-1-yl)			
	Boc	73 (**7i**: E=cyclohex-2-en-1-yl)			

[a] Yields based on **1** [b] Ref. 6 [c] Ref. 7 [d] Ref.8

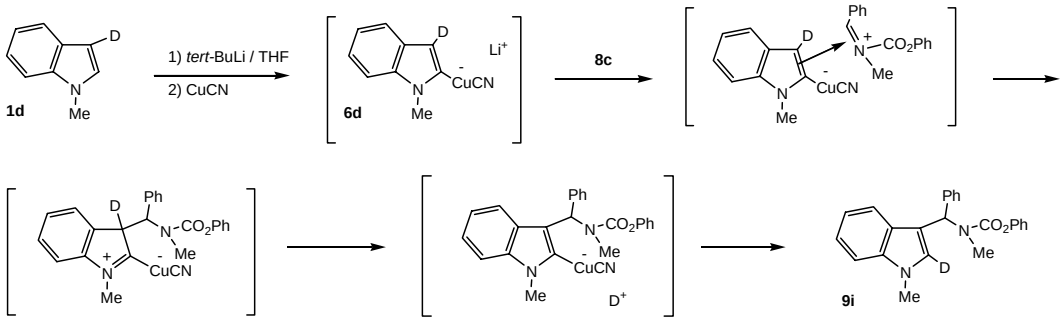
Next, we turned our attention to the reaction of **6** with cationic electrophiles (**8**). Treatment of **6a** with *N*-acylpyridinium chloride (**8a**) in THF at -20 ℃ allowed the isolation of 3-pyridylindoles (**9a** and **9b**) without the isolation of 2-pyridylindoles. Application of the same conditions to the reaction of **6** with other cationic electrophiles (**8**) also revealed the sole formation of 3-substituted indoles (**9**) (Scheme 2).

To clarify the origin of H at the 2 position of **9h**, we undertook the reaction of (3-deutero)indolylcuprate (**6d**), derived from 3-deutero-1-methylindole (**1d**),[9] with **8c** under the same conditions, allowing the isolation of **9i**[10] with at least 70% D content at the 2 position (δ 6.77) based on NMR measurement.



Scheme 2

This might involve an initial π–complex formation between the enamine part of **6d** and **8c**, followed by nucleophilic attack on the C3 carbon of the indole ring (Scheme 3).

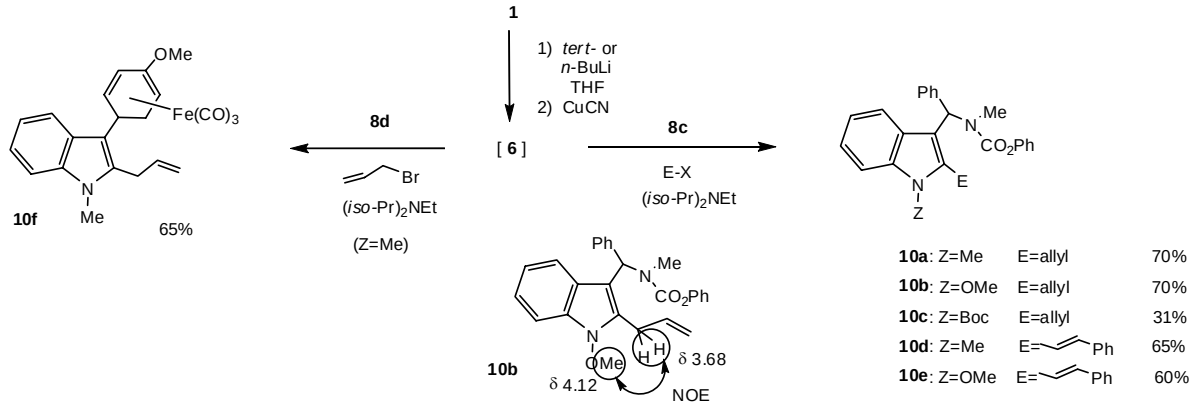


Scheme 3

Evidently, this reaction requires that the C-Cu bond is kept intact until protonolyzation by D^+ at the final step. Keeping in mind the reaction outcome, it is logical to envision that the reaction of **6a** with **8c** coexisting with allyl bromide might enable regioselective functionalization in a one-pot manner, leading to 2,3-disubstituted indole (**10a**).

