Formal Synthesis of Olivacine *via* Indolylborate

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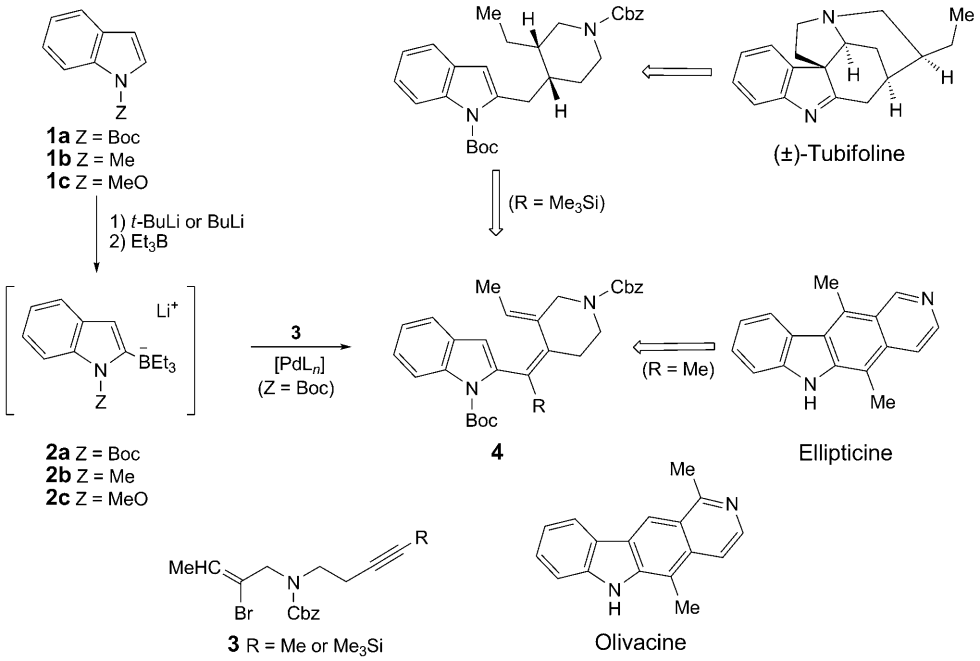
Palladium-catalyzed tandem cyclization–cross-coupling reaction of indolylborate **2** and vinyl bromide **5** was successfully applied in a short formal synthesis of olivacine. The reaction of **2** with **5** in the presence of $Pd(OAc)_2$ readily afforded three kinds of products, triene derivative **6** and vinylindole derivative **7**, along with a small amount of the piperidine derivative **8** (*Scheme 2*). On the other hand, the reactions of **2** with bromide **10** or **15** were also examined (*Schemes 4* and *5*), and their outcome markedly depended on the relative ease of ring closure as a function of ring size. Irradiation of **6** with a high-pressure mercury lamp (→ **9**; *Scheme 2*), followed by removal of the *N*-[(benzyloxy)carbonyl] group and subsequent oxidation afforded, after deprotection, pyridocarbazole **23**, and the conversion of **23** to olivacine is known (*Scheme 6*).

Introduction. – The 1*H*-indol-2-yltrialkylborates (indolylborates) **2** are readily available *in situ* from 2-lithio-1*H*-indoles (obtained from **1**) and trialkylboranes, and their chemical versatility as synthetic intermediates for the assembly of 1*H*-indole derivatives has become of continuing interest in our group [1]. During these studies, we found the use of indolylborates **2** in palladium-catalyzed cross-coupling [2] and carbonylative cross-coupling [3] reactions to be highly effective in the development of a novel strategy to 1*H*-indole derivatives. In our previous reports, the palladium-catalyzed tandem cyclization–cross-coupling reaction of **2a** with bromide **3** was successfully applied to the concise preparation of ellipticine [4] and (±)-tubifoline [5] by taking advantage of the one-pot availability of triene derivative **4** as a common strategy (*Scheme 1*; Boc = (*tert*-butoxy)carbonyl, Cbz = (benzyloxy)carbonyl).

Our interest in the development of the cross-coupling protocol for indole-alkaloid synthesis prompted us to undertake the preparation of olivacine [6], based on the reaction of **2** with **5**. We will herein describe these results.

Results and Discussion. – Initially, 1-[(*tert*-butoxy)carbonyl]-1*H*-indol-2-ylborate **2a**, derived from 1-Boc-1*H*-indole **1a** and triethylborane in THF [7], was treated with **5** at 60° in the presence of a Pd-complex (5 mol-%) for 3 h under Ar (*Scheme 2*). Careful separation of the reaction mixture by medium-pressure liquid chromatography (MPLC) allowed the isolation of three kinds of cross-coupling products, **6a**, **7a**, and a small amount of **8**. The use of a Pd-complex with Ph_3P led to an increase in the yields of **6a** to 40–45% (*Table 1*, *Runs 1–4*). A closely related result was also observed on subjecting 1-methoxy-1*H*-indol-2-ylborate **2c** [7] to the reaction with **5**, providing the

Scheme 1



cross-coupling products **6b** and **7b**, along with a small amount of **8**. The reaction proceeded to completion within 0.5 h, and a higher yield of **6b** was obtained in the presence of a Pd-complex without Ph_3P (*Table 1*, *Runs 5–7*).

The following common mechanistic scheme might account for the present reaction (*Scheme 3*) [8]. The transmetallation between **2** and complex **A** should account for the generation of **7** *via* complex **E**. On the other hand, the transmetallation between **2** and complex **B** possibly involves transfer of the indole ring and/or the Et group. The generation of complex **D** through the transfer of the indole ring led to **6**, while the competitive transfer of the Et group produced **8** through complex **C**.

Subsequently, under the previously reported conditions [4], irradiation of **6a** with a high-pressure mercury lamp in benzene at room temperature was carried out, readily producing pyridocarbazole **9** in 45% yield (*Scheme 2*).

Moreover, attention was turned to the feasibility of the cross-coupling reaction of **2** with **10** or **15**, which involves ring closure leading to a five- or seven-membered ring. Thus, the reaction of **10** with **2b** in the presence of $Pd(OAc)_2$ under the same conditions as those described above readily produced **11b** in good yields, along with a small amount of **12** (*Scheme 4*), in which the cross-coupling product **13** was notably missing (*Table 2*, *Run 3*). Similarly, subjection of **10** to the reaction with **2a**,**c** afforded **11a**,**c** and **12**, respectively.

