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Exploiting an intramolecular Diels–Alder cyclization/dehydro-aromatization sequence for the total syntheses of ellipticines and calothrixin B†

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The tetracyclic and pentacyclic skeletons of pyrido and quinolinocarbazole alkaloids have been synthesized *via* a unified strategy. The prominent key step involved a Diels–Alder intramolecular cyclization/dehydro-aromatization sequence. From these carbazole-lactam cores, linear syntheses have been developed for ellipticines and calothrixin B.

Introduction

Pyrido and quinolinocarbazole alkaloids (Fig. 1) are well-known for their wide range of potent biological activities.[1] Ellipticine (**1a**) was isolated from the leaves of *Ochrosia elliptica* Labill by Goodwin *et al.* and *Ochrosia sandwicensis* A.DC. of the Apocynaceae family in 1959.[2] In the following years, a group of related metabolites of ellipticine such as 3,4-dehydroellipticine (**1b**) and 1,2,3,4-tetrahydroellipticine (**1c**) were also isolated from different plants.[3] The biological activity of ellipticine was considered to be based mainly on DNA intercalation and topoisomerase II inhibition.[4] Calothrixin A (**2**) and B (**3**) are two cyanobacterial metabolites with quino[4,3-*b*]carbazole frameworks that were first isolated from cell extracts of *Calothrix cyanobacterium* in 1999.[5] They possess a unique framework with an assembly of quinoline, quinone, and indole pharmacophores. Calothrixin A is known to be an *N*-oxide analog of calothrixin B. They act as human DNA topoisomerase I poisons exhibiting lethal effects on human cancer cell lines at low nano-molar concentrations, and inhibit *in vitro* growth of a chloroquine-resistant strain of the human parasite *Plasmodium falciparum*.[6]

To date, numerous efforts have also been invested in developing efficient synthetic avenues to ellipticines[7,8] and calothrixins,[9,10] which are well documented. In 2018, we reported that an oxidative Heck reaction could trigger a domino process to deliver the basic framework of natural quino[4,3-*b*]carbazoles (Scheme 1a), thus achieving a novel total synthesis of calothrixin B.[11] Very recently, we further discovered a DBU-catalyzed intermolecular cyclization to construct the pentacyclic skeleton of calothrixin alkaloids (Scheme 1b), permitting us to accomplish a total synthesis of calothrixin B with atom and step economy.[12] The intramolecular Diels–Alder reaction is a powerful strategy for the construction of multicyclic natural products.[13] Due to our continued interest in the synthesis of biologically active carbazoles, we seek to develop a unified synthetic strategy involving a tandem Diels–Alder cyclization/dehydro-aromatization sequence (Scheme 1c) for construction of the tetracyclic and pentacyclic cores of pyrido and quinolino carbazoles.

The retrosynthetic strategy is shown in Scheme 2. We envisaged that both ellipticines and calothrixin B could be derived from carbazole-lactam precursors **4**, then the most salient feature of this strategy is the creation of the C and D rings of intermediates **4** using an intramolecular Diels–Alder cyclization/dehydro-aromatization tandem transformation from amides **5**. In turn, the amides **5** could be readily produced

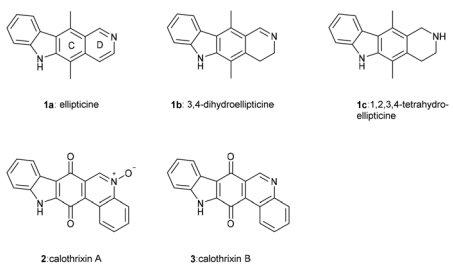

Fig. 1 Ellipticines (**1a–c**) and calothrixins A–B (**2,3**).

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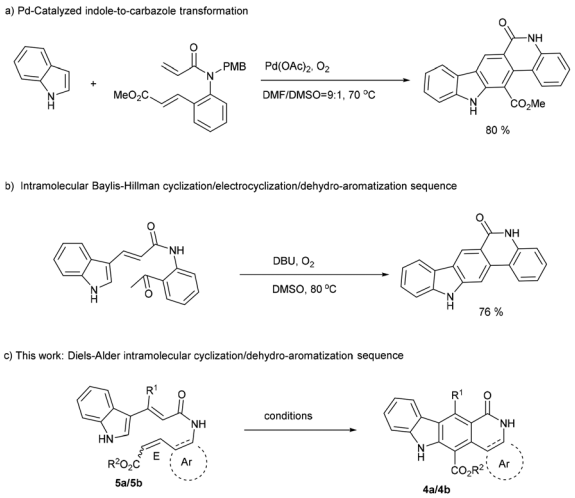
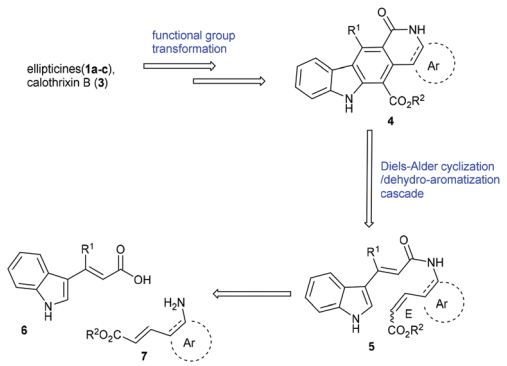


Scheme 1 Key domino processes in our previous work and the present study.



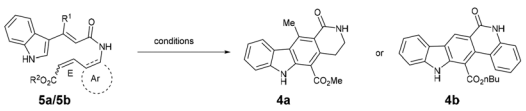
Scheme 2 Retrosynthetic plan.

from the coupling of 3-(1*H*-indol-3-yl) acrylic acids **6** and amines **7**.

Results and discussion

We started the above proposed synthetic route by conducting a DCC coupling of acid **6** and methyl (*E*)-5-aminopent-2-enoate or butyl (*E*)-3-(2-aminophenyl) acrylate **7**,[14,15] thus to produce two type of amides: **5a** and **5b** in 58 and 65% yield respectively. Next step was to realize the designed cascade and generate cyclic products **4a–b**. Attempts focused on heating the precursors in different solvents to initiate the domino sequence, and a wide range of oxidants used in dehydro-aromatic processes including O_2, $Cu(OAc)_2$, $CuCl_2$,[16] I_2,[17] and DDQ[18] were identified for this specific transformation (Table 1). Initial investigation was performed with O_2 or $Cu(OAc)_2$ as the oxidant in DMF/DMSO (9 : 1) at 90 °C (Table 1, entries 1 and 2); these conditions, related to our previous work,[11] did not catalyze the cyclization at all. In further screenings, to maximize technical simplicity and eco-friendliness, we tried to employ O_2 as the terminal oxidant, and more solvents such as isopropanol, glycol, glycerine, pivalic acid, PEG200, PEG400 and 1,2-dichlorobenzene were examined as the reaction medium (Table 1, entries 3–9). Among these screenings, the two substrates **5a** and **5b** demonstrated different reactivity: designed conversion of **5a** to **4a** could take place in 64% yield when glycol was adopted as the solvent, also it was interesting to discover that the PEG200/O_2 system could furnish **4b** in 81% yield. Moreover, to increase the yields of the cyclic products, other oxidants [$CuCl_2$, $Cu(OAc)_2$, I_2 and DDQ] were also investigated (Table 1, entries 10–14); no improvement was observed in the yield of **4a** with these conditions, however, it was gratifyingly found that 0.1 equiv. I_2 in hot DMSO was the most effective system to furnish **4b** which significantly raised the reaction yield up to 96% (Table 1, entry 11), and there was no obvious change in the yield on a higher loading of I_2 (Table 1, entry 12). Notably, general routes that convert 2- or 3-alkenyl indoles to carbazole derivatives involving a Diels–Alder reaction and dehydro-aromatization process have been developed through two-step procedures, also stoichiometric DDQ was required for the transformation.[18] Since DDQ was relatively expensive and toxic, the adoption of O_2 or a catalytic amount of I_2 as the oxidant in the above optimized conditions was economical and eco-friendly.