To examine such a possibility, we simply undertook the reaction as follows; To a THF solution of **6a** was added **8c** at -78 ℃ in the presence of amine as a proton scavenger. After 30min allyl bromide was added and the mixture was gradually warmed to room temperature and then stirred overnight to give rise to **10a** in good yield. Other results are shown in Scheme 4, and lower efficiency of the reaction observed using **6c** is possibly attributable to steric and electronic factors. The structure of **10b** was confirmed based on

NOE experiments.



Scheme 4

In summary, a noteworthy discrepancy was observed in the regioselectivity of the reaction of **6** depending on the nature of the electrophiles used, which prompted us to develop a novel one-pot protocol leading to 2,3-disubstituted indoles (**10**).

EXPERIMENTAL

General: Melting points were recorded on a Yamato MP21 and are uncorrected. MS and high-resolution MS spectra were recorded on a Micromass AutoSpec 3100 mass spectrometer. IR spectra were measured on a Hitachi Model 270-30 spectrometer. The NMR experiments were performed with a JEOL JNM-LA300 or JNM-ECA500 spectrometer, and chemical shifts are expressed in ppm (δ) with TMS as an internal reference. Medium pressure liquid chromatography (MPLC) was performed on silica gel (Silica Gel 60N, Kanto Chemical Co., Ltd.).

Reaction of 6a with allyl bromide: Typical procedure:

To a THF solution of **1a** (262mg, 2mmol), *tert*-BuLi (1.5M solution in pentane, 1.6mL, 2.4mmol) was added at 0℃ under argon, and the mixture was then stirred at rt for 1h. The mixture was cooled to -20℃, and CuCN (215mg, 2.4mmol) was added. After 20 min, allyl bromide (0.26mL, 3mmol) was added to the resultant clear solution. The mixture was gradually raised to rt and stirred for 1h, then the mixture was diluted with AcOEt, washed with brine, and dried over $MgSO_4$. The solvent was removed and the residue was separated by MPLC with hexane:AcOEt=100:1 to give 273mg (80%) of **7a**.[6]

2-Allyl-1-methoxy-1*H*-indole (7b):

IR (neat): 1630 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 3.58 (d, 2H, *J*=6.3, Hz), 4.04 (s, 3H),5.15 (dd, 1H, *J*=1.7, 10.3 Hz), 5.22 (dd, 1H, *J*=1.7,10.3 Hz), 6.04 (ddt, 1H, *J*=17.1, 10.3, 6.3 Hz), 6.10 (s, 1H), 7.07 (dt, 1H, *J*=1.1, 7.4 Hz), 7.17 (dt, 1H, *J*=1.1, 7.4 Hz), 7.38 (d, 1H, *J*=7.4 Hz), 7.50 (d, 1H, *J*=8.0 Hz). ^{13}C-NMR ($CDCl_3$) δ: 29.9, 65.2, 96.2, 108.0, 117.0, 120.0, 120.4, 121.6, 124.0, 132.4, 134.5, 135.8. HR-MS *m/z*: Calcd for $C_{12}H_{13}NO$: 187.0997. Found: 187.0990.

***tert*-Butyl 2-Allyl-1*H*-indole-1-carboxylate (7c):**

IR (neat): 1726 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 1.67 (s, 9H), 3.77 (dd, 2H, *J*=1.1, 6.3 Hz), 5.12, (dd, 1H, *J*=1.7, 17.2 Hz), 5.15 (dd, 1H, *J*=1.7, 10.3 Hz), 6.08 (ddt, 1H, *J*=17.2, 10.3, 6.3 Hz), 6.37 (s, 1H), 7.18 (dt, 1H, *J*=1.1, 7.5 Hz), 7.23 (dt, 1H, *J*=1.1, 8.0 Hz), 7.45 (d, 1H, *J*=7.0 Hz), 8.10 (d, 1H, *J*=8.0 Hz). ^{13}C-NMR ($CDCl_3$) δ: 29.9, 65.2, 96.2, 108.0, 117.0, 120.0, 120.4, 121.6, 124.0, 132.4, 134.5, 135.8. HR-MS *m/z*: Calcd for $C_{16}H_{19}NO_2$: 257.1415. Found: 257.1408.

