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SYNTHESIS OF 3-ETHENYLINDOLES VIA INTRAMOLECULAR CYCLIZATION OF ARYL RADICAL WITH ALLENE GENERATED BY SAMARIUM(II) DIIODIDE

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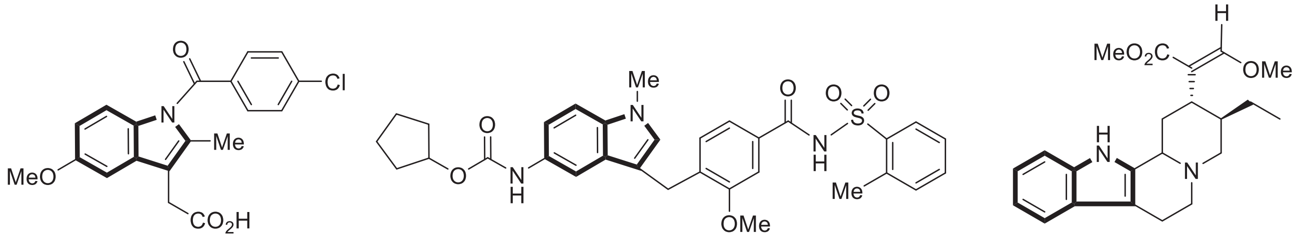
Abstract–*N*-(2,3-Butadien-1-yl)-*N*-(*tert*-butoxycarbonyl)-2-iodoanilines cyclized intramolecularly to form 3-ethenyl-2,3-dihydroindoles after treatment with samarium(II) diiodide. The dihydroindoles were easily oxidized to the corresponding 3-ethenylindoles in good to moderate yields.

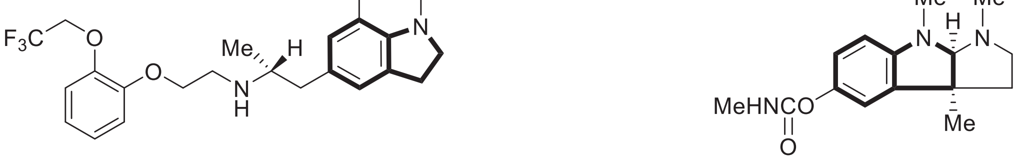
As indole and dihydroindole scaffolds are found in various chemical agents, such as medicines and natural products, *etc.*,[1] the development of new methods for their synthesis is one of the important subjects in synthetic chemistry (Figure 1). Various methods for their construction have been developed.[2]



indometacin
(antifebrile)

zafirlukast
(leukotriene receptor antagonist)

hirstine
[*Uncaria rhynchophylla* (Rubiaceae)]

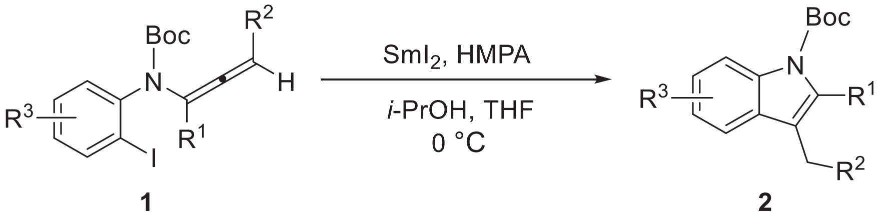


silodosin
(selective α_{1A} blocker)

physostigmine
[*Physostigma venenosum* (Leguminosae)]

Figure 1. Example of medicines and natural products possessing indole and dihydroindole scaffolds

