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Synthesis of 4-Vinylindoles Using Ruthenium-Catalyzed Ring-Closing Enyne Metathesis

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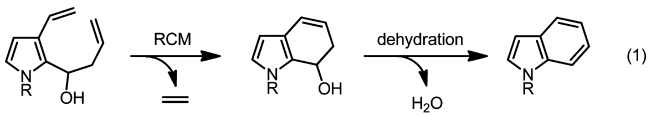
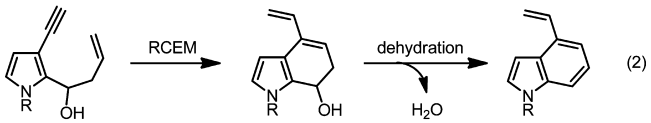
Supporting Information

ABSTRACT: The selective synthesis of substituted 4-vinylindoles by the ring-closing enyne metathesis (RCEM)/dehydration sequence is reported. In contrast with many known methods in which a pyrrole ring is constructed onto a functionalized benzene precursor, this method enables the construction of a benzene ring onto a pyrrole precursor. The RCEM/tautomerization sequence for the synthesis of 7-hydroxy-4-vinylindole is also presented as an application of this method.

The construction of aromatic rings using ruthenium-catalyzed ring-closing metathesis[1,2] has recently emerged as a powerful method for the preparation of aromatic compounds.[3−6] During the course of our study on this field,[7] we reported in 2011 a new method for the synthesis of substituted indoles, which are important nuclei for a variety of natural products and medicinal agents,[8] by using the ring-closing olefin metathesis (RCM)/dehydration sequence (eq 1).[7c] The



(1)



(2)

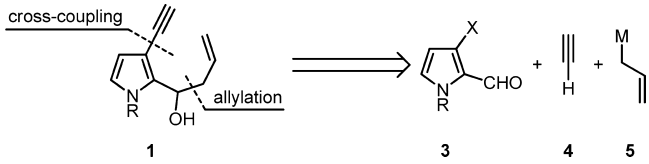
1 2

most common method for the construction of the indole skeleton involves pyrrole ring formation from a benzene precursor.[9] It is, however, quite rare to construct the benzene ring of indole from a pyrrole precursor, similar to our method mentioned above.[10] Considering the product variations between the two approaches, enriching this rare approach will be of great value.

Herein, we report the synthesis of substituted 4-vinylindoles **2** from new pyrrole precursors **1** using the ring-closing enyne metathesis (RCEM)/dehydration sequence (eq 2). The employment of RCEM enables not only the formation of the carbocyclic six-membered ring but also the concurrent introduction of a vinyl group to the ring. As vinyl groups can be easily converted into other functional groups, products **2** are considered to be attractive intermediates for various indole derivatives.

As shown in Scheme 1, our retrosynthetic analysis revealed that precursors **1** could be prepared from three basic parts, namely pyrroles **3**,[11] terminal alkynes **4**, and allylic metal reagents

Scheme 1. Retrosynthetic Analysis of Substrates 1



5. In fact, cross-coupling **3** with **4**, followed by allylation of the resulting products with **5**, yielded **1** successfully.[12]

With the desired precursors **1** in hand, we examined the synthesis of 4-vinylindoles **2** by the RCEM/dehydration sequence using Grubbs second-generation catalyst **6**[13] (Table 1). As our previous work on styrene ring formation revealed that RCEM proceeded more smoothly under ethylene gas than under nitrogen gas,[7b] we carried out the reaction of **1a** under ethylene atmosphere. As a result, **2a** was obtained in 99% yield (entry 1). In contrast, the reaction of **1a** under nitrogen atmosphere gave **2a** in only 59% yield (entry 2). Lowering the catalyst loading from 7.5 mol % to 1 mol % decreased the product yield slightly, but it was still sufficiently high (86% yield) (entry 1 vs 3). Under the same reaction conditions as those for entry 1, substrates **1b** and **1c** having the same substitution pattern as **1a** were converted into corresponding 4-vinylindoles **2b** and **2c**, respectively, in good yields (entries 4 and 5). The introduction of additional substituents at the R^6 or R^7 position was also accomplished, and various indoles **2d−g** were obtained in moderate to good yields (entries 6−9). It was, however, found that RCEM of **1h**, which had a methyl group at R^5 position, did not occur at all (entry 10).[14] As an application of the RCEM/dehydration sequence, we next examined the construction of two or three benzene rings simultaneously. As a result, **2i** and **2j** were successfully formed from **1i** and **1j**, respectively (entries 11 and 12). Furthermore, the RCEM/dehydration of **1k**, an indole

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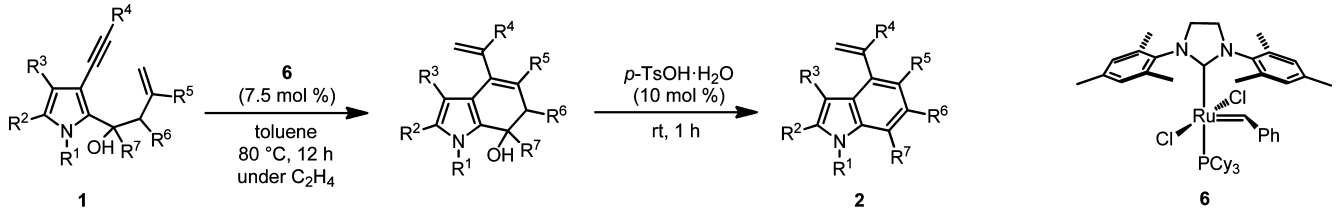
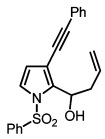
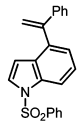
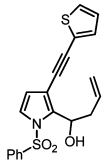
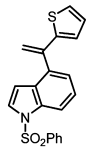
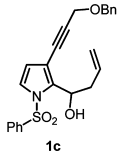
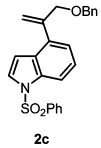
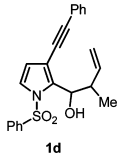
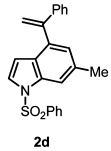
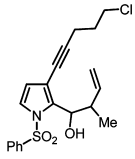
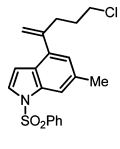
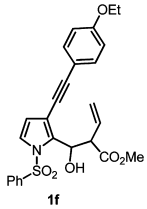
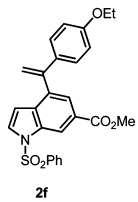
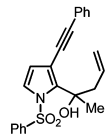
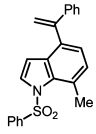
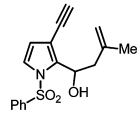
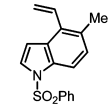
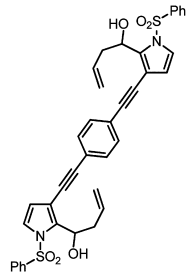
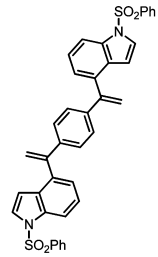
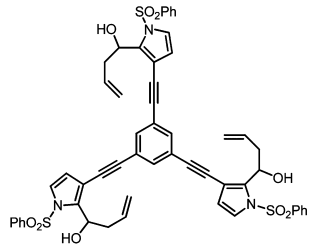
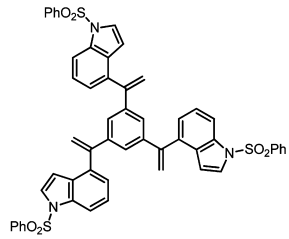
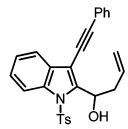
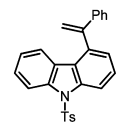
Table 1. Synthesis of Substituted 4-Vinylindoles 2 by RCEM/Dehydration Sequence[a]