2-(2-Bromoprop-2-en-1-yl)-1-methoxy-1*H*-indole (7e):

IR (neat): 1645 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 3.95 (s, 2H), 4.07 (s, 3H), 5.60 (s, 3H), 5.69 (d, 1H, *J*=1.7 Hz),

6.27 (s, 1H), 7.11 (t, 1H, *J*=7.5 Hz), 7.23 (t, 1H, *J*=7.5 Hz), 7.42 (d, 1H, *J*=8.0 Hz), 7.56 (d, 1H, *J*=8.0 Hz). ^{13}C-NMR ($CDCl_3$) δ: 37.8, 65.4, 98.1, 108.7, 120.3, 120.8, 122.1, 123.8, 129.6, 132.4, 132.7. HR-MS *m/z*: Calcd for $C_{12}H_{12}NBrO$: 265.0102. Found: 265.0110.

***tert*-Butyl 2-(2-Bromoprop-2-en-1-yl)-1*H*-indole-1-carboxylate (7f):**

IR (neat): 1728 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 1.67 (s, 9H), 4.16 (s, 2H), 5.47 (d, 1H, *J*=1.8 Hz), 5.53 (s, 1H), 6.51 (s, 1H), 7.21 (t, 1H, *J*=7.5 Hz), 7.27 (t, 1H, *J*=7.5 Hz), 7.50 (d, 1H, *J*=7.5 Hz), 8.12 (d, 1H, *J*=8.0 Hz). ^{13}C-NMR ($CDCl_3$) δ: 28.2, 42.1, 82.5, 110.0, 115.7, 118.1, 120.3, 122.9, 120.4, 128.9, 130.5, 136.3, 136.9, 150.3. HR-MS *m/z*: Calcd for $C_{16}H_{18}NBrO_2$: 335.0520. Found: 335.0537.

2-Cyclohex-2-en-1-yl-1-methoxy-1*H*-indole (7h):

IR ($CHCl_3$): 1450 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 1.62-1.71 (m, 1H), 1.75-1.85 (m, 2H), 2.06-2.17 (m, 3H), 3.68-3.71 (m, 1H), 4.07 (s, 3H), 5.80-5.84 (m, 1H), 5.90-5.95 (m, 1H), 6.09 (s, 1H), 7.07 (t, 1H, *J*=7.5 Hz), 7.18 (t, 1H, *J*=7.5 Hz), 7.39 (d, 1H, *J*=8.0 Hz), 7.51 (d, 1H, *J*=7.5 Hz). ^{13}C-NMR ($CDCl_3$) δ: 20.5, 25.0, 29.3, 32.4, 65.1, 95.8, 108.0, 119.9, 120.4, 121.4, 123.9, 127.7, 128.9, 132.4, 141.5. HR-MS *m/z*: Calcd for $C_{15}H_{17}NO$: 227.1310. Found: 227.1310.

***tert*-Butyl 2-Cyclohex-2-en-1-yl-1*H*-indole-1-carboxylate (7i):**

IR ($CHCl_3$): 1726 cm^{-1}. 1H-NMR ($CDCl_3$) δ: 1.57-1.75 (m, 3H), 1.69 (s, 9H), 2.05-2.11 (m, 3H), 4.21-4.29 (m, 1H), 5.78-5.83 (m, 1H), 5.87-5.93 (m, 1H), 6.41 (s, 1H), 7.17 (dt, 1H, *J*=1.5, 7.5 Hz), 7.26 (dt, 1H, *J*=1.5, 7.5 Hz), 7.45 (d, 1H, *J*=7.0 Hz), 8.12 (d, 1H, *J*=8.0 Hz). ^{13}C-NMR ($CDCl_3$) δ: 19.7, 25.3, 28.3, 29.5, 34.7, 83.8, 108.2, 115.8, 119.9, 122.6, 123.4, 128.8, 129.2, 137.0, 145.3, 150.6. HR-MS *m/z*: Calcd for $C_{19}H_{23}NO_2$: 297.1728. Found: 297.1720.

Reaction of 6a with 8a: Typical procedure:

To a THF solution of pyridine (0.24mL, 3mmol), phenyl chloroformate (0.38mL, 3mmol) was added at -20℃ under argon, and the mixture was stirred for 20 min, producing **8a**. To this solution of **8a**, a THF solution of **6a**, generated *in situ* from **1a** (262 mg, 2mmol) as described as above, was added. The mixture was gradually warmed to rt and stirred for 1h at rt. Then, the mixture was diluted with AcOEt, washed with brine, and dried over $MgSO_4$. The solvent was removed, and the residue was separated by MPLC with hexane:AcOEt=10:1 to give 244mg (37%) of **9a** and 46mg (7%) of **9b**.