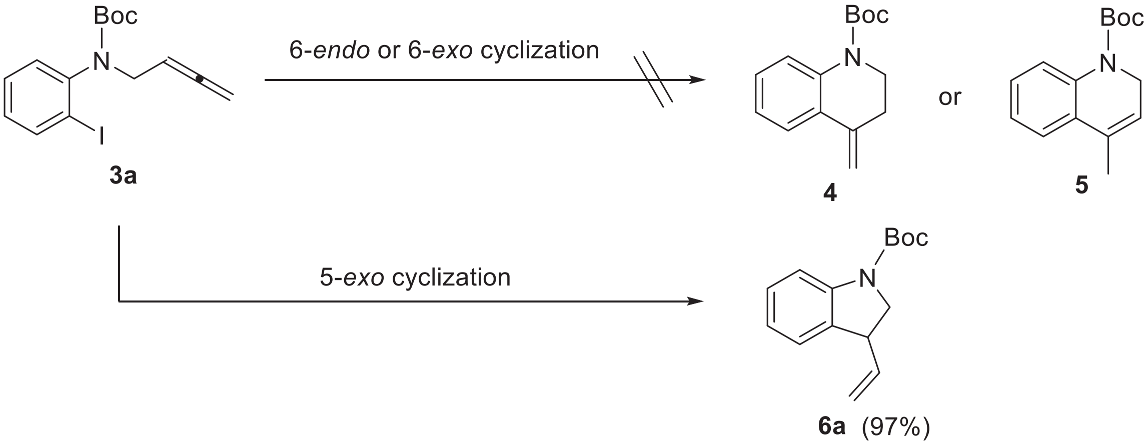
Samarium(II) diiodide (SmI_2), which is easily prepared from Sm metal and 1,2-diiodoethane, diiodomethane, iodine or so on, is a low-toxicity single-electron reducing agent.[3] SmI_2 can work in neutral conditions at room temperature or below, and SmI_2-mediated reactions for the synthesis of complicated products exhibit functional group tolerance.[4] In addition, the fact that SmI_2 has high affinity for heteroatoms (oxygen, *etc.*) makes control of the reductive ability possible through the use of appropriate additives.[5] Reactions mediated by SmI_2 are classified into two types: 1) carbon-carbon bond formation reaction, such as the Barbier-type reaction and the pinacol-type reaction; and 2) functional group selective reduction, such as amide, ester, cyano, and nitro group reduction.[6] In a previous communication, we reported an intramolecular cyclization reaction of *N*-allenyl-2-iodoanilines (**1**) with SmI_2 to produce indole derivatives (**2**) (Scheme 1).[7]



Scheme 1. SmI_2-mediated indole synthesis using *N*-allenyl-2-iodoanilines (**1**)

In this paper, we report a novel method for the formation of 3-ethenylindole scaffolds under mild conditions.

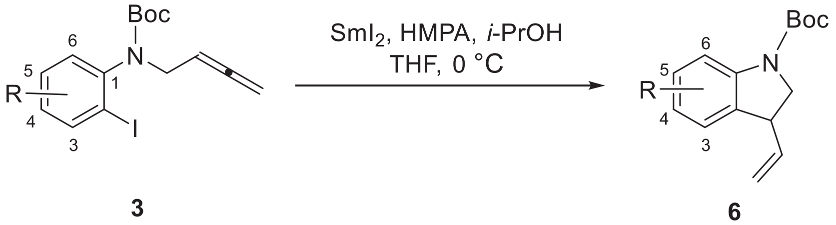
A SmI_2-mediated intramolecular cyclization of **3a** having a methylene group between the allene group and the nitrogen atom was designed. The possible product would be tetrahydroquinoline (**4**) via 6-*endo* cyclization, dihydroquinoline (**5**) via 6-*exo* cyclization, or 2,3-dihydroindole **(6a)** via 5-*exo* cyclization (Scheme 2). Aniline having an allene group (**3a**) was subjected to the same reaction conditions as those described in Scheme 1, namely, SmI_2 in the presence of hexamethylphosphoramide (HMPA) and *i*-PrOH. The radical cyclization proceeded selectively via 5-*exo* cyclization to afford 2,3-dihydroindole **(6a)** in high yield (Scheme 2). This fact was consistent with the result reported in the literatures.[8]



Scheme 2. Intramolecular cyclization of **3a**

To examine the scope of the reaction, substrates **3b-h** possessing a substituent on the aromatic ring were prepared and subjected to the same reaction conditions. The results are shown in Table 1.

Table 1. Intramolecular cyclization of **3**



3 **6**

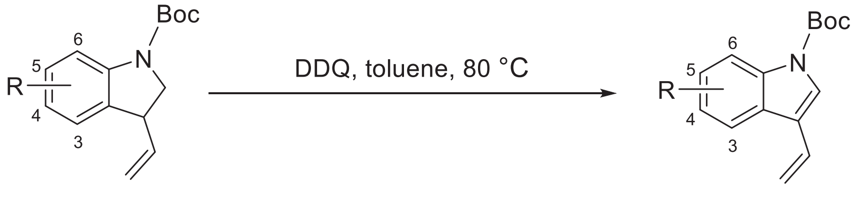
Entry	Substrate	R	Yield (%)[a]
1	**3a**	H	**6a**: 97
2	**3b**	4-OMe	**6b**: 89
3	**3c**	4-Me	**6c**: 81
4	**3d**	4-CO_2Me	**6d**: 48
5	**3e**	4-Cl	**6e**: 62
6	**3f**	6-OMe	**6f**: 90
7	**3g**	5-OMe	**6g**: 85
8	**3h**	3-OMe	**6h**: 88

[a] Isolated yield.