On the other hand, applying the same treatment as that described above to **2b** and **15** in the presence of $Pd(OAc)_2$ allowed the isolation of **16** and **17** without **19**, the formation of **17** being favored over that of **16** (*Scheme 5*).

Scheme 2

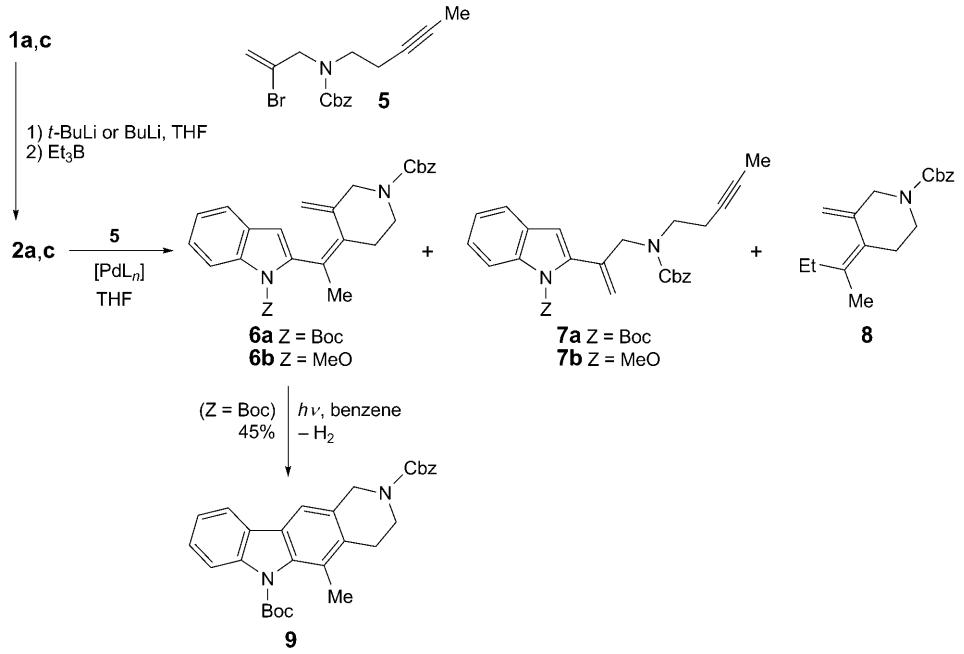


Table 1. *Palladium-Catalyzed Cross-Coupling Reaction of* **2** *with* **5**

Run	Indolylborate	Catalyst [PdL_n]	Time [h]	Yield [%][a])		
				6	**7**	**8**
1	**2a**	$Pd(OAc)_2$	3	20 (**6a**)	35 (**7a**)	10
2	**2a**	$[PdCl_2(MeCN)_2]$	3	25 (**6a**)	41 (**7a**)	5
3	**2a**	$[PdCl_2(PPh_3)_2]$	3	45 (**6a**)	15 (**7a**)	5
4	**2a**	$Pd(OAc)_2 + 2PPh_3$	3	40 (**6a**)	19 (**7a**)	6
5	**2c**	$Pd(OAc)_2$	0.5	38 (**6b**)	18 (**7b**)	10
6	**2c**	$[PdCl_2(MeCN)_2]$	0.5	43 (**6b**)	15 (**7b**)	5
7	**2c**	$[PdCl_2(PPh_3)_2]$	0.5	28 (**6b**)	36 (**7b**)	8

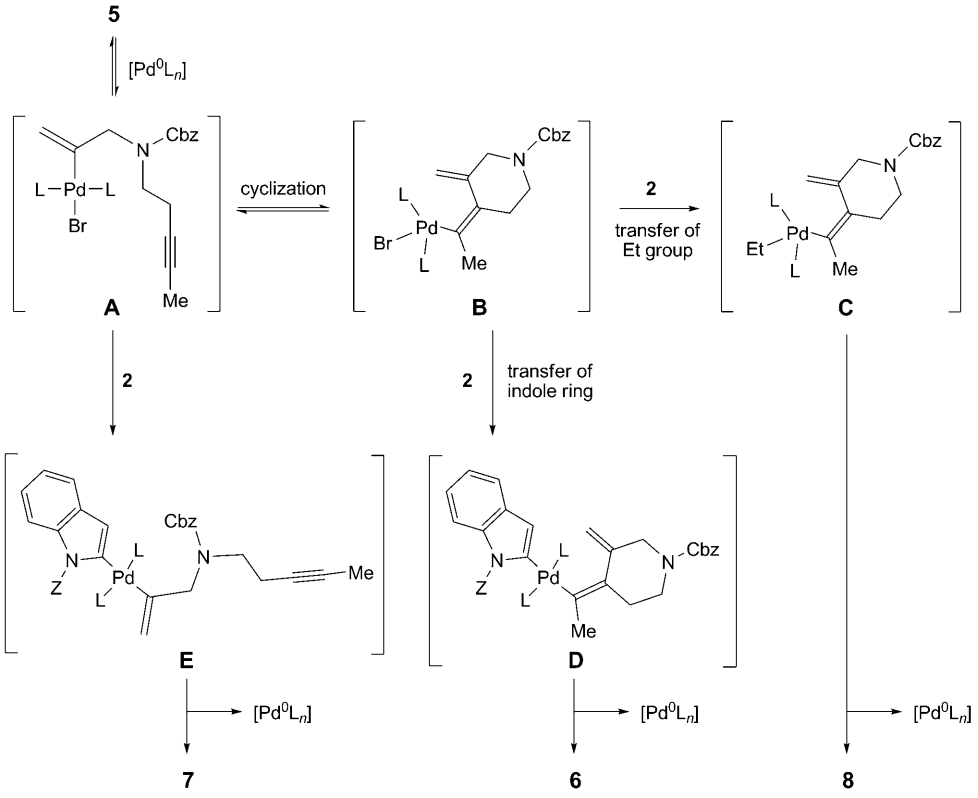
[a]) Yield based on **5**, after isolation.

These results are associated with the relative ease of ring closure as a function of ring size. The reaction of **2** with **10** *via* the most favorable five-membered-ring closure reflects the lack of product **13**, while the less favorable seven-membered-ring closure in the reaction of **2** with **15** is responsible for the predominant generation of **17** over **16**.