entry	substrate	product	yield (%)[b]
1	 **1a**	 **2a**	99
2[c]			59
3[d]			86
4	 **1b**	 **2b**	98
5	 **1c**	 **2c**	74
6[e]	 **1d**	 **2d**	85
7[f]	 **1e**	 **2e**	82
8[g]	 **1f**	 **2f**	67
9	 **1g**	 **2g**	97
10[h]	 **1h**	 **2h**	0
11[i]	 **1i**	 **2i**	94
12[i,j]	 **1j**	 **2j**	78
13	 **1k**	 **2k**	99

[a]Ring-closing enyne metathesis was carried out with **1** and ruthenium catalyst (**6**, 7.5 mol %) in toluene under ethylene atmosphere (1 atm). The reaction mixture was treated with *p*-toluenesulfonic acid (10 mol %) at rt for 1 h. [b]Isolated yield by silica gel chromatography. [c]The reaction was carried out under N_2 atmosphere. [d]The reaction was carried out with 1 mol % of **6**. [e]Because of the presence of a trace impurity with **1d**, **2a** was also obtained in 2% yield (see the Supporting Information for details). [f]Because of the presence of a trace impurity with **1e**, 4-(5-chloropent-1-en-2-yl)-1-(phenylsulfonyl)-1*H*-indole was obtained in 3% yield (see the Supporting Information for details). [g]A mixture of **1f** and its positional isomer (1/0.014) was used as the starting material (see the Supporting Information for details). [h]**1h** was recovered in 35% yield. [i]The reaction was carried out with 15 mol % of **6**. [j]A high temperature (80 °C) was required for the dehydration step with *p*-toluenesulfonic acid.

derivative, gave the corresponding unsymmetrical carbazole **2k** quantitatively (entry 13).[15]

Finally, we applied the RCEM/tautomerization sequence to **7**, which was prepared by the IBX oxidation of **1a**. As a result, the desired 7-hydroxy-4-vinylindole **8** was obtained in good yield (Scheme 2). As the transformation of **7** into **8** involves no elimination step, the RCEM/tautomerization sequence is a 100% atom-economical process. Moreover, 7-hydroxy-4-vinylindoles are particularly useful building blocks because the vinyl and phenolic hydroxyl groups can be converted in many ways.

In conclusion, we have presented a new method for the selective synthesis of substituted 4-vinylindoles that uses RCEM. As the method employs a rare approach by which the carbocyclic rings of indoles are constructed, it provides novel access to unique indoles.

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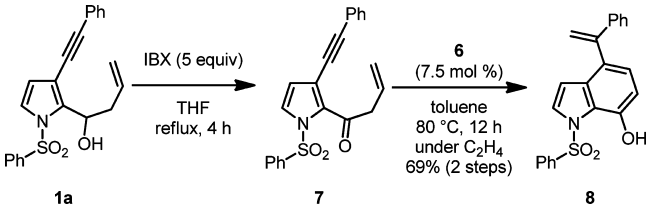
Scheme 2. Synthetic Sequence for 7-Hydroxy-4-vinylindole 8



EXPERIMENTAL SECTION

Unless otherwise noted, silica gel column chromatography or PTLC was performed with hexane/EtOAc (1.5/1−4.5/1).

General Procedure A: Sonogashira Coupling. To a mixture of $PdCl_2(PPh_3)_2$ (5 mol %) and 3-bromo-1-(phenylsulfonyl)-1*H*-pyrrole-2-carbaldehyde (**3a**) or 3-iodo-1-tosyl-1*H*-indole-2-carbaldehyde (**3b**) in THF (1/7 M for **3**) was added NEt_3 (3 equiv). After the mixture was stirred for 10 min at rt, terminal acetylene **4** (1.3 equiv) and CuI (5 mol %) were added. After being stirred overnight (ca. 16 h), the reaction mixture was diluted with saturated aqueous NH_4Cl, extracted with EtOAc, washed with brine, dried over Na_2SO_4, and evaporated. Purification by silica gel column chromatography gave the corresponding 3-ethynylpyrrole-2-carbaldehydes or 3-ethynylindole-2-carbaldehyde **9**.

General Procedure B: Allylation with Allyltrifluoroborate. The reaction was performed according to the reported procedure.[16] Purification by silica gel column chromatography gave **1**.

General Procedure C: Allylation with Indium and 1-Bromo-2-butene. The reaction was performed according to the reported procedure.[17] Purification by silica gel column chromatography gave **1**.

General Procedure D: Alkylation with Grignard Reagent. To a solution of carbonyl compound in THF (0.033−0.05 M) was added Grignard reagent (1.5 equiv) at −80 °C. After being stirred for 1.4−3 h, the mixture was quenched by saturated aqueous NH_4Cl at the same temperature, warmed to rt, extracted with EtOAc, washed with brine, dried over Na_2SO_4, and evaporated. Purification by silica gel column chromatography gave corresponding alcohols.

*1-(3-(Phenylethynyl)-1-(phenylsulfonyl)-1H-pyrrol-2-yl)but-3-en-1-ol (**1a**).* General procedure A (**3a**, phenylacetylene **4a**, hexane/toluene = 1/3 to toluene), B: orange gum (99.1 mg, 97% yield); ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.73−2.90 (m, 3H), 5.01−5.12 (m, 2H), 5.25 (td, J = 8.2, 6.2 Hz, 1H), 5.76 (ddt, J = 17.4, 10.3, 7.1 Hz, 1H), 6.39 (d, J = 3.4 Hz, 1H), 7.25 (d, J = 3.4 Hz, 1H), 7.30−7.35 (m, 3H), 7.42−7.46 (m, 2H), 7.53 (t, J = 8.1 Hz, 2H), 7.64 (tt, J = 7.6, 1.2 Hz, 1H), 7.84 (dd, J = 8.2, 1.4 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 41.3, 66.8, 82.3, 94.1, 109.2, 115.0, 118.1, 122.8, 122.9, 126.8, 128.37, 128.41, 129.6, 131.2, 133.8, 134.2, 138.9, 139.2; HRMS (ESI) calcd for $C_{22}H_{19}NNaO_3S$ (M^+ + Na) 400.0978, found 400.0971.