The reaction of substrates possessing an electron-donating group, such as methoxy group **3b** and methyl group **3c**, afforded corresponding **6b** and **6c** in good yields (Entries 2 and 3). The reaction of substrates possessing an electron-withdrawing group, such as methoxycarbonyl group **3d** and chloro group **3e**, gave corresponding **6d** and **6e** in moderate yields (Entries 4 and 5). Judging from the results, the electronic density on the aromatic ring would be an important factor for the intramolecular cyclization of a phenyl radical onto an allene group. Next, the effect of substitution position was examined, and the reaction of substrate **3f**, **3g** or **3h** having a methoxy group at 6-, 5- or 3-position afforded corresponding **6f**, **6g** or **6h** in good yields, respectively (Entries 6-8).

Prepared dihydroindoles (**6**) were easily converted into corresponding 3-ethenylindoles (**7**) by oxidation with 2,3-dichloro-5,6-dicyano-1,4-benzoquinone (DDQ) in the usual manner (Table 2).[9] The reaction of **6a** afforded **7a** in 70% yield (Entry 1). Substrates possessing an electron-donating group (**6b** and **6c**) afforded corresponding **7b** and **7c** in good to moderate yields (Entries 2 and 3), and those possessing an electron-withdrawing group (**6d** and **6e**) gave **7d** and **7e** in moderate yields (Entries 4 and 5). To clarify the effect of substitution position in the aromatic ring, the results of **6f-h** having a methoxy group were compared with that of **6b**. The reaction of 4-methoxy-substituted **6b** gave the best yield (Entries 2, 6, 7, and 8). The reaction of 6-methoxy-substituted **6f** afford **7f** in only 9% yield. This is probably due to the steric interaction between the 6-methoxy group and the Boc group in **7f** (Entry 6).[10,11]

Table 2. Oxidation of **6**



6 **7**

Entry	Substrate	R	Yield (%)[a]
1	**6a**	H	**7a**: 70
2	**6b**	4-OMe	**7b**: 89
3	**6c**	4-Me	**7c**: 61
4	**6d**	4-CO_2Me	**7d**: 63
5	**6e**	4-Cl	**7e**: 41
6	**6f**	6-OMe	**7f**: 9
7	**6g**	5-OMe	**7g**: 62
8	**6h**	3-OMe	**7h**: 63

[a] Isolated yield

In general, 3-ethenylindole derivatives are prepared by the Wittig reaction, Peterson reaction, and use of Nysted reagent of the corresponding 3-formylindoles,[12] and are useful as building blocks in the functionalization of the ethenyl group,[13] side chain elongation,[14] and further ring formation by the Diels-Alder reaction,[15] the Povarov reaction,[16] or so on.[17]

In conclusion, we have developed an easy and useful method for the preparation of 3-ethenyldihydroindoles (**6**) and 3-ethenylindoles (**7**). The method involves treatment of *N*-(2,3-butadien-1-yl)-*N*-(*tert*-butoxycarbonyl)-2-iodoanilines (**3**) with samarium(II) diiodide to afford intramolecularly cyclized products (**6**). Subsequent oxidation with DDQ gave corresponding **7** in good to moderate yields in two steps.

EXPERIMENTAL

All reactions were performed using dried glasswares under an atmosphere of argon. Anhydrous THF and anhydrous toluene were purchased from Kanto Chemicals Inc. and used without further purification. HMPA was distilled from CaH_2 under reduced pressure. All other chemicals were purchased at the highest commercial grade and used without further purification. Melting point was measured with a

Yanaco MP micro-melting apparatus and uncorrected. NMR spectra were measured on JEOL JNM-LA-500 (^{1}H: 500 MHz; ^{13}C: 125 MHz), JEOL ECS-400 (^{1}H: 400 MHz; ^{13}C: 100 MHz), and Varian INOVA 400NB (^{1}H: 400 MHz, ^{13}C: 100 MHz) spectrometers with tetramethylsilane as an internal standard. Chemical shifts are reported in ppm. IR spectra were taken with Shimadu FTIR-8400 spectrophotometers. A JEOL JMS-GC mate spectrometer was used for low-resolution and high-resolution electron ionizations MS (LR-EIMS and HR-EIMS). Silica gel 60N (60-230 mesh, Kanto Chemical Co., Inc.) for column chromatography, silica gel 60 F_{254} pre-coated glass plates (0.25 mm-thickness, Merck) for analytical thin-layer chromatography (TLC) and silica gel 60 F_{254} (0.5 mm and 1.0 mm-thickness, Merck) for preparative TLC were used.