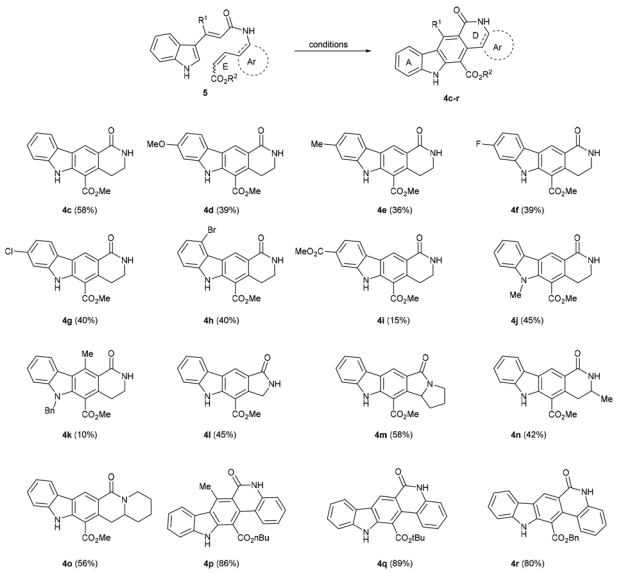
Table 1 Conditions screening for cascade ring closure[a]



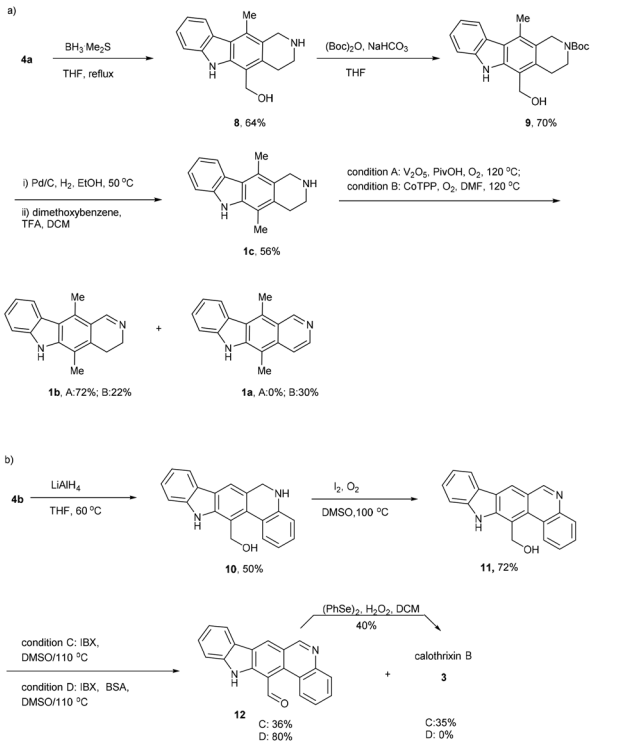
Entry	Solvent/oxidant	Temp. (°C)	Yield[b] (%): **4a**/**4b**
1	DMSO : DMF(9 : 1)/O_2	90	0/0
2	DMSO : DMF(9 : 1)/2 eq. $Cu(OAc)_2$	90	0/0
3	i-PrOH/O_2	85	0/38
4	**Glycol/O_2**	**120**	**64**/50
5	Glycerine/O_2	120	15/29
6	Pivalic acid/O_2	120	5/35
7	PEG200/O_2	120	23/81
8	PEG400/O_2	120	10/71
9	1,2-Dichlorobenzene/O_2	200	15/20
10	DMSO/0.2 eq. $CuCl_2$	100	0/64
11	**DMSO/0.1 eq. I_2**	**100**	0/**96**
12	DMSO/0.2 eq. I_2	100	0/95
13	1,2-Dichlorobenzene/2 eq. $Cu(OAc)_2$	200	56/92
14	1,2-Dichlorobenzene/2 eq. DDQ	180	49/0

[a] Reactions were performed using amide **5a**/**5b** (0.6 mmol) in 3.0 mL of solvent. [b] Isolated yield.

With a view to briefly understand the generality of this protocol, we have prepared a number of amide substrates (**5c–r**). These functionalized precursors were then respectively subjected to one of the above two optimized conditions (Scheme 3). Substrates bearing electron-donating groups (OMe, Me group) or mild electron-withdrawing substituents (F, Cl and Br) on the A ring gave the desired products **4d–h** in moderate yields (36–40%), however, a precursor bearing a strong electron-withdrawing group such as an ester group on



Scheme 3 Substrate scope for tandem process. **5c–5o** (0.6 mmol) in 2.0 mL glycol under O_2 at 120 °C, **5p–5r** (0.6 mmol) with I_2 (15 mg, 0.06 mmol) in 2.0 mL DMSO at 100 °C. Yields refer to the isolated yield.



Scheme 4 Completion of the syntheses of ellipticines (**1a–c**) and calothrixin B (**3**).

the A ring significantly reduced the efficiency, as the resulting derivative **4i** was obtained in lower yield (15%). Functional group substitution of the N–H atom (Me, Bn) of the indole fragment apparently affected the reactivity, although the Me substituted substrate gave the corresponding product **4j** in a normal yield, the substrate with the larger steric Bn substitution only produced **4k** in 10% yield under the favourable conditions. Moreover, four D ring modified substrates also formed the expected products **4l–o** uneventfully. In a parallel investigation, three **4b**-type compounds **4p–r** with a Me substituent or different ester group (–CO_2tBu and –CO_2Bn) on the C ring could be generated in 80–89% yields.

