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Facile assembly of cyclopenta[*c*]quinolin-3-ols via a palladium-catalyzed reaction of 2-alkynylaniline with 2-alkynylvinyl bromide

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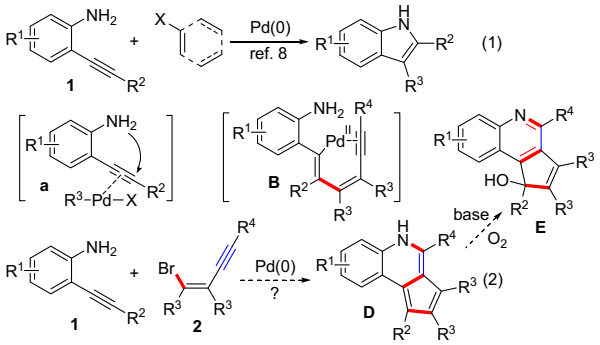
ABSTRACT

A palladium-catalyzed tandem reaction of 2-alkynylaniline with 2-alkynylvinyl bromide provides an efficient route for the assembly of cyclopenta[*c*]quinolin-3-ols. A double insertion of triple bonds is the key step during the transformation.

1. Introduction

Currently, small molecule modulators used for the systematic perturbation of gene products are of high demand in the field of chemical biology.[1] Therefore, efficient and facile approaches for the collection of novel drug-like small molecules are needed.[2] In the past decade, diversity-oriented synthesis has been used as an attractive strategy for the preparation of natural product-like compounds.[3,4] Among the synthetic approaches applied, tandem reactions have been demonstrated as a powerful method for the generation of molecular diversity and complexity.[5] The importance of nitrogen-containing heterocycles embedded with privileged substructures is well-known, due to their remarkable biological properties.[6] Thus, continuous efforts have been underway for the methods development for the rapid access to privileged scaffold-based *N*-heterocycles.

The quinoline core is a well-known privileged structural motif presented in a number of natural and synthetic products with interesting pharmacological or physical properties.[7] To construct the novel molecular frameworks via a tandem process, we aimed to develop a practical synthetic route for unique polyheterocycles containing a quinoline substructure. Recently, we are interested in the palladium-catalyzed tandem reactions of 2-alkynylanilines **1** for the generation of *N*-heterocycles.[8] The palladium-catalyzed reaction of 2-alkynylaniline **1** with aryl/alkenyl halide is known,[9] which proceeds through an intermediate **a** to afford the indole compound (Scheme 1, Eq 1). We envisioned that 2-alkynylvinyl



Scheme 1. A proposed palladium-catalyzed tandem reaction of 2-alkynylaniline with 2-alkynylvinyl bromide.

bromide **2** might be a good reactant as well in the palladium-catalyzed reaction of 2-alkynylaniline **1** (Scheme 1, Eq. 2). The presence of an additional alkynyl moiety would enable its double insertion of triple bonds (intermediate **B**), and the generation of a fused quinoline **D** or **E** would be expected. Recently, the highly selective intramolecular or intermolecular double insertion of triple bonds has been successfully applied in the construction of heterocyclic or carbocyclic compounds.[10] Encouraged by these

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results, we envisioned that the hypothesis presented in Scheme 1 was possible although the competitive pathway for the formation of indole seemed inevitable. If the transformation proceeded smoothly as expected, the fused quinoline compounds would be generated and the formation of three bonds in a tandem one-pot procedure would be anticipated.

