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Synthesis of 8-aryl substituted benzo[*a*]phenanthridine derivatives by consecutive three component tandem reaction and 6-*endo* carbocyclization☆

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ABSTRACT

A concise construction of benzo[*a*]phenanthridines involving multicomponent tandem reaction/carbocyclization in a sequential format is described. The reaction proceeds initially via formation of a 4-aryl-3-arylethynyl-isoquinoline from 2-bromobenzaldehyde/*tert*-butylamine/1,3-diyne in a three component format followed by a second ring closure either via gold/silver catalyzed intramolecular hydroarylation or via iodo-catalyzed regioselective 6-*endo*-dig electrophilic cyclization. The salient feature of the strategy involves a three component reaction followed by transformation of the resulting product in to polyheterocycles with increased structural complexity in two steps.

1. Introduction

Multicomponent tandem reactions remain one of the most powerful approaches for the one pot transformation of three or more reactants into new products.[1] They have been used widely for the synthesis of natural products and heterocyclic structures of therapeutic interest.[1b,2] In an attempt to introduce further structural complexity in the multicomponent tandem reaction products, *post*-multicomponent transformations are being combined with multicomponent reactions either in tandem or in a sequential format. This in turn, provides greater flexibility, novelty, and efficiency for the rapid access to annulated polyheterocycles.[3] In recent years, terminal and internal alkynes have been extensively used as versatile building blocks in multicomponent formats that have led to the synthesis of structurally diverse five-, six-, seven-, and eight-membered heterocycles of therapeutic importance.[4] However, the above applications predominantly remained limited to terminal/internal alkynes only and report involving 1,3-diynes as reactants in a multicomponent format is scarce.[5] We envisaged that the use of 1,3-diyne as one of the reactants in a multicomponent format may initially undergo annulation to furnish a functionalized heterocycle with an alkynyl handle attached to it, which can then be subjected to *post*-multicomponent transformation for enhancing the structural diversity following the alkyne activation to enforce a second annulation.

In view of our ongoing interest in the synthesis of annulated polyheterocycles involving alkynes as one of the reactants in one pot/three component tandem formats,[6] we proposed to extend the studies to 1,3-diynes in a three component format by initially synthesizing functionalized isoquinolines followed by their conversion to afford tetracyclic scaffold benzophenanthridine and its analogues.

Benzophenanathridines are one of the widely distributed alkaloids and associated with DNA-chain intercalating ability and potent antitumor and antiinfectious activities.[7] A careful survey of the literature revealed multistep synthetic strategies for this class of compounds associated with low yields and poor generality[8] and to the best of our knowledge there is no report dealing with multicomponent format-based protocols. In this communication, we report sequenced three component tandem reaction and 6-*endo* carbocyclization reactions for the concise construction of benzo[*a*]phenanthridines by treating 2-bromobenzaldehyde with *tert*-butylamine and 1,3-diynes.

2. Results and discussion

In the first instance we explored the formation of functionalized isoquinolines using 1,3-diyne in a three component format. For this, we initially studied the condensation of the preformed imines with 1,3-diynes to afford functionalized isoquinolines.[9] Accordingly, we screened a variety of Pd-catalyzed conditions for the condensation

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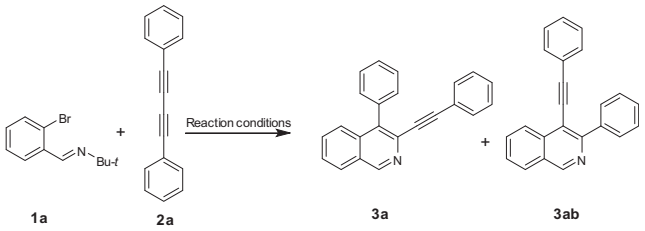
of preformed (2-bromo-benzylidene)-*tert*-butylamine **1a** with 1,3-diyne **2a** and the results have been summarized in Table 1. The reactions were generally performed in the presence of a variety of Pd-complex, LiCl, and a base by heating at 120 °C in DMF from 22 to 42 h. For most of the Pd-catalyzed conditions examined, we obtained formation of isoquinoline as a mixture of two isomers **3a** and **3ab** with the former being obtained as a major isomer. In general, use of strong bases was found to be detrimental (entry 2, 3, 6, and 9), whereas use of mild base furnished **3a** in comparatively higher yields (entry 1, 4, 7, 10). The highest isolated yields for the isomer **3a** was obtained either by employing $Pd(PPh_3)_4/LiCl/K_2CO_3$ in DMF under heating for 25 h (70%; entry 4) or by employing $Pd(PPh_3)_4/TPP/Na_2CO_3$ in DMF under heating for 22 h (68%; entry 7). For our studies, we selected $Pd(PPh_3)_4/LiCl/K_2CO_3$ as the method of choice for our further studies.

Table 1
Screening of reaction conditions for the formation isoquinoline derivative **3a** from the preformed (2-bromo-benzylidene)-*tert*-butylamine **1a** and 1,3-diyne **2a**



1a 2a 3a 3ab

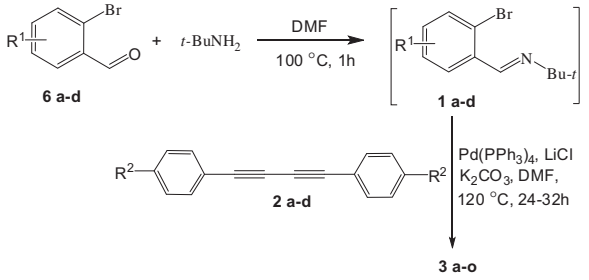
Entry	Pd-catalyst	Base	Time (h)	Yield (%)[a] **3a**/**3ab**
1	$Pd(OAc)_2$	Na_2CO_3	32	62:13
2	$Pd(dppf)_2Cl_2/LiCl$	KOAc	36	47:25
3	$Pd(PPh_3)_4/LiCl$	KOAc	42	56:18
4	$Pd(PPh_3)_4/LiCl$	K_2CO_3	25	70:12
5	$Pd(dppf)_2Cl_2$	K_2CO_3	32	48:19
6	$Pd(PPh_3)_4$	Cs_2CO_3	36	42:16
7	$Pd(PPh_3)_4/TPP$	Na_2CO_3	22	68:11
8	$Pd(PPh_3)_4/TPP$	K_2CO_3	24	<10
9	$Pd(PPh_3)_4/TPP$	KOAc	24	<10
10	$Pd(OAc)_2/TPP$	Na_2CO_3	24	65:14

[a] Imine **1a** (1.0 mmol, 0.239 g) and bis alkyne **2a** (1.2 mmol, 0.286 g), 5 mL of DMF, Pd catalyst (0.05 mmol), TPP (0.1 mmol, 0.027 g) or LiCl (1.0 mmol, 0.041 g), and base (2.0 mmol) heated at 120 °C.

Once the conditions for the synthesis of functionalized isoquinoline **3a** was established, we embarked with the development of a three component tandem format for its synthesis. For this, we treated 2-bromobenzaldehyde **6a** with *tert*-butylamine in DMF for 1 h followed by addition of 1,3-diyne **2a** in the presence of the optimized reaction condition $Pd(PPh_3)_4/LiCl/K_2CO_3$ at 120 °C for 25 h. After work up, the product **3a** was isolated in 65% yield, which was marginally less than 70% yield obtained when preformed imine **1a** was treated with 1,3-diyne **2a** (entry 4; Table 1). Next, the scope and limitation of our methodology was established by treating a series of 1,3-diynes (**2a**–**d**) with 2-bromobenzadehydes (**6a**–**d**) in the presence of *tert*-butylamine in a three component tandem format and the results have been summarized in Table 2. In all cases, the substrates underwent annulation to afford 11 isoquinoline derivatives (**3a**–**o**) in 58–70% yield. In general, the three component tandem synthesis to isoquinoline was not sensitive to electronic substitution present on 1,3-diynes and 2-bromobenzaldehydes.

After successfully establishing the reaction condition for the synthesis of functionalized isoquinolines **3**, we next screened the reaction conditions for enforcing the second cyclization using 6-*endo* carbocyclization route in these two isomers. In the first instance we proposed to effect this via 6-*endo*-dig carbocyclization

Table 2
Three component tandem synthesis of isoquinoline derivatives **3a**–**o** in one-pot



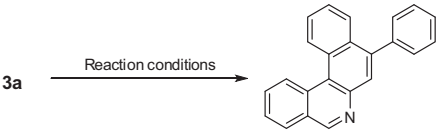
6 a-d 1 a-d 2 a-d 3 a-o

entry	R^1	R^2	Time	Compound no (% yield)[a]
1	H	H	25	**3a** (65)
2	H	CH_3	28	**3b** (64)
3	H	^{t}Bu	25	**3c** (66)
4	H	OCH_3	26	**3d** (65)
5	5-OCH_3	H	28	**3e** (68)
6	5-OCH_3	CH_3	30	**3f** (65)
7	5-OCH_3	^{t}Bu	26	**3g** (66)
8	5-OCH_3	OCH_3	24	**3h** (64)
9	4,5-di OCH_3	H	25	**3i** (70)
10	4,5-di OCH_3	CH_3	30	**3j** (65)
11	4,5-di OCH_3	^{t}Bu	26	**3k** (68)
12	5-F	H	24	**3l** (62)
13	5-F	CH_3	32	**3m** (60)
14	5-F	^{t}Bu	28	**3n** (58)
15	5-F	OCH_3	26	**3o** (61)

[a] Reaction condition: 5 mL of DMF, 1.0 mmol of **6**, 1.5 mmol of ^{t}BuNH$_2$ were placed in a 4 dram vial heated at 100 °C for 1 h followed by the addition of 1.2 mmol of **2**, 0.05 mmol of $Pd(PPh_3)_4$, 1.0 mmol of LiCl, and 2.0 mmol of K_2CO_3 and were heated at 120 °C for indicated time.