Notably, carbazolelactams **4a–b** provided by the above tandem approach possess the basic skeleton of natural pyrido and quinolinocarbazoles. Reduction of compound **4a** by $BH_3{\cdot}Me_2S$ afforded alcohol **8** in 64% yield (Scheme 4a). An attempt for the direct conversion of **8** to **1c** by catalytic hydrogenation with Pd/C failed, which reveals that the presence of the free piperidyl NH would be problematic. Further, to conquer this problem, compound **9** bearing a Boc group was prepared, then it was successfully converted into compound **1c** through hydrogenation and deprotection. A previously reported effort using MnO_2 as the oxidant to directly transform **1c** to ellipticine was not successful.[19] We turned to examine other dehydrogenative reagents. Treatment of **1c** with 2 equivalents of V_2O_5 in pivalic acid[20] under an O_2 atmosphere only afforded 3,4-dehydroellipticine **1b** in 72% yield. Notably, **1b** was a known intermediate to generate ellipticine through Pd/C catalyzed aromatization.[8n] Although several oxidants[16,21a–b] such as $CuCl_2{\cdot}2H_2O$, I_2, and IBX have been reported for directly oxidative didehydrogenation to generate isoquinoline fragments, we found **1c** could only be provided by a CoTPP/O_2 [21c] system, thus delivering the ellipticine (**1c**) in 30% yield, and 3,4-dehydroellipticine (**1b**) was also in accompaniment (22%). In a parallel synthesis (Scheme 4b), for establishment of the approach to calothrixin B, complete reduction of **4b** using $LiAlH_4$ led to alcohol **10** in moderate yield (50%). Further regioselective oxidation of compound **10** using I_2/DMSO afforded phenanthridine product **11** in 72% yield. With the critical intermediate **11** in hand, although no similar transformation has been achieved, we planned to realize the one-step conversion of **11** to calothrixin B. After a series of oxidants were examined (IBX, Dess–Martin periodinane, TBHP), we found that IBX in hot DMSO could promote the demanding transformation to provide the requisite product in 35% yield, also an aldehyde derivative **12** was concurrently formed. Product **12** was nonreactive when subjected to the IBX oxidative conditions again, however, it could be directly converted to calothrixin B in 40% yield through a Baeyer–Villiger procedure.[10k] Further attempt to enhance the selectivity of the IBX-mediated oxidative transformation using base or acid as additives was not successful; the adoption of pyridine decreased the yield of calothrixin B, and aldehyde **12** was even formed as the sole product in 80% yield when catalytic benzenesulfonic acid (BSA) was used.

Conclusions

In summary, we have developed a unified strategy to construct the basic frameworks of ellipticines and calothrixins.

Additionally, highlighting the advantages of the protocol, further syntheses provide expedient entries to these biologically active alkaloids in short reaction sequences. Although the synthesis of ellipticines and calothrixins are intensively studied, the synthetic sequence used for conversion of amides **5** into ellipticines and calothrixin B has its own characteristics, for example, the conversion of **1c** to ellipticine and intermediate **11** or **12** to calothrixin B has been achieved as directly as possible. Moreover, this synthetic method is also having the advantage of using simple reagents for the transformations.

Experimental

The solvents were dried and distilled prior to use according to the literature methods. Column chromatographic purifications were performed on SDZF silica gel 160. ^{1}H and ^{13}C NMR spectra were obtained on a Bruker NMR spectrometer at 600 MHz and 150 MHz, respectively, and referenced internally based on the residual solvent signal. The data reported for the ^{1}H NMR spectra are as follows: chemical shift (δ, ppm), multiplicity (s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet), coupling constant in hertz, and number of protons. The data reported for the ^{13}C spectra are given as chemical shift (δ, ppm). High-resolution mass spectra (HRMS) were obtained on an Agilent mass spectrometer by electrospray ionization-time of flight (ESI-TOF) analysis. Melting points were measured with a melting point instrument without correction. All the chemical reagents were purchased from commercial sources and used as received unless otherwise indicated.

General procedure for the synthesis of carbazolelactams (4a, 4c–o)

Synthesis of 4a. Compound **5a** (0.6 mmol) was dissolved in ethylene glycol (2.0 mL). The mixture was heated to 120 °C and stirred under O_2 for 24 h. The reaction solution was cooled to room temperature and diluted with ethyl acetate. The organic phase washed with H_2O, brine, and dried over anhydrous Na_2SO_4. After evaporation, the crude product was purified by flash column chromatography (DCM/EA = 6 : 1–3 : 1) to obtain product **4a**.

Methyl 11-methyl-1-oxo-2,3,4,6-tetrahydro-1*H*-pyrido[4,3-*b*]carbazole-5-carboxylate (4a). 118 mg, yield 64%, white solid, IR (KBr) 3450, 3016, 1729, 1650, 1198, 1094 cm^{-1}. ^{1}H NMR (600 MHz, DMSO-d_6) δ 11.35 (s, 1H), 8.24 (d, J = 8.4 Hz, 1H), 8.02 (s, 1H), 7.73 (d, J = 7.8 Hz, 1H), 7.47 (t, J = 7.8 Hz, 1H), 7.26 (t, J = 7.2 Hz, 1H), 4.00 (s, 3H), 3.26 (s, 4H), 3.17 (s, 3H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 166.8, 165.7, 140.3, 140.1, 139.0, 125.8, 122.7, 122.6, 122.0, 121.3, 119.9, 111.9, 108.8, 52.2, 38.6, 29.1, 18.7. HRMS (ESI) m/z calcd for $C_{18}H_{17}N_2O_3$ [M + H]$^+$: 309.1239, found: 309.1245.

Methyl 1-oxo-2,3,4,6-tetrahydro-1*H*-pyrido[4,3-*b*]carbazole-5-carboxylate (4c). 97 mg, yield 58%, yellow solid, IR (KBr) 3350, 3016, 1664, 1344, 1082 cm^{-1}. ^{1}H NMR (600 MHz, DMSO-d_6) δ 11.37 (s, 1H), 8.91 (s, 1H), 8.25 (d, J = 7.8 Hz, 1H), 7.99 (s, 1H), 7.69 (d, J = 7.8 Hz, 1H), 7.46 (t, J = 7.2 Hz, 1H), 7.24 (t, J = 7.2 Hz, 1H), 4.01 (s, 3H), 3.40–3.37 (m, 4H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 166.6, 164.9, 140.6, 140.4, 139.0, 126.6, 124.0, 122.3, 122.0, 121.5, 120.4, 120.0, 112.0, 110.5, 52.2, 38.9, 27.1. HRMS (ESI) m/z calcd for $C_{17}H_{15}N_2O_3$ [M + H]$^+$: 295.1083, found: 295.1088.

Methyl 8-methoxy-1-oxo-2,3,4,6-tetrahydro-1*H*-pyrido[4,3-*b*]carbazole-5-carboxylate (4d). 75 mg, yield 39%, brown solid, IR (KBr) 3321, 3012, 1714, 1654, 1504, 1078, 1007 cm^{-1}. ^{1}H NMR (600 MHz, DMSO-d_6) δ 11.26 (s, 1H), 8.76 (s, 1H), 8.10 (d, J = 8.4 Hz, 1H), 7.93 (s, 1H), 7.20 (d, J = 2.4 Hz, 1H), 6.86 (dd, J = 8.4 Hz, 1H), 4.00 (s, 3H), 3.85 (s, 3H), 3.38–3.34 (m, 4H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 166.4, 166.1, 156.0, 147.2, 138.3, 133.1, 129.3, 121.9, 120.5, 119.0, 115.8, 112.2, 110.2, 95.3, 55.2, 51.2, 37.2, 32.0. HRMS (ESI) m/z calcd for $C_{18}H_{17}N_2O_4$ [M + H]$^+$: 325.1188, found: 325.1187.

