Palladium-Catalyzed Construction of Polycyclic Heterocycles by an Alkyne Insertion and Direct Arylation Cascade

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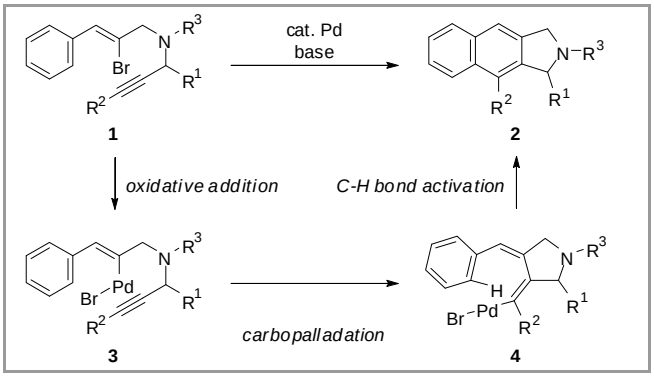
Abstract: Cascade cyclization of bromoenynes bearing an aryl group with catalytic $Pd(OAc)_2$ and Cs_2CO_3 led to direct construction of tri- or tetracyclic heterocycles. Direct arylation of a pyrrole, furan or thiophene ring in the cascade reaction affords the corresponding fused heteroarenes in moderate to good yields.

Key words: tandem reaction, palladium, polycycles, fused-ring systems, ring closure

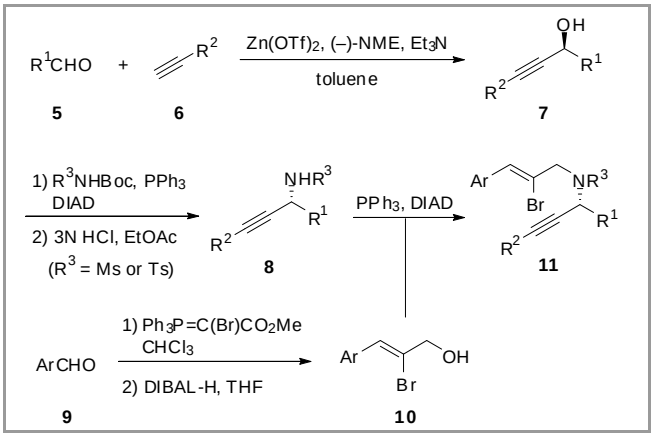
The development of cascade reactions that realize step-economical synthesis of complex compounds by multiple bond formation represents one of the most attractive subjects in modern organic chemistry.[1] Another challenge in this area is to improve atom economy by minimizing waste product formation.[2] C-H bond activation (including direct arylation), which avoids pre-activation of the substrate and thus minimizes the production of waste, is an important strategy for this purpose.[3] As a result, considerable attention has been paid recently to catalytic cascade reactions including a C-H bond activation step.[4]

Palladium catalysts are well known to promote a variety of transformations including C-H bond activation. Several palladium-catalyzed cascade reactions have been reported recently, including carbopalladation onto a carbon-carbon multiple bond followed by C-H bond activation to form cyclic products.[4,5] Reactions involving carbopalladation onto a carbon-carbon triple bond are especially useful for direct construction of fused aromatic ring systems[6,7] such as oxindoles,[6a,6b] fluorenes,[6c] indoles,[6d] phenanthrenes,[6e] biarylidenes,[7a,7b] acenaphthylenes,[7c] and fused fulvenes.[7d] We recently found that palladium-catalyzed cascade cyclization of bromoenynes **1** provides direct access to benzoisoindole derivatives **2** (Scheme 1).[8] This reaction proceeds through oxidative addition of a bromoenyne **1** to palladium(0), carbopalladation, and aromatic C-H bond activation. Herein, our detailed studies on this cascade cyclization including aromatic C-H bond activation for the synthesis of various tri- and tetracyclic heterocycles are reported. A reaction involving direct arylation with heteroarenes is also described.



Scheme 1 Synthesis of Isoindoles by Palladium-Catalyzed Cascade Reaction *via* C-H Bond Activation

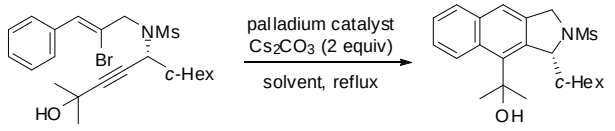
The cinnamylamine-type bromoenynes **11** required for the cascade reaction were prepared according to the general route shown in Scheme 2. Carreira asymmetric alkynylation[9] of aldehydes **5** with alkynes **6** gave propargylic alcohols **7**, which were converted to the corresponding protected propargylic amines **8** by Mitsunobu reaction with Boc-amides followed by acid treatment. In some cases, racemic propargylamines, which were readily prepared by reaction of lithium acetylide with aldehydes followed by amination, were used. A second Mitsunobu condensation with 2-bromocinnamyl alcohols **10**, which were obtained by Wittig reaction of aldehydes **9** followed by reduction with DIBAL-H, afforded the desired bromoenynes **11** in good yields. Other substrates were also prepared using a similar protocol (see the Supporting Information).



Scheme 2 General Syntheses of Substrates. *Abbreviations*: NME = *N*-methylephedrine, DIAD = diisopropyl azodicarboxylate

First, the reaction conditions were optimized using bromoenyne **11a** (Table 1). After considerable experimentation, it was found that the conditions used by Oh *et al.*[10] [cat. $Pd(PPh_3)_4$, Cs_2CO_3, EtOH] for a cascade cyclization–cross-coupling reaction of 2-bromo-1,6-enynes with an arylboronic acid promoted the desired bis-cyclization to give **12a**, albeit in low yield (26%, entry 1). Fortunately, use of $Pd(OAc)_2$ instead of $Pd(PPh_3)_4$ produced **12a** in 74% yield (entry 2). Decreasing the catalyst loading to 2 mol % slightly decreased the yield (64%, entry 3). A similar result was obtained using $Pd_2(dba)_3{\cdot}CHCl_3$ as the catalyst (entry 5). Among several solvents examined, EtOH was the most effective (entries 3, 6, and 7). Other bases such as K_2CO_3 and NaOAc proved ineffective for the reaction.[11]

Table 1 Optimization of Reaction Conditions Using Bromoenyne **11a**[a]



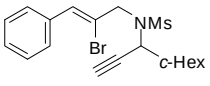
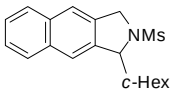
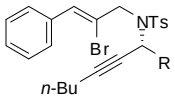
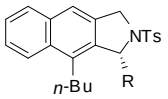
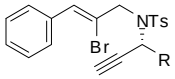
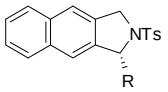
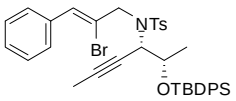
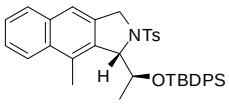
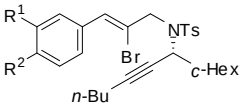
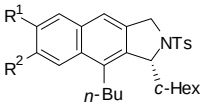
11a **12a**

entry	catalyst (mol %)	solvent	time (h)	yield (%)[b]
1	$Pd(PPh_3)_4$ (6)	EtOH	1	26
2	$Pd(OAc)_2$ (6)	EtOH	2.5	74
3	$Pd(OAc)_2$ (2)	EtOH	7	64
4	$Pd(dppf)_2Cl_2$ (2)	EtOH	3.5	38
5	$Pd_2(dba)_3{\cdot}CHCl_3$ (2)	EtOH	5	59
6[c]	$Pd(OAc)_2$ (2)	DMF	21	35
7	$Pd(OAc)_2$ (2)	dioxane	21	27

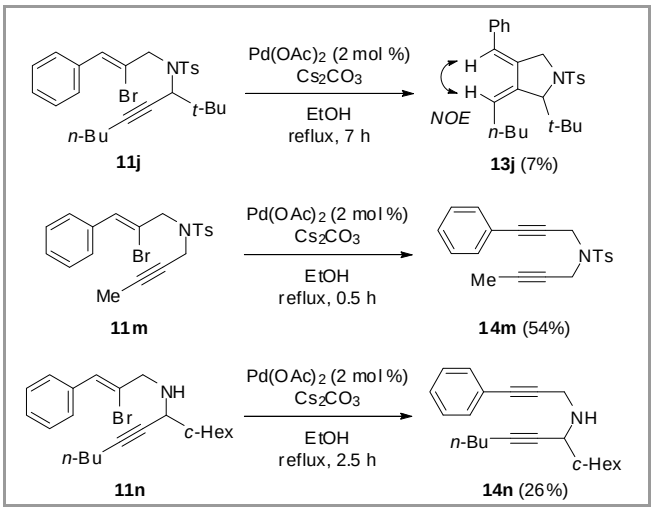
[a] Reactions were performed using Cs_2CO_3 (2 equiv). [b] Isolated yields. [c] The reaction was performed at 100 °C.

The reactions of various cinnamylamine-type enynes **11** using the optimized reaction conditions shown in entry 3 (Table 1) were investigated. The results of these reactions are summarized in Table 2. The influence of the substituent at the alkyne terminus was examined using *N*-tosylamides **11b–f**. 2-Hydroxypropan-2-yl, *n*-butyl, and unsubstituted derivatives **11b–d** gave the corresponding bis-cyclization products **12b–d** in 56–79% yield (entries 1–3). On the other hand, benzyloxymethyl derivative **11e** gave a complex mixture of unidentified products (entry 4). For an unclear reason, phenyl substitution also had a negative effect on the reaction, giving **12f** in just 27% yield (entry 5). Using different sulfonamide moieties (Ts *vs.* Ms) was relatively unimportant (Table 2, entry 3 vs. 6, and Table 2, entry 1 vs. Table 1, entry 3). In contrast, the reaction is sensitive to the substituent at the propargylic position (entries 7–11); unfortunately, substitution with a phenyl group was not tolerated (entry 7). The presence of a relatively bulky substituent such as an isopropyl or 1-siloxyethyl group at this position decreased the reaction yield (entries 10 and 11). When *tert*-butyl derivative **11j** was used (Scheme 3), only the monocyclization product **13j** was obtained in 7% yield; the desired bis-cyclization product did not form. These bulky substituents might hamper the access of the palladium(II) intermediate of type **3** (Scheme 1) to the alkyne moiety. It should be noted that enynes **11m** and **11n** without propargylic or nitrogen substitution formed elimination products **14** (Scheme 3).[12] From these observations, the presence of both a substituent with appropriate bulkiness at the propargylic position and at the nitrogen atom are important for the cascade cyclization to proceed. Methoxy substitution at the *para*-position of the benzene ring decreased the reaction yield (37%, entry 13), while *meta*-methoxy substitution was tolerated (57%, entry 12).