following the activation of the alkyne moiety with transition metals.[4e,9,10] The annulation of alkyne containing intramolecular nucleophilic centers via activation of the alkyne moiety has been documented[11] as the most efficient strategy for the straight forward and rapid access to heterocyclic scaffolds. Accordingly, we initiated our studies by examining the ability of the isoquinoline intermediates **3a** and **3ab** to undergo intramolecular hydroarylation by employing a variety of transition metal catalysts in different solvents and the results have been summarized in Table 3. After extensive screening of a metal catalysts, such as CuI (entry 1), $AuCl_3$

Table 3
Optimization of reaction conditions for the conversion of **3a** to **4a**



4a

Entry	Solvent	Catalyst(s)	Yield (%)[a]
1	Toluene	CuI	NR
2	Toluene	$AuCl_3$	NR
3	Toluene	$Cu(OTf)_2$	NR
4	Toluene	$Zn(OTf)_2$	NR
5	Toluene	$AgSbF_6$	NR
6	Toluene	$AuClPPh_3$	NR
7	Toluene	$AgSbF_6/AuClPPh_3$	65[b]
8	DCE	$AgSbF_6/AuClPPh_3$	58[b]
9	DME	$AgSbF_6/AuClPPh_3$	17
10	DMF	$AgSbF_6/AuClPPh_3$	NR
11	DMSO	$AgSbF_6/AuClPPh_3$	NR
12	THF	$AgSbF_6/AuClPPh_3$	NR[c]

[a] All reactions were carried out with using 0.5 mmol of **3a** (0.152 g), 0.05 mmol of catalyst(s), and monitored for 24 h at 120 °C. NR=No Reaction.
[b] Reaction completed in 5 h.
[c] Reaction carried out at 60 °C for 24 h.

(entry 2), $Cu(OTf)_2$ (entry 3), $Zn(OTf)_2$ (entry 4), $AgSbF_6$ (entry 5), $AuClPPh_3$ (entry 6) and pleasingly, the presence of $AgSbF_6$/$AuClPPh_3$ in toluene (entry 7) afforded benzo[*a*]phenanthridine **4a** in 65% isolated yield. Switching solvent from toluene to DCE (entry 8), DME (entry 9) afforded **4a** in 58 and 17% yield, respectively. Whereas DMF (entry 10), DMSO (entry 11), THF (entry 12) failed to yield the desired product. In contrast, intermediate **3ab** completely failed to undergo 6-*endo*-dig carbocyclization.

The plausible mechanism (Fig. 1) shown reveals that the coordination of the triple bond of **3a** to Au(I) catalyst enhances the electrophilicity of alkyne and the subsequent nucleophilic attack of the carbon of the arene ring to the electron-deficient alkyne would form the intermediate Au(0) species, which on further protodemetallation affords **4a** with the regeneration of cationic Au(I) catalyst. Au(I) catalyst did not promote the reaction without the presence of silver. $AgSbF_6$ used as the activation factor to initiate the gold catalysis.[12]

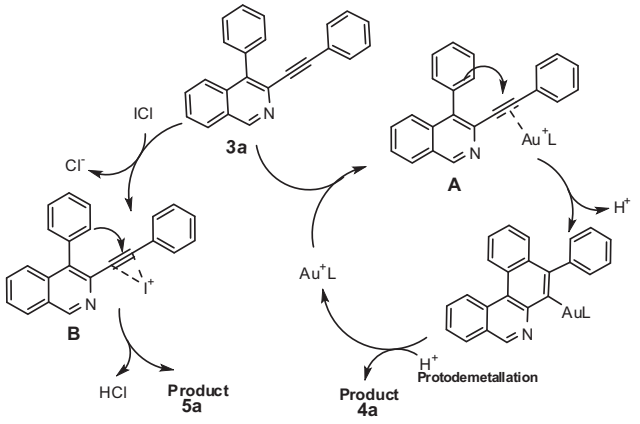


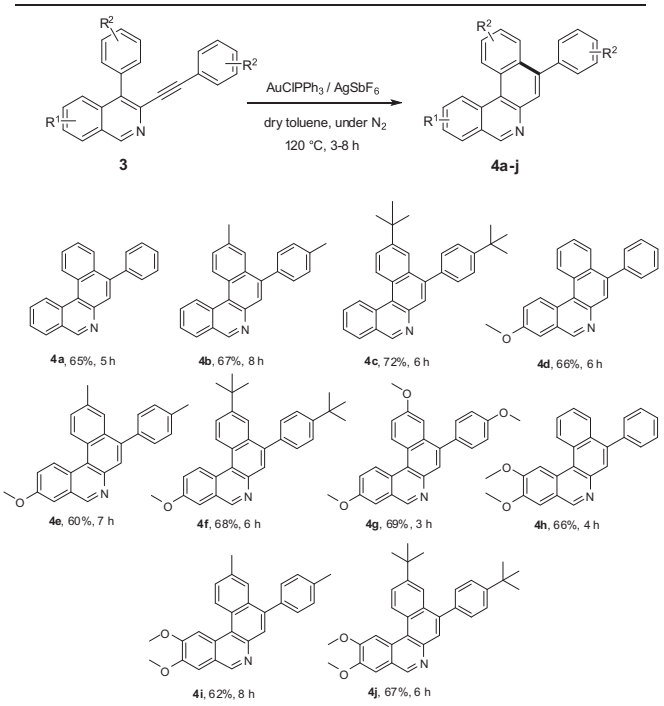
Fig. 1. Plausible mechanism for the formation of **4a** and **5a** from **3a**.

The scope and limitation of Au-catalyzed carbocyclization of the isoquinoline derivative **3a**–**o** was established by subjecting them to hydroarylation by treating with $AgSbF_6$/$AuClPPh_3$ catalyst system. The substrates **3a**–**k** underwent annulation to afford benzo[*a*] phenanthridine derivatives **4a**–**j** in 60–72 % yield (Table 4).

However, substrates **3l**–**o** with 5-F group in the arene ring failed to undergo 6-*endo*-dig carbocyclization, thereby limiting the application of Au-activated hydroarylation. This prompted us to explore an alternative route for the carbocyclization by replacing metal catalyzed cyclization with electrophilic iodo-reagents with the view to develop a versatile method for the intramolecular cyclization step. The iodo-reagents are known to initiate intramolecular 6-*endo*-dig iodocyclization[13] following the activation of the alkyne moiety. Besides, such iodocyclizations, generally leave an iodine atom attached to the product, that is, amenable to further elaboration using palladium-catalyzed coupling reactions.[14]

Accordingly, we screened several electrophilic reagents with the view to promote intramolecular iodocyclization of the intermediate **3a** and results have been summarized in Table 5. In our initial experiments, we treated intermediate **3a** with molecular iodine (3 equiv) in the presence of K_2CO_3 (entry 1) in acetonitrile at 0 °C to furnish cyclized product 7-iodo-8-phenyl-benzo[*a*]phenanthridine **5a** in 48% isolated yield. Analogus iodo-cyclization using NIS (3 equiv) furnished **5a** in 35% isolated yield (entry 2). Switching solvents from acetonitrile to THF and DCM had a detrimental effect on the yield (entries 3–5). However, replacing the molecular iodine with a strong iodo-based electrophile ICl in acetonitrile at 0 °C furnished **5a** in 84% isolated yield (entry 6), whereas

Table 4
Scope and limitation of Au-catalyzed synthesis of benzo[*a*]phenanthridines **4a**–**j**



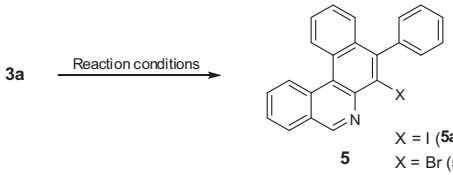
Reactions conditions: 0.5 mmol of **3** and 0.05 mmol of $AgSbF_6$, 0.05 mmol of $AuClPPh_3$, 5 mL freshly dried toluene under N_2 at 120 °C.

bromocyclization using Br_2/NBS (entries 7 and 8) furnished 7-bromo-8-phenyl-benzo[*a*]phenanthridine **5p** in 68% isolated yield.

Mechanistically (Fig. 1), in case of ICl mediated cyclization, it is presumed that the iodine first forms iodonium complex coordinating with alkyne thereby enhancing its electrophilicity to generate intermediate **B**. The activated (electron-deficient) triple bond then undergoes nucleophilic attack by the carbon from the phenyl ring to form **5a** via electrophilic 6-*endo*-dig iodocyclization.

The scope and limitation of the optimized reaction condition leading to 6-*endo*-dig iodocyclization was examined on intermediates **3a**–**o** obtained via three component tandem format and the results have been summarized in Table 6.