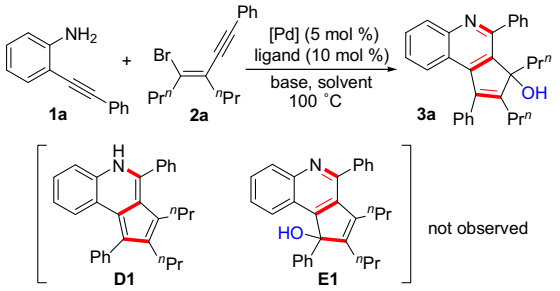
2. Results/discussion

Initially, a model reaction of 2-(2-phenylethynyl)benzenamine **1a** with 2-alkynylvinyl bromide **2a** in the presence of a palladium catalyst (5 mol %) was studied (Table 1). At the outset, the reaction was catalyzed by $Pd(OAc)_2$ (5 mol %) and PPh_3 (10 mol %) in the presence of *t*-BuONa (2.0 equiv) in 1,4-dioxane at 100 °C (Table 1, entry 1). Disappointingly, only a trace amount of product was detected. A similar outcome was observed when the ligand was replaced by DPPP (Table 1, entry 2). No reaction occurred when *N*-heterocyclic carbene (IPr) was used in the reaction (Table 1, entry 3). To our delight, a product was isolated in 26% yield when X-phos was utilized as the ligand (Table 1, entry 4). However, the structural illustration revealed that this product was cyclopenta[*c*]quinolin-3-ol **3a** instead of the expected compound **D** or **E** (Fig. 1). This unexpected result was reasonable, since the cyclopenta[*c*]quinoline **D** could be easily converted to cyclopenta[*c*]quinolin-3-ol **3** in the presence of a base under air.[11] This promising result prompted us for further investigation. The yield was increased to 43% when PCy_3 was employed as the ligand (Table 1, entry 5). A better yield was obtained by evaluation of other palladium sources (Table 1, entries 6 and 7). Interestingly, cyclopenta[*c*]quinolin-3-ol **3a** could be isolated in 60% yield without the addition of a phosphine ligand (Table 1, entry 8). In light of this result, we further screened different bases (Table 1, entries 9–12). The yield was lower when *t*-BuOK was employed in the reaction (Table 1, entry 9). The reaction was inert when K_2CO_3, Cs_2CO_3, or NaOMe was utilized. Furthermore, the reaction was retarded when the temperature was lower (data not shown in Table 1). The transformation afforded the corresponding product **3a** in 51% yield when the reaction took place in toluene (Table 1, entry 13). The reaction failed when the solvent was changed to DMF, DMSO, or NMP (Table 1, entries 14–16).

After establishing the optimized conditions (5 mol % of $PdCl_2(PPh_3)_2$, 2.0 equiv of *t*-BuONa, 1,4-dioxane, 100 °C), we next explored the generality of this palladium-catalyzed tandem reaction of 2-alkynylanilines **1** with 2-alkynylvinyl bromides **2**. The results are summarized in Table 2. We found that the reactions worked well leading to a range of cyclopenta[*c*]quinolin-3-ols **3** in moderate yields. Various 2-alkynylanilines **1** were demonstrated to be good reactants in the transformation. The substituents attached to the triple bond were all tolerated under the standard conditions. 2-Alkynylanilines **1** with different substituents on the aromatic ring were examined as well, which reacted with 2-alkynylvinyl bromides **2** affording the corresponding products. During the reaction process, only a trace amount of indole was detected, which demonstrated the high selectivity of the double insertion of triple bonds. Subsequently, several 2-alkynylvinyl bromides **2** were employed in the reactions of 2-alkynylanilines **1**, and the desired products were afforded as expected.

The possible mechanism was proposed in Scheme 2. An oxidative addition of Pd(0) to vinyl bromide **2** would occur first, which would then coordinate with the triple bond of 2-alkynylanilines **1**. After insertion, a vinyl Pd(II) **B** would be generated, which would subsequently undergo an intramolecular insertion of another triple bond to produce intermediate **C**. Further C–N coupling and base-promoted hydroxylation in the presence of dioxygen would afford the unexpected cyclopenta[*c*]quinolin-3-ol **3**.

Table 1
Initial studies for the palladium-catalyzed reaction of 2-(2-phenylethynyl)benzenamine **1a** with 2-alkynylvinyl bromide **2a**[a]