Phenyl 4-(1-Methyl-1*H*-indol-3-yl)pyridine-1(4*H*)-carboxylate (**9a**):

IR (neat): 1728, 1690, 1632, 1614 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 3.76 (s, 3H), 4.53 (br s, 1H), 5.18 (dt, 1H, *J*=8.0, 2.3 Hz), 5.25 (dt, 1H, *J*=8.0, 2.3 Hz), 7.01 (d, 1H, *J*=8.0 Hz), 7.04 (d, 1H, *J*=8.0 Hz), 7.14 (t, 1H, *J*=8.0 Hz), 7.19 (d, 2H, *J*=7.9 Hz), 7.25 (d, 1H, *J*=4.0 Hz), 7.27 (d, 2H, *J*=6.8 Hz), 7.33 (d, 1H, *J*=7.5 Hz), 7.41 (t, 2H, *J*=8.0 Hz), 7.69 (d, 1H, *J*=7.0 Hz). ^{13}C-NMR ($CDCl_3$) δ: 30.1, 32.7, 109.5, 110.7, 111.0, 115.5, 119.0, 119.1, 121.6, 121.9, 122.0, 125.9, 126.8, 129.5, 137.4, 149.9, 150.1, 150.9. HR-MS *m/z*: Calcd for $C_{21}H_{18}N_2O_2$: 330.1368. Found: 330.1379.

Phenyl 2-(1-Methyl-1*H*-indol-3-yl)pyridine-1(2*H*)-carboxylate (**9b**):

mp 148-150℃ (hexane-AcOEt). IR ($CHCl_3$): 1718, 1642 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 3.74&3.77 (two s, 3H), 5.53-5.61 (m, 1H), 5.81 (dd, 1H, *J*=5.7, 9.2 Hz), 6.09&6.16 (two dd, 1H, *J*=5.7, 9.2 Hz), 6.28&6.33 (two d, 1H, *J*=5.7 Hz), 6.81&6.87 (two d, 1H, *J*=8.0 Hz), 6.85-6.93 (m, 1H), 6.99-7.40 (m, 8H), 7.83&7.98 (two d, 1H, *J*=8.0 Hz). ^{13}C-NMR ($CDCl_3$) δ: 32.8, 49.1, 106.7, 109.3, 113.2, 115.4, 119.6, 120.5, 120.9, 121.7, 121.8, 121.9, 123.1, 125.6, 126.3, 129.4, 129.6, 129.7, 137.5, 151.2, 152.2. MS *m/z*: 330 (M^+). *Anal*. Calcd for $C_{21}H_{18}N_2O_2$: C, 76.34; H, 5.49; N, 8.48. Found: C, 76.35; H, 5.47; N, 8.40.

Phenyl 4-(1-Methoxy-1*H*-indol-3-yl)pyridine-1(4*H*)-carboxyrate (9c):

IR (neat): 1730, 1710 cm^{-1}. ^{1}H-NMR (acetone-d_6) δ: 4.07 (s, 3H), 4.48-4.52 (m, 1H), 5.15 (br s, 1H), 6.94 (br s, 1H), 7.06 (t, 2H, *J*=7.5 Hz), 7.21 (t, 1H, *J*=7.5 Hz), 7.25 (t, 4H, *J*=7.5 Hz), 7.40-7.45 (m, 3H), 7.67 (d, 1H, *J*=8.0 Hz). ^{13}C-NMR (acetone-d_6) δ: 65.3, 108.3, 109.8, 110.6, 116.3, 119.3, 119.6, 121.2, 121.7, 121.9, 122.4, 122.6, 125.8, 129.4, 133.1, 149.7, 151.4. HR-MS *m/z*: Calcd for $C_{21}H_{18}N_2O_3$: 346.1317. Found: 346.1302.

***tert*-Butyl 3-[1-(Phenoxycarbonyl)-1,4-dihydropyridin-4-yl]-1*H*-indole-1-carboxylate (9d):**

IR ($CHCl_3$): 1726, 1692 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 1.67 (s, 9H), 4.49 (s, 1H), 5.14 (dd, 1H, *J*=1.6, 6.3 Hz), 5.21 (dd, 1H, *J*=1.6, 6.3 Hz), 7.03 (d, 1H, *J*=8.6 Hz), 7.07 (d, 1H, *J*=8.6 Hz), 7.19 (d, 2H, *J*=7.5 Hz),

7.23-7.29 (m, 3H), 7.33 (t, 1H, *J*=7.5 Hz), 7.38-7.43 (m, 3H), 7.63 (d, 1H, *J*=8.0 Hz). ^{13}C-NMR ($CDCl_3$) δ: 28.3, 30.0, 83.7, 109.1, 109.6, 115.6, 119.1, 121.0, 121.6, 122.6, 122.9, 123.2, 124.4, 124.6, 126.1, 129.6, 136.0, 149.8, 150.1, 150.7. HR-MS *m/z*: Calcd for $C_{25}H_{24}N_2O_4$: 416.1736. Found: 416.1752.