Table 2 Synthesis of Benzoisoindole Derivatives[a]

entry	substrate	time (h)	product (yield)[b]
1	**11b** (R = CMe_2OH)	2.5	**12b** (64%)
2	(±)-**11c** (R = *n*-Bu)	6	(±)-**12c** (79%)
3	(±)-**11d** (R = H)	2	(±)-**12d** (56%)
4	**11e** (R = CH_2OBn)	1.5	**12e** (0%)[c]
5	**11f** (R = Ph)	6	**12f** (27%)
6	 **11g**	6	 **12g** (46%)
7	 **11h** (R = Ph)	1	 **12h** (0%)[c]
8	(±)-**11i** (R = *n*-Pent)	3	(±)-**12i** (65%)
9	 (±)-**11k** (R = *n*-Pent)	1.5	 (±)-**12k** (48%)
10	**11l** (R = *i*-Pr)	4	**12l** (24%)
11[d]	 **11o**	24	 **12o** (39%)
12	 **11p** (R^1 = OMe, R^2 = H)	5	 **12p** (57%)
13	**11q** (R^1 = H, R^2 = OMe)	8	**12q** (37%)

[a] Unless otherwise noted, reactions were carried out using $Pd(OAc)_2$ (2 mol %) and Cs_2CO_3 (2 equiv) in EtOH under reflux. [b] Isolated yields. [c] A complex mixture of unidentified products was formed. [d] An increased amount of $Pd(OAc)_2$ (4 mol %) was used.



Scheme 3 Unsuccessful Results using Bromoenynes **11j**,**m**,**n**.

Table 3 Synthesis of Tricyclic Heterocycles[a]

entry	substrate	conditions[b]	product (yield)[c]
1	**15a**	2 mol %, EtOH, 2 h	**16a** (43%)
2	**15b** (R = Ts)	10 mol %, DMF, 72 h	**16b** (27%)[d]
3	**15b** (R = Ts)	20 mol %, DMF, 2 h	**16b** (75%)
4	**15c** (R = Mts)	10 mol %, DMF, 2 h	**16c** (42%)
5	**15c** (R = Mts)	20 mol %, DMF, 2 h	**16c** (81%)
6	**15c** (R = Mts)	10 mol %, EtOH, 12 h	**16c** (36%)
7	**15d** (R = SO_2NMe_2)	10 mol %, EtOH, 12 h	**16d** (52%)
8	**15d** (R = SO_2NMe_2)	10 mol %, DMF, 3 h	**16d** (33%)
9	**15e**	20 mol %, DMF, 4 h	**16e** (42%)

[a] The reactions were carried out using $Pd(OAc)_2$ and Cs_2CO_3 (2 equiv) in EtOH (under reflux) or DMF (at 120 °C). [b] Catalyst loading, reaction solvent, and reaction time are shown. [c] Isolated yields. [d] The starting material was recovered (27%).
Abbreviation: Mts = 2,4,6-trimethylbenzenesulfonyl.

To expand the reaction to construct various heterocyclic ring systems, the direct arylation[13] of heterocyclic substrates **15a–e** was investigated (Table 3). The reaction of furan-substituted enyne **15a** was complete within 2 h to afford furo[2,3-*f*]isoindole **16a** in moderate yield (43%, entry 1). Bromoenynes **15b–e** bearing a pyrrole ring exhibited relatively low reactivity and thus required an increased loading of the palladium catalyst (entries 2–9). For example, the reaction of tosylamide **15b** with 10 mol % $Pd(OAc)_2$ and Cs_2CO_3 in DMF did not reach completion within 72 h, giving the desired tetrahydropyrrolo[3,4-*f*]indole **16b** in 27% yield along with the recovered starting material (entry 2). In contrast, the yield of **16b** was improved to 75% when 20 mol % of the catalyst was used (entry 3). Similar results were obtained using *N*-Mts derivative **15c** (Mts = 2,4,6-trimethylbenzenesulfonyl, entries 4 and 5). It is worth noting that DMF was the solvent of choice for the reaction of protected pyrroles **15b** and **15c** because the reaction in EtOH was relatively inefficient and caused decomposition of the starting material (entry 6). When using electron-rich sulfonamide **15d**, the decomposition of the substrate in EtOH was suppressed to some extent, and the desired fused indole **16d** was produced in 52% yield (entry 7). The 2-position of the pyrrole was less reactive toward direct arylation than the 3-position in this cascade reaction (entry 3 *vs*. entry 9).

Table 4 Synthesis of Tetracyclic Heterocycles[a]

entry	substrate	conditions[b]	product (yield)[c]
1	**17a** (R = Ts)	5 mol %, DMF, 18 h	**18a** (51%)
2	**17b** (R = Mts)	5 mol %, DMF, 3 h	**18b** (31%)
3	**17c** (R = CO_2Me)	5 mol %, DMF, 4 h	**18c** (0%)[d]
4	**17c** (R = CO_2Me)	5 mol %, EtOH, 1 h	**18c** (0%)[e]
5	**17d** (R = Me)	10 mol %, EtOH, 36 h	**18d** (43%)
6	**17e**	2 mol %, EtOH, 3 h	**18e** (49%)
7	**17f**	2 mol %, EtOH, 1 h	**18f** (59%)
8	**17g**	5 mol %, DMF, 5 h[f]	**18g** (43%)

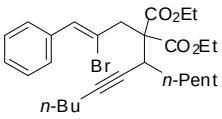
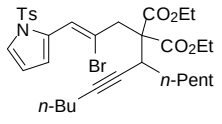
[a] Reactions were carried out using $Pd(OAc)_2$ and Cs_2CO_3 (2 equiv) in EtOH (under reflux) or DMF (at 120 °C). [b] Catalyst loading, reaction solvent, and reaction time are shown. [c] Isolated yields. [d] A complex mixture of unidentified products was formed. [e] The demethoxycarbonylation product was obtained (67%). [f] 2 h with 2 mol % catalyst and a further 3 h with an additional 3 mol % catalyst.
Abbreviation: Mts = 2,4,6-trimethylbenzenesulfonyl.

The synthesis of tetracyclic fused ring systems was investigated next (Table 4). Among the protected indole-derived bromoenynes **17a–c** (entries 1–4), tosylate **17a** proved the most efficient substrate for the cascade reaction, giving the desired tetrahydropyrrolo[3,4-*b*]carbazole **18a** upon reaction in DMF (entry 1). The reaction of carbamate **17c** in EtOH only promoted demethoxycarbonylation of the substrate (entry 4). Interestingly, the electron-rich *N*-

methylindole-derived enyne **17d** was less reactive, affording **18d** in 43% yield using an increased loading of the palladium catalyst (10 mol %, entry 5). These results suggest that the direct arylation of indole derivatives **17** proceeds through a concerted metalation-deprotonation (CMD) pathway rather than electrophilic aromatic substitution (S_EAr).[14] The reaction of benzothiophen-3-yl- and benzofuran-2-ylenynes **17e** and **17f** produced the corresponding benzothiophene- and benzofuran-fused isoindoles **18e** and **18f**, respectively, in moderate yields (entries 6 and 7). 2,3-Dihydronaphtho[2,3-*f*]isoindole **18g** was obtained in 43% yield by activation of the naphthalene C-H bond (entry 8).

Finally, construction of an indane skeleton using malonate congeners **19** was investigated (Table 5). The reaction of **19a** with $Pd(OAc)_2$ in EtOH produced tricyclic carbocycle **20a** in 68% yield (entry 2). Other palladium catalysts such as $Pd_2(dba)_3{\cdot}CHCl_3$ (entry 3) and $Pd(PPh_3)_4$ (entry 4) were less effective. The presence of a substituent at the propargylic position was important to promote the desired cascade cyclization also in the reactions using malonate derivatives.[12] The reaction of pyrrole-derived malonate **19b** in DMF at 140 °C resulted in the formation of cyclopenta[*f*]indole derivative **20b** in low yield (35%, entry 5).

Table 5 Synthesis of Indane Derivatives[a]

entry	substrate	conditions[b]	product (yield)[c]
1		**19a**	5 mol %, DMF, 6 h	**20a** (0%)[d]
2		**19a**	5 mol %, EtOH, 2 h	**20a** (68%)
3		**19a**	5 mol %,[e] DMF, 4 h	**20a** (34%)
4		**19a**	5 mol %,[f] DMF, 4 h	**20a** (17%)
5		**19b**	5 mol%, DMF, 24 h[g]	**20b** (35%)

[a] Unless otherwise stated, reactions were performed using $Pd(OAc)_2$ and Cs_2CO_3 (2 equiv) in EtOH (under reflux) or DMF (at 120 °C). [b] Catalyst loading, reaction solvent, and reaction time are shown. [c] Isolated yields. [d] A complex mixture of unidentified products was formed. [e] $Pd_2(dba)_3{\cdot}CHCl_3$ was used. [f] $Pd(PPh_3)_4$ was used. [g] The reaction was conducted at 140 °C.

In conclusion, we have developed a palladium-catalyzed cascade for cyclization of bromoenynes. The reaction proceeds through carbopalladation onto a carbon-carbon triple bond and C-H bond activation of a benzene ring, leading to the direct construction of isoindole derivatives. The presence of a propargylic substituent is quite important for the progress of the reaction. Direct arylation of heteroarenes such as pyrrole, furan, thiophene and their benzene-fused rings allows various types of tri- and tetracyclic heterocycles to be produced from readily prepared enynes.

Melting points are uncorrected. Nominal (LRMS) and exact mass (HRMS) spectra were recorded on a JEOL JMS-700 or JMS-600 mass spectrometer. ^{1}H NMR spectra were recorded in $CDCl_3$. Chemical shifts are reported in parts per million downfield from internal Me_4Si (s = singlet, d = doublet, dd = double doublet, ddd = doublet of double doublet, t = triplet, dt = double triplet, tt = triple triplet, q = quartet, m = multiplet). Optical rotations were measured in $CHCl_3$ with a JASCO DIP-360 digital polarimeter. For flash chromatography, silica gel 60 H (silica gel for thin-layer chromatography, Merck) or silica gel 60 (finer than 230 mesh, Merck) was employed.