Methyl 8-methyl-1-oxo-2,3,4,6-tetrahydro-1*H*-pyrido[4,3-*b*]carbazole-5-carboxylate (4e). 66 mg, yield 36%, light pink solid, IR (KBr) 3342, 3020, 1665, 1493, 1210, 1081 cm^{-1}. ^{1}H NMR (600 MHz, DMSO-d_6) δ 11.25 (s, 1H), 8.83 (s, 1H), 8.11 (d, J = 7.8 Hz, 1H), 7.96 (s, 1H), 7.47 (s, 1H), 7.07 (d, J = 7.8 Hz, 1H), 4.00 (s, 3H), 3.39–3.36 (m, 4H), 2.48 (s, 3H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 166.7, 165.0, 140.9, 140.7, 138.4, 136.2, 123.5, 122.4, 121.6, 121.4, 120.1, 119.8, 112.0, 110.4, 52.2, 38.9, 27.1, 21.8. HRMS (ESI) m/z calcd for $C_{18}H_{17}N_2O_3$ [M + H]$^+$: 309.1239, found: 309.1234.

Methyl 8-fluoro-1-oxo-2,3,4,6-tetrahydro-1*H*-pyrido[4,3-*b*]carbazole-5-carboxylate (4f). 73 mg, yield 39%, off-white solid, IR (KBr) 3350, 3010, 1662, 1507, 1402, 1081 cm^{-1}. ^{1}H NMR (600 MHz, DMSO-d_6) δ 11.47 (s, 1H), 8.90 (s, 1H), 8.30–8.28 (m, 1H), 8.00 (s, 1H), 7.43 (dd, J = 9.6, 2.4 Hz, 1H), 7.10–7.06 (m, 1H), 4.01 (s, 3H), 3.39–3.36 (m, 4H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 166.5, 164.8, 162.3, 160.7, 141.2, 141.1, 138.7, 123.9, 122.1, 122.0, 121.9, 118.8, 110.6, 108.1, 108.0, 98.6, 98.4, 52.3, 38.9, 27.1. ^{19}F NMR (564 MHz, DMSO-d_6) δ −114.24. HRMS (ESI) m/z calcd for $C_{17}H_{14}N_2O_3F$ [M + H]$^+$: 313.0988, found: 313.0989.

Methyl 8-chloro-1-oxo-2,3,4,6-tetrahydro-1*H*-pyrido[4,3-*b*]carbazole-5-carboxylate (4g). 79 mg, yield 40%, yellow solid, IR (KBr) 3371, 3016, 1705, 1664, 1520, 1076, 980 cm^{-1}. ^{1}H NMR (600 MHz, DMSO-d_6) δ 11.48 (s, 1H), 8.93 (s, 1H), 8.29 (d, J = 8.4 Hz, 1H), 8.02 (s, 1H), 7.71 (d, J = 1.8 Hz, 1H), 7.26 (dd, J = 8.4, 2.4 Hz, 1H), 4.01 (s, 3H), 3.38 (s, 4H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 166.5, 164.7, 141.0, 141.0, 139.4, 130.9, 124.3, 122.2, 122.0, 121.7, 121.0, 120.2, 111.7, 110.8, 52.3, 38.8, 27.2. HRMS (ESI) m/z calcd for $C_{17}H_{14}N_2O_3Cl$ [M + H]$^+$: 329.0693, found: 329.0697.

Methyl 10-bromo-1-oxo-2,3,4,6-tetrahydro-1*H*-pyrido[4,3-*b*]carbazole-5-carboxylate (4h). 89 mg, yield 40%, light brown solid, IR (KBr) 3354, 3020, 1654, 1489, 1082, 1014 cm^{-1}. ^{1}H NMR (600 MHz, DMSO-d_6) δ 11.68 (s, 1H), 9.40 (s, 1H), 8.07 (s, 1H), 7.76 (d, J = 7.8 Hz, 1H), 7.48 (d, J = 7.2 Hz, 1H), 7.41 (t, J = 7.8 Hz, 1H), 4.02 (s, 3H), 3.39 (s, 4H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 166.9, 165.2, 142.2, 141.2, 140.1, 128.1, 125.7, 124.4, 122.2, 122.0, 120.8, 115.7, 112.1, 111.3, 63.3, 52.9, 27.6. HRMS (ESI) m/z calcd for $C_{17}H_{14}N_2O_3Br$ [M + H]$^+$: 373.0188, found: 373.0187.

Dimethyl 1-oxo-2,3,4,6-tetrahydro-1*H*-pyrido[4,3-*b*]carbazole-5,8-dicarboxylate (4i). 31 mg, yield 15%, white solid, IR (KBr) 3346, 3018, 1733, 1661, 1473, 1078 cm^{-1}. ^1H NMR (600 MHz, DMSO-d_6) δ 11.62 (s, 1H), 8.99 (s, 1H), 8.38–8.36 (m, 2H), 8.04 (s, 1H), 7.85 (dd, J = 8.4, 1.2 Hz, 1H), 4.02 (s, 3H), 3.91 (s, 3H), 3.40 (s, 4H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 167.2, 166.8, 165.1, 142.2, 141.1, 140.3, 127.8, 126.3, 125.6, 122.7, 122.0, 121.1, 121.0, 114.0, 111.3, 52.8, 52.7, 39.3, 27.7. HRMS (ESI) m/z calcd for $C_{19}H_{17}N_2O_5$ $[M + H]^+$: 353.1137, found: 353.1132.

Methyl 6-methyl-1-oxo-2,3,4,6-tetrahydro-1*H*-pyrido[4,3-*b*]carbazole-5-carboxylate (4j). 83 mg, yield 45%, white solid, IR (KBr) 3327, 2929, 2860, 1718, 1666, 1471, 1084 cm^{-1}. ^1H NMR (600 MHz, DMSO-d_6) δ 8.81 (s, 1H), 8.29 (d, J = 7.8 Hz, 1H), 7.98 (s, 1H), 7.68 (d, J = 7.8 Hz, 1H), 7.54 (t, J = 7.2 Hz, 1H), 7.30 (t, J = 7.8 Hz, 1H), 4.02 (s, 3H), 3.76 (s, 3H), 3.44–3.41 (m, 2H), 2.99 (t, J = 6.0 Hz, 2H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 168.2, 164.7, 141.7, 138.1, 134.3, 126.8, 122.2, 121.7, 121.6, 120.8, 120.5, 120.3, 114.3, 109.9, 52.7, 39.0, 30.8, 26.3. HRMS (ESI) m/z calcd for $C_{18}H_{17}N_2O_3$ $[M + H]^+$: 309.1239, found: 309.1235.

Methyl 6-benzyl-11-methyl-1-oxo-2,3,4,6-tetrahydro-1*H*-pyrido[4,3-*b*]carbazole-5-carboxylate (4k). 24 mg, yield 10%, yellow solid, IR (KBr) 3420, 3211, 2948, 1725, 1665, 1454, 1340, 742 cm^{-1}. ^1H NMR (600 MHz, $CDCl_3$) δ 8.40 (d, J = 7.8 Hz, 1H), 7.45 (t, J = 7.8 Hz, 1H), 7.35 (t, J = 7.2 Hz, 1H), 7.31–7.28 (m, 3H), 7.26–7.23 (m, 2H), 7.04 (d, J = 7.2 Hz, 2H), 5.52 (s, 2H), 3.49–3.47 (m, 2H), 3.44 (s, 3H), 3.35 (s, 3H), 2.98 (t, J = 6.0 Hz, 2H); ^{13}C NMR (150 MHz, $CDCl_3$) δ 169.0, 166.9, 141.7, 139.6, 137.2, 136.3, 135.5, 128.4, 127.1, 126.0, 125.4, 123.4, 123.3, 120.5, 119.9, 112.7, 109.3, 51.9, 47.5, 39.3, 28.5, 18.6. HRMS (ESI) m/z calcd for $C_{25}H_{23}N_2O_3$ $[M + H]^+$: 399.1709, found: 399.1706.