Entry	[Pd]	Ligand	Base	Solvent	Yield[b] (%)
1	$Pd(OAc)_2$	PPh_3	*t*-BuONa	1,4-Dioxane	Trace
2	$Pd(OAc)_2$	DPPP	*t*-BuONa	1,4-Dioxane	Trace
3	$Pd(OAc)_2$	IPr	*t*-BuONa	1,4-Dioxane	nr
4	$Pd(OAc)_2$	X-Phos	*t*-BuONa	1,4-Dioxane	26
5	$Pd(OAc)_2$	PCy_3	*t*-BuONa	1,4-Dioxane	43
6	$Pd_2(dba)_3$	PCy_3	*t*-BuONa	1,4-Dioxane	17
7	$PdCl_2(PPh_3)_2$	PCy_3	*t*-BuONa	1,4-Dioxane	47
8	$PdCl_2(PPh_3)_2$	—	*t*-BuONa	1,4-Dioxane	60
9	$PdCl_2(PPh_3)_2$	—	*t*-BuOK	1,4-Dioxane	36
10	$PdCl_2(PPh_3)_2$	—	K_2CO_3	1,4-Dioxane	Trace
11	$PdCl_2(PPh_3)_2$	—	Cs_2CO_3	1,4-Dioxane	Trace
12	$PdCl_2(PPh_3)_2$	—	NaOMe	1,4-Dioxane	Trace
13	$PdCl_2(PPh_3)_2$	—	*t*-BuONa	Toluene	51
14	$PdCl_2(PPh_3)_2$	—	*t*-BuONa	DMF	Trace
15	$PdCl_2(PPh_3)_2$	—	*t*-BuONa	DMSO	Trace
16	$PdCl_2(PPh_3)_2$	—	*t*-BuONa	NMP	nr

[a] Reaction conditions: 2-(2-phenylethynyl)benzenamine **1a** (1.0 equiv), 2-alkynylvinyl bromide **2a** (1.2 equiv), palladium catalyst (5 mol %), ligand (10 mol %), base (2.0 equiv), 100 °C.
[b] Isolated yield based on 2-(2-phenylethynyl)benzenamine **1a**.

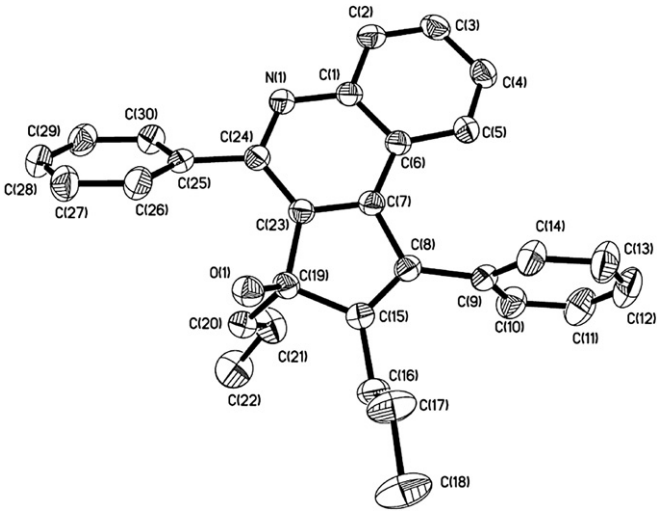
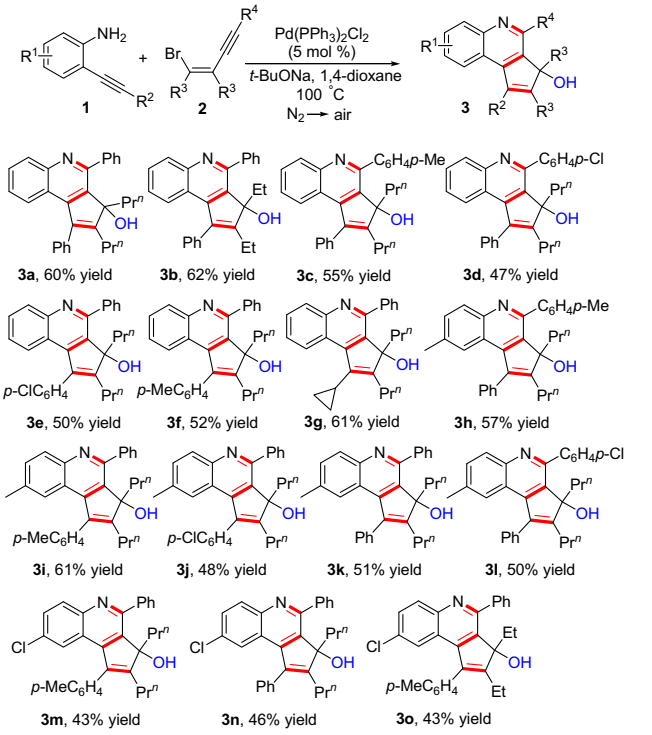


Fig. 1. X-ray ORTEP illustration of cyclopenta[*c*]quinolin-3-ol **3a** (30% probability ellipsoids).