General procedure for samarium(II)-mediated cyclization of 3.

***N*-(*tert*-Butoxycarbonyl)-3-ethenyl-2,3-dihydroindole (6a)**

A mixture of samarium (190 mg, 1.26 mmol) and 1,2-diiodoethane (266 mg, 0.943 mmol) in THF (9.0 mL) was stirred for 1.5 h at room temperature. After cooling to 0 ºC, HMPA (0.59 mL, 3.39 mmol) was added to the mixture, and stirring was continued for 20 min at 0 ºC. A solution of allene **3a** (70.0 mg, 0.189 mmol) and *i*-PrOH (0.03 mL, 0.377 mmol) in THF (4.6 mL) was added dropwise to the mixture, and the mixture was stirred for additional 20 min. After the mixture was exposed to air, saturated $NaHCO_3$ was added to the mixture, and the whole was extracted with Et_2O. The extracts were washed with saturated aq. $NaHCO_3$ and brine, and dried over $MgSO_4$. The filtrate was concentrated under reduced pressure to leave a residue, which was purified by column chromatography over silica gel with *n*-hexane- EtOAc (12:1) to give **6a** (44.7 mg, 97% yield).

Colorless oil; IR ($CHCl_3$) cm^{-1}; 1693; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.56 (s, 9H), 3.68 (brs, 1H), 3.95 (q, J = 8.5 Hz, 1H), 4.13-4.26 (m, 1H), 5.14 (dd, J = 10.0, 1.0 Hz, 1H), 5.20 (dt, J = 17.0, 1.0 Hz, 1H), 5.83 (ddd, J = 17.0, 10.0, 8.0 Hz, 1H), 6.95 (td, J = 7.5, 1.0 Hz, 1H), 7.08 (d, J = 7.5 Hz, 1H), 7.19 (t, J = 7.5 Hz, 1H), 7.78-7.92 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 28.4 (3C), 44.5, 53.6, 81.5, 98.0, 114.7, 116.4, 122.3 (2C), 124.6, 128.0, 138.6, 152.4; LR-EIMS *m/z* (%) 245 (M^+, 25.7), 190 (13), 189 (100), 145 (27), 144 (23), 130 (13), 117 (12), 57 (69); HR-EIMS calcd for $C_{15}H_{19}NO_2$ (M^+): 245.1416; found: 245.1410.

***N*-(*tert*-Butoxycarbonyl)-3-ethenyl-2,3-dihydro-5-methoxyindole (6b)**

2,3-Dihydroindole **6b** was synthesized with a similar manner to **6a**. Colorless oil (149 mg, 89%); IR ($CHCl_3$) cm^{-1}; 1686; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.55 (brs, 9H), 3.61-3.72 (m, 1H), 3.76 (s, 3H), 3.88-3.97 (m, 1H), 4.12-4.25 (m, 1H), 5.15 (ddd, J = 10.0, 1.2, 0.4 Hz, 1H), 5.21 (dt, J = 17.2, 1.2 Hz, 1H), 5.82 (ddd, J = 17.2, 10.0, 8.4 Hz, 1H), 6.65 (dd, J = 2.8, 0.8 Hz, 1H), 6.72 (dd, J = 8.8, 2.8 Hz, 1H), 7.68-7.81 (m, 1H); ^{13}C NMR (100 MHz, CDCl$_3$) δ 28.5 (3C), 44.8, 53.8, 55.7, 80.3, 110.9, 112.8, 113.2, 115.2, 116.1, 116.6, 138.3, 152.3, 155.5; LR-EIMS *m/z* (%) 275 (M$^+$, 18.7), 220 (19), 219 (100), 175 (17), 174 (12), 160 (30), 57 (20); HR-EIMS calcd for $C_{16}H_{21}NO_3$ (M$^+$): 275.1521; found: 275.1524.