General procedure for Synthesis of Bromoenynes (11) by Condensation of Propargyl Amine Derivatives (8) with 3-Aryl-2-bromoprop-2-en-1-ols (10)

To a stirred mixture of protected propargylic amine **8** (*ca*. 3 mmol), alcohol **10** (2.2 equiv), and PPh_3 (2.2 equiv) in THF (30 mL) was added dropwise diisopropyl azodicarboxylate (DIAD; 2.2 equiv) at 0 °C. The mixture was stirred for 4 h at room temperature and concentrated under reduced pressure. The residue was purified by column chromatography over silica gel with an eluent of *n*-hexane–EtOAc to give **11**.

General Procedure for the Palladium-Catalyzed Cascade Cyclization of Bromoenynes: Synthesis of (1*R*)-1-Cyclohexyl-9-(2-hydroxypropan-2-yl)-2-methylsulfonyl-2,3-dihydro-1*H*-benzo[*f*]isoindole (12a) (Table 1, Entry 3)

A mixture of **11a** (124 mg, 0.265 mmol), Cs_2CO_3 (173 mg, 0.531 mmol), and $Pd(OAc)_2$ (1.2 mg, 0.0531 mmol; 2 mol %) in EtOH (1.5 mL) was heated under reflux for 7 h. After cooling the mixture, saturated NH_4Cl was added. The mixture was then extracted with EtOAc and dried over $MgSO_4$. Concentration under reduced pressure gave an oily residue, which was purified by column chromatography over silica gel with *n*-hexane–EtOAc (10:1) to give **12a** (65.7 mg, 64% yield) along with an unidentified minor product (2.5 mg, 3% yield).

Compound **12a**: colorless oil; $[\alpha]^{28}_D$ +31.4 (*c* 0.62, $CHCl_3$).

IR (KBr): 3545 (OH), 1336 (NSO_2), 1153 cm^{-1} (NSO_2).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.90–1.28 (m, 5H), 1.58–1.85 (m, 6H), 1.96 (s, 3H, CMe), 2.03 (s, 3H, CMe), 2.55 (s, 3H, SO_2Me), 4.65 (dd, *J* = 16.8, 1.2 Hz,

1H, NC*H*H), 4.80 (dd, *J* = 16.8, 1.2 Hz, 1H, NCH*H*), 5.97 (d, *J* = 1.2 Hz, 1H, 1-H), 7.42–7.50 (m, 2H, Ar), 7.61 (s, 1H, Ar), 7.79–7.82 (m, 1H, Ar), 8.25 (dd, *J* = 9.9, 2.7 Hz, 1H, Ar).

^{13}C NMR (67.5 MHz, $CDCl_3$): δ = 26.2, 26.3, 26.7 (2C), 31.4, 32.6, 34.2 (2C), 47.0, 53.4, 71.9, 75.2, 120.8, 125.0, 125.1, 126.5, 129.0, 130.3, 134.6, 136.4, 137.3, 139.0.

MS (FAB): *m/z* (%) = 388 [MH^+] (53), 154 (100).

HRMS–FAB: *m/z* [M + H]$^+$ calcd for $C_{22}H_{30}NO_3S$: 388.1946; found: 388.1948.

Minor product: colorless oil; $[\alpha]^{22}_D$ –114 (*c* 0.14, $CHCl_3$).

IR (KBr): 3519 (OH), 1338 (NSO_2), 1159 cm^{-1} (NSO_2).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.10 (s, 3H, CMe), 1.15–1.96 (m, 12H), 1.31 (s, 3H, CMe), 2.79 (s, 3H, SO_2Me), 4.47 (d, *J* = 1.2 Hz, 2H), 5.84 (s, 1H, C=CH), 7.13–7.27 (m, 5H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 26.1, 26.2, 26.3, 27.5, 28.8, 29.1, 29.4, 34.5, 43.2, 49.7, 67.6, 70.8, 113.8, 127.4 (2C), 127.6, 128.7 (2C), 136.7, 138.6, 148.9, 149.3.

MS (FAB): *m/z* (%) = 410 (40) [M + Na^+], 176 (100).

HRMS–FAB: *m/z* [M + Na]$^+$ calcd for $C_{22}H_{29}NNaO_3S$: 410.1766; found: 410.1789.

(1*R*)-1-Cyclohexyl-9-(2-hydroxypropan-2-yl)-2-(4-methylphenylsulfonyl)-2,3-dihydro-1*H*-benzo[*f*]isoindole (12b)

Bromoenyne **11b** (124 mg, 0.227 mmol) was converted to **12b** (67.6 mg, 64% yield) and minor product (17.1 mg, 16% yield) by the reaction for 2.5 h.

12b: Colorless oil; $[\alpha]^{23}_D$ +50.6 (*c* 0.60, $CHCl_3$).

IR (KBr): 3525 (OH), 1599 (naphthalene), 1340 ($NHSO_2$), 1161 cm^{-1} ($NHSO_2$).

^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.86–1.94 (m, 11H), 1.76 (s, 3H, CMe), 1.96 (s, 3H, CMe), 2.12 (s, 3H, PhMe), 4.62 (d, *J* = 16.5 Hz, 1H, NC*H*H), 4.75 (d, *J* = 16.5 Hz, 1H, NCH*H*), 6.08 (d, *J* = 1.5 Hz, 1H, 1-H), 7.00 (d, *J* = 7.9 Hz, 2H, Ph), 7.35–7.40 (m, 3H, Ar), 7.64–7.70 (m, 3H, Ar), 8.14 (d, *J* = 8.5 Hz, 1H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 21.3, 26.27, 26.30, 26.8 (2C), 31.5, 32.3, 33.7, 47.3, 53.5, 72.2, 75.1, 120.2, 124.6, 124.7, 126.4 (2C), 127.5, 128.8 (2C), 129.1, 130.1, 134.3, 135.1, 136.5, 137.4, 138.0, 143.0.

MS (FAB): *m/z* (%) = 464 (38) [M + H^+], 380 (100).

HRMS–FAB: *m/z* [M + H]$^+$ calcd for $C_{28}H_{34}NO_3S$: 464.2259; found: 464.2270.

Minor product: colorless crystals; Mp 152–154 °C (*n*-hexane–EtOAc); $[\alpha]^{23}_D$ +280 (*c* 0.33, $CHCl_3$).

IR (KBr): 3523 (OH), 1344 ($NHSO_2$), 1166 cm^{-1} ($NHSO_2$).

^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.86–1.98 (m, 11H), 1.00 (s, 3H, CMe), 1.20 (s, 3H, CMe), 2.41–2.43 (m, 1H), 2.53 (s, 3H, PhMe), 4.36 (s, 1H), 4.41 (s, 1H), 5.93 (s, 1H, C=CH), 6.66 (d, 2H, *J* = 7.3 Hz, Ar), 7.13–7.35 (m, 5H, Ar), 7.66 (d, 2H, *J* = 8.5 Hz, Ph).

^{13}C NMR (67.8 MHz, $CDCl_3$): δ = 21.8, 26.2, 26.35, 26.42, 27.8, 29.0, 29.1, 29.2, 43.1, 49.4, 67.3, 70.6, 114.0, 127.2, 127.4 (2C), 128.0 (2C), 128.2 (2C), 129.4 (2C), 133.2, 137.1, 138.5, 143.3, 148.5, 149.1.

MS (FAB): *m/z* (%) = 464 (56) [M + Na^+], 154 (100).

HRMS–FAB: *m/z* [M + Na]$^+$ calcd for $C_{28}H_{33}NNaO_3S$: 486.2074; found: 486.2079.

Anal. Calcd for $C_{28}H_{33}NO_3S$: C, 72.54; H, 7.17; N, 3.02. Found: C, 72.50; H, 7.19; N, 2.99.

(±)-9-Butyl-1-cyclohexyl-2-(4-methylphenylsulfonyl)-2,3-dihydro-1*H*-benzo[*f*]isoindole (12c)

Bromoenyne **11c** (130 mg, 0.240 mmol) was converted to **12c** (87.8 mg, 79% yield) by the reaction for 6 h.

Colorless oil; IR (KBr): 1346 (NSO_2), 1163 cm^{-1} (NSO_2).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.90–2.16 (m, 18H), 2.38 (s, 3H, PhMe), 2.81–2.91 (m, 1H, 1'-C*H*H), 2.95–3.05 (m, 1H, 1'-CH*H*), 4.71 (d, *J* = 16.2 Hz, 1H, 3-C*H*H), 4.83 (d, *J* = 16.2 Hz, 1H, 3-CH*H*), 5.12 (s, 1H, 1-H), 6.99 (d, *J* = 8.1 Hz, 2H, Ph), 7.34–7.46 (m, 3H, Ar), 7.57 (d, *J* = 8.1 Hz, 2H, Ph), 7.70 (d, *J* = 7.5 Hz, 1H, Ar), 7.92 (d, *J* = 8.1 Hz, 1H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.0, 21.3, 23.2, 26.1, 26.4, 26.5, 26.7, 29.5, 31.5, 32.9, 45.4, 54.9, 70.4, 118.6, 124.0, 125.3, 125.4, 127.2 (2C), 128.5, 129.3 (2C), 131.5, 132.6, 133.6, 135.1, 135.8, 136.8, 143.1.

MS (FAB): *m/z* (%) = 462 (60) [M + H^+], 378 (100).

HRMS–FAB: *m/z* [M + H]$^+$ calcd for $C_{29}H_{36}NO_2S$: 462.2467; found: 462.2467.

(±)-1-Cyclohexyl-2-(4-methylphenylsulfonyl)-2,3-dihydro-1*H*-benzo[*f*]isoindole (12d)

Bromoenyne **11d** (63.9 mg, 0.131 mmol) was converted to **12d** (29.7 mg, 56% yield) by the reaction for 2 h.

Colorless oil; IR (KBr): 1346 (NSO_2), 1161 cm^{-1} (NSO_2).

^{1}H NMR (270 MHz, $CDCl_3$): δ = 0.89–1.34 (m, 5H), 1.50–1.75 (m, 6H), 2.24 (s, 3H, PhMe), 4.74 (d, *J* = 15.5 Hz, 1H, 3-C*H*H), 4.78 (d, *J* = 15.5 Hz, 1H, 3-CH*H*), 5.02 (d, *J* = 4.3 Hz, 1H, 1-H), 7.10 (d, *J* = 8.4 Hz, 2H, Ph), 7.41–7.44 (m, 2H, Ar), 7.53 (d, *J* = 9.5 Hz, 2H, Ar), 7.64 (d, *J* = 8.4 Hz, 2H, Ph), 7.71–7.79 (m, 2H, Ar).