Subjection of **11b** and **16** to photocyclization afforded **14** and **18** in 40 and 41% yield, respectively (*Schemes 4* and *5*).

With pyridocarbazole **9** in hand, the preparation of olivacine involved first the removal of the *N*-Cbz group of **9** by catalytic hydrogenation to give amine **20** (*Scheme 6*). Subsequent oxidation of **20** with MnO_2 in AcOEt at room temperature for

Scheme 3



Scheme 4

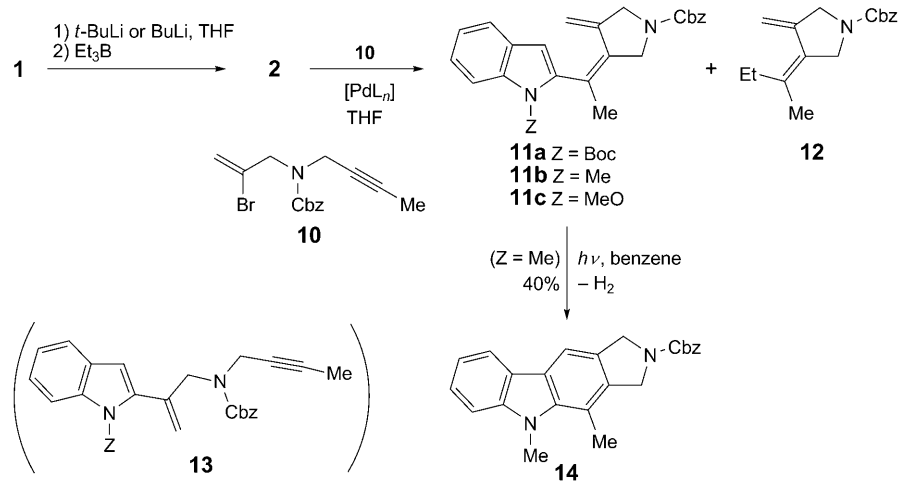
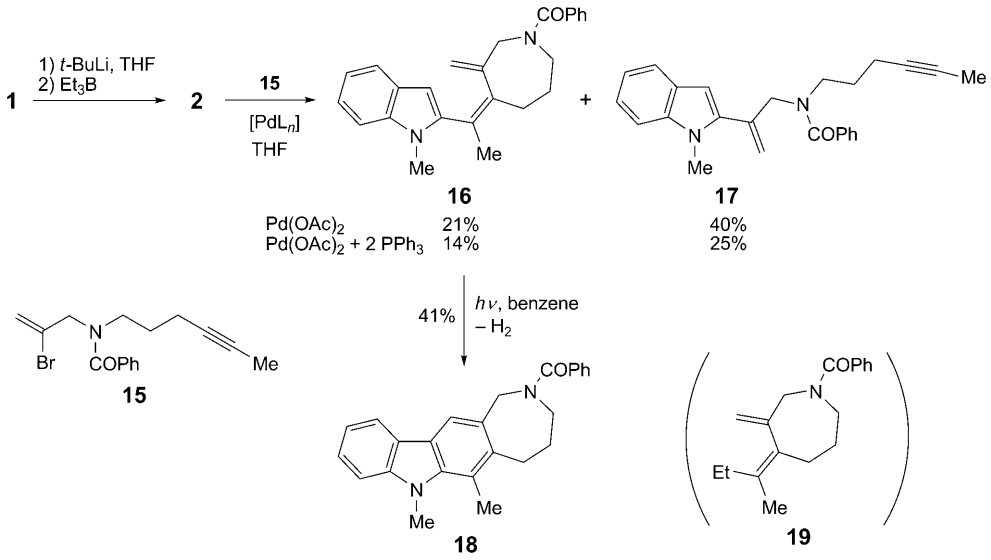


Table 2. *Palladium-Catalyzed Cross-Coupling Reaction of* **2** *with* **10**

Run	Indolylborate	Catalyst [PdL_n]	Time [h]	Yield [%][a])	
				11	**12**
1	**2a**	$Pd(OAc)_2$	2	23 (**11a**)	20
2	**2a**	$Pd(OAc)_2 + 2PPh_3$	2	40 (**11a**)	15
3	**2b**	$Pd(OAc)_2$	0.5	61 (**11b**)	10
4	**2b**	$Pd(OAc)_2 + 2PPh_3$	0.5	44 (**11b**)	15
5	**2c**	$Pd(OAc)_2$	0.5	58 (**11c**)	10
6	**2c**	$Pd(OAc)_2 + 2PPh_3$	0.5	40 (**11c**)	15

[a]) Yield based on **10**, after isolation.

Scheme 5



20 h led to **21** and **22**, whereas heating **20** with MnO_2 under reflux in AcOEt for 3 h afforded pyridocarbazole **22**, solely. Finally, the *N*-Boc group of **22** was removed by heating with Cs_2CO_3 in MeOH/THF to give **23**. As the conversion of **23** to olivacine is known [9], the formal synthesis of olivacine was achieved.

Herein, we reported a short route to olivacine and its analogues based on the palladium-catalyzed tandem cyclization–cross-coupling reaction of indolylborate **2a** with vinyl bromide **5**.

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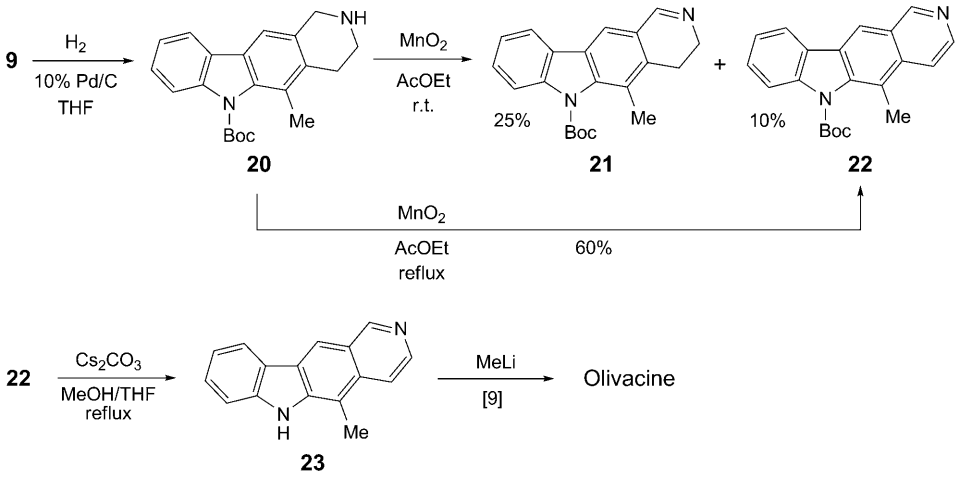
Scheme 6