***N*-(*tert*-Butoxycarbonyl)-3-ethenyl-2,3-dihydro-5-methylindole (6c)**

2,3-Dihydroindole **6c** was synthesized with a similar manner to **6a**. Colorless oil (163 mg, 81%); IR (CHCl$_3$) cm^{-1}; 1686; ^{1}H NMR (400 MHz, CDCl$_3$) δ 1.56 (s, 9H), 2.29 (s, 3H), 3.58-3.78 (m, 1H), 3.91 (q, *J* = 8.4 Hz, 1H), 4.18 (t, *J* = 10.0 Hz, 1H), 5.14 (dd, *J* = 10.0, 1.2 Hz, 1H), 5.20 (dt, *J* = 16.8, 1.2 Hz, 1H), 5.82 (ddd, *J* = 16.8, 10.0, 8.4 Hz, 1H), 6.89 (s, 1H), 6.99 (d, *J* = 8.0 Hz, 1H), 7.62-7.83 (m, 1H); ^{13}C NMR (100 MHz, CDCl$_3$) δ 20.8, 28.5 (3C), 44.6, 53.7, 80.4, 114.4, 116.3, 125.3, 128.4, 131.8 (2C), 138.7 (2C), 152.4; LR-EIMS *m/z* (%) 259 (M$^+$, 25.0), 204 (18), 203 (100), 188 (11), 159 (25), 158 (27), 144 (25), 132 (11), 131 (16), 57 (33); HR-EIMS calcd for $C_{16}H_{21}NO_2$ (M$^+$): 259.1572; found: 259.1566.

***N*-(*tert*-Butoxycarbonyl)-3-ethenyl-2,3-dihydro-5-methoxycarbonylindole (6d)**

2,3-Dihydroindole **6d** was synthesized with a similar manner to **6a**. Colorless prisms (23.8 mg, 48%); mp 118-20 ºC (*n*-hexane-AcOEt = 10:1); IR (KBr) cm^{-1}; 1710; ^{1}H NMR (400 MHz, CDCl$_3$) δ 1.57 (s, 9H), 3.74 (dd, *J* = 10.8, 7.6 Hz, 1H), 3.87 (s, 3H), 3.97 (q, *J* = 8.8 Hz, 1H), 4.24 (t, *J* = 10.8 Hz, 1H), 5.19 (dt, *J* = 10.0, 1.2 Hz, 1H), 5.23 (dt, *J* = 16.8, 1.2 Hz, 1H), 5.83 (ddd, *J* = 16.8, 10.0, 8.4 Hz, 1H), 7.77-7.96 (m, 1H), 7.74 (s, 1H), 7.92 (dd, *J* = 8.0, 0.8 Hz, 1H); ^{13}C NMR (100 MHz, CDCl$_3$) δ 28.3 (3C), 43.7, 51.8, 54.0, 81.5, 113.9, 117.0, 124.0, 126.1, 130.6, 133.2, 137.8, 146.6, 152.0, 166.7; LR-EIMS *m/z* (%) 303 (M$^+$, 21.9), 248 (18), 247 (100), 216 (12), 203 (31), 202 (11), 188 (32), 144 (19), 115 (11), 57 (61); HR-EIMS calcd for $C_{17}H_{21}NO_4$ (M$^+$): 303.1471; found: 303.1474.

***N*-(*tert*-Butoxycarbonyl)-5-chloro-3-ethenyl-2,3-dihydroindole (6e)**

2,3-Dihydroindole **6e** was synthesized with a similar manner to **6a**. Colorless oil (29.9 mg, 62%); IR (CHCl$_3$) cm^{-1}; 1697; ^{1}H NMR (400 MHz, CDCl$_3$) δ 1.55 (s, 9H), 3.69 (t, *J* = 8.8 Hz, 1H), 3.93 (q, *J* = 8.8 Hz, 1H), 4.20 (t, *J* = 8.8 Hz, 1H), 5.16-5.24 (m, 2H), 5.81 (ddd, *J* = 17.2, 10.0, 8.8 Hz, 1H), 7.02-7.04 (m, 1H), 7.14 (dd, *J* = 8.8, 2.0 Hz, 1H), 7.58-7.89 (m, 1H); ^{13}C NMR (100 MHz, CDCl$_3$) δ 28.4 (3C), 44.3, 53.8, 81.0, 115.6, 116.3, 117.1, 119.6, 124.9, 127.2, 127.9, 137.7, 152.2; LR-EIMS *m/z* (%) 281 (M$^+$+2, 15), 279 (M$^+$, 42.3), 225 (35), 224 (13), 223 (100), 179 (11); HR-EIMS calcd for $C_{15}H_{18}ClNO_2$ (M$^+$): 279.1026; found: 279.1022.