^{13}C NMR (68 MHz, $CDCl_3$): δ = 21.5, 26.2, 26.3, 26.5, 28.2, 28.8, 45.9, 53.8, 70.6, 120.4, 121.8, 125.7, 125.8,

127.0 (2C), 127.5, 127.9, 129.4 (2C), 132.6, 132.8, 135.2, 135.8, 137.9, 143.1.

MS (FAB): *m/z* (%) = 406 (70) [M + H^+], 322 (100).

HRMS–FAB: *m/z* [M + H]$^+$ calcd for $C_{25}H_{28}NO_2S$: 406.1841; found: 406.1823.

(1*R*)-1-Cyclohexyl-2-(4-methylphenylsulfonyl)-9-phenyl-2,3-dihydro-1*H*-benzo[*f*]isoindole (12f)

Bromoenyne **11f** (64.0 mg, 0.114 mmol) was converted to **12f** (15.0 mg, 27% yield) by the reaction for 6 h.

Colorless oil; $[\alpha]^{25}_D$ –46.5 (*c* 0.60, $CHCl_3$).

IR (KBr): 1346 (NSO_2), 1163 cm^{-1} (NSO_2).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.83–1.05 (m, 6H), 1.22–1.64 (m, 5H), 2.25 (s, 3H, PhMe), 4.75 (d, *J* = 16.5 Hz, 1H, 3-C*H*H), 4.93 (d, *J* = 16.5 Hz, 1H, 3-CH*H*), 5.02 (d, *J* = 2.4 Hz, 1H, 1-H), 6.94–6.97 (m, 1H, Ar), 7.13 (d, *J* = 8.4 Hz, 2H, Ph), 7.28–7.74 (m, 2H, Ar), 7.41 (dd, *J* = 8.1, 8.1 Hz, 1H, Ar), 7.48–7.51 (m, 5H, Ar), 7.66 (d, *J* = 8.4 Hz, 2H, Ph), 7.76 (d, *J* = 8.1 Hz, 1H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 21.4, 26.1, 26.2, 26.5 (2C), 31.2, 43.7, 55.0, 70.5, 119.9, 125.65, 125.70, 125.9, 127.3 (2C), 127.8 (2C), 128.2, 128.6, 129.1, 129.5 (2C), 130.5, 132.0, 133.3, 134.1, 135.1, 135.8, 137.3, 137.6, 143.4.

MS (FAB): *m/z* (%) = 482 (6.8) [M + H^+], 154 (100).

HRMS–FAB: *m/z* [M + H]$^+$ calcd for $C_{31}H_{32}NO_2S$: 482.2154; found: 482.2159.

(±)-1-Cyclohexyl-2-methylsulfonyl-2,3-dihydro-1*H*-benzo[*f*]isoindole (12g)

Bromoenyne **11g** (36.8 mg, 0.0897 mmol) was converted to **12g** (13.7 mg, 46% yield) by the reaction for 6 h.

Colorless oil; IR (KBr): 1346 (NSO_2), 1161 cm^{-1} (NSO_2).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.99–1.33 (m, 6H), 1.61–1.80 (m, 5H), 2.60 (s, 3H, SO_2Me), 4.76 (d, *J* = 16.2 Hz, 1H, 3-C*H*H), 4.86 (d, *J* = 16.2 Hz, 1H, 3-CH*H*), 4.92 (d, *J* = 4.5 Hz, 1H, 1-H), 7.48–7.51 (m, 2H, Ar), 7.71 (s, 2H, 4-H and 9-H), 7.82–7.87 (m, 2H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 26.1, 26.17, 26.21, 28.5, 28.6, 34.8, 45.3, 53.8, 70.4, 120.9, 122.3, 126.2, 126.3, 127.8, 128.0, 132.9, 133.2, 135.9, 138.2.

MS (FAB): *m/z* (%) = 330 (34) [M + H^+], 246 (100).

HRMS–FAB: *m/z* [M + H]$^+$ calcd for $C_{19}H_{24}NO_2S$: 330.1528; found: 330.1514.

(±)-9-Butyl-2-(4-methylphenylsulfonyl)-1-pentyl-2,3-dihydro-1*H*-benzo[*f*]isoindole (12i)

Bromoenyne **11i** (72.0 mg, 0.136 mmol) was converted to **12i** (39.9 mg, 65% yield) by the reaction for 3 h.

Colorless oil; IR (KBr): 1346 (NSO_2), 1161 cm^{-1} (NSO_2).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.82 (t, *J* = 7.2 Hz, 3H, CMe), 0.97 (t, *J* = 7.2 Hz, 3H, CMe), 1.15–1.28 (m, 5H), 1.39–1.54 (m, 5H), 1.74–1.85 (m, 1H), 1.98–2.10 (m, 1H), 2.24 (s, 3H, PhMe), 2.88 (dt, *J* = 13.8, 3.3 Hz, 1H, 1'-C*H*H), 2.98 (dt, *J* = 13.8, 3.3 Hz, 1H, 1'-CH*H*), 4.78 (d, *J* = 16.5 Hz, 1H, 3-C*H*H), 4.84 (d, *J* = 16.5 Hz, 1H, 3-CH*H*), 5.29 (dd, *J* = 5.7, 3.3 Hz, 1H, 1-H), 7.09 (d, *J* = 8.7 Hz, 2H, Ph), 7.39–7.47 (m, 3H, Ar), 7.64 (d, *J* = 8.7 Hz, 2H, Ph), 7.73 (dd, *J* = 7.8, 1.8 Hz, 1H, Ar), 7.93 (dd, *J* = 7.5, 1.8 Hz, 1H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.0, 14.1, 21.3, 22.5, 23.3, 24.1, 29.2, 31.8, 32.8, 36.4, 53.3, 65.4, 119.1, 123.9, 125.4, 125.5, 127.0 (2C), 128.5, 129.5 (2C), 131.5, 132.5, 133.7, 135.2, 135.6, 137.1, 143.2.

MS (FAB): *m/z* (%) = 450 (62) [M + H^+], 378 (100).

HRMS–FAB: *m/z* [M + H]$^+$ calcd for $C_{28}H_{36}NO_2S$: 450.2467; found: 450.2458.

(±)-2-(4-Methylphenylsulfonyl)-1-pentyl-2,3-dihydro-1*H*-benzo[*f*]isoindole (12k)

Bromoenyne **11k** (94.2 mg, 0.199 mmol) was converted to **12k** (37.8 mg, 48% yield) by the reaction for 1.5 h.

Colorless oil; IR (KBr): 1346 (NSO_2), 1163 cm^{-1} (NSO_2).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.81 (t, *J* = 6.9 Hz, 3H, CMe), 1.02–1.10 (m, 1H), 1.18–1.25 (m, 4H), 1.39–1.47 (m, 1H), 1.89–2.00 (m, 1H), 2.13–2.25 (m, 1H), 2.31 (s, 3H, PhMe), 4.77 (d, *J* = 14.7 Hz, 1H, 3-C*H*H), 4.83 (d, *J* = 14.7 Hz, 1H, 3-CH*H*), 5.16 (t, *J* = 4.5 Hz, 1H, 1-H), 7.20 (d, *J* = 8.1 Hz, 2H, Ph), 7.40–7.46 (m, 2H, Ar), 7.53 (s, 1H, Ar), 7.57 (s, 1H, Ar), 7.72 (d, *J* = 8.1 Hz, 2H, Ph), 7.75–7.79 (m, 2H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.0, 21.4, 22.5, 23.2, 31.8, 37.0, 53.4, 65.5, 120.8, 120.9, 125.88, 125.93, 127.3 (2C), 127.67, 127.68, 127.8, 129.7 (2C), 133.0, 134.9, 135.0, 139.3, 143.4.

(1*R*)-1-Isopropyl-2-(4-methylphenylsulfonyl)-2,3-dihydro-1*H*-benzo[*f*]isoindole (12l)

Bromoenyne **11l** (52.8 mg, 0.118 mmol) was converted to **12l** (10.5 mg, 24% yield) by the reaction for 4 h.

Colorless oil; $[\alpha]^{27}_D$ –20.8 (*c* 0.60, $CHCl_3$).

IR (KBr): 1344 (NSO_2), 1161 cm^{-1} (NSO_2).

^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.80 (d, *J* = 6.7 Hz, 3H, CMe), 0.99 (d, *J* = 7.3 Hz, 3H, CMe), 2.19 (s, 3H, PhMe), 2.32–2.36 (m, 1H, Me_2C*H*), 4.71 (s, 1H, *J* = 15.5 Hz, 3-C*H*H), 4.74 (d, *J* = 15.5 Hz, 1H, 3-CH*H*), 4.99 (d, *J* = 4.3 Hz, 1H, 1-H), 7.06 (d, *J* = 7.9 Hz, 2H,

Ph), 7.357 (d, *J* = 6.1 Hz, 1H, Ar), 7.365 (d, *J* = 6.1 Hz, 1H, Ar), 7.47 (s, 1H, Ar), 7.50 (s, 1H, Ar), 7.59 (d, *J* = 7.9 Hz, 2H, Ph), 7.66–7.71 (m, 2H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 17.3, 18.4, 21.4, 35.8, 53.8, 70.9, 120.6, 121.9, 125.8, 125.9, 127.1 (2C), 127.6, 128.0, 129.6 (2C), 132.8, 133.0, 135.3, 135.9, 137.6, 143.3.

MS (FAB): *m/z* (%) = 366 (22) [M + H^+], 154 (100).

HRMS–FAB: *m/z* [M + H]$^+$ calcd for $C_{22}H_{24}NO_2S$: 366.1528; found: 366.1523.

(1*S*)-1-{(1*S*)-1-[*tert*-Butyl(diphenyl)silyloxy]ethyl}-9-methyl-2-(4-methylphenylsulfonyl)-2,3-dihydro-1*H*-benzo[*f*]isoindole (12o)

Bromoenyne **11o** (57.3 mg, 0.0818 mmol) was converted to **12o** (20.0 mg, 39% yield) by the reaction using $Pd(OAc)_2$ (0.8 mg, 0.00327 mmol) for 24 h.

Colorless oil; $[\alpha]^{23}_D$ –86.5 (*c* 0.60, $CHCl_3$).