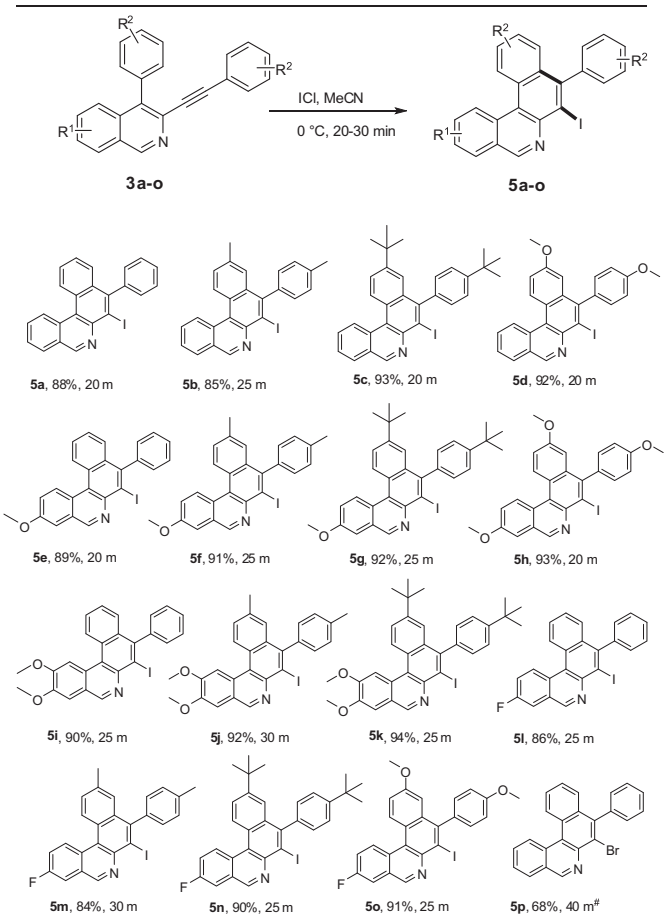
Table 5
Optimization of reaction conditions for the conversion of **3a** to **5a** and **5p**



Entry	Solvent	Reagent system	% Yield (product)
1	MeCN	I_2/K_2CO_3	48(**5a**)[a]
2	MeCN	NIS	35(**5a**)[a]
3	THF	I_2/K_2CO_3	NR
4	DCM	I_2/K_2CO_3	52(**5a**)[a]
5	THF	NIS	35(**5a**)[a]
6	MeCN	ICl	84(**5a**)[b]
7	MeCN	NBS	42(**5p**)[c]
8	MeCN	Br_2	68(**5p**)[c]

NR=No Reaction.
[a] Conversion of **3a** to **5a** after prolong stirring for 48 h.
[b] **3a** (0.5 mmol, 0.152 g), 0.75 mmol of ICl (0.076 mL) (1 M solution in DCM) used, conversion of **3a** to **5a** completed in 20 min.
[c] 6-*endo*-cyclization using 0.6 mmol of Br_2 (0.061 mL).

Table 6
Scope and limitation of ICl-catalyzed synthesis of 7-iodo, 8-phenyl-benzo[*a*]phenanthridines **5a**–**o**



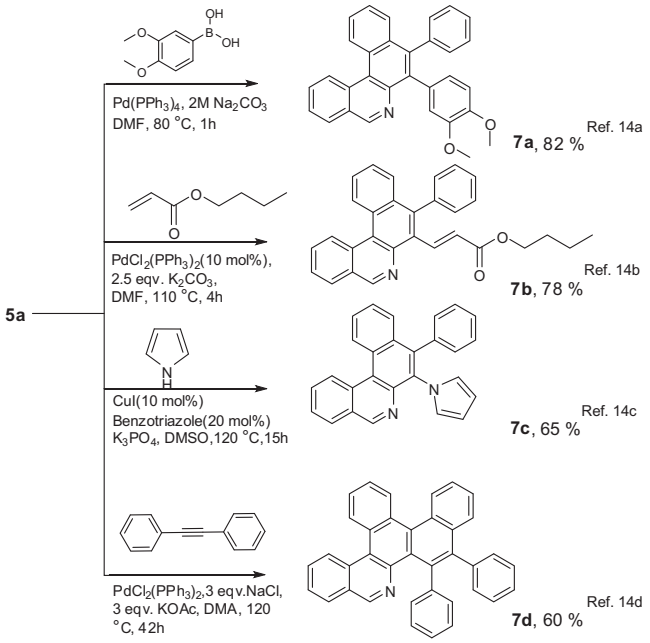
[a] Reaction conditions: 0.5 mmol of **3a**, 0.75 mmol of ICl (1 M solution in DCM) in acetonitrile (5 mL) under N_2 atmoshere at 0 °C for 20-30 min.
[#] Reaction carried out with 0.5 mmol of **3a** and 0.6 mmol Br_2 at 0 °C

Unlike hydroarylation involving Au-catalyzed 6-*endo* cyclization where substrates **3l**–**o** having 5-F group in the arene ring failed to undergo cyclization, iodocyclization in general were not sensitive to substituents on substrates **3a**–**o** thereby offering products **5a**–**o** with minimal variation in the yields (84–94%). Thus, iodocyclizations in comparison to Au-catalyzed cyclization were fast, efficient, versatile, and required mild reaction conditions.

In our subsequent studies, we proposed to demonstrate the efficacy of iodo functionality in 7-iodo, 8-phenyl-benzo[*a*]phenanthridines **5** (Scheme 1) for introducing further diversity. In the first set of experiments, we applied metal catalyzed Suzuki coupling and Heck reaction on **5a** to furnish **7a** and **7b** in 82% and 78% yield, respectively. In addition we treated **5a** with pyrrole in the presence of CuI/benzotriazole to furnish **7c** in 65% isolated yield. Finally, we demonstrated the utility of iodo functionality in **5a** for increasing the structural complexity by treating it with an internal alkyne in the presence of $PdCl_2(PPh_3)_2$ to afford a novel pentacyclic aromatic annulated polycycle **7d** in 60% isolated yield.

3. Conclusion

In summary we have developed an efficient method for the construction of benzo[*a*]phenanthridines involving multicomponent tandem reaction/carbocyclization in a sequential format.



Scheme 1. Functionalization of **5a**.

Further studies with the application of 1,3-diyne in a multicomponent format followed by *post*-multicomponent conversion for the synthesis of natural product inspired polyheterocycles is in progress and results will be published elsewhere.

4. Experimental section

4.1. General information

All reagents and solvents were purchased from commercial sources and used without purification. The ^1H NMR spectra were recorded with 300 or 600 MHz spectrometer, while ^{13}C was recorded with 50, 75, 100, 150 MHz spectrometer. Chemical shifts δ are given in parts per million relative to the residual signals of tetramethylsilane in $CDCl_3$ or deuterated solvent $CDCl_3$ for ^1H and ^{13}C NMR. Multiplicities are reported as follows: singlet (s), doublet (d), doublet of doublets (dd), doublet of triplets (dt), triplet (t), quartet (q), multiplet (m). High resolution mass spectra were taken with a 3000 mass spectrometer. Column chromatography was performed using silica gel 60 Thomas Baker (100–200 mesh) as the stationary phase. All reactions were monitored by thin layer chromatography (TLC). The purity and characterization of these compounds were further established using HR/EI Mass spectroscopy. High resolution mass spectra were taken with a 3000 mass spectrometer, using Waters Agilent 6520-Q-TofMS/MS system and JEOL-AccuTOF JMS-T100LC. Melting points were determined with a Büchi B-545 apparatus and are uncorrected.

4.2. General annulation procedure for preparation of 4-phenyl-3-phenylethynyl-isoquinolines 3a–o

To a stirred solution of 2-bromobenzaldehydes **6a**–**d** (1 mmol) in DMF (5 mL) was added *tert*-butylamine (1.5 mmol) and the reaction mixture was allowed to stirr under a nitrogen atmosphere at 100 °C for 1 h. This was followed by the sequential addition of the $Pd(PPh_3)_4$ (0.05 mmol), K_2CO_3 (2 mmol), LiCl (1 mmol), and the bis alkynes **2a**–**d** (1.2 mmol) to the reaction mixture and was left for stirring at 120 °C for indicated time (Table 2). The reaction was monitored by TLC to establish completion and the reaction mixture,

was cooled to room temperature and passed through bed of Celite, and filtrate was diluted with EtOAc (100 mL) and washed with saturated NH_4Cl (50 mL) and brine solution (100 mL). The organic layer was dried over anhydrous sodium sulfate and evaporated to dryness under reduced pressure. The crude product so obtained was purified by column chromatography by using EtOAc/hexane as eluent to afford **3**.

*4.2.1. 4-Phenyl-3-(2-phenylethynyl)isoquinoline (**3a**).* White solid; yield 65% (0.198 g); mp 115–117 °C; R_f=0.48 (2:8 EtOAc/hexane); FT-IR (KBr) 3061, 2958, 1619, 1559, 1490, 1217 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 9.26 (1H, s), 8.03–8.01 (1H, m), 7.69–7.60 (3H, m), 7.59–7.51 (5H, m), 7.25 (5H, s) ppm; ^{13}C NMR (50 MHz, $CDCl_3$): δ 152.2, 136.5, 135.5, 135.0, 131.8, 130.9, 130.7, 128.5, 128.3, 127.8, 127.7, 125.5, 122.9, 92.6, 89.5 ppm; HRMS (ESI) calcd for $C_{23}H_{16}N$ [M+H] 306.1283 found 306.1282.

*4.2.2. 4-(4-Methylphenyl)-3-[2-(4-methylphenyl)ethynyl] isoquinoline (**3b**).* Orange solid; yield 64% (0.213 g); mp 112–114 °C; R_f=0.46 (2:8 EtOAc/hexane); FT-IR (KBr) 3051, 2930, 1640, 1560, 1440, 1219 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 9.22 (1H, s), 8.00–7.97 (1H, m), 7.69–7.58 (3H, m), 7.38 (4H, m), 7.17 (2H, d, J=7.9 Hz), 7.06 (2H, d, J=7.7 Hz), 2.48 (3H, s), 2.31 (3H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 152.0, 138.7, 137.7, 136.1, 135.6, 135.1, 133.4, 131.7, 130.8, 130.7, 129.0, 128.9, 127.8, 127.6, 127.5, 125.5, 119.9, 92.6, 89.0, 21.5, 21.4 ppm; HRMS (ESI) calcd for $C_{25}H_{20}N$ [M+H] 334.1596 found 334.1596.

*4.2.3. 4-(4-tert-Butylphenyl)-3-[2-(4-tert-butylphenyl)ethynyl] isoquinoline (**3c**).* Light orange solid; yield 66% (0.275 g); mp 120–122 °C; R_f=0.44 (2:8 EtOAc/hexane); FT-IR (KBr) 3019, 2962, 1641, 1515, 1445, 1216 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 9.24 (1H, s), 8.02–7.99 (1H, m), 7.74–7.69 (1H, m), 7.65–753 (m, 4H), 7.45 (2H, d, J=8.3 Hz), 7.25 (2H, d, J=8.4 Hz), 7.14 (2H, d, J=8.5 Hz), 1.46 (9H, s), 1.28 (9H, s) ppm; ^{13}C NMR (100 MHz, $CDCl_3$): δ 152.1, 151.8, 151.0, 136.5, 135.9, 135.1, 133.6, 132.1, 131.7, 131.0, 130.8, 130.7, 130.4, 130.2, 127.8, 127.6, 125.7, 125.4, 125.2, 120.0, 92.9, 89.2, 34.8, 31.7, 31.6 ppm; HRMS (ESI) calcd for $C_{31}H_{32}N$ [M+H] 418.2535 found 418.2535.