3-Methyl 1-Phenyl 4-(1-Methyl-1*H*-indol-3-yl)pyridine-1,3(4*H*)-dicarboxylate (9e):

IR (neat): 1742, 1710, 1626, 1592 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 3.64 (s, 3H) 3.75 (s,3H), 4.83 (d, 1H, *J*=4.5 Hz), 5.40 (br s, 1H), 6.95 (s, 1H), 7.14 (t, 1H, *J*=8.0 Hz), 7.22-7.26 (m, 3H), 7.29-7.32 (m, 2H), 7.35 (t, 1H, *J*=8.0 Hz), 7.45 (t, 2H, *J*=8.0 Hz), 7.69 (d, 1H, *J*=8.0 Hz), 8.19 (br s, 1H). ^{13}C-NMR ($CDCl_3$) δ: 29.6, 32.5, 51.3, 109.3, 113.1, 118.1, 119.0, 112.6, 119.2, 120.0, 121.3, 121.5, 126.2, 126.5, 127.5, 129.5, 137.1, 130.9, 149.7, 150.5, 166.9. HR-MS *m/z*: Calcd for $C_{23}H_{20}N_2O_4$: 388.1423. Found: 388.1427.

3-Methyl 1-Phenyl 4-(1-Methoxy-1*H*-indol-3-yl)pyridine-1,3(4*H*)-dicarboxylate (9f):

IR (neat): 1738, 1706, 1624, 1590 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 3.64 (s, 3H), 4.07 (s, 3H), 4.79 (d, 1H, *J*=4.6 Hz), 5.30 (br s, 1H), 7.01 (d, 1H, *J*=7.4 Hz), 7.12 (t, 1H, *J*=7.5 Hz), 7.23 (t, 3H, *J*=8.0 Hz), 7.30 (t, 1H, *J*=7.5 Hz), 7.35 (t, 1H, *J*=7.5 Hz), 7.40-7.48 (m, 3H), 7.67 (d, 1H, *J*=8.0 Hz), 8.16 (s, 1H). ^{13}C-NMR ($CDCl_3$) δ: 51.6, 52.2, 65.9, 66.1, 108.5, 115.5, 119.5, 119.8, 120.4, 120.5, 121.4, 121.5, 122.4, 122.6, 126.4, 129.6, 129.7, 132.6, 150.5, 166.5, 167.2. HR-MS *m/z*: Calcd for $C_{23}H_{20}N_2O_5$: 404.1372. Found: 404.1374.

3-Methyl 1-Phenyl 4-[1-(*tert*-Butoxycarbonyl)-1*H*-indol-3-yl]pyridine-1,3(4*H*)-dicarboxylate (9g):

IR (neat): 1738, 1716 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 1.67 (s, 9H), 3.65 (s, 3H), 4.80 (d, 1H,*J*=4.5 Hz), 5.34 (br s, 1H), 7.03 (br s, 1H), 7.20-7.50 (m, 8H), 7.66 (d, 1H, *J*=8.0 Hz), 8.11 (br s, 1H), 8.23 (br s, 1H). ^{13}C-NMR ($CDCl_3$) δ: 28.2, 28.3, 29.7, 51.7, 83.8, 115.3, 115.5, 119.3, 120.9, 121.4, 122.6, 123.0, 124.5, 126.3, 126.5, 129.6, 129.7, 129.8, 132.0, 135.7, 149.9, 150.5, 166.9. HR-MS *m/z*: Calcd for $C_{27}H_{26}N_2O_6$: 474.1790. Found: 474.1786.