IR (KBr): 1346 (NSO_2), 1161 cm^{-1} (NSO_2).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.63 (s, 9H, CMe_3), 1.26 (d, *J* = 6.0 Hz, 3H, CMe), 2.17 (s, 3H, CMe), 2.32 (s, 3H, PhMe), 4.27 (d, *J* = 6.0 Hz, 1H, OCH), 4.81 (d, *J* = 15.6 Hz, 1H, 3-C*H*H), 5.00 (d, *J* = 15.6 Hz, 1H, 3-CH*H*), 5.13 (s, 1H, 1-H), 6.99–7.02 (m, 6H, Ar), 7.27–7.58 (m, 11H, Ar), 7.75 (d, *J* = 7.5 Hz, 1H, Ar), 7.90 (d, *J* = 8.1 Hz, 1H, Ar).

^{13}C NMR (68 MHz, $CDCl_3$): δ = 15.5, 18.8, 21.4, 21.6, 26.6 (3C), 55.0, 70.8, 72.8, 118.7, 123.7, 125.3 (2C), 127.0 (2C), 127.23 (2C), 127.25 (2C), 127.6, 128.2, 129.2 (2C), 129.37, 129.40, 132.1, 132.7, 133.4, 134.1, 135.0, 135.5 (2C), 135.9 (2C), 136.2, 136.8, 143.1.

MS (FAB): *m/z* (%) = 620 (21) [M + H^+], 336 (100).

HRMS–FAB: *m/z* [M + H]$^+$ calcd for $C_{38}H_{42}NO_3SSi$: 620.2665; found: 620.2663.

(1*R*)-9-Butyl-1-cyclohexyl-6-methoxy-2-(4-methylphenylsulfonyl)-2,3-dihydro-1*H*-benzo[*f*]iso indole (12p)

Bromoenyne **11p** (60.2 mg, 0.105 mmol) was converted to **12p** (29.4 mg, 57% yield) by the reaction for 5 h.

Colorless oil; $[\alpha]^{26}_D$ –63.9 (*c* 0.82, $CHCl_3$).

IR (KBr): 1348 (NSO_2), 1163 cm^{-1} (NSO_2).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.97 (t, *J* = 7.2 Hz, 3H, CMe), 1.11–1.46 (m, 9H), 1.60–1.94 (m, 6H), 2.20 (s, 3H, PhMe), 2.82 (dt, *J* = 11.7, 4.8 Hz, 1H, 1'-C*H*H), 3.40 (dt, *J* = 11.7, 5.1 Hz, 1H, 1'-CH*H*), 3.91 (s, 3H, OMe), 4.70 (d, *J* = 16.5 Hz, 1H, NC*H*H), 4.79 (d, *J* = 16.5 Hz, 1H, NCH*H*), 5.10 (s, 1H, 1-H), 6.77 (dd, *J* = 5.7, 3.3 Hz, 1H, 7-H), 7.01 (d, *J* = 8.4 Hz, 2H, Ph), 7.26–7.28 (m, 3H, Ar), 7.57 (d, *J* = 8.4 Hz, 2H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.2, 21.3, 23.5, 26.2, 26.5, 26.6, 26.7, 31.5, 33.3, 34.5, 45.7, 55.0, 55.2, 70.8, 105.2, 118.6, 121.3, 123.9, 125.4, 127.2 (2C), 129.4 (2C), 134.1, 135.2, 136.0, 136.4, 137.7, 143.1, 157.7.

MS (FAB): *m/z* (%) = 492 (38) [M + H^+], 408 (100).

HRMS–FAB: *m/z* [M + H]$^+$ calcd for $C_{30}H_{38}NO_3S$: 492.2572; found: 492.2575.

(1*R*)-9-Butyl-1-cyclohexyl-7-methoxy-2-(4-methylphenylsulfonyl)-2,3-dihydro-1*H*-benzo[*f*]isoindole (12q)

Bromoenyne **11q** (57.6 mg, 0.101 mmol) was converted to **12q** (18.5 mg, 37% yield) by the reaction for 8 h.

Colorless oil; $[\alpha]^{28}_D$ –88.2 (*c* 0.40, $CHCl_3$).

IR (KBr): 1344 (NSO_2), 1163 cm^{-1} (NSO_2).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.00 (t, *J* = 6.9 Hz, 3H, CMe), 1.10–1.92 (m, 15H), 2.19 (s, 3H, PhMe), 2.81–2.95 (m, 2H, 1'-CH_2), 3.91 (s, 3H, OMe), 4.68 (d, *J* = 16.2 Hz, 1H, NC*H*H), 4.78 (d, *J* = 16.2 Hz, 1H, NCH*H*), 5.11 (s, 1H, 1-H), 7.01 (d, *J* = 8.1 Hz, 2H, Ph), 7.09 (dd, *J* = 9.0, 3.0 Hz, 1H, 6-H), 7.20 (d, *J* = 3.0 Hz, 1H, 8-H), 7.27 (s, 1H, 4-H), 7.59 (d, *J* = 8.1 Hz, 2H, Ph), 7.61 (d, *J* = 9.0 Hz, 1H, 5-H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.0, 21.3, 23.3, 26.2, 26.5 (2C), 26.7, 29.5, 31.6, 32.3, 45.5, 54.8, 55.3, 70.5, 103.1, 117.4, 118.4, 127.2 (2C), 129.0, 129.3 (2C), 129.9, 131.1, 132.6, 133.6, 135.2, 137.4, 143.1, 157.4.

MS (FAB): *m/z* (%) = 492 (30) [M + H^+], 408 (100).

HRMS–FAB: *m/z* [M + H]$^+$ calcd for $C_{30}H_{38}NO_3S$: 492.2572; found: 492.2581.

(±)-4-[(*Z*)-Benzylidene]-2-*tert*-butyl-1-(4-methylphenylsulfonyl)-3-[(*Z*)-pentylidene]-1*H*-pyrrole (13j)

Bromoenyne **11j** (61.3 mg, 0.119 mmol) was converted to **13j** (3.6 mg, 7% yield) by the reaction for 7 h.

Colorless oil; IR (KBr): 1348 (NSO_2), 1163 cm^{-1} (NSO_2).

^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.93 (t, *J* = 7.5 Hz, 3H, CMe), 0.97 (s, 9H, CMe_3), 1.25–1.37 (m, 4H), 1.89–2.04 (m, 2H), 2.37 (s, 3H, PhMe), 4.24 (s, 1H, 2-H), 4.35 (dd, *J* = 17.1, 1.8 Hz, 1H, 5-C*H*H), 4.58 (dd, *J* = 17.1, 2.4 Hz, 1H, 5-CH*H*), 5.60 (dd, *J* = 9.2, 5.5 Hz, 1H, C=CH), 6.48 (s, 1H, C=CH), 7.19–7.21 (m, 4H, Ph), 7.23 (d, *J* = 7.3 Hz, 1H, Ph), 7.34 (d, *J* = 7.3 Hz, 1H, Ph), 7.36 (d, *J* = 7.9 Hz, 1H, Ph), 7.63 (d, *J* = 7.9 Hz, 2H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.1, 21.5, 22.7, 27.3 (3C), 31.0, 31.7, 38.2, 52.8, 69.6, 118.0, 125.5, 126.9, 127.5 (2C), 128.4 (2C), 128.7 (2C), 129.5 (2C), 135.2, 136.8, 137.4, 138.7, 143.2.

MS (FAB): *m/z* (%) = 438 (15) [M + H^+], 154 (100).

HRMS–FAB: *m*/*z* [M + H]$^+$ calcd for $C_{27}H_{36}NO_2S$: 438.2467; found: 438.2481.

_N_-(But-2-ynyl)-_N_-(3-phenylprop-2-ynyl)-4-methylbenzenesulfonamide (14m)

Bromoenyne **11m** (43.7 mg, 0.105 mmol) was converted to **14m** (19.2 mg, 54% yield) by the reaction for 0.5 h.

Colorless oil; IR (KBr): 2362 (C≡C), 2330 (C≡C), 1352 (NSO_2), 1165 cm^{-1} (NSO_2).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.69 (t, *J* = 2.4 Hz, 3H, CMe), 2.35 (s, 3H, PhMe), 4.13 (q, *J* = 2.4 Hz, 2H, NCH_2), 4.38 (s, 2H, NCH_2), 7.16 (dd, *J* = 6.6, 1.8 Hz, 2H, Ph), 7.23–7.30 (m, 5H, Ph), 7.75 (dd, *J* = 6.6, 1.8 Hz, 2H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 3.46, 21.4, 37.0, 37.1, 71.6, 81.6, 81.9, 85.6, 122.2, 128.0 (2C), 128.1 (2C), 128.4, 129.4 (2C), 131.6 (2C), 135.4, 143.6.

(±)-_N_-(1-Cyclohexylhept-2-ynyl)-_N_-(3-phenylprop-2-ynyl)amine (14n)

Bromoenyne **11n** (59.2 mg, 0.152 mmol) was converted to **14n** (12.0 mg, 26% yield) by the reaction for 2.5 h.

Colorless oil; IR (KBr): 3317 (NH), 2237 cm^{-1} (C≡C).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.92 (t, *J* = 7.5 Hz, 3H, CMe), 1.13–1.55 (m, 10H), 1.65–1.85 (m, 5H), 2.22 (td, *J* = 6.9, 1.8 Hz, 2H, CH_2C≡C), 3.42 (dt, *J* = 5.1, 1.8 Hz, 1H, NCH), 3.68 (d, *J* = 16.8 Hz, 1H, NC*H*H), 3.84 (d, *J* = 16.8 Hz, 1H, NCH*H*), 7.28–7.30 (m, 3H, Ph), 7.39–7.44 (m, 2H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 13.6, 18.4, 22.0, 26.1, 26.2, 26.5, 28.4, 30.2, 31.1, 37.2, 42.5, 55.0, 79.2, 83.1, 85.1, 87.7, 123.3, 127.9, 128.2 (2C), 131.7 (2C).

(5_R_)-4-Butyl-5-cyclohexyl-6-(4-methylphenylsulfonyl)-6,7-dihydro-5_H_-furo[2,3-_f_]isoindole (16a)

Bromoenyne **15a** (58.2 mg, 0.109 mmol) was converted to **16a** (21.3 mg, 43% yield) by the reaction for 2 h.

Colorless oil; $[\alpha]^{29}_D$ –67.2 (*c* 1.02, $CHCl_3$).

IR (KBr): 1344 (NSO_2), 1163 cm^{-1} (NSO_2).