*4.2.4. 4-(4-Methoxyphenyl)-3-[2-(4-methoxyphenyl)ethynyl] isoquinoline (**3d**).* Gray solid; yield 65% (0.237 g); mp 132–134 °C; R_f=0.38 (2:8 EtOAc/hexane); FT-IR (KBr) 2934, 2848, 1622, 1508, 1425, 1258 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 8.90 (1H, s), 8.25 (1H, d, J=8.2 Hz), 7.77–7.71 (2H, m), 7.35–7.23 (5H, m), 7.13–7.10 (2H, m), 6.88 (2H, d, J=8.7 Hz), 3.91 (3H, s), 3.83 (3H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 160.1, 159.2, 150.2, 133.4, 133.1, 132.8, 132.2, 132.1, 131.5, 131.1, 127.9, 127.6, 127.4, 126.3, 125.5, 116.5, 114.2, 114.0, 113.5, 99.9, 84.0, 55.6, 55.5 ppm; HRMS (ESI) calcd for $C_{25}H_{20}NO_2$ [M+H] 366.1494 found 366.1478.

*4.2.5. 7-Methoxy-4-phenyl-3-(2-phenylethynyl)isoquinoline (**3e**).* Brown solid; yield 68% (0.228 g); mp 136–138 °C; R_f=0.40 (2:8 EtOAc/hexane); FT-IR (KBr) 3018, 2844, 1622, 1564, 1492, 1215 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 9.15 (1H, s), 7.58–7.51 (6H, m), 7.26–7.23 (7H, m), 3.95 (3H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 158.9, 150.8, 136.6, 136.5, 133.7, 131.7, 130.7, 130.5, 129.1, 128.4, 128.3, 128.1, 127.3, 123.8, 123.1, 105.3, 91.8, 89.5, 55.7 ppm; HRMS (ESI) calcd for $C_{24}H_{18}NO$ [M+H] 336.1388 found 336.1380.

*4.2.6. Methyl 4-(4-methylphenyl)-3-[2-(4-methylphenyl)ethynyl] isoquinolin-7-yl ether (**3f**).* Light orange solid; yield 65% (0.236 g); mp 186–188 °C; R_f=0.35 (2:8 EtOAc/hexane); FT-IR (KBr) 2951, 2844, 1631, 1417, 1234 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 9.13 (1H, s), 7.60 (1H, d, J=9.8 Hz), 7.37 (4H, m), 7.25 (2H, d, J=5.8 Hz), 7.16 (2H, d, J=8.0 Hz), 7.06 (2H, d, J=7.8 Hz), 3.96 (3H, s), 2.48 (3H, s), 2.31 (3H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 158.7, 150.5, 138.4, 137.7, 136.2, 133.9, 133.5, 131.6, 130.6, 129.0, 128.8, 127.3, 123.6, 120.1, 105.1, 91.8, 89.1, 55.6, 21.5, 21.4 ppm; HRMS (ESI) calcd for $C_{26}H_{22}NO$ [M+H] 364.1701 found 364.1696.

*4.2.7. Methyl 4-(4-tert-butylphenyl)-3-[2-(4-tert-butylphenyl) ethynyl]isoquinolin-7-yl ether (**3g**).* Brown solid; yield 66% (0.295 g); mp 174–176 °C; R_f=0.34 (2:8 EtOAc/hexane); FT-IR (KBr) 3019, 2962, 1626, 1492, 1216 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 9.13 (1H, s), 7.65–7.65 (2H, m), 7.45–7.32 (3H, m), 7.25–7.22 (3H, m), 7.14 (2H, d, J=9.5 Hz), 7.06 (1H, d, J=7.9 Hz), 3.96 (3H, s), 1.27 (9H, s), 1.25 (9H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 158.8, 151.6, 150.9, 150.6, 150.5, 138.5, 137.7, 133.7, 133.5, 131.6, 131.5, 130.7, 130.5, 129.0, 128.9, 127.5, 127.4, 125.2, 125.1, 123.7, 120.2, 114.2, 105.2, 92.1, 89.2, 55.6, 34.8, 31.6, 31.2 ppm; HRMS (ESI) calcd for $C_{32}H_{34}NO$ [M+H] 448.2640 found 448.2600.

*4.2.8. Methyl 4-(4-methoxyphenyl)-3-[2-(4-methoxyphenyl)ethynyl] isoquinolin-7-yl ether (**3h**).* Orange solid; yield 64% (0.253 g); mp 166–168 °C; R_f=0.30 (2:8 EtOAc/hexane); FT-IR (KBr) 3019, 2956, 1617, 1513, 1217 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 9.12 (1H, s), 7.63–7.59 (1H, m), 7.45 (2H, d, J=8.2 Hz), 7.25–7.22 (4H, m), 7.08 (2H, d, J=8.1 Hz), 6.79 (2H, d, J=8.4 Hz), 3.96 (3H, s), 3.92 (3H, s), 3.78 (3H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 159.7, 159.5, 158.7, 150.5, 135.6, 134.2, 133.2, 132.1, 130.8, 129.0, 128.8, 127.3, 123.7, 115.2, 113.9, 113.6, 105.2, 91.7, 88.5, 55.6, 55.5, 55.3 ppm; HRMS (ESI) calcd for $C_{26}H_{22}NO_3$ [M+H] 396.1600 found 396.1574.

*4.2.9. 6,7-Dimethoxy-4-phenyl-3-(2-phenylethynyl)isoquinoline (**3i**).* Orange solid; yield 70% (0.256 g); mp 156–158 °C; R_f=0.30 (2:8 EtOAc/hexane); FT-IR (KBr) 3020, 2929, 1629, 1501, 1465, 1217 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 9.07 (1H, s), 7.56–7.51 (5H, m), 7.27–7.24 (6H, m), 6.90 (1H, s), 4.06 (3H, s), 3.81 (3H, s) ppm; ^{13}C NMR (50 MHz, $CDCl_3$): δ 153.4, 150.7, 149.5, 136.9, 135.4, 134.2, 131.7, 130.6, 128.4, 128.2, 128.1, 124.0, 123.0, 105.7, 103.8, 91.8, 89.5, 56.2, 56.0 ppm; HRMS (ESI) calcd for $C_{25}H_{20}NO_2$ [M+H] 366.1494 found 366.1477.

*4.2.10. 6,7-Dimethoxy-4-(4-methylphenyl)-3-[2-(4-methylphenyl) ethynyl]isoquinoline (**3j**).* Brown solid; yield 65% (0.255 g); mp 162–164 °C; R_f=0.28 (2:8 EtOAc/hexane); FT-IR (KBr) 3018, 2928, 1624, 1503, 1426, 1217 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 9.03 (1H, s), 7.43 (2H, d, J=7.8 Hz), 7.35 (2H, d, J=7.8 Hz), 7.26 (2H, s), 7.16 (2H, d, J=7.8 Hz), 7.06 (2H, d, J=7.8 Hz), 6.94 (1H, s), 4.05 (3H, s), 3.82 (3H, s), 2.49 (3H, s), 2.32 (3H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 153.2, 150.5, 149.4, 138.4, 137.6, 135.0, 134.5, 133.8, 131.7, 131.6, 130.5, 129.0, 128.98, 124.0, 120.1, 105.7, 103.9, 91.7, 89.2, 56.2, 56.0, 21.5, 21.4 ppm; HRMS (ESI) calcd for $C_{27}H_{24}NO_2$ [M+H] 394.1807 found 394.1799.

*4.2.11. 6,7-Dimethoxy-4-(4-tert-butylphenyl)-3-[2-(4-tert-butylphenyl) ethynyl]isoquinoline (**3k**).* Orange solid; yield 68% (0.324 g); mp 166–168 °C; R_f=0.25 (2:8 EtOAc/hexane); FT-IR (KBr) 2926, 2838, 1624, 1504, 1425, 1254 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 9.05 (1H, s), 8.09 (2H, d, J=8.3 Hz), 7.75 (1H, s), 7.52 (2H, d, J=8.3 Hz), 7.46–7.38 (4H, m), 7.25 (1H, d, J=6.9 Hz), 4.11 (3H, s), 4.05 (3H, s), 1.39 (9H, s), 1.33 (9H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 153.3, 151.6, 150.9, 150.6, 149.3, 139.3, 135.4, 134.7, 133.9, 131.7, 131.6, 131.5, 130.5, 130.4, 129.0, 125.2, 125.1, 124.0, 120.1, 114.2, 105.7, 103.9, 92.1, 89.4, 56.2, 56.1, 34.88, 34.8, 31.5, 31.2 ppm; HRMS (ESI) calcd for $C_{33}H_{36}NO_2$ [M+H] 478.2746 found 478.2744.

*4.2.12. 7-Fluoro-4-phenyl-3-(2-phenylethynyl)isoquinoline (**3l**).* Gray solid; yield 62% (0.200 g); mp 126–128 °C; R_f=0.30 (2:8 EtOAc/hexane); FT-IR (KBr) 3020, 2856, 1628, 1489, 1217 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 9.21 (1H, s), 7.70–7.49 (7H, m), 7.43–7.36

(1H, m), 7.25 (5H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 162.9, 159.6, 151.4, 151.3, 136.4, 136.2, 135.2, 132.2, 131.8, 130.7, 128.7, 128.6, 128.5, 128.4, 128.39, 128.3, 122.7, 121.6, 121.2, 111.1, 110.9, 92.6, 89.1 ppm; HRMS (ESI) calcd for $C_{23}H_{15}FN$ [M+H] 324.1189 found 324.1171.