*1-(1-(Phenylsulfonyl)-3-(thiophene-2-ylethynyl)-1H-pyrrol-2-yl)-but-3-en-1-ol (**1b**).* General procedure A (**3a**, 2-ethynylthiophene **4b**), B: yellowish brown oil (217 mg, 93% yield); ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.74 (dddt, J = 14.1, 7.2, 6.0, 1.1 Hz, 1H), 2.79 (d, J = 8.3 Hz, 1H), 2.83 (dddt, J = 14.3, 8.1, 6.9, 1.1 Hz, 1H), 5.03−5.06 (m, 1H), 5.09 (dq, J = 17.2, 1.5 Hz, 1H), 5.22 (td, J = 8.1, 6.9 Hz, 1H), 5.74 (ddt, J = 17.2, 10.0, 7.2 Hz, 1H), 6.38 (d, J = 3.5 Hz, 1H), 6.99 (dd, J = 5.2, 3.7 Hz, 1H), 7.20 (dd, J = 3.7, 1.1 Hz, 1H), 7.24 (d, J = 3.4 Hz, 1H), 7.28 (dd, J = 5.1, 1.1 Hz, 1H), 7.51−7.56 (m, 2H), 7.64 (tt, J = 7.4, 1.2 Hz, 1H), 7.81−7.85 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 41.2, 66.7, 85.9, 87.2, 109.0, 114.9, 118.2, 122.9, 126.8, 127.1, 127.4, 129.6, 131.8, 133.8, 134.3, 138.8, 139.3; HRMS (ESI) calcd for $C_{20}H_{17}NNaO_3S_2$ (M^+ + Na) 406.0542, found 406.0533.

*1-(3-(3-(Benzyloxy)prop-1-yn-1-yl)-1-(phenylsulfonyl)-1H-pyrrol-2-yl)but-3-en-1-ol (**1c**).* General procedure A (**3a**, 3-phenoxy-1-propyne **4c**, first: hexane/EtOAc = 3/1, second: hexane/toluene = 10/1 to toluene to toluene/Et_2O = 15/1), B: yellow oil (104 mg, 92% yield); ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.69 (quint, J = 6.9 Hz, 1H), 2.75−2.84 (m, 2H), 4.35 (s, 2H), 4.62 (s, 2H), 5.00−5.08 (m, 2H), 5.19 (q, J = 6.6 Hz, 1H), 7.52 (ddt, J = 17.2, 10.4, 6.8 Hz, 1H), 6.32 (d, J = 3.5 Hz, 1H), 7.21 (d, J = 3.4 Hz, 1H), 7.27−7.36 (m, 5H), 7.52 (t, J = 7.8 Hz, 2H), 7.63 (t, J = 7.7 Hz, 1H), 7.81 (d, J = 8.0 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 41.3, 57.8, 66.8, 71.6, 79.5, 90.2, 108.6, 115.2, 118.1, 122.7, 126.8, 127.9, 128.0, 128.4, 129.6, 133.8, 134.3, 137.3, 138.8, 139.6; HRMS (ESI) calcd for $C_{24}H_{23}NNaO_4S$ (M^+ + Na) 444.1240, found 444.1233.

*2-Methyl-1-(3-(phenylethynyl)-1-(phenylsulfonyl)-1H-pyrrol-2-yl)-but-3-en-1-ol (**1d**).* General procedure A (**3a**, **4a**, hexane/toluene = 1/3 to toluene), C: diastereomeric mixture of **1d** (0.58/0.42); pale brown solid (205 mg, 83% yield); ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.88 (d, J = 6.9 Hz, 3H (minor)), 1.23 (d, J = 6.9 Hz, 3H (major)), 2.69 (d, J = 8.0 Hz, 1H (minor)), 2.82 (d, J = 9.4 Hz, 1H (major)), 3.09 (sextet, J = 7.7 Hz, 1H (major)), 3.15 (sextet, J = 8.0 Hz, 1H (minor)), 4.80 (ddd, J = 10.4, 1.7, 0.9 Hz, 1H (major)), 4.90 (ddd, J = 17.2, 1.7, 1.1 Hz, 1H (major)), 4.98 (t, J = 8.8 Hz, 1H (major), 1H (minor)), 5.17−5.23 (m, 2H (minor)), 5.51 (ddd, J = 17.2, 10.3, 8.0 Hz, 1H (major)), 5.92 (ddd, J = 17.2, 10.4, 8.1 Hz, 1H (minor)), 6.37 (d, J = 6.8 Hz, 1H (major)), 6.40 (d, J = 3.5 Hz, 1H (minor)), 7.20 (d, J = 3.4 Hz, 1H (major)), 7.25 (d, J = 3.4 Hz, 1H (minor)), 7.30−7.35 (m, 3H (major), 3H (minor)), 7.41−7.46 (m, 2H (major), 2H (minor)), 7.50−7.55 (m, 2H (major), 2H (minor)), 7.59−7.65 (m, 1H (major), 1H (minor)), 7.82−7.87 (m, 2H (major), 2H (minor)); ^{13}C NMR (125 MHz, $CDCl_3$) δ 16.66, 16.69, 44.5, 44.6, 70.8, 71.5, 82.4, 82.5, 94.0, 94.1, 109.5, 109.8, 115.0, 115.1, 116.7, 122.77, 122.87, 122.95, 123.1, 126.77, 126.82, 128.39, 128.42, 129.49, 129.53, 131.18, 131.22, 134.15, 134.19, 138.9, 139.0, 139.6, 140.5; HRMS (ESI) calcd for $C_{23}H_{21}NNaO_3S$ (M^+ + Na) 414.1134, found 414.1134.

*1-(3-(5-Chloropent-1-yn-1-yl)-1-(phenylsulfonyl)-1H-pyrrol-2-yl)-2-methylbut-3-en-1-ol (**1e**).* General procedure A (**3a**, 5-chloro-1-pentyne **4d**), C: diastereomeric mixture of **1e** (0.56/0.44); yellowish-brown oil (219 mg, 92% yield); ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.82 (d, J = 6.9 Hz, 3H (minor)), 1.19 (d, J = 6.9 Hz, 3H (major)), 2.00 (quintet, J = 6.6 Hz, 2H (minor)), 2.01 (quintet, J = 6.6 Hz, 2H (major)), 2.58 (t, J = 6.6 Hz, 2H (minor)), 2.58 (t, J = 6.8 Hz, 2H (major)), 2.65 (d, J = 8.0 Hz, 1H (minor)), 2.80 (d, J = 9.5 Hz, 1H (major)), 2.99 (sextet, J = 7.4 Hz, 1H (major)), 3.05 (sextet, J = 7.8 Hz, 1H (minor)), 3.67 (t, J = 6.3 Hz, 2H (minor)), 3.67 (t, J = 6.3 Hz, 2H (major)), 4.78 (ddd, J = 10.3, 1.7, 0.5 Hz, 1H (major)), 4.86 (ddd, J = 17.2, 1.7, 1.1 Hz, 1H (major)), 4.89 (t, J = 8.9 Hz, 1H (major), 1H (minor)), 5.15−5.21 (m, 2H (minor)), 5.46 (ddd, J = 17.2, 10.3, 8.0 Hz, 1H (major)), 5.88 (ddd, J = 17.2, 10.4, 7.7 Hz, 1H (minor)), 6.24 (d, J = 3.4 Hz, 1H (major)) 6.27 (d, J = 3.4 Hz,.1H (minor)), 7.14 (d, J = 3.5 Hz, 1H (major)), 7.19 (d, J = 3.4 Hz, 1H (minor)), 7.49−7.54 (m, 2H (major), 2H (minor)), 7.59−7.64 (m, 1H (major), 1H (minor)), 7.78−7.84 (m, 2H (major), 2H (minor)); ^{13}C NMR (125 MHz, $CDCl_3$) δ 16.5, 16.6, 16.9, 31.1, 43.6, 44.3, 44.4, 70.7, 71.5, 74.5, 74.6, 92.9, 93.1, 109.8, 110.1, 114.9, 115.19, 115.22, 116.5, 122.5, 122.8, 126.7, 126.8, 129.45, 129.49, 134.08, 134.13, 138.5, 138.99, 139.02, 139.2, 139.6, 140.6; HRMS (ESI) calcd for $C_{20}H_{22}ClNNaO_3S$ (M^+ + Na) 414.0901, found 414.0899.