Phenyl Methyl [(1-Methyl-1*H*-indol-3-yl)(phenyl)methyl]carbamate (9h):

mp 143-144 ℃ (hexane-AcOEt). IR ($CHCl_3$): 1714 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 2.89&2.97 (two s, 3H), 3.77 (s, 3H), 6.75&6.80 (two s, 1H), 7.00 (br s, 1H), 7.04-7.23 (m, 4H), 7.25-7.31 (m, 1H), 7.31-7.47 (m, 8H), 7.52 (br s, 1H). ^{13}C-NMR ($CDCl_3$) δ: 31.1, 32.7, 57.1, 109.4, 113.0, 119.6, 121.8, 122.1, 125.1, 127.3, 127.5, 128.4, 129.1, 137.3, 139.8, 151.6, 155.1. MS *m/z*: 370 (M^+). *Anal*. Calcd for $C_{24}H_{22}N_2O_2$: C, 77.81; H, 5.99; N, 7.56. Found: C, 78.00; H, 5.94; N, 7.53.

Phenyl [(1-Methoxy-1*H*-indol-3-yl)(phenyl)methyl]methylcarbamate (9i):

IR (neat): 1714 cm^{-1}. ^{1}H-NMR (acetone-d_6) δ: 2.84&2.93 (two s, 3H), 4.07 (s, 3H), 6.96(s, 1H), 7.07 (t, 1H, *J*=7.5 Hz), 7.13-7.20 (m, 2H), 7.21-7.26 (m, 2H), 7.30-7.50 (m, 10H). ^{13}C-NMR (acetone-d_6) δ: 29.5, 30.0, 65.7, 108.5, 110.2, 119.5, 120.3, 121.9, 122.9, 123.4, 123.7, 125.1, 127.5, 127.7, 128.6, 128.7, 129.1, 132.8, 151.9. HR-MS *m/z*: Calcd for $C_{24}H_{22}N_2O_3$: 386.1630. Found: 386.1649.

***tert*-Butyl 3-[[Methyl(phenoxycarbonyl)amino](phenyl)methyl]-1*H*-indole-1-carboxylate (9j):**

IR (neat): 1720 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 1.66 (s, 9H), 2.93&2.98 (two s, 3H), 6.87-6.94 (m,1H), 7.08-7.30 (m, 5H), 7.31-7.48 (m, 9H), 8.13 (br s, 1H). ^{13}C-NMR ($CDCl_3$) δ: 28.3, 31.5, 31.6, 56.5, 57.1, 84.2, 115.2, 115.4, 119.4, 119.7, 120.0, 121.8, 122.4, 123.0, 124.9, 125.4, 125.6, 127.8, 128.7, 129.3, 135.7, 149.8, 151.5. HR-MS *m/z*: Calcd for $C_{28}H_{28}N_2O_4$: 456.2049. Found: 456.2053.

[3-(4-Methoxycyclohexa-2,4-η-dienyl)-1-methyl-1*H*-indol-3-yl]tricarboniliron (9k):

mp 87-88 ℃ (hexane-AcOEt). IR ($CHCl_3$): 2048, 1966 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 1.97 (ddd, 1H, *J*=2.2, 3.5, 18.0 Hz), 2.42 (ddd, 1H, *J*=4.0, 11.0, 18.0 Hz), 2.88 (dd, 1H, *J*=3.5, 6.6 Hz), 3.30-3.60 (m, 2H), 3.68 (s, 3H), 3.70 (s, 3H), 5.16 (dd, 1H, *J*=2.2, 6.6 Hz), 6.78 (s, 1H), 7.08 (t, 1H, *J*=7.4 Hz), 7.20 (t, 1H, *J*=8.0 Hz), 7.26 (d, 1H, *J*=7.4 Hz), 7.51 (d, 1H, *J*=8.0 Hz). ^{13}C-NMR ($CDCl_3$) δ: 32.8, 34.8, 53.2, 54.4, 55.3, 67.0, 109.4, 118.8, 119.2, 120.5, 121.7, 125.2, 126.5, 137.3, 140.1, 207.0, 211.5. MS *m/z*: 379 (M^+). *Anal.* Calcd for $C_{19}H_{17}NO_4Fe$: C, 60.18; H, 4.52; N, 3.69. Found: C, 60.12; H, 4.54; N, 3.82.