*4.2.13. 7-Fluoro-4-(4-methylphenyl)-3-[2-(4-methylphenyl) ethynyl] isoquinoline (**3m**).* Light green solid; yield 60% (0.210 g); mp 130–132 °C; R_f=0.25 (2:8 EtOAc/hexane); FT-IR (KBr) 3018, 2927, 2854, 1629, 1513, 1440, 1218 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.18 (1H, s), 7.73–7.68 (1H, m), 7.61 (1H, m), 7.41–7.35 (5H, m), 7.16 (2H, d, *J*=8.0 Hz), 7.07 (2H, d, *J*=7.9 Hz), 2.49 (3H, s), 2.32 (3H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 162.9, 159.5, 151.15, 151.1, 138.8, 138.1, 136.2, 135.4, 133.1, 132.3, 131.7, 130.6, 129.1, 129.0, 128.7, 128.6, 128.5, 128.4, 121.4, 121.1, 119.8, 111.1, 110.8, 92.7, 88.7, 21.6, 21.5 ppm; HRMS (ESI) calcd for $C_{25}H_{19}FN$ [M+H] 352.1502 found 352.1482.

*4.2.14. 7-Fluoro-4-(4-tert-butylphenyl)-3-[2-(4-tert-butylphenyl) ethynyl]isoquinoline (**3n**).* Pale brown; yield 58% (0.252 g); mp 140–142 °C; R_f=0.22 (2:8 EtOAc/hexane); FT-IR (KBr) 2960, 2859, 1626, 1462, 1221 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.18 (1H, s), 7.77–7.72 (1H, m), 7.62–7.56 (3H, m), 7.44–7.38 (3H, m), 7.25 (2H, d, *J*=8.3 Hz), 7.13 (2H, d, *J*=8.4 Hz), 1.45 (9H, s), 1.27 (9H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 159.6, 151.9, 151.3, 151.2, 151.1, 136.5, 135.7, 133.3, 132.3, 131.6, 130.5, 128.9, 128.8, 128.5, 128.4, 125.3, 125.2, 121.4, 121.1, 119.9, 114.2, 111.1, 110.8, 93.0, 88.9, 34.9, 31.6, 31.2 ppm; HRMS (ESI) calcd for $C_{31}H_{31}FN$ [M+H] 436.2441 found 436.2426.

*4.2.15. 4-{7-Fluoro-3-[2-(4-methoxyphenyl)ethynyl]isoquinolin-4-yl}phenyl methyl ether (**3o**).* Brown solid; yield 61% (0.234 g); mp 135–137 °C; R_f=0.20 (2:8 EtOAc/hexane); FT-IR (KBr) 2952, 2844, 1619, 1512, 1217 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.19 (1H, s), 7.71–7.69 (1H, m), 7.61–7.58 (1H, m), 7.46–7.38 (3H, m), 7.26–7.22 (2H, m), 7.09 (2H, d, *J*=6.8 Hz), 6.80 (2H, d, *J*=7.0 Hz), 3.92 (3H, s), 3.79 (3H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 162.8, 159.9, 159.7, 151.1, 151.0, 135.6, 135.5, 133.3, 132.0, 128.7, 128.6, 128.5, 121.4, 121.1, 114.9, 114.0, 113.8, 111.1, 110.8, 92.6, 88.2, 55.5, 55.4 ppm; HRMS (ESI) calcd for $C_{25}H_{19}FNO_2$ [M+H] 384.1400 found 384.1405.

4.3. General procedure for the Au-catalyzed cyclizations 4a–j

A 50 mL sealed tube equipped with a magnetic stir bar, was charged with the substrate 4-phenyl-3-phenylethynyl-isoquinolines **3a–k** (0.5 mmol), 5 mL freshly dried toluene, $Au(PPh_3)Cl$ (0.05 mmol), and $AgSbF_6$ (0.05 mmol) under nitrogen atmosphere. The reaction tube was transferred to an oil bath and continued to stir at 120 °C. After being allowed to stir vigorously for the appropriate time, the reaction vessel was removed from the oil bath and cooled to room temperature and filtered through bed of Celite-R, diluted with water (50 mL) and the reaction mixture was extracted with ethyl acetate (3×30 mL). The resulting organic solution was washed with brine (25 mL), dried over anhydrous Na_2SO_4, filtered, and concentrated in vacuo. The resulting residue was purified by silica gel flash column chromatography using EtOAc/hexane as the eluent to afford **4**.

*4.3.1. 8-Phenylbenzo[a]phenanthridine (**4a**).* Light yellow solid; yield 65% (0.099 g); mp 132–134 °C; R_f=0.45 (2:8 EtOAc/hexane); FT-IR (KBr) 2924, 2853, 1634, 1460, 1218 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.42 (1H, s), 9.15 (2H, dd, J_1=3.6 Hz, J_2=8.2 Hz), 8.21 (1H, d, *J*=7.9 Hz), 8.14–8.09 (2H, m), 7.98–7.93 (1H, m), 7.80–7.72 (2H, m), 7.64–7.48 (6H, m) ppm; ^{13}C NMR (50 MHz, $CDCl_3$): δ 152.9, 141.6, 139.9, 132.5, 132.1, 131.2, 130.0, 129.0, 128.5, 128.2, 127.9, 127.7, 127.1, 126.9, 126.6, 114.1 ppm; HRMS (ESI) calcd for $C_{23}H_{16}N$ [M+H] 306.1283 found 306.1271.

*4.3.2. 10-Methyl-8-(4-methylphenyl)benzo[a]phenanthridine (**4b**).* Brown solid; yield 67% (0.112 g); mp 146–148 °C; R_f=0.44 (2:8 EtOAc/hexane); FT-IR (KBr) 2926, 1602, 1550, 1460, 1218 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.36 (1H, s), 9.07 (2H, m), 8.17 (1H, d, *J*=7.9 Hz), 8.06 (1H, s), 7.94–7.89 (2H, m), 7.76–7.71 (1H, m), 7.57–7.50 (3H, m), 7.36 (2H, d, *J*=7.7 Hz), 2.52 (3H, s), 2.49 (3H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 152.5, 143.0, 141.3, 137.4, 137.2, 136.6, 132.6, 132.5, 131.1, 130.0, 129.3, 129.1, 128.5, 128.4, 128.3, 128.2, 127.9, 127.8, 126.8, 126.7, 126.6, 125.8, 21.8, 21.4 ppm; HRMS (ESI) calcd for $C_{25}H_{20}N$ [M+H] 334.1596 found 334.1596.

*4.3.3. 10-tert-Butyl-8-(4-tert-butylphenyl)benzo[a]phenanthridine (**4c**).* Light yellow solid; yield 72% (0.150 g); mp 138–140 °C; R_f=0.40 (2:8 EtOAc/hexane); FT-IR (KBr) 3122, 2961, 1642, 1534, 1219 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.37 (1H, s), 9.14–9.07 (2H, m), 8.18–8.14 (2H, m), 8.10 (1H, s), 7.92–7.87 (1H, m), 7.80 (1H, dd, J_1=2.1 Hz, J_2=8.9 Hz), 7.72 (1H, t, *J*=7.1 Hz), 7.62–7.55 (4H, m), 1.44 (9H, s), 1.39 (9H, s) ppm; ^{13}C NMR (50 MHz, $CDCl_3$): δ 152.7, 150.6, 149.4, 143.4, 141.6, 137.2, 134.4, 134.1, 132.6, 132.1, 130.9, 129.8, 129.5, 129.2, 129.0, 128.6, 128.3, 127.8, 126.7, 125.5, 125.0, 122.9, 120.1, 35.1, 34.8, 31.6, 31.4 ppm; HRMS (ESI) calcd for $C_{31}H_{32}N$ [M+H] 418.2535 found 418.2535.

*4.3.4. 3-Methoxy-8-phenylbenzo[a]phenanthridine (**4d**).* Light yellow solid; yield 66% (0.111 g); mp 142–144 °C; R_f=0.38 (2:8 EtOAc/hexane); FT-IR (KBr) 2925, 2856, 1620, 1579, 1460, 1219 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.32 (1H, s), 9.06–8.98 (2H, m), 8.07 (2H, d, *J*=7.9 Hz), 8.68 (1H, t, *J*=7.0 Hz), 7.61–7.46 (8H, m), 4.00 (3H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 158.2, 152.2, 142.5, 140.5, 140.2, 139.4, 132.3, 130.2, 128.6, 128.3, 128.0, 127.7, 127.4, 127.1, 126.6, 126.4, 122.5, 114.2, 107.7, 55.7 ppm; HRMS (ESI) calcd for $C_{24}H_{18}NO$ [M+H] 336.1388 found 336.1384.

*4.3.5. 3-Methoxy-10-methyl-8-(4-methylphenyl)benzo[a]phenanthridine (**4e**).* Yellow solid; yield 60% (0.109 g); mp 190–192 °C; R_f=0.40 (2:8 EtOAc/hexane); FT-IR (KBr) 2924, 2853, 1635, 1441, 1218 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.28 (1H, s), 9.01–8.94 (2H, m), 8.02 (1H, s), 7.87 (1H, s), 7.51–7.45 (4H, m), 7.35 (1H, d, *J*=7.7 Hz), 7.24 (2H, s) 4.01 (3H, s), 2.50 (3H, s), 2.48 (3H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 158.1, 151.8, 142.3, 140.2, 139.4, 137.4, 137.3, 136.4, 132.5, 130.1, 129.3, 128.7, 128.3, 128.2, 127.9, 127.4, 126.5, 122.3, 114.2, 107.6, 55.7, 21.8, 21.4 ppm; HRMS (ESI) calcd for $C_{26}H_{22}NO$ [M+H] 364.1701 found 364.1678.