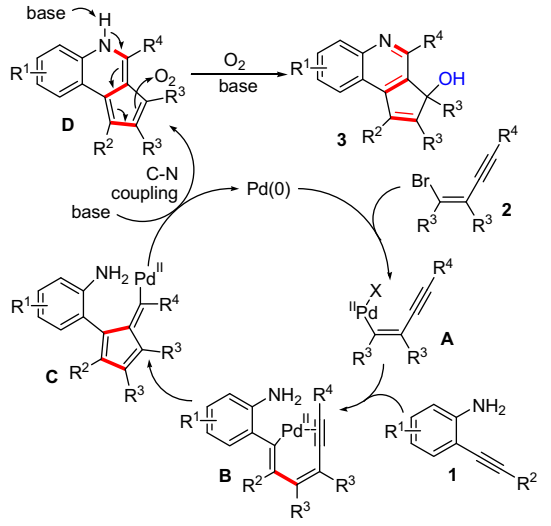
3. Conclusions

In conclusion, we have described a novel and efficient pathway for the preparation of cyclopenta[*c*]quinolin-3-ols via a palladium-catalyzed tandem reaction of 2-alkynylaniline with 2-alkynylvinyl bromide. The complexity could be easily introduced with the formation of three bonds in a one-pot procedure. During the reaction process, the double insertion of triple bonds was highly selective, and the competitive pathway for the formation of indole was minimized. Currently, application of the strategy of double

Table 2
Synthesis of cyclopenta[*c*]quinolin-3-ols **3** via a palladium-catalyzed reaction of 2-alkynylaniline **1** with 2-alkynylvinyl bromide **2**[a]



[a] Isolated yield based on 2-alkynylaniline **1**.



Scheme 2. A proposed mechanism for the generation of cyclopenta[*c*]quinolin-3-ol **3**.

insertion of triple bonds for the generation of other *N*-heterocycles is ongoing in our laboratory.

4. Experimental section

4.1. General methods

Unless otherwise stated, all commercial reagents were used as received. All solvents were dried and distilled according to standard procedures. Flash column chromatography was performed using silica gel (60-Å pore size, 32–63 μm, standard grade). Analytical thin-layer chromatography was performed using glass plates pre-coated with 0.25 mm 230–400 mesh silica gel impregnated with a fluorescent indicator (254 nm). Thin-layer chromatography plates were visualized by exposure to ultraviolet light. Organic solutions were concentrated on rotary evaporators at ~20 Torr at 25–35 °C. Nuclear magnetic resonance (NMR) spectra are recorded in parts per million from internal tetramethylsilane on the δ scale. ^{1}H and ^{13}C NMR spectra were recorded in $CDCl_3$ on a Bruker DRX-400 spectrometer operating at 400 MHz and 100 MHz, respectively. All chemical shift values are quoted in parts per million and coupling constants quoted in hertz. High-resolution mass spectrometry (HRMS) spectra were obtained on a microTOF II Instrument.

4.2. General procedure for the palladium-catalyzed tandem reaction of 2-alkynylaniline with 2-alkynylvinyl bromide

2-Alkynylvinyl bromide **2** (0.2 mmol) was added to a mixture of $PdCl_2(PPh_3)_2$ (5 mol %), *t*-BuONa (0.6 mmol), and 2-alkynylaniline (0.2 mmol) in 1,4-dioxane (2.0 mL) under nitrogen atmosphere. The mixture was heated at 100 °C. After consumption of the starting material as indicated by TLC, the reaction mixture was stirred in air. After 1 h, the reaction was quenched by water (10 mL). The mixture was extracted with ethyl acetate (10 mL×3), and the combined organic layers were washed with brine (15 mL), dried over Na_2SO_4. The solvent was evaporated under reduced pressure and the residue was purified by column chromatography on silica gel (eluted with PE/EA=5:1) to provide the compound **3**.