[3-(4-Methoxycyclohexa-2,4-η-dienyl)-1-methoxy-1*H*-indol-3-yl]tricarboniliron (9l):

IR (neat): 2040, 1974 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 1.90 (dt, 1H, *J*=2.8, 14.3 Hz), 2.41 (ddd, 1H, *J*=4.0, 10.9, 14.9 Hz), 2.86 (dd, 1H, *J*=3.4, 6.3 Hz), 3.40 (dt, 1H, *J*=3.4, 10.9 Hz), 3.44-3.45 (m, 1H), 3.69 (s, 3H), 4.04 (dt, 1H, *J*=3.4, 10.9 Hz), 5.17 (dd, 1H, *J*=2.3, 6.8 Hz), 7.01 (s, 1H), 7.08 (t, 1H, *J*=7.4 Hz), 7.22 (t, 1H, *J*=7.4 Hz), 7.37 (d, 1H, *J*=8.0 Hz), 7.48 (d, 1H, *J*=8.0 Hz). ^{13}C-NMR ($CDCl_3$) δ: 32.8, 34.7, 53.1,

54.5, 54.7, 65.6, 66.9, 108.5, 118.2, 119.4, 119.6, 122.5, 122.7, 133.0, 140.2, 211.3. HR-MS *m/z*: Calcd for $C_{19}H_{17}NO_5Fe$: 395.0691. Found: 395.0688.

Preparation of 10a by way of a one-pot reaction of 6a with 8a and allylbromide: Typical procedure: To a THF solution of **8a** derived from pyridine (0.24 mL, 3mmol) and phenyl chloroformate (0.38mL, 3mmol), a THF solution of **6a** generated from **1a** (262mg, 2mmol) was added at -78°C, and the mixture was stirred for 30 min. To this mixture, allyl bromide (0.26mL, 3mmol) was added, and the mixture was gradually warmed to rt. After stirring for an additional 1h at rt, the mixture was diluted with AcOEt, washed with brine, and dried over $MgSO_4$. The solvent was removed, and the residue was separated by MPLC with hexane:AcOEt=10:1 to give 574mg (70%) of **10a**.

Phenyl [(2-Allyl-1-methyl-1*H*-indol-3-yl)(phenyl)methyl]methylcarbamate (10a): mp 168-169 °C (hexane-AcOEt). IR ($CHCl_3$): 1706, 1596, 1550 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 2.96 (s, 3H), 3.60-3.80 (m, 2H), 3.71 (s, 3H), 4.88 (d, 1H, *J*=17.0 Hz), 5.09 (dd, 1H, *J*=1.8, 10.0 Hz), 5.90 (ddt, 1H, *J*=17.0, 10.0, 5.3 Hz), 7.04 (s, 1H), 6.60-7.60 (m, 14H). ^{13}C-NMR ($CDCl_3$) δ: 28.9, 29.7, 31.5, 56.3, 109.1, 109.4, 116.3, 119.4, 120.3, 120.9, 121.8, 125.1, 126.5, 126.7, 127.0, 128.5, 129.2, 134.4, 137.0, 138.1, 139.6, 151.7. MS *m/z*: 410 (M^+). *Anal*. Calcd for $C_{27}H_{26}N_2O_2$: C, 79.00; H, 6.38; N, 6.83. Found: C, 78.88; H, 6.41; N, 6.90.

Phenyl [(2-Allyl-1-methoxy-1*H*-indol-3-yl)(phenyl)methyl]methylcarbamate (10b): IR (neat): 1710 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 2.92&3.10 (two s, 3H), 3.68 (br s, 2H), 4.12 (s, 3H), 5.00-5.15 (m, 2H), 5.94-6.06 (m, 1H), 6.70-6.83 (m, 1H), 6.90 (t, 1H, *J*=7.0 Hz), 6.98 (s, 1H), 7.10-7.24 (m, 5H), 7.29-7.58 (m, 7H). ^{13}C-NMR ($CDCl_3$) δ: 28.0, 31.6, 56.1, 65.7, 108.2, 116.1, 116.9, 120.2, 120.7, 121.6, 121.7, 121.8, 123.2, 125.3, 126.8, 127.0, 128.6, 129.4, 129.5, 129.6, 132.1, 151.8. HR-MS *m/z*: Calcd for $C_{27}H_{26}N_2O_3$: 426.1943. Found: 426.1932.