Methyl 1-oxo-1,2,3,5-tetrahydropyrrolo[3,4-*b*]carbazole-4-carboxylate (4l). 75 mg, yield 45%, brown solid, IR (KBr) 3340, 3026, 1653, 1456, 1076 cm^{-1}. ^1H NMR (600 MHz, DMSO-d_6) δ 11.62 (s, 1H), 8.75 (s, 1H), 8.54 (s, 1H), 8.34 (d, J = 7.2 Hz 1H), 7.77 (d, J = 7.8 Hz, 1H), 7.49 (t, J = 7.8 Hz, 1H), 7.27 (t, J = 7.8 Hz, 1H), 4.69 (s, 2H), 4.03 (s, 3H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 169.7, 165.9, 144.2, 141.3, 140.8, 126.8, 125.0, 124.4, 121.8, 120.8, 120.1, 120.1, 112.3, 106.7, 52.1, 46.6. HRMS (ESI) m/z calcd for $C_{16}H_{13}N_2O_3$ $[M + H]^+$: 281.0926, found: 281.0924.

Methyl 5-oxo-1,2,3,5,11,12*b*-hexahydropyrrolizino[1,2-*b*]carbazole-12-carboxylate (4m). 111 mg, yield 58%, white solid, IR (KBr) 3342, 3010, 1653, 1401, 1076 cm^{-1}. ^1H NMR (600 MHz, DMSO-d_6) δ 11.64 (s, 1H), 8.71 (s, 1H), 8.33 (d, J = 7.8 Hz, 1H), 7.77 (d, J = 8.4 Hz, 1H), 7.49 (t, J = 7.2 Hz, 1H), 7.26 (t, J = 7.8 Hz, 1H), 5.10–5.08 (m, 1H), 4.04 (s, 3H), 3.67–3.62 (m, 1H), 3.31–3.27 (m, 1H), 2.59–2.55 (m, 1H), 2.27–2.22 (m, 2H), 1.20 (d, J = 9.6 Hz, 1H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 170.6, 165.5, 146.3, 141.4, 140.8, 126.9, 125.3, 124.5, 121.8, 120.8, 120.4, 120.2, 112.4, 106.9, 65.4, 52.0, 41.9, 29.7, 28.1. HRMS (ESI) m/z calcd for $C_{19}H_{17}N_2O_3$ $[M + H]^+$: 321.1239, found: 321.1236.

Methyl 3-methyl-1-oxo-2,3,4,6-tetrahydro-1*H*-pyrido[4,3-*b*]carbazole-5-carboxylate (4n). 77 mg, yield 42%, light brown solid, IR (KBr) 3340, 3018, 1682, 1603, 1456, 1071 cm^{-1}. ^1H NMR (600 MHz, DMSO-d_6) δ 11.37 (s, 1H), 8.91 (s, 1H), 8.25 (d, J = 7.8 Hz, 1H), 7.98 (s, 1H), 7.69 (d, J = 8.4 Hz, 1H), 7.46 (t, J = 7.2 Hz, 1H), 7.25 (t, J = 7.8 Hz, 1H), 4.02 (s, 3H), 3.69–3.68 (m, 1H), 3.58 (dd, J = 16.8, 4.2 Hz, 1H), 2.99–2.95 (m, 1H), 1.25 (d, J = 6.6 Hz, 3H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 167.0, 165.4, 141.1, 140.9, 138.5, 127.1, 124.3, 122.8, 122.5, 121.5, 120.9, 120.5, 112.5, 111.2, 52.7, 46.2, 35.2, 21.5. HRMS (ESI) m/z calcd for $C_{18}H_{17}N_2O_3$ $[M + H]^+$: 309.1239, found: 309.1242.

Methyl 13-oxo-5,7,7*a*,8,9,10,11,13-octahydroquinolizino[2,3-*b*]carbazole-6-carboxylate (4o). 117 mg, yield 56%, white solid, IR (KBr) 3332, 3024, 1712, 1617, 1458, 1105 cm^{-1}. ^1H NMR (600 MHz, DMSO-d_6) δ 11.38 (s, 1H), 8.96 (s, 1H), 8.25 (d, J = 7.8 Hz, 1H), 7.69 (d, J = 7.8 Hz, 1H), 7.46 (t, J = 7.2 Hz, 1H), 7.24 (t, J = 7.2 Hz, 1H), 4.51 (d, J = 12.6 Hz, 1H), 4.01 (s, 3H), 3.75–3.70 (m, 2H), 3.54 (s, 1H), 2.69 (t, J = 10.2 Hz, 1H), 1.86 (d, J = 11.4 Hz, 1H), 1.76 (s, 2H), 1.42 (s, 2H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 166.4, 164.6, 140.7, 140.4, 137.1, 126.7, 124.6, 122.5, 122.1, 120.4, 120.4, 120.1, 112.0, 109.9, 53.8, 52.3, 43.0, 33.1, 32.6, 24.4, 23.1. HRMS (ESI) m/z calcd for $C_{21}H_{21}N_2O_3$ $[M + H]^+$: 349.1547, found: 349.1542.

General procedure for the synthesis of carbazolelactams (4b, 4p–r)

Synthesis of 4b. Compound **5b** (0.6 mmol) and I_2 (15 mg, 0.06 mmol) were dissolved in DMSO (2.0 mL) and stirred at 100 °C in air for 24 h. The reaction was cooled to room temperature, extracted with ethyl acetate and washed with H_2O, the organic phase was dried over anhydrous Na_2SO_4 and concentrated under reduced pressure to obtain a crude product. The crude product was purified by trituration with Et_2O to obtain product **4b**.

Butyl 6-oxo-6,12-dihydro-5*H*-indolo[3,2-*j*]phenanthridine-13-carboxylate (4b). 220 mg, yield 96%, IR (KBr) 3016, 2873, 1687, 1660, 1595 cm^{-1}. ^1H NMR (600 MHz, DMSO-d_6) δ 11.71 (s, 1H), 11.70 (s, 1H), 9.28 (s, 1H), 8.37 (d, J = 7.2 Hz, 1H), 7.83 (d, J = 8.4 Hz, 1H), 7.69 (d, J = 7.8 Hz, 1H), 7.54 (t, J = 7.8 Hz, 1H), 7.49 (t, J = 8.4 Hz, 1H), 7.45 (d, J = 7.8 Hz, 1H), 7.30 (t, J = 7.8 Hz, 1H), 7.23 (t, J = 7.8 Hz, 1H), 4.52 (t, J = 6.6 Hz, 2H), 1.70–1.66 (m, 2H), 1.31–1.27 (m, 2H), 0.86 (t, J = 7.2 Hz, 3H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 169.0, 161.1, 141.8, 140.7, 136.8, 129.4, 129.0, 127.7, 125.8, 123.8, 122.0, 121.8, 121.5, 121.2, 120.3, 118.6, 116.9, 116.4, 112.0, 110.8, 65.8, 29.7, 18.7, 13.5. HRMS (ESI) m/z calcd for $C_{24}H_{20}N_2O_3$ $[M + H]^+$: 385.1547, found: 385.1539.