*4.3.6. 3-Methoxy-10-tert-butyl-8-(4-tert-butylphenyl)benzo[a]phenanthridine (**4f**).* Yellow solid; yield 68% (0.152 g); mp 144–146 °C; R_f=0.35 (2:8 EtOAc/hexane); FT-IR (KBr) 2919, 2858, 1622, 1561, 1474, 1218 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.27 (1H, br s), 9.00 (2H, dd, J_1=2.8 Hz, J_2=9.2 Hz), 8.16 (1H, d, *J*=1.8 Hz), 8.07 (1H, s), 7.76 (1H, dd, J_1=2.0 Hz, J_2=8.9 Hz), 7.60–7.54 (4H, m), 7.49 (1H, dd, J_1=2.5 Hz, J_2=9.2 Hz), 7.42 (1H, d, *J*=2.4 Hz), 3.97 (3H, s), 1.43 (9H, s), 1.38 (9H, s) ppm; ^{13}C NMR (50 MHz, $CDCl_3$): δ 157.9, 150.4, 149.2, 140.4, 137.3, 132.0, 129.8, 128.8, 128.2, 127.8, 127.3, 125.3, 124.6, 122.7, 122.1, 107.4, 55.5, 35.0, 34.7, 31.5, 31.3 ppm; HRMS (ESI) calcd for $C_{32}H_{34}NO$ [M+H] 448.2640 found 448.2635.

*4.3.7. 3,10-Dimethoxy-8-(4-methoxyphenyl)benzo[a]phenanthridine (**4g**).* Yellow solid; yield 69% (0.136 g); mp 162–164 °C; R_f=0.32 (2:8 EtOAc/hexane); FT-IR (KBr) 2920, 2878, 1621, 1532, 1458, 1262 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.26 (1H, s), 9.00–8.94 (2H, m), 8.02 (1H, s), 7.59–7.50 (2H, m), 7.49–7.46 (2H, m), 7.36–7.32 (1H, m), 7.08 (2H, d, *J*=8.5 Hz), 4.03 (3H, s), 3.92 (3H, s), 3.85 (3H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 159.3, 158.1, 158.0, 151.3, 141.6, 139.4, 134.1, 132.7, 131.1, 129.5, 129.4, 129.1, 128.2, 127.2, 124.8, 122.3, 120.8, 116.8, 114.1, 107.6, 107.4, 55.7, 55.5, 55.4 ppm; HRMS (ESI) calcd for $C_{26}H_{21}NO_3$ [M+H] 396.1600 found 396.1574.

*4.3.8. 2-Methoxy-8-phenylbenzo[a]phenanthridin-3-yl methyl ether (**4h**).* Colorless solid; yield 66% (0.121 g); mp 185–187 °C; R_f=0.34 (2:8 EtOAc/hexane); FT-IR (KBr) 2963, 1622, 1511, 1462, 1215 cm^{-1};

^{1}H NMR (300 MHz, $CDCl_3$): δ 9.25 (1H, s), 9.15 (1H, d, J=7.9 Hz), 8.52 (1H, s), 8.10 (2H, d, J=7.9 Hz), 7.60–7.48 (8H, m), 4.07 (6H, s) ppm; ^{13}C NMR (50 MHz, $CDCl_3$): δ 153.3, 151.0, 149.6, 140.2, 134.2, 132.2, 130.2, 129.5, 128.6, 127.7, 127.4, 127.1, 126.4, 107.6, 106.7, 56.4 ppm; HRMS (ESI) calcd for $C_{25}H_{20}NO_2$ [M+H] 366.1494 found 366.1489.

*4.3.9. 2,3-Dimethoxy-10-methyl-8-(4-methylphenyl)benzo[a]phenanthridine (**4i**).* Off white solid; yield 62% (0.122 g); mp 136–138 °C; R_f=0.33 (2:8 EtOAc/hexane); FT-IR (KBr) 3015, 2922, 1619, 1578, 1456, 1246 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.18 (1H, s), 8.99 (1H, d, J=8.5 Hz), 8.44 (1H, s), 8.00 (1H, s), 7.88 (1H, s), 7.50–7.48 (3H, m), 7.41 (1H, s), 7.34 (2H, d, J=7.6 Hz), 4.12 (3H, s), 4.08 (3H, s), 2.50 (3H, s), 2.48 (3H, s) ppm; ^{13}C NMR (50 MHz, $CDCl_3$): δ 153.0, 150.5, 149.4, 142.6, 140.2, 139.3, 136.2, 132.4, 130.0, 129.2, 128.7, 128.5, 128.3, 128.1, 126.9, 126.7, 123.7, 119.9, 114.2, 107.5, 106.6, 56.2, 56.1, 21.7, 21.4 ppm; HRMS (ESI) calcd for $C_{27}H_{24}NO_2$ [M+H] 394.1807 found 394.1802.

*4.3.10. 2,3-Dimethoxy-10-tert-butyl-8-(4-tert-butylphenyl)benzo[a]phenanthridine (**4j**).* Yellow solid; yield 67% (0.159 g); mp 176–178 °C; R_f=0.28 (2:8 EtOAc/hexane); FT-IR (KBr) 3018, 2925, 1615, 1580, 1512, 1460, 1262 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.19 (1H, s), 8.99 (1H, d, J=8.5 Hz), 8.44 (1H, s), 8.00 (1H, s), 7.88 (1H, s), 7.52–7.48 (3H, m), 7.42 (1H, s), 7.35 (2H, d, J=7.7 Hz), 4.12 (3H, s), 4.08 (3H, s), 1.25 (9H, s), 1.23 (9H, s), ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 153.0, 150.4, 149.4, 142.4, 142.2, 140.2, 139.3, 137.3, 137.2, 136.1, 132.3, 129.9, 129.2, 128.5, 128.4, 128.2, 128.0, 126.8, 126.6, 123.6, 119.9, 114.1, 107.5, 106.5, 56.2, 56.1, 32.0, 29.8 ppm; HRMS (ESI) calcd for $C_{33}H_{36}NO_2$ [M+H] 478.2746 found 478.2735.

4.4. General procedure for the 6-*endo*-iodocyclizations 5a–o

A flame dried round-bottom flask was charged with 5 mL of acetonitrile and 4-phenyl-3-phenylethynyl-isoquinolines **3a–o** (0.5 mmol), under a nitrogen atmosphere, followed by dropwise addition of 0.75 mmol of ICl (1 M solution in DCM) at 0 °C. The reaction mixture was allowed to stir for indicated time (20–30 min), the disappearance of the starting material was determined by TLC. The reaction was then quenched with a saturated solution of $NaHCO_3$ (10 mL) and extracted with EtOAc (3×20 mL). The organic phases were combined, dried over Na_2SO_4, and concentrated under reduced pressure, and the crude mixture was purified by column chromatography on silica gel (60–120 mesh) using EtOAc/hexane as the eluent to afford **5**.

*4.4.1. 7-Iodo-8-phenylbenzo[a]phenanthridine (**5a**).* Light brown solid; yield 88% (0.189 g); mp 192–194 °C; R_f=0.55 (2:8 EtOAc/hexane); FT-IR (KBr) 2939, 2891, 1598, 1442, 1280 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.45 (s, 1H), 9.06 (t, J=9.1 Hz, 2H), 8.23 (1H, d, J=7.8 Hz), 7.94 (1H, t, J=7.1 Hz), 7.81–7.68 (2H, m), 7.62–7.47 (5H, m), 7.37–7.35 (2H, m) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 153.0, 147.1, 144.4, 142.0, 133.4, 132.2, 131.1, 130.1, 129.7, 128.7, 128.6, 128.4, 128.2, 128.0, 127.9, 127.5, 127.1, 126.8, 121.6, 109.9 ppm; HRMS (ESI) calcd for $C_{23}H_{15}IN$ [M+H] 432.0249 found 432.0244.

*4.4.2. 7-Iodo-10-methyl-8-(4-methylphenyl)benzo[a]phenanthridine (**5b**).* Light orange solid; yield 85% (0.195 g); mp 208–210 °C; R_f=0.52 (2:8 EtOAc/hexane); FT-IR (KBr) 3024, 2926, 1625, 1507, 1454, 1217 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.38 (1H, s), 9.02 (1H, d, J=8.5 Hz), 8.89 (1H, d, J=8.6 Hz), 8.17 (1H, d, J=7.5 Hz), 7.88 (1H, t, J=7.1 Hz), 7.74 (1H, t, J=7.2 Hz), 7.51 (1H, d, J=7.4 Hz), 7.39–7.37 (3H, m), 7.23 (2H, d, J=7.9 Hz), 2.52 (3H, s), 2.44 (3H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 152.5, 146.8, 141.6, 137.6, 137.1, 133.8, 132.2, 130.9, 129.9, 129.3, 128.7, 128.1, 127.8, 127.6, 127.4, 127.0, 121.6, 110.3, 21.7, 21.6 ppm; HRMS (ESI) calcd for $C_{25}H_{19}IN$ [M+H] 460.0562 found 460.0549.

*4.4.3. 7-Iodo-10-tert-butyl-8-(4-tert-butylphenyl)benzo[a]phenanthridine (**5c**).* Gray solid; yield 93% (0.252 g); mp 228–230 °C; R_f=0.48 (2:8 EtOAc/hexane); FT-IR (KBr) 2960, 2868, 1618, 1503, 1461, 1215 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.42 (1H, s), 9.10 (1H, d, J=8.5 Hz), 8.98 (1H, d, J=8.9 Hz), 8.21 (1H, d, J=7.8 Hz), 7.94–7.89 (1H, m), 7.79–7.74 (2H, m), 7.60–7.55 (3H, m), 7.30–7.25 (2H, m), 1.45 (9H, s), 1.28 (9H, s) ppm; ^{13}C NMR (50 MHz, $CDCl_3$): δ 152.6, 150.9, 149.9, 147.6, 141.8, 141.5, 133.8, 132.3, 131.0, 129.6, 128.7, 128.1, 127.6, 127.4, 127.0, 125.3, 124.3, 121.4, 109.5, 34.9, 31.6, 31.1 ppm; HRMS (ESI) calcd for $C_{31}H_{31}IN$ [M+H] 544.1501 found 544.1496.