*Methyl 2-((3-((4-Ethoxyphenyl)ethynyl)-1-(phenylsulfonyl)-1H-pyrrol-2-yl)(hydroxy)methyl)but-3-enoate (**1f**).* General procedure A (**3a**, 4-ethoxyphenylacetylene **4e**, substantial amount of CH_2Cl_2 was used for loading the crude product on silica gel). The allylation with methyl 4-bromocrotonate **11** was performed according to the reported procedure (reaction time: 18 h).[18] Purification by silica gel column chromatography (CH_2Cl_2 to CH_2Cl_2/EtOAc = 100/1−50/1−30/1−15/1) gave a diastereomeric mixture of **1f** (0.64/0.36) with trace of inseparable byproducts such as isomerized product or α-adduct, which are tentatively assigned by ^{1}H NMR: yellowish-brown oil (379 mg, 93% yield; ca. 95% purity estimated by ^{1}H NMR analysis). Further purification was performed by recycling gel permeation chromatography before use for the next step: ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.41 (t, J = 6.9 Hz, 3H (major), 3H (minor)), 3.19 (d, J = 8.3 Hz, 1H (major)), 3.20 (d, J = 8.3 Hz, 1H (minor)), 3.57 (s, 3H (major)), 3.76 (s, 3H (minor)), 4.03 (q, J = 7.1 Hz, 2H (major)), 4.03 (q, J = 6.9 Hz, 2H (minor)), 4.08 (t, J = 8.6 Hz, 1H (major)), 4.22 (t, J = 9.4 Hz, 1H (minor)), 4.91 (dd, J = 10.3, 1.1 Hz, 1H (minor)), 5.03 (dt, J = 16.8, 1.2 Hz, 1H (minor)), 5.24 (dt, J = 17.1, 0.9 Hz, 1H (major)), 5.32 (dd, J = 10.0, 1.2 Hz, 1H (major)), 5.46−5.62 (m, 1H (major), 2H (minor)), 6.09 (ddd, J = 17.2, 10.1, 9.2 Hz, 1H (major)), 6.34 (d, J = 3.4 Hz, 1H (major)), 6.35 (d, J = 3.4 Hz, 1H (minor)), 6.82−6.87 (m, 2H (major), 2H (minor)), 7.22 (d, J = 3.4 Hz, 1H (major)), 7.24 (d, J = 3.4 Hz, 1H (minor)), 7.37−7.44

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(m, 2H (major), 2H (minor)), 7.52 (t, J = 8.3 Hz, 2H (major), 2H (minor)), 7.60−7.64 (m, 1H (major), 1H (minor)), 7.84−7.89 (m, 2H (major), 2H (minor)); ^{13}C NMR (125 MHz, $CDCl_3$) δ 14.7, 52.0, 52.2, 55.9, 56.3, 63.5, 67.6, 67.8, 80.5, 94.2, 94.7, 110.9, 114.3, 114.51, 114.54, 114.6, 114.7, 114.8, 115.2, 119.5, 120.6, 123.1, 123.4, 126.8, 127.0, 129.5, 131.2, 132.4, 132.70, 132.73, 134.19, 134.22, 135.9, 136.4, 138.7, 138.8, 159.1, 159.2, 171.3, 172.7; HRMS (ESI) calcd for $C_{26}H_{25}NNaO_6S$ (M^+ + Na) 502.1295, found 502.1296.

*2-(3-(Phenylethynyl)-1-(phenylsulfonyl)-1H-pyrrol-2-yl)pent-4-en-2-ol (**1g**).* General procedure A (**3a**, **4a**), D (MeMgBr (3.0 M in Et_2O)). MnO_2 (230 mg, 2.65 mmol, 40 equiv) was added to a solution of the alcohol (23.2 mg, 0.0660 mmol) in CH_2Cl_2 (1.3 mL) at rt under air. After being stirred at 50 °C with a coldfinger condenser for 3 h, the mixture was cooled to rt and filtered through Celite. The residual solid was washed thoroughly with CH_2Cl_2, and the filtrate was evaporated. Silica gel column chromatography gave corresponding ketone (20.5 mg, 89% yield). General procedure D (allylmagnesium bromide **5b** (0.52 M in Et_2O)): yellowish-brown oil (22.6 mg, 95% yield); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.63 (s, 3H), 2.53 (dd, J = 13.8, 8.0 Hz, 1H), 3.21 (dd, J = 13.8, 6.5 Hz, 1H), 3.56 (s, 1H), 5.00−5.09 (m, 2H), 5.55 (dddd, J = 17.2, 10.1, 8.1, 6.6 Hz, 1H), 6.41 (d, J = 3.7 Hz, 1H), 7.29−7.35 (m, 3H), 7.41−7.46 (m, 3H), 7.49 (t, J = 7.5 Hz, 2H), 7.59 (tt, J = 7.5, 1.1 Hz, 1H), 7.72 (dd, J = 8.3, 0.9 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 28.8, 47.2, 73.1, 83.9, 94.1, 108.2, 114.4, 119.3, 123.2, 124.3, 126.4, 128.3, 128.4, 129.0, 131.0, 133.1, 133.5, 140.5, 143.4; HRMS (ESI) calcd for $C_{23}H_{21}NNaO_3S$ (M^+ + Na) 414.1134, found 414.1131.

*1-(3-Ethynyl-1-(phenylsulfonyl)-1H-pyrrol-2-yl)-3-methylbut-3-en-1-ol (**1h**).* General procedure A (**3a**, trimethylsilylacetylene **4f**), D ((2-methylallyl)magnesium chloride **5e** (0.67 M in THF)). To a solution of the corresponding 3-((trimethylsilyl)ethynyl)pyrrole (113 mg, 0.290 mmol) in degassed methanol (5.8 mL) was added K_2CO_3 (100 mg, 0.726 mmol, 2.5 equiv). After being stirred for 1 h at rt, the mixture was diluted with water at 0 °C, extracted with CH_2Cl_2, dried over Na_2SO_4, and evaporated. Silica gel column chromatography followed by further purification by recycling gel permeation chromatography ($CHCl_3$) gave **1h**: yellow oil (61.6 mg, 67% yield); ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.76 (s, 3H), 2.56 (dd, J = 13.9, 4.8 Hz, 1H), 2.68 (d, J = 7.9 Hz, 1H), 2.78 (ddd, J = 14.1, 9.2, 0.7 Hz, 1H), 3.24 (s, 1H), 4.76 (d, J = 0.9 Hz, 1H), 4.84 (t, J = 1.3 Hz, 1H), 5.31 (ddd, J = 9.3, 7.9, 4.9 Hz, 1H), 6.34 (d, J = 3.4 Hz, 1H), 7.20 (d, J = 3.4 Hz, 1H), 7.53 (t, J = 8.2 Hz, 2H), 7.64 (tt, J = 7.5, 1.2 Hz, 1H), 7.81−7.85 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 22.1, 45.1, 65.1, 76.8, 82.4, 107.8, 113.9, 115.2, 122.5, 126.8, 129.6, 134.3, 138.8, 141.0, 141.7; HRMS (ESI) calcd for $C_{17}H_{17}NNaO_3S$ (M^+ + Na) 338.0821, found 338.0817.