Butyl 7-methyl-6-oxo-6,12-dihydro-5*H*-indolo[3,2-*j*]phenanthridine-13-carboxylate (4p). 206 mg, yield 86%, yellow solid, IR (KBr) 3566, 2359, 1716, 1653, 1558, 1458 cm^{-1}. ^1H NMR (600 MHz, DMSO-d_6) δ 11.54 (s, 1H), 11.37 (s, 1H), 8.37 (d, J = 7.8 Hz, 1H), 7.74–7.70 (m, 2H), 7.53 (t, J = 7.8 Hz, 1H), 7.45 (t, J = 6.6 Hz, 1H), 7.35 (d, J = 7.2 Hz, 1H), 7.31 (t, J = 7.8 Hz, 1H), 7.16 (t, J = 8.4 Hz, 1H), 4.40 (t, J = 6.6 Hz, 2H), 3.51 (s, 3H), 1.61–1.56 (m, 2H), 1.21–1.17 (m, 2H), 0.81 (t, J = 7.2 Hz, 3H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 169.1, 162.5, 141.6, 140.6, 139.7, 136.6, 131.9, 129.3, 127.0, 126.8, 123.4, 123.4, 122.5, 121.0, 120.3, 117.2, 116.7, 115.3, 112.0, 108.4, 65.4, 29.6, 19.4,

18.6, 13.5. HRMS (ESI) *m*/*z* calcd for $C_{25}H_{23}N_2O_3$ $[M + H]^+$: 399.1703, found: 399.1692.

***Tert*-butyl 6-oxo-6,12-dihydro-5*H*-indolo[3,2-*j*]phenanthridine-13-carboxylate (4q).** 205 mg, yield 89%, white solid, IR (KBr) 3311, 3286, 2978, 1660, 1597, 1456, 1150 cm^{-1}. ^1H NMR (600 MHz, DMSO-d_6) δ 11.66 (s, 1H), 11.33 (s, 1H), 9.26 (s, 1H), 8.37 (d, J = 7.2 Hz, 1H), 7.99 (d, J = 7.8 Hz, 1H), 7.75 (d, J = 8.4 Hz, 1H), 7.55–7.49 (m, 2H), 7.42 (d, J = 7.8 Hz, 1H), 7.30 (t, J = 7.8 Hz, 1H), 7.24 (t, J = 7.8 Hz, 1H), 1.59 (s, 9H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 168.4, 161.6, 142.3, 141.4, 137.1, 129.9, 128.0, 127.7, 124.5, 122.4, 122.2, 121.5, 121.3, 120.8, 119.2, 117.5, 116.6, 112.8, 112.3, 83.5, 28.0. HRMS (ESI) *m*/*z* calcd for $C_{24}H_{21}N_2O_3$ $[M + H]^+$: 385.1547, found: 385.1537.

Benzyl 6-oxo-6,12-dihydro-5*H*-indolo[3,2-*j*]phenanthridine-13-carboxylate (4r). 201 mg, yield 80%, white solid, IR (KBr) 3586, 2359, 1670, 1507, 1418, 1184 cm^{-1}. ^1H NMR (600 MHz, DMSO-d_6) δ 11.75 (s, 1H), 11.63 (s, 1H), 9.28 (s, 1H), 8.39 (d, J = 7.8 Hz, 1H), 7.69 (d, J = 7.8 Hz, 1H), 7.66 (d, J = 8.4 Hz, 1H), 7.56 (t, J = 7.2 Hz, 1H), 7.48–7.47 (m, 2H), 7.43–7.38 (m, 5H), 7.32 (t, J = 7.2 Hz, 1H), 6.93 (t, J = 7.2 Hz, 1H), 5.59 (s, 2H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 168.6, 161.0, 141.7, 140.7, 136.8, 134.8, 129.3, 129.3, 129.0, 128.6, 127.7, 125.9, 123.8, 122.1, 121.8, 121.4, 121.2, 120.3, 118.6, 116.7, 116.3, 111.8, 110.4, 67.9. HRMS (ESI) *m*/*z* calcd for $C_{27}H_{19}N_2O_3$ $[M + H]^+$: 419.1390, found: 419.1375.

(11-Methyl-2,3,4,6-tetrahydro-1*H*-pyrido[4,3-*b*]carbazol-5-yl) methanol (8). Compound **4a** (3.00 g, 9.7 mmol) was dissolved in dry THF (50 mL), borane dimethyl sulfide complex (10 mol L^{-1} in DMS, 97.3 mmol) was slowly added at 0 °C, and the reaction was refluxed for 5 h. The reaction was cooled to room temperature, and methanol was added dropwise at 0 °C. The solution was evaporated under reduced pressure. The crude product was purified by flash column chromatography (DCM/MeOH = 30 : 1) to obtain product **8**. 1.63 g, yield 64%, light brown solid, IR (KBr) 3383, 3012, 1652, 1163, 1078 cm^{-1}. ^1H NMR (600 MHz, DMSO-d_6) δ 11.05 (s, 1H), 8.16 (d, J = 7.8 Hz, 1H), 7.53 (d, J = 8.4 Hz, 1H), 7.35 (t, J = 7.2 Hz, 1H), 7.13 (t, J = 7.8 Hz, 1H), 6.43 (s, 1H), 5.01 (s, 1H), 4.84 (d, J = 6.0 Hz, 2H), 4.19 (d, J = 13.8 Hz, 1H), 3.75–3.70 (m, 1H), 3.32 (d, J = 13.2 Hz, 2H), 3.14 (d, J = 4.2 Hz, 2H), 2.65 (s, 3H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 140.3, 138.0, 129.0, 127.9, 124.8, 122.8, 122.1, 120.6, 119.9, 118.6, 118.3, 110.9, 56.3, 52.1, 48.8, 24.5, 15.0. HRMS (ESI) *m*/*z* calcd for $C_{17}H_{19}N_2O$ $[M + H]^+$: 267.1497, found: 267.1502.