*4.4.4. 7-Iodo-10-methoxy-8-(4-methoxyphenyl)benzo[a]phenanthridine (**5d**).* Yellow solid; yield 92% (0.226 g); mp 214–216 °C; R_f=0.45 (2:8 EtOAc/hexane); FT-IR (KBr) 3019, 2938, 1617, 1561, 1464, 1217 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.27 (1H, br s), 7.56 (1H, d, J=8.6 Hz), 7.36–7.30 (4H, m), 6.90 (2H, d, J=8.7 Hz), 6.64–6.54 (4H, m), 3.96 (3H, s), 3.83 (3H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 159.9, 158.2, 154.8, 153.0, 150.2, 147.2, 132.3, 130.2, 129.5, 127.4, 126.9, 126.4, 125.2, 122.6, 113.8, 106.1, 103.1, 55.6, 55.3 ppm; HRMS (ESI) calcd for $C_{25}H_{19}INO_2$ [M+H] 492.0460 found 492.0438.

*4.4.5. 7-Iodo-3-methoxy-8-phenylbenzo[a]phenanthridine (**5e**).* Light yellow solid; yield 89% (0.205 g); mp 229–231 °C; R_f=0.48 (2:8 EtOAc/hexane); FT-IR (KBr) 3022, 2915, 1619, 1592, 1428 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.37 (1H, s), 8.99 (2H, d, J=8.9 Hz), 7.69 (1H, t, J=6.9 Hz), 7.60–7.46 (7H, m), 7.37–7.34 (2H, m), 7.25 (1H, s), 4.06 (3H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 158.7, 152.1, 146.1, 144.5, 141.1, 139.4, 133.5, 130.2, 129.8, 129.5, 128.6, 128.4, 128.0, 127.9, 127.1, 126.6, 122.7, 121.9, 114.2, 110.0, 107.1, 55.8 ppm; HRMS (ESI) calcd for $C_{24}H_{17}INO$ [M+H] 462.0355 found 462.0350.

*4.4.6. 7-Iodo-10-methyl-8-(4-methylphenyl)benzo[a]phenanthridin-3-yl methyl ether (**5f**).* Colorless solid; yield 91% (0.223 g); mp>250 °C; R_f=0.44 (2:8 EtOAc/hexane); FT-IR (KBr) 3022, 2929, 1625, 1512, 1217 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.32 (1H, s), 8.95 (1H, d, J=9.1 Hz), 8.85 (1H, d, J=8.5 Hz), 7.54–7.48 (3H, m), 7.39 (3H, d, J=7.5 Hz), 7.23 (2H, d, J=7.8 Hz), 4.04 (3H, s), 2.52 (3H, s), 2.44 (3H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 158.6, 151.6, 145.8, 141.7, 140.8, 137.6, 137.0, 133.8, 130.0, 129.8, 129.3, 128.6, 128.5, 127.8, 127.5, 127.0, 122.6, 121.8, 114.2, 110.4, 107.1, 55.8, 21.7, 21.6 ppm; HRMS (ESI) calcd for $C_{26}H_{21}INO$ [M+H] 490.0668 found 490.0644.

*4.4.7. 7-Iodo-10-tert-butyl-8-(4-tert-butylphenyl)benzo[a]phenanthridin-3-yl methyl ether (**5g**).* Brown solid; yield 92% (0.264 g); mp 225–227 °C; R_f=0.40 (2:8 EtOAc/hexane); FT-IR (KBr) 2957, 1628, 1510, 1459, 1222 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.34 (1H, s), 9.00 (1H, d, J=9.2 Hz), 8.92 (1H, d, J=8.8 Hz), 7.75 (1H, dd, J_1=1.9 Hz, J_2=8.9 Hz), 7.59–7.48 (5H, m), 7.28 (2H, d, J=8.3 Hz), 4.05 (3H, s), 1.45 (9H, s), 1.27 (9H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 158.6, 151.7, 150.8, 149.9, 146.5, 141.6, 141.0, 133.8, 129.7, 128.6, 127.6, 127.4, 127.1, 125.3, 125.0, 124.3, 122.6, 121.7, 109.7, 107.1, 55.8, 34.96, 34.9, 31.6, 31.1 ppm; HRMS (ESI) calcd for $C_{32}H_{33}INO$ [M+H] 574.1607 found 574.1599.

*4.4.8. 7-Iodo-3,10-dimethoxy-8-(4-methoxyphenyl)benzo[a]phenanthridine (**5h**).* Orange solid; yield 93% (0.242 g); mp 242–244 °C; R_f=0.36 (2:8 EtOAc/hexane); FT-IR (KBr) 2922, 2854, 1619, 1580, 1460, 1219 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.15 (1H, s), 7.37 (2H, d, J=8.8 Hz), 7.28 (1H, s), 6.90 (2H, d, J=8.8 Hz), 6.81 (1H, s), 6.69–6.57 (4H, m), 4.03 (3H, s), 3.83 (3H, s), 3.80 (3H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 160.0, 155.5, 154.0, 151.6, 150.3, 150.1, 147.6, 132.1, 130.1, 128.5, 126.6, 124.9, 124.4, 113.8, 106.5, 103.2, 98.7, 56.1,

56.0, 55.3 ppm; HRMS (ESI) calcd for $C_{26}H_{21}INO_3$ [M+H] 522.0566 found 522.1478.

*4.4.9. 7-Iodo-2,3-dimethoxy-8-phenylbenzo[a]phenanthridine (**5i**).* Pale brown solid; yield 90% (0.221 g); mp 210–212 °C; R_f=0.42 (2:8 EtOAc/hexane); FT-IR (KBr) 2924, 1622, 1509, 1459, 1262 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 9.28 (1H, s), 9.03 (1H, d, J=8.3 Hz), 8.44 (1H, s), 7.67 (1H, t, J=7.0 Hz), 7.60–7.44 (6H, m), 7.35 (2H, d, J=6.4 Hz), 4.13 (6H, s) ppm; ^{13}C NMR (50 MHz, $CDCl_3$): δ 153.3, 150.9, 150.1, 146.2, 144.4, 141.4, 133.3, 130.1, 129.7, 128.6, 128.2, 128.0, 126.8, 126.5, 124.2, 121.1, 110.1, 107.1, 106.8, 56.3 ppm; HRMS (ESI) calcd for $C_{25}H_{19}INO_2$ [M+H] 492.0461 found 492.0433.

*4.4.10. 7-Iodo-2,3-dimethoxy-10-methyl-8-(4-methylphenyl)benzo[a]phenanthridine (**5j**).* Pale green solid; yield 92% (0.238 g); mp 216–218 °C; R_f=0.35 (2:8 EtOAc/hexane); FT-IR (KBr) 2924, 2854, 1617, 1511, 1460, 1218 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 9.25 (1H, s), 8.93 (1H, d, J=8.6 Hz), 8.42 (1H, s), 7.52–7.46 (2H, m), 7.38 (3H, s), 7.22 (3H, d, J=7.8 Hz), 4.12 (6H, s), 2.52 (3H, s), 2.45 (3H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 153.2, 150.5, 150.0, 146.0, 141.7, 141.2, 139.4, 137.6, 136.8, 133.7, 129.9, 129.3, 128.9, 128.4, 128.2, 128.0, 127.7, 126.8, 124.2, 114.2, 107.1, 106.9, 56.3, 21.7, 21.6 ppm; HRMS (ESI) calcd for $C_{27}H_{23}INO_2$ [M+H] 520.0773 found 520.0762.

*4.4.11. 7-Iodo-2,3-dimethoxy-10-tert-butyl-8-(4-tert-butylphenyl)benzo[a]phenanthridine (**5k**).* Light yellow solid; yield 94% (0.283 g); mp 215–217 °C; R_f=0.33 (2:8 EtOAc/hexane); FT-IR (KBr) 2958, 1641, 1509, 1462, 1218 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 9.26 (1H, s), 8.99 (1H, d, J=8.5 Hz), 8.47 (1H, s), 7.75 (1H, d, J=8.3 Hz), 7.57 (3H, t, J=7.3 Hz), 7.47 (1H, s), 7.28 (2H, d, J=8.0 Hz), 4.15 (3H, s), 4.13 (3H, s), 1.45 (9H, s), 1.28 (9H, s) ppm; ^{13}C NMR (50 MHz, $CDCl_3$): δ 153.3, 150.9, 150.5, 150.1, 149.7, 146.8, 141.5, 133.7, 129.7, 128.4, 127.7, 126.6, 125.3, 124.9, 124.6, 124.2, 121.0, 107.2, 106.9, 56.4, 56.3, 34.9, 31.6, 31.2 ppm; HRMS (ESI) calcd for $C_{33}H_{35}INO_2$ [M+H] 604.1713 found 604.1698.

*4.4.12. 3-Fluoro-7-iodo-8-phenylbenzo[a]phenanthridine (**5l**).* Pale yellow solid; yield 86% (0.193 g); mp 219–221 °C; R_f=0.44 (2:8 EtOAc/hexane); FT-IR (KBr) 2967, 1628, 1518, 1444, 1222 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 9.39 (1H, s), 9.08 (1H, dd, J_1=4.8 Hz, J_2=9.1 Hz), 8.95 (1H, d, J=8.4 Hz), 7.84 (1H, dd, J_1=2.5 Hz, J_2=8.1 Hz), 7.74–7.67 (2H, m), 7.62–7.49 (5H, m), 7.35 (2H, d, J=6.2 Hz) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 163.6, 158.6, 151.9, 147.1, 144.2, 133.6, 130.0, 129.8, 129.6, 129.3, 129.0, 128.6, 128.5, 128.1, 127.8, 127.4, 127.0, 121.5, 120.9, 120.5, 112.5, 112.1, 109.7 ppm; HRMS (ESI) calcd for $C_{23}H_{14}FIN$ [M+H] 450.0155 found 450.0147.