*1,1′-(3,3′-(1,4-Phenylenebis(ethyne-2,1-diyl))bis(1-(phenylsulfonyl)-1H-pyrrole-3,2-diyl))bis(but-3-en-1-ol) (**1i**).* General procedure A (**3a**, 1,4-diethynylbenzene **4g**, CH_2Cl_2/EtOAc = 99/1−50/1), B (CH_2Cl_2/EtOAc = 80/1−35/1−10/1): diastereomeric mixture of **1i**; yellow solid (47.5 mg, 87% yield); ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.73−2.88 (m, 6H), 5.02−5.05 (m, 2H), 5.07 (dd, J = 17.2, 1.7 Hz, 2H), 5.24 (t, J = 6.9 Hz, 2H), 5.73 (ddt, J = 17.2, 10.1, 6.9 Hz, 2H), 6.39 (d, J = 3.4 Hz, 2H), 7.25 (d, J = 3.4 Hz, 2H), 7.38 (s, 4H), 7.54 (t, J = 8.3 Hz, 4H), 7.64 (tt, J = 7.5, 1.1 Hz, 2H), 7.84 (dd, J = 8.3, 1.1 Hz, 4H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 41.2, 66.7, 84.3, 93.6, 109.0, 115.0, 118.2, 122.8, 126.8, 129.6, 131.1, 133.7, 134.3, 138.8, 139.3; HRMS (ESI) calcd for $C_{38}H_{32}N_2NaO_6S_2$ (M^+ + Na) 699.1594, found 699.1585.

*1,1′,1″-(3,3′,3″-(Benzene-1,3,5-triyltris(ethyne-2,1-diyl))tris(1-(phenylsulfonyl)-1H-pyrrole-3,2-diyl))tris(but-3-en-1-ol) (**1j**).* General procedure A (**3a**, 1,3,5-triethynylbenzene **4g**, first: $CHCl_3$ to $CHCl_3$/EtOAc = 100/1, second: $CHCl_3$, third: CH_2Cl_2 to CH_2Cl_2/EtOAc = 100/1), B (CH_2Cl_2/EtOAc = 20/1): diastereomeric mixture of **1j**; beige solid (130 mg, 69% yield); ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.72−2.86 (m, 9H), 5.00−5.04 (m, 3H), 5.06 (dq, J = 17.2, 1.7 Hz, 3H), 5.23 (q, J = 6.6 Hz, 3H), 5.71 (ddt, J = 17.2, 10.3, 7.2 Hz, 3H), 6.38 (d, J = 3.4 Hz, 3H), 7.25 (d, J = 3.5 Hz, 3H), 7.42 (s, 3H), 7.53 (tt, J = 7.4, 1.7 Hz, 6H), 7.64 (tt, J = 7.4, 1.1 Hz, 3H), 7.81−7.85 (m, 6H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 41.2, 66.7, 83.9, 92.1, 108.7, 115.0, 118.2, 122.9, 123.9, 126.8, 129.6, 133.2, 133.6, 134.3, 138.8, 139.6; HRMS (ESI) calcd for $C_{54}H_{45}N_3NaO_9S_3$ (M^+ + Na) 998.2210, found 998.2228.

*1-(3-(Phenylethynyl)-1-tosyl-1H-indol-2-yl)but-3-en-1-ol (**1k**).* General procedure A (**3b**, **4a**, hexane/toluene = 1/4−1/6), B: orange oil (110 mg, 90% yield); ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.32 (s, 3H), 2.93−3.06 (m, 2H), 3.63 (d, J = 10.3 Hz, 1H), 5.08−5.12 (m, 1H), 5.19 (dq, J = 17.2, 1.7 Hz, 1H), 5.64 (ddd, J = 10.3, 7.4, 6.3 Hz, 1H), 5.87 (ddt, J = 17.2, 10.0, 6.8 Hz, 1H), 7.19 (d, J = 8.0 Hz, 2H), 7.28−7.40 (m, 5H), 7.52−7.57 (m, 2H), 7.64−7.68 (m, 1H), 7.74 (dt, J = 8.6, 1.8 Hz, 2H), 8.10 (d, J = 8.0 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.6, 41.9, 68.3, 80.3, 97.8, 106.4, 115.0, 118.3, 120.2, 122.8, 124.3, 125.9, 126.6, 128.5, 128.7, 129.7, 129.9, 131.4, 133.8, 135.0, 136.1, 144.8, 145.3; HRMS (ESI) calcd for $C_{27}H_{23}NNaO_3S$ (M^+ + Na) 464.1291, found 464.1284.

General Procedure E: RCEM/Dehydration. To a solution of **1** in toluene (0.01 M) was added catalyst **6** (7.5 mol %) under nitrogen, and then the system was evacuated carefully and filled with ethylene gas in three cycles. The reaction mixture was stirred for 12 h at 80 °C. After being cooled to rt, the reaction mixture was treated with *p*-TsOH (10 mol %) and stirred for 1 h at rt. The mixture was concentrated under reduced pressure and purified by PTLC on silica gel to give **2**.

*1-(Phenylsulfonyl)-4-(1-phenylvinyl)-1H-indole (**2a**).* General procedure E: yellow oil (38.1 mg, 99% yield); ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.39 (d, J = 1.1 Hz, 1H), 5.68 (d, J = 1.4 Hz, 1H), 6.28 (d, J = 3.6 Hz, 1H), 7.19 (dd, J = 7.6, 0.7 Hz, 1H), 7.22−7.32 (m, 6H), 7.40−7.46 (m, 3H), 7.52 (t, J = 7.3 Hz, 1H), 7.86−7.91 (m, 2H), 7.97 (d, J = 8.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 108.9, 112.8, 116.1, 124.0, 124.5, 125.9, 126.8, 127.5, 127.8, 128.3, 129.2, 129.6, 133.8, 134.9, 135.2, 138.2, 141.0, 148.0; HRMS (ESI) calcd for $C_{22}H_{17}NNaO_2S$ (M^+ + Na) 382.0872, found 382.0870.