Experimental Part

General. Medium-pressure liquid chromatography (MPLC): silica gel *60N* (*Kanto Chemical Co., Ltd.*). Melting points: *Yamato-MP21* apparatus; uncorrected. IR Spectra: *Hitachi-270-30* spectrometer; in cm^{-1}. NMR Experiments: *Jeol-JNM-ECA500* spectrometer; at 500 (^1H) and 125 (^{13}C) MHz; chemical shifts δ in ppm rel. to Me_4Si as internal reference and coupling constants J in Hz. MS and HR-MS: *Micromass-AutoSpec-3100* mass spectrometer; in *m/z*.

Benzyl (2-Bromoprop-2-en-1-yl)(pent-3-yn-1-yl)carbamate (**5**). From 2,3-dibromoprop-1-ene *via* 2-bromoprop-2-en-1-amine [4][10]. Colorless oil. B.p. 160–161°/1 Torr. IR (neat): 1708. ^1H-NMR ($CDCl_3$): 1.74 (*t*, $J = 2.5$, 3 H); 2.30–2.50 (*m*, 2 H); 3.30–3.50 (*m*, 2 H); 4.21, 4.24 (2*s*, 2 H); 5.14, 5.17 (2*s*, 2 H); 5.55, 5.58 (2*s*, 2 H); 5.67, 5.75 (2*s*, 1 H); 7.20–7.50 (*m*, 5 H). ^{13}C-NMR ($CDCl_3$): 3.7; 18.5; 19.1; 46.2; 46.9; 55.5; 67.3; 67.4; 75.9; 76.2; 77.4; 77.5; 117.5; 118.2; 127.8; 128.0; 128.4; 128.5; 129.0; 136.8; 155.8; 156.2. EI-MS: 335, 337 (M^+). Anal. calc. for $C_{16}H_{18}BrNO_2$: C 57.16, H 5.40, N 4.17; found: C 57.30, H 5.48, N 4.12.

Benzyl (2-Bromoprop-2-en-1-yl)(but-2-yn-1-yl)carbamate (**10**). As described for **5**: Colorless oil. B.p. 184–185°/1 Torr. IR (neat): 1702. ^1H-NMR ($CDCl_3$): 1.80 (*s*, 3 H); 4.06, 4.13 (2*s*, 2 H); 4.25 (*s*, 2 H); 5.16, 5.19 (2*s*, 2 H); 5.56 (*s*, 1 H); 5.72, 5.79 (2*s*, 1 H); 7.03–7.05 (*m*, 5 H). ^{13}C-NMR ($CDCl_3$): 36.1; 36.3; 53.5; 53.7; 67.7; 73.5; 73.7; 80.3; 80.5; 118.0; 118.6; 128.0; 128.1; 128.5; 136.3; 136.5; 155.5. EI-HR-MS: 321.0362 (M^+, $C_{15}H_{16}BrNO_2^+$; calc. 321.0364).

N-*(2-Bromoprop-2-en-1-yl)*-N-*(hex-4-yn-1-yl)benzamide* (**15**). Similar to the synthesis of **5**: Colorless oil. IR (neat): 1620. ^1H-NMR ($CDCl_3$): 1.59–1.90 (*m*, 5 H); 1.98 (*m*, 1 H); 2.23 (*m*, 1 H); 3.37 (*m*, 1 H); 3.58 (*m*, 1 H); 4.11 (*s*, 1 H); 4.44 (*s*, 1 H); 5.66 (*s*, 1 H); 5.84 (*s*, 1 H); 7.40–7.48 (*m*, 5 H). ^{13}C-NMR ($CDCl_3$): 3.5; 16.0; 16.5; 26.5; 27.5; 44.0; 47.5; 51.4; 57.2; 76.5; 76.9; 78.1; 118.6; 118.7; 126.7; 128.5; 128.8; 129.2; 129.6; 129.8; 136.0; 136.2; 172.0; 172.2. EI-HR-MS: 319.0571 (M^+, $C_{16}H_{18}BrNO^+$; calc. 319.0572).

Cross-Coupling Reaction of **2** *with* **5**, **10**, *or* **14**: *General Procedure*. To a THF soln. of **2**, generated from 1*H*-indole **1** (2 mmol) and triethylborane (2.2 mmol) under Ar, bromide **5**, **10**, or **15** (1 mmol) and a palladium complex (0.05 mmol) were added. The mixture was heated at 60° for the time given in *Tables 1* and *2*. After treatment of the mixture with 10% aq. NaOH soln. (2 ml) and 30% aq. H_2O_2 soln. (1 ml) under ice cooling for 10 min, the mixture was extracted with AcOEt (100 ml), and the extract was washed

with brine and dried ($MgSO_4$). The solvent was evaporated, and the residue separated by MPLC (hexane/AcOEt).

tert-*Butyl 2-{(1Z)-1-{1-[(Benzyloxy)carbonyl]-3-methylidenepiperidin-4-ylidene}ethyl}-1*H-*indole-1-carboxylate* (**6a**): Light brown oil. IR ($CHCl_3$): 1726, 1700. ^{1}H-NMR ($CDCl_3$): 1.60 (*s*, 9 H); 1.94 (*s*, 3 H); 2.30–2.41 (*m*, 1 H); 2.61–2.71 (*m*, 1 H); 3.48–3.58 (*m*, 1 H); 3.72–3.92 (*m*, 2 H); 4.16–4.28 (*m*, 1 H); 4.62 (*s*, 1 H); 4.74–4.86 (*m*, 1 H); 5.15 (*s*, 2 H); 6.13 (*s*, 1 H); 7.18 (*t*, J = 7.5, 1 H); 7.24 (*t*, J = 7.5, 1 H); 7.28–7.39 (*m*, 6 H); 7.42 (*d*, J = 7.5, 1 H); 8.15 (*d*, J = 8.5, 1 H). ^{13}C-NMR ($CDCl_3$): 20.5; 28.1; 30.1; 42.6; 42.9; 52.0; 67.2; 83.5; 106.7; 114.7; 115.5; 120.3; 122.8; 123.7; 126.3; 127.9; 128.1; 128.6; 129.6; 133.8; 136.4; 136.9; 141.7; 142.2; 149.9; 155.3. EI-HR-MS: 472.2370 (M^+, $C_{29}H_{32}N_2O_4^+$; calc. 472.2362).