*4.4.13. 3-Fluoro-7-iodo-10-methyl-8-(4-methylphenyl)benzo[a]phenanthridine (**5m**).* Pale yellow solid; yield 84% (0.200 g); mp 232–234 °C; R_f=0.40 (2:8 EtOAc/hexane); FT-IR (KBr) 3015, 2922, 1614, 1507, 1453, 1218 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 9.35 (1H, s), 9.06 (1H, dd, J_1=4.8 Hz, J_2=9.2 Hz), 8.84 (1H, d, J=8.5 Hz), 7.82 (1H, dd, J_1=2.3 Hz, J_2=7.9 Hz), 7.71–7.64 (1H, m), 7.54 (1H, d, J=8.5 Hz), 7.41–7.38 (3H, m), 7.23 (2H, d, J=7.9 Hz), 2.53 (3H, s), 2.46 (3H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 151.5, 151.4, 146.8, 141.5, 137.7, 137.4, 133.9, 129.9, 129.7, 129.6, 129.3, 129.2, 129.0, 128.9, 127.9, 127.7, 127.3, 121.5, 120.7, 120.3, 112.4, 112.0, 110.1, 21.8, 21.6 ppm; HRMS (ESI) calcd for $C_{25}H_{18}FIN$ [M+H] 478.0468 found 478.0453H]$^+$.

*4.4.14. 3-Fluoro-7-iodo-10-tert-butyl-8-(4-tert-butylphenyl)benzo[a]phenanthridine (**5n**).* Yellow solid; yield 90% (0.252 g); mp 140–142 °C; R_f=0.37 (2:8 EtOAc/hexane); FT-IR (KBr) 2924, 2857, 1610, 1457, 1218 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 9.36 (1H, s), 9.09 (1H, dd, J_1=4.8 Hz, J_2=8.8 Hz), 8.88 (1H, d, J=8.8 Hz), 7.83–7.76 (2H, m), 7.69–7.55 (4H, m), 7.28 (2H, d, J=8.2 Hz), 1.45 (9H, s), 1.28 (9H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 162.7, 159.4, 151.5, 151.4, 150.9, 150.2, 147.5, 141.3, 133.9, 131.0, 129.7, 129.6, 127.5, 127.3, 125.4, 125.3, 124.4, 121.3, 120.7, 120.3, 114.2, 112.4, 112.1, 109.4, 35.0, 34.9, 31.6, 31.3 ppm; HRMS (ESI) calcd for $C_{31}H_{30}FIN$ [M+H] 562.1407 found 562.1408.

*4.4.15. 4-(3-Fluoro-7-iodo-10-methoxybenzo[a]phenanthridin-8-yl) phenyl methyl ether (**5o**).* Brown solid; yield 91% (0.232 g); mp 184–186 °C; R_f=0.33 (2:8 EtOAc/hexane); FT-IR (KBr) 2958, 1617, 1524, 1448, 1215 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 8.84 (1H, s), 7.98–7.94 (2H, m), 7.81–7.78 (1H, m), 7.60–7.55 (1H, m), 7.49 (2H, d, J=8.6 Hz), 7.32–7.27 (2H, m), 6.98 (2H, d, J=8.7 Hz), 3.91 (3H, s), 3.86 (3H, s) ppm; ^{13}C NMR (50 MHz, $CDCl_3$): δ 160.4, 159.4, 150.3, 144.1, 139.5, 135.8, 135.1, 132.9, 132.0, 131.5, 131.3, 130.6, 128.3, 127.7, 126.9, 125.7, 124.1, 117.1, 113.9, 113.2, 55.6, 55.5 ppm; HRMS (ESI) calcd for $C_{25}H_{18}FINO_2$ [M+H] 510.0366 found 510.1747.

*4.4.16. 7-Bromo-8-phenylbenzo[a]phenanthridine (**5p**).* Yellow solid; yield 68% (0.130 g); mp 206–208 °C; R_f=0.50 (2:8 EtOAc/hexane); FT-IR (KBr) 2935, 2888, 1578, 1442, 1278 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 9.49 (1H, s), 9.09–9.03 (2H, m), 8.22 (1H, d, J=7.7 Hz), 7.96–7.90 (1H, m), 7.81–7.76 (1H, m), 7.72–7.67 (1H, m), 7.62–7.50 (5H, m), 7.41 (2H, d, J=6.6 Hz) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 153.1, 141.9, 140.7, 140.5, 133.5, 132.2, 131.2, 130.1, 129.0, 128.8, 128.6, 128.0, 127.9, 127.8, 127.6, 127.1, 127.0, 126.7, 125.5, 122.2 ppm; HRMS (ESI) calcd for $C_{23}H_{15}BrN$ [M+H] 384.0388 found 384.0369.

*4.4.17. 7-(3,4-Dimethoxyphenyl)-8-diphenylbenzo[a]phenanthridine (**7a**).* Brown solid; yield 82% (0.181 g); mp 174–176 °C; R_f=0.30 (2:8 EtOAc/hexane); FT-IR (KBr) 3020, 2928, 2855, 1581, 1513, 1466, 1217 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 9.36 (1H, s), 9.11 (2H, dd, J_1=2.7 Hz, J_2=8.2 Hz), 8.13 (1H, d, J=7.4 Hz), 7.89 (1H, t, J=7.1 Hz), 7.78–7.66 (3H, m), 7.53 (1H, t, J=7.4 Hz), 7.25–7.00 (5H, m), 6.83–6.76 (2H, m), 6.68 (1H, s), 3.84 (3H, s), 3.64 (3H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 152.3, 147.7, 147.3, 142.8, 140.0, 139.4, 138.2, 132.7, 132.3, 131.5, 131.0, 130.6, 129.3, 128.5, 127.7, 127.4, 127.0, 126.9, 126.8, 126.5, 126.1, 124.4, 120.7, 115.2, 110.1, 55.66, 55.6 ppm; HRMS (ESI) calcd for $C_{31}H_{24}NO_2$ [M+H] 442.1807 found 442.1799.

*4.4.18. Butyl (E)-3-(8-phenylbenzo[a]phenanthridin-7-yl)prop-2-enoate (**7b**).* Yellow solid; yield 78% (0.168 g); mp 194–196 °C; R_f=0.42 (2:8 EtOAc/hexane); FT-IR (KBr) 3069, 2926, 1631, 1457, 1218 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 9.43 (1H, s), 9.04 (2H, t, J=8.2 Hz), 8.25 (1H, s), 8.19 (1H, d, J=7.8 Hz), 7.90 (1H, t, J=7.0 Hz), 7.78–7.66 (3H, m), 7.54–7.49 (4H, m), 7.37–7.35 (2H, m), 6.62 (1H, d, J=16.3 Hz), 4.11 (2H, t, J=6.5 Hz), 1.65 (2H, m), 1.34 (2H, q, J_1=7.5 Hz, J_2=15.1 Hz), 0.92 (3H, t, J=7.3 Hz) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 167.5, 152.0, 142.0. 138.6, 135.9, 132.8, 132.3, 130.8, 130.7, 130.1, 129.9, 128.6, 128.5, 128.4, 127.9, 127.8, 127.6, 127.2, 127.1, 126.7, 126.1, 125.7, 125.6, 120.7, 64.2, 30.8, 19.3, 13.9 ppm; HRMS (ESI) calcd for $C_{30}H_{26}NO_2$ [M+H] 432.1964 found 432.1950.

*4.4.19. 8-Phenyl-7-(1H-pyrrol-1-yl)benzo[a]phenanthridine (**7c**).* Colorless solid; yield 65% (0.120 g); mp 223–225 °C; R_f=0.40 (2:8 EtOAc/hexane); FT-IR (KBr) 3058, 2925, 1576, 1488, 1360 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 9.39 (1H, s), 9.14 (2H, dd, J_1=2.8 Hz, J_2=7.8 Hz), 8.18 (1H, d, J=7.7 Hz), 7.95 (1H, t, J=7.1 Hz), 7.85–7.73 (3H, m), 7.60 (1H, t, J=7.3 Hz), 7.37–7.29 (5H, m), 6.71 (2H, s), 6.16 (2H, s) ppm; ^{13}C NMR (75 MHz, $CDCl_3$): δ 153.6, 140.8, 138.4, 136.4, 135.5, 132.3, 132.2, 131.0, 130.0, 129.4, 128.8, 128.1, 128.0, 127.9, 127.6, 127.4, 126.9, 124.4, 121.4, 108.1 ppm; HRMS (ESI) calcd for $C_{27}H_{19}N_2$ [M+H] 371.1548 found 371.1542.

*4.4.20. 7,8-Diphenylbenzo[a]naphtho[1,2-c]phenanthridine (**7d**).* Light orange solid; yield 60% (0.144 g); mp>250 °C; R_f=0.48 (2:8 EtOAc/hexane); FT-IR (KBr) 3006, 2926, 2858, 1638, 1437, 1217 cm^{-1}; ^1H NMR (600 MHz, $CDCl_3$): δ 9.13 (1H, d, J=9.0 Hz), 8.99

(1H, d, *J*=8.4 Hz), 8.68 (1H, d, *J*=7.8 Hz), 7.92 (2H, t, *J*=9.0 Hz), 7.70 (1H, t, *J*=7.2 Hz), 7.64 (1H, t, *J*=7.3 Hz), 7.45 (1H, d, *J*=7.0 Hz), 7.36–7.35 (2H, m), 7.28–7.25 (4H, m), 7.11–7.05 (5H, m), 6.90 (1H, t, *J*=7.2 Hz), 6.81 (2H, t, *J*=7.2 Hz), 6.72 (2H, d, *J*=8.4 Hz) ppm; ^{13}C NMR (150 MHz, $CDCl_3$): δ 159.1, 139.9, 135.9, 134.6, 132.6, 132.5, 131.59, 131.58, 130.9, 130.5, 130.4, 129.9, 128.8, 128.3, 128.2, 128.0, 127.4, 127.3, 127.2, 127.1, 127.0, 126.5, 126.2, 125.9, 125.8, 124.7, 124.2, 110.6, 105.0 ppm; HRMS (ESI) calcd for $C_{37}H_{24}N$ [M+H] 482.1909 found 482.1903.

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Supplementary data

Copies of ^{1}H, ^{13}C NMR and HRMS spectra of **3a**–**o**, **4a**–**j**, **5a**–**p**, **7a**–**d**. Supplementary data related to this article can be found online at http://dx.doi.org/10.1016/j.tet.2012.07.067.

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