*1-(Phenylsulfonyl)-4-(1-(thiophene-2-yl)vinyl)-1H-indole (**2b**).* General procedure E: dark blue-green oil (36.1 mg, 98% yield); ^{1}H NMR (500 MHz, $CDCl_3$) δ 5.20 (s, 1H), 5.75 (d, J = 0.5 Hz, 1H), 6.49 (dd, J = 3.7, 0.8 Hz, 1H), 6.69 (dd, J = 3.7, 1.1 Hz, 1H), 6.89 (dd, J = 5.2, 3.7 Hz, 1H), 7.20 (dd, J = 5.1, 1.1 Hz, 1H), 7.25 (dd, J = 7.5, 1.1 Hz, 1H), 7.32 (t, J = 7.4 Hz, 1H), 7.43−7.48 (m, 2H), 7.51 (d, J = 3.7 Hz, 1H), 7.55 (tt, J = 7.4, 1.5 Hz, 1H), 7.88−7.92 (m, 2H), 7.99 (dt, J = 8.3, 0.8 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 108.7, 113.1, 114.8, 123.7, 124.5, 125.1, 126.0, 126.5, 126.8, 127.3, 129.3, 129.6, 133.8, 134.4, 134.9, 138.2, 141.1, 144.5; HRMS (ESI) calcd for $C_{20}H_{15}NNaO_2S_2$ (M^+ + Na) 388.0436, found 388.0430.

*4-(3-(Benzyloxy)prop-1-en-2-yl)-1-(phenylsulfonyl)-1H-indole (**2c**).* General procedure E (first: hexane/EtOAc = 3/1, second: toluene): yellowish-brown oil (26.1 mg, 74% yield); ^{1}H NMR (500 MHz, $CDCl_3$) δ 4.36 (t, J = 1.2 Hz, 2H), 4.55 (s, 2H), 5.40−5.42 (m, 1H), 5.60 (q, J = 1.4 Hz, 1H), 6.81 (dd, J = 3.8, 0.9 Hz, 1H), 7.17 (dd, J = 7.7, 0.9 Hz, 1H), 7.24−7.32 (m, 6H), 7.44 (tt, J = 8.0, 1.5 Hz, 2H), 7.54 (tt, J = 7.5, 1.1 Hz, 1H), 7.58 (d, J = 3.8 Hz, 1H), 7.88−7.91 (m, 2H), 7.93 (dt, J = 8.3, 0.9 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 72.3, 72.6, 108.6, 112.8, 116.9, 122.0, 124.6, 126.3, 126.9, 127.7, 127.8, 128.5, 129.1, 129.4, 133.6, 134.0, 135.2, 138.1, 138.3, 143.7; HRMS (ESI) calcd for $C_{24}H_{20}NO_3S$ (M^- − H) 402.1169, found 402.1180.

*6-Methyl-1-(phenylsulfonyl)-4-(1-phenylvinyl)-1H-indole (**2d**).* General procedure E: pale green solid; mixture of **2d** (31.4 mg, 85% yield) and **2a** (0.81 mg, 2% yield). The byproduct **2a** which was assigned by ^{1}H NMR might be derived from trace of impurity with **1d** (see the Supporting Information): ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.47 (s, 3H), 5.37 (d, J = 1.4 Hz, 1H), 5.66 (d, J = 1.4 Hz, 1H), 6.21 (d, J = 3.9 Hz, 1H), 7.03 (s, 1H), 7.23−7.30 (m, 5H), 7.37 (d, J = 3.6 Hz, 1H), 7.44 (t, J = 8.0 Hz, 2H), 7.54 (tt, J = 7.6, 1.8 Hz, 1H), 7.79 (s, 1H), 7.85−7.90 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.9, 108.8, 113.0, 115.9, 125.2, 125.5, 126.8, 127.4, 127.5, 127.8, 128.2, 129.2, 133.7, 134.65, 134.74, 135.3, 138.4, 141.1, 148.0; HRMS (ESI) calcd for $C_{23}H_{19}NNaO_2S$ (M^+ + Na) 396.1029, found 396.1028.

*4-(5-Chloropent-1-en-2-yl)-6-methyl-1-(phenylsulfonyl)-1H-indole (**2e**).* General procedure E: yellowish-brown oil; mixture of **2e** (29.9 mg, 82% yield) and 4-(5-chloropent-1-en-2-yl)-1-(phenylsulfonyl)-1*H*-indole (0.98 mg, 3% yield). The byproduct which was assigned by ^{1}H NMR might be derived from trace of impurity with **1e** (see the Supporting Information); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.81 (quint, J = 7.1 Hz, 2H), 2.46 (s, 3H), 2.66 (t, J = 7.1 Hz, 2H), 3.49 (t, J = 6.6 Hz, 2H), 5.17 (d, J = 1.7 Hz, 1H), 5.29 (d, J = 1.7 Hz, 1H), 6.71

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(dd, J = 3.7, 0.6 Hz, 1H), 6.94 (s, 1H), 7.45 (t, J = 8.0 Hz, 2H), 7.50 (d, J = 3.7 Hz, 1H), 7.54 (tt, J = 7.8, 1.1 Hz, 1H), 7.73 (s, 1H), 7.89 (dd, J = 8.3, 1.5 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.9, 30.7, 33.9, 44.4, 108.3, 112.5, 115.8, 123.1, 125.5, 126.6, 126.8, 129.3, 133.8, 134.6, 135.0, 135.4, 138.3, 145.9; HRMS (ESI) calcd for $C_{20}H_{20}ClNNaO_2S$ (M^+ + Na) 396.0795, found 396.0793.

*Methyl 4-(1-(4-Ethoxyphenyl)vinyl)-1-(phenylsulfonyl)-1H-indole-6-carboxylate (**2f**).* General procedure E (CH_2Cl_2): mixture of **1f** and its positional isomer (1/0.014) (**1f**: 71.4 mg, 0.149 mmol, dr = 0.65/0.35) was used; pale yellow solid (45.9 mg, 67% yield); mp 141−144 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.40 (t, J = 6.9 Hz, 3H), 3.95 (s, 3H), 4.02 (q, J = 6.9 Hz, 2H), 5.31 (d, J = 1.2 Hz, 1H), 5.64 (d, J = 1.2 Hz, 1H), 6.29 (dd, J = 3.7, 0.8 Hz, 1H), 6.79 (dt, J = 8.6, 2.0 Hz, 2H), 7.15 (dt, J = 8.9, 2.3 Hz, 2H), 7.47 (t, J = 8.3 Hz, 2H), 7.54−7.59 (m, 2H), 7.91−7.94 (m, 3H), 8.67 (t, J = 1.1 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 14.8, 52.3, 63.4, 108.9, 114.2, 114.4, 115.0, 124.8, 126.6, 126.9, 128.57, 128.59, 129.4, 132.9, 133.3, 134.1, 134.4, 135.5, 138.0, 146.7, 158.9, 167.2; HRMS (ESI) calcd for $C_{26}H_{23}NNaO_5S$ (M^+ + Na) 484.1189, found 484.1188.