*Benzyl (4Z)-4-[1-(1-Methoxy-1*H-*indol-2-yl)ethylidene]-3-methylidenepiperidine-1-carboxylate* (**6b**): Light brown oil. IR ($CHCl_3$): 1724. ^{1}H-NMR ($CDCl_3$): 2.13 (*s*, 3 H); 2.62 (br. *s*, 2 H); 3.68 (br. *s*, 2 H); 3.84 (*s*, 3 H); 4.17 (*s*, 2 H); 4.50 (br. *s*, 1 H); 4.81–4.86 (*m*, 1 H); 5.18 (*s*, 2 H); 6.19 (*s*, 1 H); 7.08 (*t*, J = 8.0, 1 H); 7.18 (*t*, J = 7.5, 1 H); 7.32–7.39 (*m*, 6 H); 7.51 (*d*, J = 8.0, 1 H). ^{13}C-NMR ($CDCl_3$): 20.2; 30.9; 42.8; 51.6; 64.9; 67.2; 97.6; 108.2; 114.8; 120.1; 120.4; 120.5; 121.9; 123.7; 127.9; 128.1; 128.6; 132.0; 136.9; 137.0; 137.9; 142.0; 155.4. EI-HR-MS: 402.1944 (M^+, $C_{25}H_{26}N_2O_3^+$; calc. 402.1943).

tert-*Butyl 2-{1-{{[(Benzyloxy)carbonyl](pent-3-yn-1-yl)amino}methyl}ethenyl}-1*H-*indole-1-carboxylate* (**7a**): Light brown oil. IR (neat): 1732, 1702. ^{1}H-NMR ($CDCl_3$): 1.57, 1.68 (2*s*, 9 H); 1.72, 1.75 (2*s*, 3 H); 2.29–2.44 (*m*, 2 H); 3.34, 3.39 (2*t*, J = 6.9, 2 H); 4.33, 4.37 (2*s*, 2 H); 4.86, 5.05 (2*s*, 2 H); 5.25–5.32 (*m*, 2 H); 6.37, 6.47 (2*s*, 1 H); 7.11–7.31 (*m*, 7 H); 7.47 (*t*, J = 7.2, 1 H); 8.02, 8.05 (2*d*, J = 8.6, 1 H). ^{13}C-NMR ($CDCl_3$) : 3.56; 18.1; 28.6; 28.1; 28.2; 45.2; 45.9; 52.0; 52.2; 67.0; 67.1; 76.3; 76.6; 84.2; 84.3; 110.6; 115.7; 116.7; 117.4; 120.6; 122.8; 122.9; 124.3; 127.6; 127.8; 128.4; 129.2; 136.6; 136.7; 136.9; 138.9; 139.3; 139.5; 139.7; 150.0; 150.2; 155.9; 156.2. EI-HR-MS: 472.2368 (M^+, $C_{29}H_{32}N_2O_4^+$; calc. 472.2362).

*Benzyl [2-(1-Methoxy-1*H-*indol-2-yl)prop-2-en-1-yl](pent-3-yn-1-yl)carbamate* (**7b**): Light brown oil. IR (neat): 1692. ^{1}H-NMR ($CDCl_3$): 1.55 (*s*, 3 H); 1.74, 1.76 (2*s*, 2 H); 2.35, 2.44 (2*s*, 2 H); 3.38–3.52 (*m*, 2 H); 3.74, 3.85, 3.86 (3*s*, 3 H); 4.44, 4.48 (2*s*, 1 H); 5.05–5.21 (*m*, 2 H); 5.28, 5.35 (2*s*, 1 H); 5.91, 6.01, 6.33, 6.50 (4*s*, 1 H); 7.09 (*t*, J = 7.5, 1 H); 7.20–7.27 (*m*, 1 H); 7.28–7.43 (*m*, 5 H); 7.53 (*d*, J = 8.0, 1 H). ^{13}C-NMR ($CDCl_3$): 3.5; 18.3; 18.7; 45.2; 46.7; 50.7; 51.1; 63.7; 67.3; 96.2; 98.8; 99.6; 108.4; 108.5; 114.4; 115.5; 120.4; 120.6; 121.1; 121.4; 122.2; 123.2; 127.8; 127.9; 128.0; 128.5; 133.4; 136.7; 156.5; 156.3. EI-HR-MS: 402.1942 (M^+, $C_{25}H_{26}N_2O_3^+$; calc. 402.1943).

Benzyl (4Z)-3-Methylidene-4-(1-methylpropylidene)piperidine-1-carboxylate (**8**): Light brown oil. IR (neat): 1698. ^{1}H-NMR ($CDCl_3$): 0.99 (*t*, J = 7.5, 3 H); 1.67 (*s*, 3 H); 2.21 (*q*, J = 7.5, 2 H); 2.31–2.40 (*m*, 2 H); 3.50–3.58 (*m*, 2 H); 4.00 (br. *s*, 2 H); 4.83 (*s*, 1 H); 5.08 (br. *s*, 1 H); 5.13 (*s*, 2 H); 7.34–7.39 (*m*, 5 H). ^{13}C-NMR ($CDCl_3$): 13.9; 17.4; 28.1; 30.6; 30.8; 42.9; 43.2; 52.3; 67.0; 113.4; 113.5; 127.9; 128.0; 128.1; 128.5; 129.2; 133.9; 137.0; 141.9; 155.3. EI-HR-MS: 285.1731 (M^+, $C_{18}H_{23}NO_2^+$; calc. 285.1728).