4.2.1. 1,4-Diphenyl-2,3-dipropyl-3H-cyclopenta[c]quinolin-3-ol ***3a***. ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.61 (t, *J*=6.9 Hz, 3H), 0.83 (t, *J*=6.9 Hz, 3H), 1.40–1.49 (m, 2H), 1.52–1.62 (m, 2H), 1.77–1.74 (m, 2H), 1.87 (br, 1H), 2.06–2.15 (m, 2H), 2.17–2.22 (m, 2H), 7.09–7.15 (m, 1H), 7.19 (d, *J*=8.0 Hz, 1H), 7.22–7.30 (m, 1H), 7.36–7.55 (m, 8H), 7.72 (d, *J*=6.4 Hz, 2H), 8.10 (d, *J*=8.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 13.8, 14.8, 16.4, 21.7, 27.9, 36.8, 86.1, 122.5, 124.5, 125.4, 127.9, 128.1, 128.7, 129.0, 129.2, 136.3, 136.6, 139.3, 140.3, 148.6, 149.0, 154.7, 155.3; HRMS calcd for $C_{30}H_{30}NO^+$ $[M+H]^+$: 420.2322, found: 420.2309. IR: 3322.1, 3044.8, 2958.8, 2930.7, 2870.9, 1560.9, 1490.9, 1442.6, 1417.0 cm^{-1}.

4.2.2. 2,3-Diethyl-1,4-diphenyl-3H-cyclopenta[c]quinolin-3-ol ***3b***. ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.36 (t, *J*=7.3 Hz, 3H), 1.03 (t, *J*=7.3 Hz, 3H), 1.66–1.71 (m, 1H), 1.79–1.86 (m, 1H), 2.16 (q, *J*=7.3 Hz, 2H), 2.18 (q, *J*=7.3 Hz, 2H), 7.12 (d, *J*=7.8 Hz, 1H), 7.21 (d, *J*=7.8 Hz, 1H), 7.29–7.30 (m, 1H), 7.41–7.56 (m, 8H), 7.75 (d, *J*=7.8 Hz, 2H), 8.11 (d, *J*=8.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 7.49, 13.1, 18.5, 27.3, 87.0, 124.2, 127.9, 128.1, 128.4, 128.7, 128.8, 129.0, 129.1, 129.2, 129.3, 129.8, 135.6, 136.5, 139.3, 140.2, 149.0, 155.3, 155.6; HRMS calcd for $C_{28}H_{26}NO^+$ $[M+H]^+$: 392.2009, found: 392.2001. IR: 3356.8, 3047.5, 2966.8, 2933.2, 2873.5, 1554.0, 1491.2, 1442.8, 1375.2 cm^{-1}.

4.2.3. 1-Phenyl-2,3-dipropyl-4-p-tolyl-3H-cyclopenta[c]quinolin-3-ol ***3c***. ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.62 (t, *J*=6.9 Hz, 3H), 0.82 (t, *J*=6.9 Hz, 3H), 1.40–1.46 (m, 1H), 1.51–1.59 (m, 1H), 1.62–1.67 (m, 1H), 1.71–1.77 (m, 1H), 2.03 (br, 1H), 2.04–2.14 (m, 2H), 2.15–2.22 (m, 2H), 2.44 (s, 3H), 7.09–7.13 (m, 1H), 7.19 (d, *J*=8.2 Hz, 1H), 7.29 (d, *J*=8.2 Hz, 2H), 7.41 (d, *J*=6.8 Hz, 1H), 7.48–7.55 (m, 4H), 7.60 (d, *J*=8.0 Hz, 2H), 8.09 (d, *J*=8.0 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 13.8, 14.8, 16.5, 21.3, 21.7, 27.9, 36.8, 86.2, 122.4, 124.2, 125.2, 127.9, 128.7, 128.8, 128.9, 129.2, 129.9, 136.4, 136.6, 137.4, 138.1, 139.2, 148.5, 149.0, 154.6, 155.4; HRMS calcd for $C_{31}H_{32}NO^+$ $[M+H]^+$: 434.2478, found: 434.2471. IR: 3390.6, 3057.2, 2959.2, 2928.4, 1674.8, 1602.3, 1544.3, 1510.5, 1485.5 cm^{-1}.