^{1}H NMR (270 MHz, $CDCl_3$): δ = 0.94 (t, *J* = 7.3 Hz, 3H, CMe), 1.00–1.89 (m, 16H), 2.23 (s, 3H, PhMe), 2.71 (t, *J* = 6.8 Hz, 2H, 1'-CH_2), 4.63 (d, *J* = 15.9 Hz, 1H, 7-C*H*H), 4.72 (d, *J* = 15.9 Hz, 1H, 7-CH*H*), 5.02 (s, 1H, 5-H), 6.68 (d, *J* = 2.2 Hz, 1H, 2-H), 6.97 (s, 1H, 8-H), 7.03 (d, *J* = 8.4 Hz, 2H, Ph), 7.52 (d, *J* = 2.2 Hz, 1H, 3-H), 7.56 (d, *J* = 8.4 Hz, 2H, Ph).

^{13}C NMR (68 MHz, $CDCl_3$): δ = 14.1, 21.4, 23.0, 26.3, 26.5, 26.6, 26.8, 30.5, 31.6, 32.7, 45.6, 55.1, 70.0, 102.4, 105.3, 126.7, 127.1 (2C), 129.2 (2C), 129.5, 132.7, 134.5, 135.1, 143.0, 144.5, 154.7.

MS (FAB): *m*/*z* (%) = 452 (45) [M + H$^+$], 368 (100).

HRMS–FAB: *m*/*z* [M + H]$^+$ calcd for $C_{27}H_{34}NO_3S$: 452.2259; found: 452.2258.

(5_R_)-4-Butyl-5-cyclohexyl-1,6-bis(4-methylphenylsulfonyl)-1,5,6,7-tetrahydropyrrolo[3,4-_f_]indole (16b)

Bromoenyne **15b** (111 mg, 0.162 mmol) was converted to **16b** (73.3 mg, 75%) by the reaction using $Pd(OAc)_2$ (7.7 mg, 0.0346 mmol) in DMF at 120 °C for 2 h.

Colorless oil; $[\alpha]^{26}_D$ +79.7 (*c* 0.98, $CHCl_3$).

IR (KBr): 1597 (NC=C), 1360 (NSO_2), 1346 (NSO_2), 1178 (NSO_2), 1161 cm^{-1} (NSO_2).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.92 (t, *J* = 7.1 Hz, 3H, CMe), 1.01–1.37 (m, 8H), 1.61–1.85 (m, 7H), 2.20 (s, 3H, PhMe), 2.38 (s, 3H, PhMe), 2.61–2.67 (m, 2H, 1'-CH_2), 4.63 (d, *J* = 15.9 Hz, 1H, 7-C*H*H), 4.76 (d, *J* = 15.9 Hz, 1H, 7-CH*H*), 4.97 (s, 1H, 5-H), 6.57 (dd, *J* = 3.8, 0.7 Hz, 1H, 3-H), 6.97 (d, *J* = 7.9 Hz, 2H, Ph), 7.25 (d, *J* = 7.9 Hz, 2H, Ph), 7.46 (d, *J* = 3.8 Hz, 1H, 2-H), 7.48 (s, 1H, 8-H), 7.53 (ddd, *J* = 7.9, 1.8, 1.8 Hz, 2H, Ph), 7.73 (ddd, *J* = 7.9, 1.8, 1.8 Hz, 2H, Ph).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 14.0, 21.3, 21.6, 22.9, 26.2, 26.4, 26.5, 26.7, 30.1, 31.5, 32.6, 45.4, 55.2, 69.9, 104.5, 107.2, 125.8, 126.8 (2C), 127.2 (2C), 129.3 (3C), 129.6, 129.9, 130.0, 133.5, 134.7, 135.1, 135.2, 135.4, 143.0, 145.0.

MS (FAB): *m*/*z* (%) = 605 (5.2) [M + H$^+$], 521 (100).

HRMS–FAB: *m*/*z* [M + H]$^+$ calcd for $C_{34}H_{41}N_2O_4S_2$: 605.2508; found: 605.2493.

(5_R_)-4-Butyl-5-cyclohexyl-1-(2,4,6-trimethylphenylsulfonyl)-6-(4-methylphenylsulfonyl)-1,5,6,7-tetrahydropyrrolo[3,4-_f_]indole (16c)

Bromoenyne **15c** (72.0 mg, 0.101 mmol) was converted to **16c** (51.4 mg, 81%) by the reaction using $Pd(OAc)_2$ (4.5 mg, 0.0202 mmol) in DMF at 120 °C for 2 h.

Colorless oil; $[\alpha]^{26}_D$ +52.2 (*c* 1.645, $CHCl_3$).

IR (KBr): 1603 (NC=C), 1350 (NSO_2), 1161 cm^{-1} (NSO_2).

^{1}H NMR (270 MHz, $CDCl_3$): δ = 0.86 (t, *J* = 6.9 Hz, 3H, CMe), 0.91–1.34 (m, 8H), 1.40–1.86 (m, 7H), 2.23 (s, 3H, PhMe), 2.32 (s, 3H, PhMe), 2.46 (s, 6H, PhMe), 2.68 (t, *J* = 6.6 Hz, 2H, 1'-CH_2), 4.54 (d, *J* = 16.0 Hz, 1H, 7-C*H*H), 4.66 (d, *J* = 16.0 Hz, 1H, 7-CH*H*), 4.96 (s, 1H, 5-H), 6.53 (d, *J* = 3.7 Hz, 1H, 3-H), 6.94–6.99 (m, 5H, Ar), 7.39 (d, *J* = 3.7 Hz, 1H, 2-H), 7.50 (d, *J* = 8.1 Hz, 2H, Ph).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 14.0, 21.0, 21.3, 22.5 (2C), 22.9, 26.2, 26.5, 26.7, 30.1, 31.5, 32.7, 45.3, 55.2, 69.9, 103.7, 105.2 (2C), 125.9, 127.2 (2C),

129.2 (3C), 129.3, 129.6, 132.3 (3C), 132.9, 134.6, 134.7, 135.1, 140.1, 143.0, 144.1.

MS (FAB): *m*/*z* (%) = 633 (28) [M + H^+], 549 (100).

HRMS–FAB: *m*/*z* [M + H]$^+$ calcd for $C_{36}H_{45}N_2O_4S_2$: 633.2821; found: 633.2795.

(5*R*)-4-Butyl-5-cyclohexyl-*N*,*N*-dimethyl-6-(4-methylphenylsulfonyl)-6,7-dihydropyrrolo[3,4-*f*]indole-1(5*H*)-sulfonamide (16d)

Bromoenyne **15d** (49.7 mg, 0.0778 mmol) was converted to **16d** (22.7 mg, 52%) by the reaction using $Pd(OAc)_2$ (1.8 mg, 0.00802 mmol) for 12 h.

Pale orange oil; $[\alpha]^{25}_D$ +37.8 (*c* 0.740, $CHCl_3$).

IR (KBr): 1599 (NC=C), 1387 (NSO_2), 1344 (NSO_2), 1159 cm^{-1} (NSO_2).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.96 (t, *J* = 7.1 Hz, 3H, CMe), 1.03–1.54 (m, 9H), 1.61–1.94 (m, 6H), 2.23 (s, 3H, PhMe), 2.71–2.79 (m, 2H, 1'-CH_2), 2.785 (s, 3H, NMe), 2.787 (s, 3H, NMe), 4.63 (d, *J* = 16.0 Hz, 1H, 7-C*H*H), 4.73 (d, *J* = 16.0 Hz, 1H, 7-CH*H*), 5.07 (s, 1H, 5-H), 6.57 (d, *J* = 3.7 Hz, 1H, 3-H), 7.04 (d, *J* = 8.3 Hz, 2H, Ph), 7.36 (d, *J* = 3.7 Hz, 1H, 2-H), 7.42 (s, 1H, 8-H), 7.57 (d, *J* = 8.3 Hz, 2H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.0, 21.3, 22.9, 26.2, 26.4, 26.5, 26.7, 30.1, 31.5, 32.6, 38.4 (2C), 45.4, 55.1, 70.0, 104.6, 105.1, 126.6, 127.2 (2C), 129.2, 129.26 (2C), 129.29, 132.9, 134.6, 135.1, 135.3, 143.0.

MS (FAB): *m*/*z* (%) = 558 (37) [M + H^+], 474 (100).

HRMS–FAB: *m*/*z* [M + H]$^+$ calcd for $C_{29}H_{40}N_3O_4S_2$: 558.2460; found: 558.2483.

(7*R*)-8-Butyl-7-cyclohexyl-1,6-bis(4-methylphenylsulfonyl)-1,5,6,7-tetrahydropyrrolo[3,4-*f*]indole (16e)

Bromoenyne **15e** (53.5 mg, 0.0780 mmol) was converted to **16e** (20.0 mg, 42%) by the reaction using $Pd(OAc)_2$ (3.5 mg, 0.0156 mmol) in DMF at 120 °C for 4 h.

Colorless oil; $[\alpha]^{26}_D$ –349.8 (*c* 0.86, $CHCl_3$).

IR (KBr): 1597 (NC=C), 1369 (NSO_2), 1344 (NSO_2), 1174 (NSO_2), 1161 cm^{-1} (NSO_2).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.83–1.47 (m, 11H), 1.51–1.62 (m, 5H), 1.79–1.85 (m, 2H), 2.25 (s, 3H, PhMe), 2.30 (s, 3H, PhMe), 2.38–2.53 (m, 1H, 1'-C*H*H), 3.49–3.59 (m, 1H, 1'-CH*H*), 4.54 (d, *J* = 15.9 Hz, 1H, 5-C*H*H), 4.69 (dd, *J* = 15.9, 0.6 Hz, 1H, 5-CH*H*), 4.95 (s, 1H, 7-H), 6.52 (d, *J* = 3.8 Hz, 1H, 3-H), 6.91 (s, 1H, 4-H), 7.04 (d, *J* = 8.1 Hz, 2H, Ph), 7.08 (d, *J* = 8.1 Hz, 2H, Ph), 7.37 (ddd, *J* = 8.1, 1.9, 1.9 Hz, 2H, Ph), 7.56 (ddd, *J* = 8.1, 1.9, 1.9 Hz, 2H, Ph), 7.59 (d, *J* = 3.8 Hz, 1H, 2-H).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 14.0, 21.4, 21.5, 22.9, 26.2, 26.6 (2C), 26.7, 30.6, 31.0, 32.1, 45.7, 55.0, 70.5, 111.1, 111.9, 126.48, 126.49 (2C), 127.2 (2C), 129.3 (2C), 129.4 (2C), 132.1, 133.9, 134.2, 134.4, 135.1, 135.3, 137.2, 143.2, 144.6.