***N*-(*tert*-Butoxycarbonyl)-3-ethenyl-2,3-dihydro-7-methoxyindole (6f)**

2,3-Dihydroindole **6f** was synthesized with a similar manner to **6a**. Colorless oil (186 mg, 90%); IR (CHCl$_3$) cm^{-1}; 1689; ^{1}H NMR (400 MHz, CDCl$_3$) δ 1.50 (s, 9H), 3.74 (dd, *J* = 11.2, 8.0 Hz, 1H), 3.86 (s, 3H), 3.92 (q, *J* = 8.0 Hz, 1H), 4.30 (dd, *J* = 11.2, 8.0 Hz, 1H), 5.15-5.25 (m, 2H), 5.79 (ddd, *J* = 17.2, 10.4, 8.4 Hz, 1H), 6.74 (dt, J = 8.0, 1.2 Hz, 1H), 6.80 (d, J = 8.0 Hz, 1H), 7.04 (dd, J = 8.0, 7.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 28.2 (3C), 46.6, 55.6, 56.9, 80.4, 111.7, 116.6, 117.1, 125.4, 131.3, 137.6, 138.1, 149.8, 153.8; LR-EIMS *m/z* (%) 275 (M^+, 32.9), 219 (24), 202 (13), 176 (15), 175 (100), 174 (51), 160 (49), 159 (12), 147 (22), 57 (72); HR-EIMS calcd for $C_{16}H_{21}NO_3$ (M^+): 275.1521; found: 275.1518.

***N*-(*tert*-Butoxycarbonyl)-3-ethenyl-2,3-dihydro-6-methoxyindole (6g)**

2,3-Dihydroindole **6g** was synthesized with a similar manner to **6a**. Pale yellow oil (141 mg, 85%); IR ($CHCl_3$) cm^{-1}; 1697; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.57 (s, 9H), 3.69 (t, J = 8.4 Hz, 1H), 3.79 (s, 3H), 3.88 (q, J = 8.4 Hz, 1H), 4.19 (t, J = 8.4 Hz, 1H), 5.08-5.20 (m, 2H), 5.81 (ddd, J = 17.2, 10.0, 8.4 Hz, 1H), 6.50 (dd, J = 8.4, 2.4 Hz, 1H), 6.94 (d, J = 8.4 Hz, 1H), 7.46-7.61 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 28.4 (3C), 43.7, 54.3, 55.4, 80.6, 100.5, 101.5, 107.6, 108.8, 115.9, 124.9, 138.9, 152.2, 156.0; LR-EIMS *m/z* (%) 275 (M^+, 21.6), 220 (15), 219 (100), 192 (12), 175 (17), 174 (25), 160 (28), 148 (15), 147 (11), 85 (41), 83 (62), 58 (14), 57 (41); HR-EIMS calcd for $C_{16}H_{21}NO_3$ (M^+): 275.1521; found: 275.1526.

***N*-(*tert*-Butoxycarbonyl)-3-ethenyl-2,3-dihydro-4-methoxyindole (6h)**

2,3-Dihydroindole **6h** was synthesized with a similar manner to **6a**. Colorless oil (181 mg, 88%); IR ($CHCl_3$) cm^{-1}; 1690; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.56 (s, 9H), 3.80 (s, 3H), 3.82-4.01 (m, 2H), 4.05 (dd, J = 10.8, 9.6 Hz, 1H), 5.02-5.09 (m, 2H), 5.92 (ddd, J = 17.2, 10.0, 6.8 Hz, 1H), 6.52 (d, J = 8.4 Hz, 1H), 7.16 (t, J = 8.4 Hz, 1H), 7.36-7.66 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 28.4 (3C), 41.1, 53.8, 55.3, 80.3, 105.1, 107.9 (2C), 114.4 (2C), 129.4, 138.3, 152.4, 156.4; LR-EIMS *m/z* (%) 275 (M^+, 31.3), 220 (15), 219 (100), 204 (17), 191 (11), 175 (25), 174 (24), 160 (35), 148 (15), 147 (20), 85 (34), 83 (51), 57 (63); HR-EIMS calcd for $C_{16}H_{21}NO_3$ (M^+): 275.1521; found: 275.1519.

General procedure for oxidation of dihydroindoles 6.

***N*-(*tert*-Butoxycarbonyl)-3-ethenyl-5-methoxyindole (7b)**

DDQ (65.2 mg, 0.287 mmol) was added to a solution of **6b** (65.9 mg, 0.239 mmol) in toluene (2.4 mL) at room temperature and the mixture was heated at 80 ºC with stirring for 3 h. The mixture was extracted with EtOAc. The extracts were washed with H_2O and brine, and dried over $MgSO_4$. The filtrate was concentrated under reduce pressure to leave a residue, which was purified by column chromatography over silica gel with *n*-hexane-EtOAc (12:1) to give **7b** (58.5 mg, 89%).