***Tert*-butyl 5-(hydroxymethyl)-11-methyl-1,3,4,6-tetrahydro-2*H*-pyrido[4,3-*b*]carbazole-2-carboxylate (9).** The product **8** (107 mg, 0.4 mmol) was dissolved in THF, 10% $NaHCO_3$ (1.0 mL) and di-*tert*-butyl dicarbonate (131 mg, 0.6 mmol) was added. The reaction was stirred at room temperature for 6 h. After the reaction was completed, H_2O and ethyl acetate were added, the organic layer was washed with H_2O, dried with anhydrous Na_2SO_4, and concentrated under reduced pressure. The crude product was purified by silica gel chromatography (PE/EA = 2 : 1) to obtain the product **9**. 147 mg, yield 70%, white solid, IR (KBr) 3381, 3018, 1667, 1471, 1167, 1003, 976 cm^{-1}. ^1H NMR (600 MHz, DMSO-d_6) δ 11.07 (s, 1H), 8.16 (d, J = 7.8 Hz, 1H), 7.52 (d, J = 7.8 Hz, 1H), 7.35 (t, J = 7.2 Hz, 1H), 7.13 (t, J = 6.6 Hz, 1H), 4.95 (t, J = 5.4 Hz, 1H), 4.85 (d, J = 4.8 Hz, 2H), 4.64 (s, 2H), 3.58 (s, 2H), 3.04 (t, J = 6.0 Hz, 2H), 2.69 (s, 3H), 1.45 (s, 9H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 154.1, 140.2, 137.9, 131.2, 124.7, 122.9, 122.1, 119.6, 119.0, 118.3, 110.8, 78.8, 56.3, 40.0, 28.1, 15.1. HRMS (ESI) *m*/*z* calcd for $C_{22}H_{27}N_2O_3$ $[M + H]^+$: 367.2022, found: 367.2017.

5,11-Dimethyl-2,3,4,6-tetrahydro-1*H*-pyrido[4,3-*b*]carbazole (1c). The product **9** (450 mg, 1.2 mmol) was dissolved in absolute ethanol (20.0 mL), and 10% Pd/C (90 mg) was added. The reaction was stirred at 50 °C for 5 days in a hydrogen atmosphere, the resulting mixture was filtered through Celite®, and the filtrate was concentrated under reduced pressure to obtain a crude product (410 mg). The crude product was dissolved in dichloromethane (12.0 mL), 1,4-dimethoxybenzene (553 mg, 4.0 mmol) and TFA (1.0 mL, 14.0 mmol) were added, and the reaction mixture was stirred at room temperature for 6 h. The solvent and excess TFA were removed, then saturated Na_2CO_3 solution and ethyl acetate were added. The organic phase was dried over anhydrous Na_2SO_4, and concentrated to obtain a crude product. The crude product was purified by trituration with Et_2O, then filtered to obtain product **1c**. 235 mg, yield 56% (2 steps), yellow solid, IR (KBr) 3315, 3012, 2817, 1682, 1508, 1076 cm^{-1}. ^1H NMR (600 MHz, DMSO-d_6) δ 10.89 (s, 1H), 8.13 (d, J = 7.8 Hz, 1H), 7.47 (d, J = 7.8 Hz, 1H), 7.32 (t, J = 7.2 Hz, 1H), 7.10 (d, J = 7.2 Hz, 1H), 3.99 (s, 2H), 3.16 (s, 1H), 3.00 (s, 2H), 2.75 (s, 2H), 2.60 (s, 3H), 2.37 (s, 3H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 140.1, 137.8, 130.8, 125.4, 124.8, 124.2, 123.5, 122.0, 118.7, 118.1, 114.8, 110.6, 46.5, 43.3, 27.4, 14.7, 12.6. HRMS (ESI) *m*/*z* calcd for $C_{17}H_{19}N_2$ $[M + H]^+$: 251.1548, found: 251.1557.

5,11-Dimethyl-4,6-dihydro-3*H*-pyrido[4,3-*b*]carbazole (3,4-dehydroellipticine, 1b). The product **1c** (50 mg, 0.2 mmol), pivalic acid (3.0 g) and V_2O_5 (145 mg, 0.8 mmol) were heated at 120 °C for 10 h under O_2. Then the reaction was cooled, and saturated Na_2CO_3 solution was slowly added. The resulting mixture was extracted with ethyl acetate. The organic phase was concentrated under reduced pressure to obtain a crude product. The crude product was purified by flash column chromatography (DCM/MeOH = 10 : 1) to obtain **1b**. 36 mg, yield 72%, yellow solid, IR (KBr) 3421, 3032, 2924, 2850, 1923, 1653, 1558, 1082 cm^{-1}. ^1H NMR (600 MHz, DMSO-d_6) δ 11.50 (s, 1H), 8.89 (s, 1H), 8.19 (d, J = 7.8 Hz, 1H), 7.56 (d, J = 7.8 Hz, 1H), 7.41 (t, J = 7.2 Hz, 1H), 7.21 (t, J = 7.2 Hz, 1H), 3.62 (t, J = 6.6 Hz, 2H), 2.93 (s, 3H), 2.81 (t, J = 7.2 Hz, 2H), 2.44 (s, 3H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 158.5, 141.4, 140.1, 132.7, 130.9, 125.1, 123.6, 122.4, 119.4, 119.2, 118.2, 114.4, 111.2, 45.4, 23.0, 14.7, 12.4. HRMS (ESI) *m*/*z* calcd for $C_{17}H_{17}N_2$ $[M + H]^+$: 249.1392, found: 249.1398.

5,11-Dimethyl-6*H*-pyrido[4,3-*b*]carbazole (ellipticine, 1a). To the product **1c** (50 mg, 0.2 mmol) in *N*,*N*-dimethylformamide (2.0 mL) was added Co(II)TPP (25 mg, 0.1 mmol), and the reaction mixture was reacted at 120 °C for 36 h under O_2. The solution was filtered through Celite®, and ethyl acetate was added to the filtrate. The organic phase was washed with H_2O, and dried with anhydrous Na_2SO_4. After evaporation, the crude

product is purified by flash column chromatography (DCM/MeOH = 50 : 1–10 : 1) to obtain ellipticine **1a** and product **1b** (11 mg, 22%). Ellipticine: 15 mg, yield 30%, yellow solid, IR (KBr) 3434, 3145, 3091, 2958, 2922, 2851, 2869, 1653 cm^{-1}. ^1H NMR (600 MHz, DMSO-d_6) δ 11.40 (s, 1H), 9.70 (s, 1H), 8.43 (d, J = 6.0 Hz, 1H), 8.39 (d, J = 7.8 Hz, 1H), 7.93 (d, J = 6.0 Hz, 1H), 7.58 (d, J = 7.8 Hz, 1H), 7.53 (t, J = 7.2 Hz, 1H), 7.26 (t, J = 7.2 Hz, 1H), 3.26 (s, 3H), 2.79 (s, 3H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 149.6, 142.7, 140.6, 140.4, 132.5, 128.1, 127.1, 123.8, 123.4, 123.1, 122.0, 119.2, 115.9, 110.7, 108.0, 14.3, 11.9. HRMS (ESI) m/z calcd for $C_{17}H_{15}N_2$ $[M + H]^+$: 247.1230, found: 247.1227.