MS (FAB): *m*/*z* (%) = 605 (31) [M + H^+], 521 (100).

HRMS–FAB: *m*/*z* [M + H]$^+$ calcd for $C_{34}H_{41}N_2O_4S_2$: 605.2508; found: 605.2531.

(3*R*)-4-Butyl-3-cyclohexyl-2,5-bis(4-methylphenylsulfonyl)-1,2,3,5-tetrahydropyrrolo[3,4-*b*]carbazole (18a)

Bromoenyne **17a** (74.0 mg, 0.101 mmol) was converted to **18a** (33.8 mg, 51% yield) by the reaction using $Pd(OAc)_2$ (2.3 mg, 0.0101 mmol) in DMF at 120 °C for 18 h.

Colorless oil; $[\alpha]^{26}_D$ –122 (*c* 0.30, $CHCl_3$).

IR (KBr): 1597 (C=CN), 1367 (NSO_2), 1346 (NSO_2), 1173 (NSO_2), 1163 cm^{-1} (NSO_2).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.88 (t, *J* = 7.2 Hz, 3H, CMe), 1.11–1.30 (m, 9H), 1.53–1.93 (m, 6H), 2.17 (s, 3H, PhMe), 2.22 (s, 3H, PhMe), 2.63–2.73 (m, 1H, 1'-C*H*H), 3.84–3.94 (m, 1H, 1'-CH*H*), 4.61 (d, *J* = 16.5 Hz, 1H, 1-C*H*H), 4.76 (d, *J* = 16.5 Hz, 1H, 1-CH*H*), 5.07 (s, 1H, 3-H), 6.72 (d, *J* = 8.4 Hz, 2H, Ph), 6.78 (d, *J* = 8.4 Hz, 2H, Ph), 7.06 (d, *J* = 8.1 Hz, 2H, Ph), 7.12 (s, 1H, 10-H), 7.25–7.30 (m, 1H, Ar), 7.40 (dd, *J* = 7.5, 7.5, 1.5 Hz, 1H, Ar), 7.47 (dd, *J* = 7.5, 0.6 Hz, 1H, Ar), 7.61 (d, *J* = 8.4 Hz, 2H, Ph), 8.16 (d, *J* = 7.5 Hz, 1H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.0, 21.4, 21.5, 22.9, 26.3, 26.5, 26.6, 26.7, 31.0, 31.15, 31.20, 45.9, 55.3, 71.0, 110.4, 119.2, 120.6, 125.8, 127.0 (2C), 127.1, 127.3 (2C), 128.3 (2C), 129.5 (2C), 130.0, 131.08, 131.13, 131.9, 135.0, 135.8, 140.17, 140.24, 142.5, 143.4, 144.3.

MS (FAB): *m*/*z* (%) = 655 (10) [M + H^+], 154 (100).

HRMS–FAB: *m*/*z* [M + H]$^+$ calcd for $C_{38}H_{43}N_2O_4S_2$: 655.2664; found: 655.2661.

(3*R*)-4-Butyl-3-cyclohexyl-2-(4-methylphenylsulfonyl)-5-(2,4,6-trimethylphenylsulfonyl)-1,2,3,5-tetrahydropyrrolo[3,4-*b*]carbazole (18b)

Bromoenyne **17b** (53.1 mg, 0.0695 mmol) was converted to **18b** (14.9 mg, 31%) by the reaction using $Pd(OAc)_2$ (0.8 mg, 0.00356 mmol) in DMF at 120 °C for 3 h.

Pale yellow oil; $[\alpha]^{26}_D$ –107.6 (*c* 0.690, $CHCl_3$).

IR (KBr): 1601 (NC=C), 1346 (NSO_2), 1162 cm^{-1} (NSO_2).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.92 (t, *J* = 7.1 Hz, 3H, CMe), 1.01–1.37 (m, 8H), 1.61–1.85 (m, 7H), 2.11 (s, 6H, PhMe), 2.20 (s, 3H, PhMe), 2.38 (s, 3H, PhMe), 2.64 (dt, *J* = 14.6, 5.0 Hz, 1H, 1'-C*H*H), 3.55 (dt, *J* = 14.6, 5.0 Hz, 1H, 1'-CH*H*), 4.67 (d, *J* = 15.6 Hz, 1H, 1-C*H*H), 4.80 (d, *J* = 15.6 Hz, 1H, 1-CH*H*), 5.01 (s, 1H, 3-H), 6.67 (s, 2H, Ph), 7.03 (d, *J* = 7.9 Hz,

2H, Ph), 7.15–7.20 (m, 2H, Ar), 7.35 (s, 1H, 10-H), 7.56–7.59 (m, 1H, Ar), 7.58 (d, *J* = 7.9 Hz, 2H, Ph), 7.66–7.67 (m, 1H, Ar).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 14.0, 20.9, 21.4, 22.5 (2C), 22.9, 26.2, 26.4, 26.6, 26.8, 31.1, 31.2, 31.4, 45.6, 55.3, 71.0, 110.4, 116.7, 119.4 (2C), 124.1, 126.5, 127.1, 127.2 (2C), 128.7, 129.1, 129.5 (2C), 131.8 (2C), 134.1, 134.6, 135.0, 139.9 (2C), 140.1, 141.1, 143.1, 143.3.

MS (FAB): *m*/*z* (%) = 683 (16) [M + H$^+$], 154 (100).

HRMS–FAB: *m*/*z* [M + H]$^+$ calcd for $C_{40}H_{47}N_2O_4S_2$: 638.2977; found: 638.2974.

(3*R*)-4-Butyl-3-cyclohexyl-5-methyl-2-(4-methylphenylsulfonyl)-1,2,3,5-tetrahydropyrrolo[3,4-*b*]carbazole (18d)

Bromoenyne **17d** (118 mg, 0.20 mmol) was converted to **18d** (43.7 mg, 43%) by the reaction using $Pd(OAc)_2$ (4.5 mg, 0.0198 mmol) for 36 h.

Pale yellow oil; $[\alpha]^{27}_D$ +10.2 (*c* 1.28, $CHCl_3$).

IR (KBr): 1601 (NC=C), 1342 (NSO_2), 1161 (NSO_2), 1092 cm^{-1} (NC).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.96–1.00 (m, 4H), 1.04–1.48 (m, 8H), 1.60–1.64 (m, 2H), 1.77–1.92 (m, 4H), 2.19 (s, 3H, PhMe), 2.73–2.82 (m, 1H, 1'-C*H*H), 3.12–3.19 (m, 1H, 1'-CH*H*), 3.98 (s, 3H, NMe), 4.74 (d, 1H, *J* = 15.4 Hz, 1-C*H*H), 4.83 (d, 1H, *J* = 15.4 Hz, 1-CH*H*), 5.06 (s, 1H, 3-H), 7.01 (d, *J* = 7.9 Hz, 2H, Ph), 7.18 (dd, *J* = 8.0, 8.0 Hz, 1H, Ar), 7.34 (d, *J* = 8.0 Hz, 1H, Ar), 7.43 (dd, *J* = 8.0, 8.0 Hz, 1H, Ar), 7.58 (s, 1H, 10-H), 7.58 (d, *J* = 7.9 Hz, 2H, Ph), 7.94 (d, *J* = 8.0 Hz, 1H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.8, 22.1, 23.6, 27.0, 27.2, 27.3, 27.5, 29.9, 32.3, 32.8, 34.9, 46.7, 56.0, 71.5, 109.5, 111.6, 119.8, 120.3, 120.8, 123.2, 125.1, 126.5, 127.9 (2C), 129.6, 130.1 (2C), 136.0, 138.4, 139.8, 143.1, 143.8.

MS (FAB): *m*/*z* (%) = 515 (21) [M + H$^+$], 431 (100).

HRMS–FAB: *m*/*z* [M + H]$^+$ calcd for $C_{32}H_{39}N_2O_2S$: 515.2737; found: 515.2747.

(3*R*)-4-Butyl-3-cyclohexyl-2-(4-methylphenylsulfonyl)-2,3-dihydro-1*H*-benzo[4,5]thieno[2,3-*f*]isoindole (18e)

Bromoenyne **17e** (70.4 mg, 0.118 mmol) was converted to **18e** (29.7 mg, 49% yield) by the reaction for 3 h.

Colorless oil; $[\alpha]^{25}_D$ +27.8 (*c* 0.40, $CHCl_3$).

IR (KBr): 1344 (NSO_2), 1161 cm^{-1} (NSO_2).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.99 (t, *J* = 7.2 Hz, 3H, CMe), 1.05–1.92 (m, 15H), 2.20 (s, 3H, PhMe), 2.72–2.86 (m, 2H, 1'-CH_2), 4.72 (d, *J* = 15.9 Hz, 1H, 1-C*H*H), 4.83 (d, *J* = 15.9 Hz, 1H, 1-CH*H*), 5.09 (s, 1H, 3-H), 7.03 (d, *J* = 8.1 Hz, 2H, Ph), 7.40–7.43 (m, 2H, Ar), 7.59 (d, *J* = 8.1 Hz, 2H, Ph), 7.65 (s, 1H, Ar), 7.79–7.83 (m, 1H, Ar), 8.00–8.03 (m, 1H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.0, 21.3, 23.0, 26.2, 26.4, 26.5, 26.7, 30.7, 31.6, 32.2, 45.4, 55.1, 70.4, 112.3, 121.4, 122.8, 124.4, 126.7, 127.2 (2C), 129.4 (2C), 131.2, 135.0, 135.3, 135.5, 135.6, 137.3, 139.1, 139.3, 143.3.

MS (FAB): *m*/*z* (%) = 518 (23) [M + H$^+$], 154 (100).

HRMS–FAB: *m*/*z* [M + H]$^+$ calcd for $C_{31}H_{36}NO_2S_2$: 518.2187; found: 518.2188.

(3*R*)-4-Butyl-3-cyclohexyl-2-(4-methylphenylsulfonyl)-2,3-dihydro-1*H*-benzofuro[2,3-*f*]isoindole (18f)

Bromoenyne **17f** (62.0 mg, 0.106 mmol) was converted to **18f** (31.4 mg, 59% yield) by the reaction for 1 h.

Colorless oil; $[\alpha]^{26}_D$ –119 (*c* 0.35, $CHCl_3$).