*7-Methyl-1-(phenylsulfonyl)-4-(1-phenylvinyl)-1H-indole (**2g**).* General procedure E: blue-green oil (25.3 mg, 97% yield); ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.54 (s, 3H), 5.37 (d, J = 1.4 Hz, 1H), 5.72 (d, J = 1.1 Hz, 1H), 6.34 (d, J = 4.0 Hz, 1H), 7.02 (d, J = 7.5 Hz, 1H), 7.09 (d, J = 7.4 Hz, 1H), 7.23−7.30 (m, 5H), 7.42−7.47 (m, 2H), 7.56 (tt, J = 7.4, 1.1 Hz, 1H), 7.64 (d, J = 3.7 Hz, 1H), 7.67 (dd, J = 8.6, 1.1 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.7, 108.8, 115.8, 124.4, 124.6, 126.4, 127.4, 127.8, 128.1, 128.3, 129.2, 129.4, 131.8, 133.0, 133.5, 134.9, 139.8, 141.1, 147.8; HRMS (ESI) calcd for $C_{23}H_{20}NO_2S$ (M^+ + H) 374.1209, found 374.1208.

*1,4-Bis(1-(1-(phenylsulfonyl)-1H-indol-4-yl)vinyl)benzene (**2i**).* General procedure E (first: hexane/EtOAc = 2/1, second: CH_2Cl_2/EtOAc = 100/1): **6** (15 mol %) was used; pale yellow-green solid (22.1 mg, 94% yield); mp 219−222 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 5.39 (d, J = 1.1 Hz, 2H), 5.72 (d, J = 1.1 Hz, 2H), 6.31 (dd, J = 3.7, 0.6 Hz, 2H), 7.18 (s, 4H), 7.19 (dd, J = 7.8, 0.9 Hz, 2H), 7.31 (t, J = 8.3 Hz, 2H), 7.46 (t, J = 7.5 Hz, 4H), 7.47 (d, J = 3.7 Hz, 2H), 7.55 (tt, J = 7.4, 1.2 Hz, 2H), 7.88−7.92 (m, 4H), 7.97 (d, J = 8.3 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 108.8, 112.9, 116.2, 123.9, 124.5, 125.8, 126.8, 127.4, 129.3, 129.6, 133.9, 134.8, 135.0, 138.2, 140.4, 147.4; HRMS (ESI) calcd for $C_{38}H_{28}N_2NaO_4S_2$ (M^+ + Na) 663.1383, found 663.1378.

*1,3,5-Tris(1-(1-(phenylsulfonyl)-1H-indol-4-yl)vinyl)benzene (**2j**).* General procedure E: **6** (15 mol %) was used; pale brown solid (29.5 mg, 78% yield); mp 101−104 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.30 (d, J = 0.9 Hz, 3H), 5.39 (d, J = 0.9 Hz, 3H), 6.23 (dd, J = 3.6, 0.7 Hz, 3H), 7.05 (s, 3H), 7.10 (dd, J = 7.5, 0.7 Hz, 3H), 7.21 (t, J = 8.2 Hz, 3H), 7.40 (t, J = 8.2 Hz, 6H), 7.47 (d, J = 3.8 Hz, 3H), 7.51 (tt, J = 7.3, 1.2 Hz, 3H), 7.84−7.88 (m, 6H), 7.92 (d, J = 8.4 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 109.0, 113.0, 116.5, 123.9, 124.5, 125.8, 126.5, 126.7, 129.27, 129.33, 133.8, 134.6, 135.0, 138.2, 141.4, 147.6; HRMS (APCI) calcd for $C_{54}H_{40}N_3O_6S_3$ (M^+ + H) 922.2074, found 922.2083.

*4-(1-Phenylvinyl)-9-tosyl-9H-carbazole (**2k**).* General procedure E: yellow gum (35.3 mg, 99% yield); ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.28 (s, 3H), 5.37 (d, J = 0.8 Hz, 1H), 6.02 (d, J = 0.8 Hz, 1H), 7.06−7.11 (m, 1H), 7.11 (d, J = 8.0 Hz, 2H), 7.19−7.23 (m, 4H), 7.26−7.30 (m, 2H), 7.36 (ddd, J = 8.6, 7.2, 1.4 Hz, 1H), 7.49 (dd, J = 8.3, 7.4 Hz, 1H), 7.69−7.74 (m, 3H), 8.31 (d, J = 8.6 Hz, 1H), 8.38 (dd, J = 8.3, 0.6 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.5, 114.1, 114.7, 115.4, 122.9, 123.5, 124.1, 125.8, 125.9, 126.3, 126.5, 126.9, 128.0, 128.5, 129.6, 135.0, 136.7, 138.5, 138.6, 139.0, 144.8, 147.4; HRMS (ESI) calcd for $C_{27}H_{22}NO_2S$ (M^+ + H) 424.1366, found 424.1360.

Procedure for the Preparation of 1-(Phenylsulfonyl)-4-(1-phenylvinyl)-1*H*-indol-7-ol (8). To a solution of **1a** (41.8 mg, 0.111 mmol) in THF (2.2 mL) was added IBX (155 mg, 0.554 mmol, 5.0 equiv). The resulting suspension was refluxed for 4 h. The mixture was cooled to rt and filtered through a silica gel pad on Celite. The residual solid was washed thoroughly with EtOAc, and the filtrate was evaporated to give 7. The RCM/tautomerization step was carried out in the same manner as that for the general procedure E except for the treatment with *p*-TsOH (hexane/toluene = 1/3): pale brown solid (28.9 mg, 69% yield; two steps); mp 103−106 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 5.30 (d, J = 1.5 Hz, 1H), 5.61 (d, J = 1.4 Hz, 1H), 6.29 (d, J = 3.7 Hz, 1H), 6.92 (d, J = 8.0 Hz, 1H), 7.12 (d, J = 8.0 Hz, 1H), 7.18−7.29 (m, 5H), 7.32 (d, J = 3.7 Hz, 1H), 7.46 (tt, J = 7.4, 1.7 Hz, 2H), 7.56 (tt, J = 7.5, 1.2 Hz, 1H), 7.78−7.82 (m, 2H), 8.75 (s, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 111.7, 113.6, 115.3, 122.8, 126.7, 126.9, 127.2, 127.4, 127.5, 127.8, 128.2, 129.5, 133.2, 134.1, 137.0, 141.4, 144.1, 147.6; HRMS (ESI) calcd for $C_{22}H_{16}NO_3S$ (M^- − H) 374.0856, found 374.0865.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

General and additional information about materials and ^{1}H NMR and ^{13}C NMR spectra of new compounds. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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■ REFERENCES

(1) For a comprehensive review, see: (a) *Handbook of Metathesis*; Grubbs, R. H., Ed.; Wiley-VCH: Weinheim, 2003. For recent reviews, see: (b) Hoveyda, A. H.; Zhugralin, A. R. *Nature* **2007**, *450*, 243−251. (c) Samojlowicz, C.; Bieniek, M.; Grela, K. *Chem. Rev.* **2009**, *109*, 3708−3742. (d) Prunet, J. *Eur. J. Org. Chem.* **2011**, 3634−3647. (e) Kress, S.; Blechert, S. *Chem. Soc. Rev.* **2012**, *41*, 4389−4408. (f) Paek, S.-M. *Molecules* **2012**, *17*, 3348−3358.