6,12-dihydro-5*H*-indolo[3,2-*j*]phenanthridin-13-yl)methanol (10). To compound **4b** (500 mg, 1.3 mmol) in dry THF (10 mL), $LiAlH_4$ (148 mg, 3.9 mmol) was added at 0 °C. The reaction mixture was heated to 60 °C and stirred for 24 h. The reaction mixture was cooled to 0 °C, and $Na_2SO_4{\cdot}10H_2O$ was added until the reaction was completely quenched. The reaction solution was filtered, and the filtrate was evaporated under reduced pressure. The crude product was purified by flash column chromatography (DCM/MeOH = 50 : 1–10 : 1) to obtain product **10**. 195 mg, yield 50%, white solid, IR (KBr) 3413, 3018, 1654, 1560, 1457 cm^{-1}. ^1H NMR (600 MHz, DMSO-d_6) δ 11.09 (s, 1H), 8.05 (dd, J = 7.8, 2.4 Hz, 2H), 7.91 (s, 1H), 7.56 (d, J = 8.4 Hz, 1H), 7.31 (t, J = 7.2 Hz, 1H), 7.15–7.10 (m, 2H), 6.88 (d, J = 7.8 Hz, 1H), 6.81 (t, J = 7.8 Hz, 1H), 5.88 (s, 1H), 5.43 (s, 1H), 4.93 (d, J = 3.6 Hz, 2H), 4.24 (s, 2H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 149.5, 140.4, 140.3, 129.8, 128.7, 128.3, 127.9, 125.3, 122.7, 122.4, 119.9, 119.0, 118.5, 117.7, 116.3, 115.1, 111.1, 58.2, 47.5. HRMS (ESI) m/z calcd for $C_{20}H_{17}N_2O$ $[M + H]^+$: 301.1335, found: 301.1332.

(12*H*-Indolo[3,2-*j*]phenanthridin-13-yl)methanol (11). The product **10** (195 mg, 0.65 mmol) and I_2 (16 mg, 0.065 mmol) was dissolved in DMSO (2.0 mL), and the reaction mixture was heated at 100 °C under O_2 for 2 h. After cooling to room temperature, H_2O was added. The resulting mixture was extracted with ethyl acetate. The organic layer was dried over anhydrous Na_2SO_4 and concentrated under reduced pressure. The crude product was purified by flash column chromatography (DCM/EA = 2 : 1) to obtain product **11**. 137 mg, yield 72%, white solid, IR (KBr) 3411, 1654, 1617, 1558, 1072 cm^{-1}; ^1H NMR (600 MHz, DMSO-d_6) δ 11.80 (s, 1H), 9.38 (s, 1H), 9.21 (d, J = 8.4 Hz, 1H), 8.99 (s, 1H), 8.36 (d, J = 7.2 Hz, 1H), 8.10 (dd, J = 8.4, 1.2 Hz, 1H), 7.77 (t, J = 7.2 Hz, 1H), 7.71–7.67 (m, 2H), 7.56 (t, J = 7.2 Hz, 1H), 7.31 (t, J = 7.2 Hz, 1H), 5.79 (t, J = 4.8 Hz, 1H), 5.41 (d, J = 4.2 Hz, 2H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 154.8, 144.9, 143.2, 141.9, 129.2, 128.0, 127.9, 127.5, 125.8, 124.5, 123.9, 121.5, 121.3, 121.1, 119.6, 117.2, 111.4, 58.0. HRMS (ESI) m/z calcd for $C_{20}H_{13}N_2O$ $[M - H]^-$: 297.1022, found: 297.1030.

12*H*-Indolo[3,2-*j*]phenanthridine-13-carbaldehyde (12). To the solution of compound **11** (100 mg, 0.34 mmol) and benzenesulfonic acid (11 mg, 0.07 mmol) in DMSO (4.0 mL), IBX (476 mg, 1.70 mmol) was added, and the mixture was heated at 110 °C to react for 4 h. The reaction mixture was cooled to room temperature, and ethyl acetate and H_2O were added. The organic layer was washed with 10% $NaHCO_3$, dried over anhydrous Na_2SO_4 and concentrated under reduced pressure. The crude product was purified by flash column chromatography (DCM/EA = 10 : 1) to obtain product **12**. 79 mg, isolated yield 80%, yellow solid, IR (KBr) 3567, 1654, 1560, 1458, 1122 cm^{-1}. ^1H NMR (600 MHz, DMSO-d_6) δ 12.36 (s, 1H), 10.82 (s, 1H), 9.54 (s, 1H), 9.37 (s, 1H), 8.41 (d, J = 7.2 Hz, 1H), 8.37 (d, J = 8.4 Hz, 1H), 8.23 (d, J = 7.8 Hz, 1H), 7.91 (t, J = 8.4 Hz, 2H), 7.81 (t, J = 7.8 Hz, 1H), 7.61 (t, J = 7.8 Hz, 1H), 7.40 (t, J = 7.8 Hz, 1H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 191.1, 153.9, 145.5, 142.5, 141.1, 131.8, 129.8, 129.3, 129.2, 128.0, 127.0, 126.6, 125.7, 122.4, 121.3, 121.1, 120.1, 120.0, 112.9, 112.6. HRMS (ESI) m/z calcd for $C_{20}H_{13}N_2O$ $[M + H]^+$: 297.1022, found: 297.1018.

7*H*-Indolo[3,2-*j*]phenanthridine-7,13(12*H*)-dione (calothrixin B, 3). Compound **11** (100 mg, 0.34 mmol) and IBX (476 mg, 1.70 mmol) in DMSO (4.0 mL) was heated at 110 °C to react for 4 h. The reaction mixture was cooled to room temperature, and ethyl acetate and H_2O were added. The organic layer was washed with 10% $NaHCO_3$, dried over anhydrous Na_2SO_4 and concentrated under reduced pressure. The crude product was purified by flash column chromatography (DCM/EA = 30 : 1) to obtain products **12** (35 mg, 36%) and **3** (35 mg, 35%). Calothrixin B (**3**): brick red solid, IR (KBr) 3399, 1654, 1529, 1457, 1078 cm^{-1}. ^1H NMR (600 MHz, DMSO-d_6) δ 13.14 (s, 1H), 9.60 (s, 1H), 9.56 (d, J = 7.2 Hz, 1H), 8.16 (d, J = 4.2 Hz, 1H), 8.15 (d, J = 4.2 Hz, 1H), 7.94 (t, J = 7.2 Hz, 1H), 7.87 (t, J = 7.8 Hz, 1H), 7.60 (d, J = 7.8 Hz, 1H), 7.46 (t, J = 7.2 Hz, 1H), 7.38 (t, J = 7.8 Hz, 1H); ^{13}C NMR (150 MHz, DMSO-d_6) δ 180.8, 180.4, 151.2, 147.5, 138.4, 138.0, 132.6, 131.6, 130.3, 129.8, 127.2 (127.19), 127.2 (127.17), 124.9, 124.3, 123.3, 122.6, 122.3, 115.5, 113.5. HRMS (ESI) m/z calcd for $C_{19}H_{11}N_2O_2$ $[M + H]^+$: 299.0821, found: 299.0831.

To the solution of compound **12** (200 mg, 0.67 mmol) and $(PhSe)_2$ (63 mg, 0.20 mmol) in DCM (10.0 mL), 30% hydrogen peroxide (2.0 mL, 20.10 mmol) was added. The mixture was reacted at room temperature for 48 h, then 10% sodium hyposulfite solution was added to quench the reaction. The resulting mixture was extracted by ethyl acetate. The organic layer was washed with H_2O, dried over anhydrous Na_2SO_4 and concentrated under reduced pressure. The crude product was purified by flash column chromatography (DCM/EA = 30 : 1) to obtain product **3** (80 mg, 40%).

Conflicts of interest

There are no conflicts to declare.

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