tert-*Butyl 2-{(1*E*)-1-{1-[(Benzyloxy)carbonyl]-4-methylenepyrrolidin-3-ylidene}ethyl}-1*H-*indole-1-carboxylate* (**11a**): Light brown oil. IR (neat): 1709, 1707. ^{1}H-NMR ($CDCl_3$): 1.54 (*s*, 9 H); 1.99, 2.02 (2*s*, 3 H); 4.10–4.41 (*m*, 5 H); 4.74, 4.79 (2*s*, 1 H); 5.14–5.21 (*m*, 2 H); 6.35 (*s*, 1 H); 7.21 (*t*, J = 7.5, 1 H); 7.29 (*t*, J = 7.5, 1 H); 7.27–7.43 (*m*, 6 H); 7.49 (*d*, J = 7.5, 1 H); 8.17–8.23 (*m*, 1 H). ^{13}C-NMR ($CDCl_3$): 23.3; 28.1; 51.2; 51.7; 52.7; 53.1; 67.1; 83.5; 106.8; 109.1; 115.7; 120.5; 122.9; 124.2; 125.8; 128.0; 128.1; 128.6; 129.5; 131.4; 136.2; 136.8; 139.4; 140.0; 140.7; 149.7; 154.9. EI-HR-MS: 458.2208 (M^+, $C_{28}H_{30}N_2O_4^+$; calc. 458.2206).

*Benzyl (4E)-3-Methylidene-4-[1-(1-methyl-1*H-*indol-2-yl)ethylidene]pyrrolidine-1-carboxylate* (**11b**): Light brown oil. IR (neat): 1704. ^{1}H-NMR ($CDCl_3$): 2.06, 2.09 (2*s*, 3 H); 3.55 (*s*, 3 H); 4.01–4.09 (*m*, 1 H); 4.20–4.33 (*m*, 2 H); 4.37–4.51 (*m*, 2 H); 4.71–4.83 (*m*, 1 H); 5.15–5.24 (*m*, 2 H); 6.34 (*s*, 1 H); 7.12 (*t*, J = 7.5, 1 H); 7.22 (*t*, J = 7.5, 1 H); 7.20–7.48 (*m*, 6 H); 7.60 (*d*, J = 8.0, 1 H). ^{13}C-NMR ($CDCl_3$): 23.6; 29.9; 51.4; 51.9; 52.6; 53.1; 67.1; 98.7; 109.6; 109.7; 109.9; 119.8; 120.6; 121.5; 123.5; 128.1; 128.2; 128.6; 134.0; 134.7; 136.8; 137.0; 140.0; 140.5; 140.7; 154.7; 154.8. EI-HR-MS: 372.1839 (M^+, $C_{24}H_{24}N_2O_2^+$; calc. 372.1838).

*Benzyl (3*E*)-3-[1-(1-Methoxy-1*H-*indol-2-yl)ethylidene]-4-methylidenepyrrolidine-1-carboxylate* (**11c**): Light brown oil. IR (neat): 1702. ^{1}H-NMR ($CDCl_3$): 2.10, 2.13 (2*s*, 3 H); 3.93 (*s*, 3 H); 4.23–4.30 (*m*, 2 H); 4.36–4.45 (*m*, 2 H); 4.56–4.66 (*m*, 1 H); 4.80–4.90 (*m*, 1 H); 5.18–5.23 (*m*, 2 H); 6.22 (*s*, 1 H); 7.11 (*t*, J = 8.0, 1 H); 7.23 (*t*, J = 8.0, 1 H); 7.28–7.46 (*m*, 6 H); 7.55 (*d*, J = 8.0, 1 H). ^{13}C-NMR ($CDCl_3$): 22.8; 31.0; 51.5; 52.1; 52.7; 53.2; 65.7; 67.1; 96.6; 108.4; 109.7; 109.9; 120.3; 120.9; 121.3; 122.3;

123.8; 128.0; 128.1; 128.2; 128.6; 132.2; 134.3; 134.9; 136.3; 136.8; 140.0; 140.7; 154.7; 154.8. EI-HR-MS: 388.1791 (M^+, $C_{24}H_{24}N_2O_3^+$; calc. 388.1787).

Benzyl 3-Methylidene-4-(1-methylpropylidene)pyrrolidine-1-carboxylate (**12**): Light brown oil. IR (neat): 1702. ^{1}H-NMR ($CDCl_3$): 1.06 (*t*, *J* = 7.4, 3 H); 1.71, 1.74 (2*s*, 3 H); 2.33 (*q*, *J* = 7.4, 2 H); 4.11–4.22 (*m*, 4 H); 5.02–5.21 (*m*, 4 H); 7.28–7.41 (*m*, 5 H). ^{13}C-NMR ($CDCl_3$): 11.9; 20.7; 28.0; 51.1; 51.6; 53.1; 53.5; 66.9; 107.9; 108.1; 127.9; 128.0; 128.1; 128.5; 136.8; 136.9; 137.1; 154.8. EI-HR-MS: 271.1563 (M^+, $C_{17}H_{21}NO_2^+$; calc. 271.1572).

*{(4Z)-Hexahydro-3-methylidene-4-[1-(1-methyl-1*H*-indol-2-yl)ethylidene]-1*H*-azepin-1-yl}phenylmethanone* (**16**): Colorless prisms. M.p. 156–157° (recrystallized from AcOEt/hexane). IR ($CHCl_3$): 1710, 1618. ^{1}H-NMR ($CDCl_3$): 1.77, 1.96 (2*m*, 2 H); 1.96, 2.09 (2*s*, 3 H); 2.56 (*m*, 2 H); 3.48, 3.58 (2*s*, 3 H); 3.48, 3.75 (2*m*, 2 H); 3.95, 4.36 (2*s*, 2 H); 4.56, 4.64 (2*s*, 1 H); 4.60, 4.89 (2*s*, 1 H); 5.59, 6.0 (2*s*, 1 H); 6.97–7.1 (*m*, 3 H); 7.22–7.26 (*m*, 1 H); 7.35–7.55 (*m*, 5 H). ^{13}C-NMR ($CDCl_3$): 19.9; 20.8; 26.5; 29.1; 30.2; 30.3; 31.0; 32.6; 46.2; 51.1; 52.9; 57.7; 96.2; 99.3; 99.9; 109.0; 109.3; 114.0; 115.2; 119.2; 120.1; 129.0; 120.8; 124.1; 126.3; 127.7; 128.3; 128.6; 129.2; 129.9; 136.2; 136.8; 137.1; 141.3; 142.0; 142.3; 142.6; 145.9; 147.9; 171.2. EI-MS: 370 (M^+). Anal. calc. for $C_{25}H_{26}N_2O$: C 81.05, H 7.07, N 7.56; found: C 81.00, H 7.10, N 7.52.