4.2.4. 4-(4-Chlorophenyl)-1-phenyl-2,3-dipropyl-3H-cyclopenta[c] quinolin-3-ol ***3d***. ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.60 (t, *J*=7.2 Hz, 3H),

0.83 (t, J=7.3 Hz, 3H), 1.40–1.44 (m, 1H), 1.50–1.57 (m, 1H), 1.62–1.69 (m, 1H), 1.74–1.78 (m, 1H), 1.99 (s, 1H), 2.11–2.15 (m, 1H), 2.19–2.27 (m, 1H), 7.13–7.15 (m, 1H), 7.19 (d, J=8.0 Hz, 1H), 7.26 (d, J=8 Hz, 1H), 7.40 (d, J=8.0 Hz, 1H), 7.45–7.55 (m, 7H), 7.76 (d, J=8.4 Hz, 2H), 8.07 (d, J=8.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 14.0, 14.9, 16.5, 21.9, 28.0, 36.3, 86.3, 122.6, 124.3, 125.0, 125.7, 128.1, 128.3, 128.5, 128.9, 129.3, 129.9, 130.7, 131.0, 134.7, 136.3, 136.5, 138.8, 139.4, 149.1, 149.2, 154.3, 155.0; HRMS calcd for $C_{30}H_{29}ClNO^+$ $[M+H]^+$: 454.1932, found: 454.1930. IR: 3445.8, 3050.8, 2955.7, 1612.8, 1496.1, 1455.8 cm^{-1}.

4.2.5. 1-(4-Chlorophenyl)-4-phenyl-2,3-dipropyl-3H-cyclopenta[c]quinolin-3-ol ***3e***. ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.60 (t, J=7.2 Hz, 3H), 0.81 (t, J=7.2 Hz, 3H), 1.37–1.46 (m, 1H), 1.53–1.61 (m, 2H), 1.72–1.79 (m, 2H), 1.94 (s, 1H), 2.06–2.13 (m, 1H), 2.16–2.22 (m, 1H), 7.18–7.24 (m, 3H), 7.38 (d, J=8.0 Hz, 1H), 7.43–7.52 (m, 5H), 7.57 (t, J=6.8 Hz, 1H), 7.70 (d, J=6.8 Hz, 2H), 8.10 (d, J=8.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 13.7, 14.8, 16.3, 21.6, 28.1, 36.4, 86.0, 124.2, 126.2, 128.1, 129.1, 129.3, 130.6, 130.7, 134.2, 134.6, 136.8, 137.7, 139.2, 139.7, 149.9, 150.6, 153.8, 154.6; HRMS calcd for $C_{30}H_{29}ClNO^+$ $[M+H]^+$: 454.1932, found: 454.1930. IR: 3352.9, 3049.9, 2929.9, 2849.6, 1668.5, 1489.0 cm^{-1}.

4.2.6. 4-Phenyl-2,3-dipropyl-1-p-tolyl-3H-cyclopenta[c]quinolin-3-ol ***3f***. ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.59–0.60 (m, 3H), 0.83 (t, J=6.4 Hz, 3H), 1.40–1.43 (m, 1H), 1.55–1.68 (m, 2H), 1.72–1.76 (m, 1H), 1.97 (s, 1H), 2.04–2.11 (m, 1H), 2.18–2.25 (m, 1H), 2.49 (s, 3H), 7.15 (d, J=6.8 Hz, 2H), 7.26–7.31 (m, 3H), 7.48–7.55 (m, 4H), 7.72 (d, J=6.0 Hz, 2H), 8.10 (d, J=8.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 13.9, 14.9, 16.6, 21.5, 21.9, 28.0, 36.9, 86.2, 122.7, 124.4, 125.4, 128.2, 128.5, 129.1, 129.2, 129.5, 129.6, 130.0, 133.6, 136.4, 137.7, 139.5, 140.5, 148.9, 149.1, 149.2, 154.8, 155.4; HRMS calcd for $C_{31}H_{32}NO^+$ $[M+H]^+$: 434.2478, found: 434.2473. IR: 3352.0, 3057.2, 2958.5, 2929.3, 2870.6, 1547.1, 1491.0, 1370.3 cm^{-1}.