***tert*-Butyl 2-Allyl-3-[[methyl(phenoxycarbonyl)amino](phenyl)methyl]-1*H*-indole-1-carboxylate (10c):** IR (neat): 1716 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 1.70 (s, 9H), 3.01 (br s, 3H), 3.95-4.05 (m, 2H), 4.96 (br s, 1H), 5.07 (br s, 1H), 6.05-6.09 (m, 1H), 6.58-6.72 (m, 1H), 6.97 (t, 1H, *J*=7.5 Hz), 7.05 (s, 1H), 7.12-7.30 (m, 5H), 7.30-7.58 (m, 6H), 8.17 (d, 1H, *J*=8.0 Hz). ^{13}C-NMR ($CDCl_3$) δ: 28.2, 31.8, 55.5, 84.5, 115.6, 120.5, 121.6, 121.8, 122.5, 123.6, 125.4, 126.0, 126.4, 127.2, 127.3, 128.8, 129.3, 129.4, 129.5, 129.7, 136.3, 150.2, 151.6. HR-MS *m/z*: Calcd for $C_{31}H_{32}N_2O_4$: 496.2362. Found: 496.2353.

Phenyl Methyl[{1-methyl-2-[(*E*)-2-phenylvinyl]-1*H*-indol-3-yl}(phenyl)methyl]carbamate (10d): mp 160-161°C (hexane-AcOEt). IR ($CHCl_3$): 1710, 1600 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 3.01(s, 3H), 3.89 (s, 3H), 6.68-6.99 (m, 3H), 7.04-7.16 (m, 2H), 7.17-7.21 (m, 3H), 7.27-7.39 (m, 12H), 7.46 (d, 2H, *J*=7.4 Hz). ^{13}C-NMR ($CDCl_3$) δ: 31.2, 31.8, 57.1, 109.4, 111.4, 116.9, 119.9, 120.6, 121.8, 122.1, 125.0, 126.7, 126.9, 127.4, 128.3, 128.6, 128.7, 129.0, 135.0, 136.8, 138.0, 140.2, 151.6, 154.8. MS *m/z*: 472 (M^+). *Anal*. Calcd for $C_{32}H_{28}N_2O_2$: C, 81.33; H, 5.97; N, 5.93. Found: C, 81.23; H, 5.99; N, 5.89.

Phenyl [{1-Methoxy-2-[(*E*)-2-phenylvinyl]-1*H*-indol-3-yl}(phenyl)methyl]methylcarbamate (10e): mp 150-151°C (hexane-AcOEt). IR ($CDCl_3$): 1704 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 2.99 (br s, 3H), 4.01 (s, 3H), 6.80-6.89 (m, 1H), 6.93 (t, 1H, *J*=7.5 Hz), 7.03-7.15 (m, 2H), 7.16-7.38 (m, 12H), 7.39-7.48 (m, 4H), 7.46 (d, 1H, *J*=8.0 Hz), 7.49 (d, 1H, *J*=16.6 Hz). ^{13}C-NMR ($CDCl_3$) δ: 31.7, 56.1, 56.4, 64.0, 108.5, 109.1, 109.7, 114.9, 120.7, 121.9, 123.2, 123.8, 125.3, 126.8, 127.2, 128.2, 128.8, 128.9, 129.3, 131.9, 132.5, 132.8, 133.4, 137.3, 139.2, 139.6, 151.6, 154.9, 155.1. MS *m/z*: 488 (M^+). *Anal*. Calcd for $C_{32}H_{28}N_2O_3$: C, 78.67; H, 5.78; N, 5.73. Found: C, 78.73; H, 5.80; N, 5.75.

[2-Allyl-3-(4-methoxycyclohexa-2,4-η-dienyl)-1-methyl-1*H*-indol-3-yl]tricarbonyliron (10f): mp 149-150°C (hexane-AcOEt). IR (neat): 2044, 1978 cm^{-1}. ^{1}H-NMR ($CDCl_3$) δ: 2.10-2.35 (m, 2H), 2.60 (dd, 1H, *J*=3.5, 6.6 Hz), 3.30-3.80 (m, 4H), 3.59 (s, 3H), 3.73 (s, 3H), 4.70-5.30 (m, 3H), 5.91 (ddt, 1H, *J*=17.0, 10.0, 5.2 Hz), 7.00-7.40 (m, 3H), 7.40-7.60 (m, 1H). ^{13}C-NMR ($CDCl_3$) δ: 28.6, 29.5, 31.0, 35.3, 53.4, 54.4, 56.3, 67.8, 109.1, 115.1, 116.4, 118.8, 119.1, 120.9, 125.1, 133.9, 135.1, 137.2, 140.2, 211.6. MS *m/z*: 418 (M^+). *Anal*. Calcd for $C_{22}H_{21}NO_4Fe$: C, 63.02; H, 5.05; N, 3.34. Found: C, 62.99; H, 5.05; N, 3.46.

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