N-*(Hex-4-yn-1-yl)*-N-*[2-(1-methyl-1*H*-indol-2-yl)prop-2-en-1-yl]benzamide* (**17**): Light brown oil. IR (neat): 1624. ^{1}H-NMR ($CDCl_3$): 1.50–2.10 (*m*, 6 H); 2.26 (*m*, 1 H); 3.29 (*m*, 1 H); 3.48 (*m*, 4 H); 3.67 (*m*, 1 H); 3.82 (*s*, 1 H); 4.22 (*s*, 1 H); 4.59 (*s*, 1 H); 5.41 (*s*, 1 H); 5.56 (*s*, 1 H); 6.21, 6.56 (2*s*, 1 H); 7.10 (*m*, 1 H); 7.20–7.60 (*m*, 8 H). ^{13}C-NMR ($CDCl_3$): 3.6; 16.1; 16.6; 16.8; 26.7; 27.6; 30.7; 31.3; 44.6; 47.7; 48.8; 54.4; 76.5; 76.7; 78.4; 101.5; 101.8; 109.6; 117.5; 117.9; 120.0; 120.7; 122.3; 126.5; 127.4; 127.5; 128.4; 128.5; 129.3; 129.6; 136.0; 136.4; 137.8; 138.2; 138.6; 172.1; 172.3. EI-HR-MS: 370.2045 (M^+, $C_{25}H_{26}N_2O^+$; calc. 370.2045).

Irradiation of **6a**, **11**, *or* **15**: *General Procedure.* A soln. of **6a**, **11**, or **15** (100 mg) in benzene (15 ml) was irradiated with a 100 W high-pressure mercury lamp through a *Pyrex* filter under ice cooling for 2 h. The solvent was evaporated, and the residue separated by MPLC (hexane/AcOEt).

*2-Benzyl 6-(*tert*-Butyl) 3,4-Dihydro-5-methyl-1*H*-pyrido[4,3-*b*]carbazole-2,6-dicarboxylate* (**9**): Colorless prisms. M.p. 127–128° (recrystallized from AcOEt/hexane). IR ($CHCl_3$): 1726, 1696. ^{1}H-NMR ($CDCl_3$): 1.69 (*s*, 9 H); 2.35 (*s*, 3 H); 2.94 (br. *s*, 2 H); 3.80 (br. *s*, 2 H); 4.81 (*s*, 2 H); 5.20 (*s*, 2 H); 7.29–7.34 (*m*, 2 H); 7.35–7.44 (*m*, 5 H); 7.51–7.61 (*m*, 1 H); 7.87 (br. *s*, 1 H); 8.02 (*d*, *J* = 8.6, 1 H). ^{13}C-NMR ($CDCl_3$): 17.4; 26.8; 27.0; 28.2; 41.7; 41.9; 46.4; 67.2; 83.8; 114.6; 114.8; 115.4; 119.6; 123.1; 124.8; 125.8; 126.4; 126.9; 128.1; 128.6; 133.1; 136.9; 138.1; 140.7; 151.4; 155.5. EI-MS: 470 (M^+). Anal. calc. for $C_{29}H_{30}N_2O_4$: C 74.02, H 6.43, N 5.95; found: C 73.86, H 6.39, N 5.79.

*Benzyl 3,5-Dihydro-4,5-dimethylpyrrolo[3,4-*b*]carbazole-2(1*H*)-carboxylate* (**14**): Colorless prisms. M.p. 177–178° (recrystallized from AcOEt/hexane). IR ($CHCl_3$): 1690. ^{1}H-NMR ($CDCl_3$): 2.69, 2.72 (2*s*, 3 H); 4.08, 4.09 (2*s*, 3 H); 4.81–4.98 (*m*, 4 H); 5.25 (*s*, 2 H); 7.18–7.23 (*m*, 1 H); 7.31–7.50 (*m*, 7 H); 7.73, 7.79 (2*s*, 1 H); 8.00 (*t*, *J* = 7.5, 1 H). ^{13}C-NMR ($CDCl_3$): 15.8; 32.6; 52.0; 52.4; 52.6; 52.9; 67.0; 67.1; 108.6; 108.7; 111.5; 111.7; 114.9; 119.0; 119.1; 119.8; 119.9; 122.5; 124.1; 125.7; 127.5; 127.8; 127.9; 128.0; 128.1; 128.6; 134.8 135.1; 137.0; 139.4; 142.2; 155.0. EI-MS: 370 (M^+). Anal. calc. for $C_{24}H_{22}N_2O_2 \cdot 2/5\ H_2O$: C 76.30, H 6.09, N 7.42; found: C 76.20, H 5.91, N 7.37.

*Phenyl[3,4,5,7-tetrahydro-6,7-dimethylazepino[4,3-*b*]carbazol-2(1*H*)-yl]methanone* (**18**): Colorless prisms. M.p. 167–168° (recrystallized from AcOEt/hexane). IR ($CHCl_3$): 1612. ^{1}H-NMR ($CDCl_3$): 1.75 (*m*, 1 H); 1.96 (*m*, 1 H); 2.80 (*s*, 3 H); 3.21 (*m*, 2 H); 3.52 (*m*, 1 H); 4.02 (*m*, 1 H); 4.12, 4.13 (2*s*, 3 H); 4.57 (*s*, 1 H); 4.96 (*s*, 1 H); 7.15–7.26 (*m*, 3 H); 7.32–7.52 (*m*, 5 H); 7.75, 8.03 (2*d*, *J* = 8.0, 1 H); 7.99 (*s*, 1 H). ^{13}C-NMR ($CDCl_3$): 15.5; 15.7; 27.2; 27.5; 28.8; 29.0; 33.7; 48.2; 49.5; 51.7; 55.4; 96.2; 108.9; 109.0; 118.1; 118.7; 119.2; 119.4; 119.8; 120.0; 121.8; 122.9; 123.0; 125.4; 126.5; 127.2; 128.0; 128.3; 128.4; 129.0; 129.2; 129.4; 137.1; 137.5; 138.7; 140.5; 140.7; 142.6; 142.7; 170.4; 172.0. EI-MS: 368 (M^+). Anal. calc. for $C_{25}H_{24}N_2O$: C 81.49, H 6.57, N 7.60; found: C 81.22, H 6.78, N 7.48.