Pale yellow oil; IR ($CHCl_3$) cm^{-1}; 1726; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.66 (s, 9H), 3.88 (s, 3H), 5.31 (d, J = 11.2 Hz, 1H), 5.76 (d, J = 17.6 Hz, 1H), 6.78 (dd, J = 17.6, 11.2 Hz, 1H), 6.95 (dd, J = 8.8, 2.4 Hz, 1H), 7.24 (d, J = 2.4 Hz, 1H), 7.60 (brs, 1H), 8.04 (d, J = 8.0 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$)

δ 28.2 (3C), 55.8, 83.7, 103.0, 110.8, 113.0 (2C), 114.1, 116.0 (2C), 119.0, 124.5, 128.1, 156.0; LR-EIMS *m/z* (%) 273 (M^+, 66.1), 219 (16), 218 (14), 217 (100), 173 (32), 57 (10); HR-EIMS calcd for $C_{16}H_{19}NO_3$ (M^+): 273.1365; found: 273.1363.

N-(tert-Butoxycarbonyl)-3-ethenylindole (7a)[12c,f,g,k,18]

3-Ethenylindole **7a** was synthesized with a similar manner to **7b**. Pale yellow oil (66 mg, 70%).

N-(tert-Butoxycarbonyl)-3-ethenyl-5-methylindole (7c)

3-Ethenylindole **7c** was synthesized with a similar manner to **7b**. Pale yellow oil (42.6 mg, 61%); IR ($CHCl_3$) cm^{-1}; 1726; ^1H NMR (400 MHz, $CDCl_3$) δ 1.66 (s, 9H), 2.46 (s, 3H), 5.30 (dd, *J* = 11.2, 1.2 Hz, 1H), 5.79 (dd, *J* = 17.6, 1.2 Hz, 1H), 6.79 (ddd, *J* = 17.6, 11.2, 0.8 Hz, 1H), 7.15 (dd, *J* = 8.4, 1.2 Hz, 1H), 7.57-7.67 (m, 2H), 8.02 (d, *J* = 8.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.5. 28.2 (3C), 83.6, 114.1, 114.9, 119.0, 119.9, 124.0, 125.9, 128.2, 128.9, 132.3, 134.1, 149.6; LR-EIMS *m/z* (%) 257 (M^+, 28.5), 202 (11), 201 (76), 158 (16), 157 (100), 156 (29), 85 (25), 83 (39), 57 (55); HR-EIMS calcd for $C_{16}H_{19}NO_2$ (M^+): 257.1416; found: 257.1410.

N-(tert-Butoxycarbonyl)-3-ethenyl-5-methoxycarbonylndole (7d)

3-Ethenylindole **7d** was synthesized with a similar manner to **7b**. Pale yellow oil (20.8 mg, 63%); IR (KBr) cm^{-1}; 1722; ^1H NMR (400 MHz, $CDCl_3$) δ 1.68 (s, 9H), 3.96 (s, 3H), 5.38 (dd, *J* = 11.2, 0.8 Hz, 1H), 5.87 (dd, *J* = 17.6, 0.8 Hz, 1H), 6.82 (dd, *J* = 17.6, 11.2 Hz, 1H), 7.67 (s, 1H), 8.04 (dd, *J* = 8.8, 1.6 Hz, 1H), 8.21 (d, *J* = 8.8 Hz, 1H), 8.51 (d, *J* = 1.6 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 28.2 (3C), 52.1, 84.5, 114.8, 119.6, 122.0, 122.3, 124.8, 125.9, 126.2, 127.5, 128.5, 138.5, 149.2, 167.5; LR-EIMS *m/z* (%) 301 (M^+, 34.2), 247 (16), 246 (18), 245 (89), 214 (15), 202 (21), 201 (95), 170 (52), 142 (13), 115 (20), 114 (19), 57 (100): HR-EIMS calcd for $C_{17}H_{19}NO_4$ (M^+): 301.1314; found: 301.1319.