IR (KBr): 1346 (NSO_2), 1163 cm^{-1} (NSO_2).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.00 (t, *J* = 6.9 Hz, 3H, CMe), 1.15–1.93 (m, 15H), 2.19 (s, 3H, PhMe), 2.89 (dt, *J* = 14.1, 6.3 Hz, 1H, 1'-C*H*H), 3.04 (dt, *J* = 9.0, 5.4 Hz, 1H, 1'-CH*H*), 4.69 (d, *J* = 16.5 Hz, 1H, 1-C*H*H), 4.80 (d, *J* = 16.5, 1H, 1-CH*H*), 5.09 (s, 1H, 3-H), 7.03 (d, *J* = 8.1 Hz, 2H, Ph), 7.06 (s, 1H, Ar), 7.33 (ddd, *J* = 7.5, 7.5, 0.9 Hz, 1H, Ar), 7.42 (ddd, *J* = 7.5, 7.5, 0.9 Hz, 1H, Ar), 7.52 (d, *J* = 7.5 Hz, 1H, Ar), 7.59 (d, *J* = 8.1 Hz, 2H, Ph), 7.84 (d, *J* = 7.5 Hz, 1H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 14.0, 21.3, 23.2, 26.2, 26.4, 26.5, 26.7, 30.6, 31.6 (2C), 45.7, 55.4, 70.1, 102.7, 111.6, 122.1, 122.2, 122.8, 123.9, 126.5, 127.2 (2C), 129.4 (2C), 132.5, 133.1, 135.1, 137.3, 143.2, 156.3, 156.4.

MS (FAB): *m*/*z* (%) = 502 (36) [M + H$^+$], 418 (100).

HRMS–FAB: *m*/*z* [M + H]$^+$ calcd for $C_{31}H_{36}NO_3S$: 502.2416; found: 502.2409.

(1*R*)-11-Butyl-1-cyclohexyl-2-(4-methylphenylsulfonyl)-2,3-dihydro-1*H*-naphtho[2,3-*f*]isoindole (18g)

Bromoenyne **17g** (132 mg, 0.22 mmol) was converted to **18g** (48.7 mg, 43%) by the reaction using $Pd(OAc)_2$ (1.0 mg, 0.0044 mmol) in DMF at 120 °C for 2 h and a further 3 h with additional $Pd(OAc)_2$ (1.5 mg, 0.0066 mmol).

Colorless oil; $[\alpha]^{26}_D$ –165.5 (*c* 0.63, $CHCl_3$).

IR (KBr): 1344 (NSO_2), 1161 cm^{-1} (NSO_2).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.95–1.02 (m, 4H), 1.11–1.61 (m, 10H), 1.79–1.97 (m, 4H), 2.16 (s, 3H, PhMe), 3.09 (td, *J* = 12.7, 4.6 Hz, 1H, 1'-C*H*H), 3.58 (td, *J* = 12.7, 4.6 Hz, 1H, 1'-CH*H*), 4.78 (d, *J* = 16.2 Hz, 1H, 3-C*H*H), 4.90 (d, *J* = 16.2 Hz, 1H, 3-CH*H*), 5.20 (s, 1H, 1-H), 7.00 (d, *J* = 8.1 Hz, 2H, Ph), 7.41 (s,

1H, Ar), 7.54–7.64 (m, 6H, Ar), 7.86 (dd, *J* = 6.8, 2.2 Hz, 1H, Ar), 8.74 (d, *J* = 7.8 Hz, 1H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 13.9, 21.3, 23.1, 26.2, 26.5, 26.7 (2C), 31.1, 31.5, 33.9, 45.6, 55.3, 71.4, 120.1, 125.8, 125.9, 126.7, 127.2 (3C), 128.0, 128.9, 129.0, 129.4 (2C), 131.1, 133.3, 134.1, 134.6, 135.1, 135.9, 139.8, 143.2.

MS (FAB): *m*/*z* (%) = 512 (49) [M + H^+], 428 (100).

HRMS–FAB: *m*/*z* [M + H]$^+$ calcd for $C_{33}H_{38}NO_2S$: 512.2623; found: 512.2661.

Diethyl 9-Butyl-1-pentyl-2,3-dihydro-1*H*-cyclopenta[*b*]naphthalene-2,2-dicarboxylate (20a)

Bromoenyne **19a** (48.8 mg, 0.0993 mmol) was converted to **20a** (28.1 mg, 68%) by the reaction using $Pd(OAc)_2$ (1.1 mg, 0.0050 mmol) for 2 h.

Colorless oil; IR (KBr): 1733 cm^{-1} (C=O).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.82 (t, *J* = 6.7 Hz, 3H, CMe), 1.02 (t, *J* = 7.1 Hz, 3H, CMe), 1.13–1.82 (m, 18H), 2.93–3.02 (m, 1H, 1'-C*H*H), 3.07–3.17 (m, 1H, 1'-CH*H*), 3.45 (d, *J* = 16.7 Hz, 1H, 3-C*H*H), 3.96–4.37 (m, 6H, 2 × OCH_2, 1-H, and 3-CH*H*), 7.37 (ddd, *J* = 8.0, 8.0, 1.1 Hz, 1H, Ar), 7.42 (ddd, *J* = 8.0, 8.0, 1.1 Hz, 1H, Ar), 7.47 (s, 1H, 4-H), 7.73 (d, *J* = 8.0 Hz, 1H, Ar), 7.97 (d, *J* = 8.0 Hz, 1H, Ar).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 13.9, 14.0 (2C), 14.1, 22.5, 23.5, 26.9, 29.5, 31.8, 32.3, 32.8, 38.8, 48.2, 61.45, 61.50, 65.4, 121.1, 123.9, 124.8, 124.9, 128.3, 131.6, 133.6, 133.7, 137.4, 142.3, 170.0, 171.6.

MS (FAB): *m*/*z* (%) = 461 (8.2) [M + Na^+], 438 (100).

HRMS–FAB: *m*/*z* [M + Na]$^+$ calcd for $C_{28}H_{38}NaO_4$: 461.2668; found: 461.2650.

Diethyl 4-Butyl-1-(4-methylphenylsulfonyl)-5-pentyl-5,7-dihydrocyclopenta[*f*]indole-6,6-(1*H*)-dicarboxylate (20b)

Bromoenyne **19b** (104 mg, 0.157 mmol) was converted to **20b** (31.9 mg, 35%) by the reaction using $Pd(OAc)_2$ (1.8 mg, 0.00786 mmol) in DMF at 120 °C for 24 h.

Colorless oil; IR (KBr): 1732 (C=O), 1597 (NC=C), 1373 (NSO_2), 1176 cm^{-1} (NSO_2).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.80 (t, *J* = 7.0 Hz, 3H, CMe), 0.95 (t, *J* = 7.0 Hz, 3H, CMe), 1.13–1.73 (m, 18H), 2.36 (s, 3H, PhMe), 2.76 (t, *J* = 7.9 Hz, 2H, 1'-CH_2), 3.37 (d, *J* = 16.7 Hz, 1H, 7-C*H*H), 3.91–4.37 (m, 6H, 2 × OCH_2, 5-H, and 7-CH*H*), 6.61 (d, *J* = 3.8 Hz, 1H, 3-H), 7.24 (d, *J* = 8.3 Hz, 2H, Ph), 7.46 (d, *J* = 3.8 Hz, 1H, 2-H), 7.58 (s, 1H, 8-H), 7.77 (d, *J* = 8.3 Hz, 2H, Ph).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 13.9, 13.96, 13.99, 14.1, 21.6, 22.4, 23.3, 26.8, 30.2, 31.8, 32.3, 32.7, 39.0, 47.4, 61.4, 61.5, 65.6, 107.0, 107.4, 125.0, 126.9 (2C), 129.5, 129.9 (2C), 130.9, 134.4, 135.5, 136.3, 138.9, 144.7, 170.0, 171.7.

MS (FAB): *m*/*z* (%) = 604 (100) [M + Na^+], 604 (100).

HRMS–FAB: *m*/*z* [M + Na]$^+$ calcd for $C_{33}H_{43}NNaO_6S$: 604.2709; found: 604.2724.

Supporting Information for this article, including experimental procedures and full characterization for the substrates and their synthetic intermediates, is available online at http://www.thieme-connect.de/ejournals/toc/synthesis.

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(8) A portion of this study (Table 1; Table 2: entries 2, 3, 6, 11, 12; Table 4: entries 1 and 7) has already been reported in a preliminary communication: Ohno, H.; Yamamoto, M.; Iuchi, M.; Tanaka, T. *Angew. Chem., Int. Ed.* **2005**, *44*, 5103–5106.

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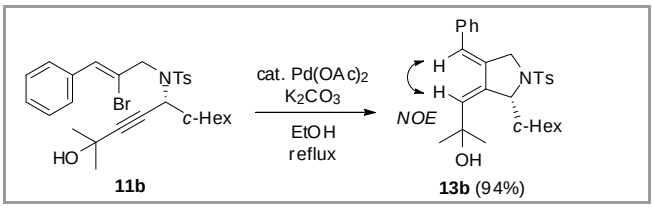
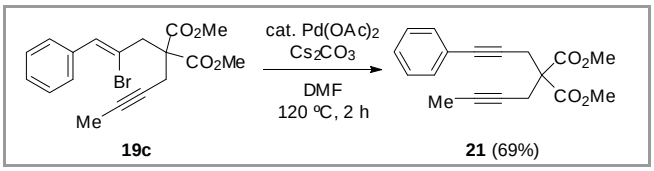
(11) For example, the reaction of **11b** with $Pd(OAc)_2$ (2 mol %) using K_2CO_3 (2 equiv) as the base stereoselectively gave the monocyclic product **13b** in 94% yield.



11b **13b** (94%)

(12) A similar result was obtained with malonate congener **19c**, which produced diyne **21** in 69% yield.



19c **21** (69%)

(13) For recent reviews on palladium-catalyzed direct arylation of heteroareres, see: (a) Ackermann, L.; Vicente, R.; Kapdi, A. R. *Angew. Chem., Int. Ed*. **2009**, *48*, 9792–9826. (b) Bellina, F.; Rossi, R. *Tetrahedron* **2009**, *65*, 10269–10310.

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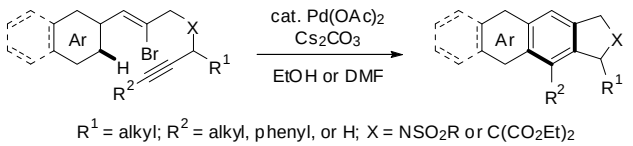
Graphical Abstract



R^1 = alkyl; R^2 = alkyl, phenyl, or H; X = NSO_2R or $C(CO_2Et)_2$

Short Title: Palladium-Catalyzed Cascade Cyclization through Direct Arylation