tert-*Butyl 1,2,3,4-Tetrahydro-5-methyl-6*H*-pyrido[4,3-*b*]carbazole-6-carboxylate* (**20**). Catalytic hydrogenation of **9** (100 mg) was carried out in the presence of 10% Pd/C (10 mg) in THF (10 ml) under 1 atm H_2 at r.t. for 4 h. The solvent and the catalyst were removed, and the residue was separated by MPLC (CH_2Cl_2/MeOH 70:1): **20** (64 mg, 90%). Light yellow powder. M.p. 129–131° (recrystallized from AcOEt/hexane). IR ($CHCl_3$): 1720. ^{1}H-NMR ($CDCl_3$): 1.68 (*s*, 9 H); 2.31 (*s*, 3 H); 3.09 (br. *s*, 2 H);

3.46 (br. *s*, 2 H); 4.41 (br. *s*, 2 H); 7.31 (*t*, *J* = 7.5, 1 H); 7.42 (*t*, *J* = 8.0, 1 H); 7.51 (*s*, 1 H); 7.86 (*d*, *J* = 7.5, 1 H); 8.01 (*d*, *J* = 8.0, 1 H). ^{13}C-NMR (CD_3OD): 15.9; 25.5; 27.0; 42.8; 83.7; 114.7; 114.8; 119.3; 123.0; 124.7; 125.5; 126.1; 126.6; 128.4; 131.5; 138.0; 140.5; 151.5. EI-MS: 336 (M^+). Anal. calc. for $C_{21}H_{24}N_2O_2$: C 74.97, H 7.19, N 8.32; found: C 74.85, H 7.30, N 8.29.

tert-*Butyl 3,4-Dihydro-5-methyl-6*H-*pyrido[4,3-*b*]carbazole-6-carboxylate* (**21**). A mixture of **20** (100 mg) and active MnO_2 (300 mg) in AcOEt (10 ml) was stirred overnight. The solvent and insoluble materials were removed, and the residue was separated by MPLC (hexane/AcOEt 1:1): **21** (25%) and **22** (10%). **21**: Colorless prisms. M.p. 126–127° (AcOEt/hexane). IR ($CHCl_3$): 1724. ^{1}H-NMR ($CDCl_3$): 1.70 (*s*, 9 H); 2.36 (*s*, 3 H); 2.84 (*t*, *J* = 7.5, 2 H); 3.83 (*t*, *J* = 7.5, 2 H); 7.35 (*t*, *J* = 7.5, 1 H); 7.44 (*t*, *J* = 7.5, 1 H); 7.75 (*s*, 1 H); 7.94 (*d*, *J* = 7.5, 1 H); 8.02 (*d*, *J* = 8.6, 1 H); 8.44 (*s*, 1 H). ^{13}C-NMR ($CDCl_3$): 16.9; 23.0; 28.2; 47.6; 84.3; 115.2; 117.0; 119.7; 123.4; 123.8; 124.9; 125.6; 126.2; 127.1; 135.1; 140.4; 140.9; 150.9; 161.0. EI-HR-MS: 334.1688 (M^+, $C_{21}H_{22}N_2O_2^+$; calc. 334.1681).

tert-*Butyl 5-Methyl-6*H-*pyrido[4,3-*b*]carbazole-6-carboxylate* (**22**). A mixture of **20** (100 mg) and active MnO_2 (300 mg) in AcOEt (10 ml) was heated under reflux for 3 h. After removal of insoluble materials by filtration, the filtrate was concentrated and the residue separated by MPLC (hexane/AcOEt 1:1): 60 mg of **22** (60%). Colorless prisms. M.p. 133–134° (AcOEt/hexane). IR ($CHCl_3$): 1724. ^{1}H-NMR ($CDCl_3$): 1.71 (*s*, 9 H); 2.74 (*s*, 3 H); 7.40 (*t*, *J* = 7.4, 1 H); 7.52 (*t*, *J* = 7.4, 1 H); 7.94 (*d*, *J* = 6.3, 1 H); 8.06–8.12 (*m*, 2 H); 8.39 (*s*, 1 H); 8.55 (*d*, *J* = 6.3, 1 H); 9.37 (*s*, 1 H). ^{13}C-NMR ($CDCl_3$): 16.9; 28.2; 84.3; 115.7; 116.0; 117.2; 119.7; 120.6; 123.7; 125.9; 126.2; 128.6; 128.8; 135.4; 139.9; 142.2; 151.1; 153.2. EI-MS: 332 (M^+). Anal. calc. for $C_{21}H_{20}N_2O_2$: C 75.88, H 6.06, N 8.42; found: C 75.68, H 6.11, N 8.37.

*5-Methyl-6*H-*pyrido[4,3-*b*]carbazole* (**23**) [9]. A mixture of **22** (40 mg) and Cs_2CO_3 (100 mg) in THF (20 ml) and MeOH (20 ml) was heated under reflux for 3 h. After the mixture was concentrated, the residue was extracted with AcOEt, the extract washed with brine and dried ($MgSO_4$), the solvent evaporated, and the residue separated by MPLC (hexane/AcOEt 1:2): 27 mg of **23** (55%). Light red prisms. M.p. 280–282° (recrystallized from MeOH) ([9]: M.p. 270–276°). IR (nujol): 3140. ^{1}H-NMR ((D_6)acetone): 2.85 (*s*, 3 H); 7.24 (*dt*, *J* = 1.1, 7.6, 1 H); 7.48 (*dt*, *J* = 1.1, 8.0, 1 H); 7.53 (*d*, *J* = 8.0, 1 H); 7.90 (*d*, *J* = 5.7, 1 H); 8.20 (*s*, 1 H); 8.29 (*d*, *J* = 7.5, 1 H); 8.39 (*d*, *J* = 5.7, 1 H); 8.71 (*s*, 1 H); 9.35 (*s*, 1 H); 10.40 (*s*, 1 H). ^{13}C-NMR (CD_3OD): 13.2; 110.4; 110.5; 116.3; 116.9; 119.2; 120.8; 122.8; 123.8; 126.4; 127.7; 132.9; 138.8; 141.8; 142.9; 152.6. EI-HR-MS: 232.1004 (M^+, $C_{16}H_{12}N_2^+$; 232.1001).

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