(2) For reports on the pharmaceutical application of ring-closing metathesis on a multikilogram scale (>400 kg of cyclized product), see: (a) Nicola, T.; Brenner, M.; Donsbach, K.; Kreye, P. *Org. Process Res. Dev.* **2005**, *9*, 513−515. (b) Yee, N. K.; Farina, V.; Houpis, I. N.; Haddad, N.; Frutos, R. P.; Gallou, F.; Wang, X.-J.; Wei, X.; Simpson, R. D.; Feng, X.; Fuchs, V.; Xu, Y.; Tan, J.; Zhang, L.; Xu, J.; Smith-Keenan, L. L.; Vitous, J.; Ridges, M. D.; Spinelli, E. M.; Johnson, M.; Donsbach, K.; Nicola, T.; Brenner, M.; Winter, E.; Kreye, P.; Samstag, W. *J. Org. Chem.* **2006**, *71*, 7133−7145. (c) Tsantrizos, Y. S.; Ferland, J.-M.; McClory, A.; Poirier, M.; Farina, V.; Yee, N. K.; Wang, X.-J.; Haddad, N.; Wei, X.; Xu, J.; Zhang, L. *J. Organomet. Chem.* **2006**, *691*, 5163−5171.

(3) For reviews, see: (a) Donohoe, T. J.; Orr, A. J.; Bingham, M. *Angew. Chem., Int. Ed.* **2006**, *45*, 2664−2670. (b) van Otterlo, W. A. L.; de Koning, C. B. *Chem. Rev.* **2009**, *109*, 3743−3782.

(4) (a) Arisawa, M.; Nishida, A.; Nakagawa, M. *J. Organomet. Chem.* **2006**, *691*, 5109−5121. (b) Donohoe, T. J.; Fishlock, L. P.; Procopiou, P. A. *Chem.—Eur. J.* **2008**, *14*, 5716−5726.

(5) For recent examples, see: (a) Donohoe, T. J.; Bower, J. F.; Basutto, J. A.; Fishlock, L. P.; Procopiou, P. A.; Callens, C. K. A. *Tetrahedron* **2009**, *65*, 8969−8980. (b) Donohoe, T. J.; Bower, J. F. *Proc. Natl. Acad. Sci. U.S.A.* **2010**, *107*, 3373−3376. (c) Ziffle, V. E.; Cheng, P.; Clive, D. L. J. *J. Org. Chem.* **2010**, *75*, 8024−8038. (d) Donohoe, T. J.; Jones, C. R.; Barbosa, L. C. A. *J. Am. Chem. Soc.* **2011**, *133*, 16418−16421. (e) Schmidt, B.; Krehl, S.; Jablowski, E. *Org. Biomol. Chem.* **2012**, *10*, 5119−5130.

(6) For examples of the construction of benzene rings fused to aromatic heterocycles, see: (a) Selvakumar, N.; Khera, M. K.; Reddy, B. Y.; Srinivas, D.; Azhagan, A. M.; Iqbal, J. *Tetrahedron Lett.* **2003**, *44*, 7071−7074. (b) Bennasar, M. L.; Zulaica, E.; Tummers, S. *Tetrahedron*

Lett. **2004**, *45*, 6283−6285. (c) Pelly, S. C.; Parkinson, C. J.; Van Otterlo, W. A. L.; De Koning, C. B. *J. Org. Chem.* **2005**, *70*, 10474−10481. (d) Mamane, V.; Fort, Y. *J. Org. Chem.* **2005**, *70*, 8220−8223.

(7) (a) Yoshida, K.; Takahashi, H.; Imamoto, T. *Chem.—Eur. J* **2008**, *14*, 8246−8261. (b) Takahashi, H.; Yoshida, K.; Yanagisawa, A. *J. Org. Chem.* **2009**, *74*, 3632−3640. (c) Yoshida, K.; Hayashi, K.; Yanagisawa, A. *Org. Lett.* **2011**, *13*, 4762−4765.

(8) For selected reviews, see: (a) Sundberg, R. J. *Indoles*; Academic Press: London, 1996. (b) Somei, M.; Yamada, F. *Nat. Prod. Rep.* **2005**, *22*, 73−103. (c) Brancale, A.; Silvestri, R. *Med. Res. Rev.* **2007**, *27*, 209−238. (d) Higuchi, K.; Kawasaki, T. *Nat. Prod. Rep.* **2007**, *24*, 843−868. (e) Sharma, V.; Kumar, P.; Pathak, D. *J. Heterocycl. Chem.* **2010**, *47*, 491−502. (f) Somei, M. *Heterocycles* **2011**, *82*, 1007−1027.

(9) For selected reviews of methods for the construction of the indole skeleton, see: (a) Gribble, G. W. *J. Chem. Soc., Perkin Trans. 1* **2000**, 1045−1075. (b) Horton, D. A.; Bourne, G. T.; Smythe, M. L. *Chem. Rev.* **2003**, *103*, 893−930. (c) Humphrey, G. R.; Kuethe, J. T. *Chem. Rev.* **2006**, *106*, 2875−2911. (d) Cacchi, S.; Fabrizi, G. *Chem. Rev.* **2011**, *111*, PR215−PR283. (e) Taber, D. F.; Tirunahari, P. K. *Tetrahedron* **2011**, *67*, 7195−7210. (f) Vicente, R. *Org. Biomol. Chem.* **2011**, *9*, 6469−6480. (g) Inman, M.; Moody, C. J. *Chem. Sci.* **2013**, *4*, 29−41.

(10) For examples, see: (a) Katritzky, A. R.; Ledoux, S.; Nair, S. K. *J. Org. Chem.* **2003**, *68*, 5728−5730 and references cited therein. (b) Barluenga, J.; Vázquez-Villa, H.; Ballesteros, A.; González, J. M. *Adv. Synth. Catal.* **2005**, *347*, 526−530. (c) Palmieri, A.; Gabrielli, S.; Lanari, D.; Vaccaro, L.; Ballini, R. *Adv. Synth. Catal.* **2011**, *353*, 1425−1428.

(11) Fukuda, T.; Ohta, T.; Sudo, E.-i.; Iwao, M. *Org. Lett.* **2010**, *12*, 2734−2737.

(12) See the Experimental Section and Supporting Information for experimental details.

(13) (a) Scholl, M.; Ding, S.; Lee, C. W.; Grubbs, R. H. *Org. Lett.* **1999**, *1*, 953−956. (b) Vougioukalakis, G. C.; Grubbs, R. H. *Chem. Rev.* **2010**, *110*, 1746−1787.

(14) Although the yield was low, a substrate having the same substitution pattern as **1h** (R^4 = H, R^5 = Me, R^6 = H, R^7 = H) could be converted into the corresponding product in our previous report on the synthesis of simple styrenes (see ref 7b).

(15) For reports on the synthesis of carbazole from a functionalized indole precursor using the RCM/dehydration sequence, see ref 6a,b.

(16) Thadani, A. N.; Batey, R. A. *Org. Lett.* **2002**, *4*, 3827−3830.

(17) Araki, S.; Ito, H.; Butsugan, Y. *J. Org. Chem.* **1998**, *53*, 1831−1833.

(18) Maruoka, K.; Hashimoto, S.; Kitagawa, Y.; Yamamoto, H.; Nozaki, H. *J. Am. Chem. Soc.* **1977**, *99*, 7705−7707.