N-(tert-Butoxycarbonyl)-5-chloro-3-ethenylindole (7e)

3-Ethenylindole **7e** was synthesized with a similar manner to **7b**. Pale yellow oil (31.4 mg, 41%); IR ($CHCl_3$) cm^{-1}; 1732; ^1H NMR (400 MHz, $CDCl_3$) δ 1.67 (s, 9H), 5.33 (dd, *J* = 11.2, 1.2 Hz, 1H), 5.76 (dd, *J* = 18.0, 1.2 Hz, 1H), 6.74 (ddd, *J* = 18.0, 11.2, 1.2 Hz, 1H), 7.28 (dd, *J* = 8.8, 2.0 Hz, 1H), 7.62 (s, 1H), 7.74 (d, *J* = 2.0 Hz, 1H), 8.08 (d, *J* = 8.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 28.1 (3C), 84.3, 116.3, 118.7, 119.5, 119.8, 124.6, 124.9, 127.5, 128.7, 129.9, 134.3, 149.2; LR-EIMS *m/z* (%) 279 (M^++2, 20), 277 (M^+, 53.4), 223 (37), 222 (13), 221 (100), 179 (18), 177 (54), 57 (29); HR-EIMS calcd for $C_{15}H_{16}ClNO_2$ (M^+): 277.0870; found: 277.0865.

N-(tert-Butoxycarbonyl)-3-ethenyl-7-methoxyindole (7f)

3-Ethenylindole **7f** was synthesized with a similar manner to **7b**. Pale yellow oil (3.1 mg, 9%); IR ($CHCl_3$) 1722 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 1.63 (s, 9H), 3.94 (s, 3H), 5.29 (d, *J* = 11.1 Hz, 1H), 5.75 (d, *J* = 18.0 Hz, 1H), 6.79 (dd, *J* = 11.1, 18.0 Hz, 1H), 6.85 (d, *J* = 7.8 Hz, 1H), 7.23 (t, *J* = 7.8 Hz, 1H), 7.39 (d, *J* = 7.8 Hz, 1H), 7.57 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 27.9 (3C), 55.8, 83.4, 107.1, 112.4, 113.9, 118.7, 123.9, 126.4 (2C), 128.0, 131.6, 148.3, 149.4; LR-EIMS *m/z* (%) 273 (M^+, 76.2), 274 (14), 217 (12), 173 (100), 130 (18); HR-EIMS calcd for $C_{16}H_{19}NO_3$ (M^+): 273.1365; found: 273.1360.

***N*-(*tert*-Butoxycarbonyl)-3-ethenyl-6-methoxyindole (7g)**

3-Ethenylindole **7g** was synthesized with a similar manner to **7b**. Pale yellow oil (43.1 mg, 62%); IR ($CHCl_3$) cm^{-1}; 1724; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.67 (s, 9H), 3.88 (s, 3H), 5.30 (dd, *J* = 11.6, 1.2 Hz, 1H), 5.77 (dd, *J* = 18.0, 1.2 Hz, 1H), 6.76 (ddd, *J* = 18.0, 11.6, 0.8 Hz, 1H), 6.91 (dd, *J* = 8.8, 2.4 Hz, 1H), 7.50 (s, 1H), 7.66 (d, *J* = 8.8 Hz, 1H), 7.77 (brs, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 28.2 (3C), 55.6, 83.7, 99.4, 112.2, 114.1, 119.2, 120.5 (2C), 122.6, 122.9, 128.3, 149.6, 157.9; LR-EIMS *m/z* (%) 273 (M^+, 65.5), 274 (12), 219 (10), 218 (15), 217 (100), 173 (13); HR-EIMS calcd for $C_{16}H_{19}NO_3$ (M^+): 273.1365; found: 273.1371.

***N*-(*tert*-Butoxycarbonyl)-3-ethenyl-4-methoxyindole (7h)**

3-Ethenylindole **7h** was synthesized with a similar manner to **7b**. Colorless oil (43.4 mg, 63%); IR ($CHCl_3$) cm^{-1}; 1726; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.66 (s, 9H), 3.91 (s, 3H), 5.17 (dd, *J* = 11.2, 1.6 Hz, 1H), 5.64 (dd, *J* = 17.6, 1.6 Hz, 1H), 6.67 (d, *J* = 8.0 Hz, 1H), 7.19-7.29 (m, 2H), 7.62 (s, 1H), 7.76 (d, *J* = 8.0 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 28.1 (3C), 55.3, 83.7, 103.6, 108.3, 113.2, 118.5, 120.0, 120.1, 125.2, 129.8, 137.0, 149.6, 154.4; LR-EIMS *m/z* (%) 273 (M^+, 28.7), 218 (15), 217 (100), 174 (11), 173 (72), 172 (21), 158 (30), 146 (16), 130 (23), 115 (16), 85 (22), 83 (33), 57 (64); HR-EIMS calcd for $C_{16}H_{19}NO_3$ (M^+): 273.1365; found: 273.1372.

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