4.2.7. 1-Cyclopropyl-4-phenyl-2,3-dipropyl-3H-cyclopenta[c]quinolin-3-ol ***3g***. ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.52 (t, J=6.9 Hz, 3H), 1.03 (t, J=7.2 Hz, 3H), 1.14–1.17 (m, 2H), 1.39–1.41 (m, 2H), 1.59–1.65 (m, 2H), 1.72–1.77 (m, 2H), 1.94–2.02 (m, 2H), 2.24–2.32 (m, 2H), 2.39–2.42 (m, 1H), 2.46–2.52 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 8.7, 9.2, 10.3, 13.8, 14.9, 16.4, 22.1, 27.9, 36.4, 85.7, 125.1, 128.1, 128.3, 129.0, 130.0, 137.9, 140.4, 149.0, 149.9, 155.1, 155.5; HRMS calcd for $C_{27}H_{30}NO^+$ $[M+H]^+$: 384.2322, found: 384.2316. IR: 3368.2, 3059.4, 2958.5, 2929.5, 2870.4, 1560.8, 1491.0, 1453.8 cm^{-1}.

4.2.8. 8-Methyl-1-phenyl-2,3-dipropyl-4-p-tolyl-3H-cyclopenta[c]quinolin-3-ol ***3h***. ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.61 (t, J=7.2 Hz, 3H), 0.83 (t, J=7.2 Hz, 3H), 1.39–14.5 (m, 1H), 1.59–1.66 (m, 1H), 1.72–1.78 (m, 1H), 1.98 (s, 1H), 2.15 (s, 3H), 2.19–2.23 (m, 1H), 2.43 (s, 3H), 6.87 (s, 1H), 7.29 (d, J=7.6 Hz, 2H), 7.37 (d, J=8.4 Hz, 1H), 7.41 (d, J=6.8 Hz, 1H), 7.48–7.49 (m, 3H), 7.59 (d, J=7.6 Hz, 2H), 7.97 (d, J=8.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 13.9, 14.8, 16.5, 21.3, 21.7, 27.9, 36.9, 86.2, 122.3, 123.2, 127.8, 128.6, 128.8, 128.9, 129.3, 129.4, 129.5, 131.1, 134.8, 136.3, 136.8, 137.5, 138.0, 139.4, 147.6, 147.8, 154.0, 154.6; HRMS calcd for $C_{32}H_{34}NO^+$ $[M+H]^+$: 448.2635, found: 448.2624. IR: 3386.9, 2958.2, 2921.8, 2870.4, 1554.0, 1496.0, 1442.8 cm^{-1}.

4.2.9. 8-Methyl-4-phenyl-2,3-dipropyl-1-p-tolyl-3H-cyclopenta[c]quinolin-3-ol ***3i***. ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.59 (t, J=7.2 Hz, 3H), 0.83 (t, J=7.2 Hz, 3H), 1.38–1.44 (m, 1H), 1.54–1.60 (m, 2H), 1.71–1.76 (m, 1H), 1.99 (s, 1H), 2.06–2.13 (m, 1H), 2.17 (s, 3H), 2.20–2.26 (m, 1H), 2.48 (s, 3H), 6.96 (s, 1H), 7.15 (d, J=8.0 Hz, 1H), 7.28–7.31 (m, 3H), 7.38 (d, J=8.8 Hz, 1H), 7.44–7.49 (m, 3H), 7.71 (d, J=7.2 Hz, 2H), 7.98 (d, J=8.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 13.8, 14.8, 16.4, 21.3, 21.8, 27.9, 36.8, 86.1, 122.4, 123.3, 128.0, 128.2, 129.1, 129.2, 129.5, 131.2, 133.6, 134.8, 136.2, 137.4, 139.4, 140.4, 147.6, 148.0, 154.0, 154.5; HRMS calcd for $C_{32}H_{34}NO^+$ $[M+H]^+$: 448.2635, found: 448.2621. IR: 3407.0, 2958.6, 1910.9, 1708.6, 1633.0, 1552.2, 1444.3 cm^{-1}.

4.2.10. 1-(4-Chlorophenyl)-8-methyl-4-phenyl-2,3-dipropyl-3H-cyclopenta[c]quinolin-3-ol ***3j***. ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.60 (t, J=6.8 Hz, 3H), 0.84 (t, J=7.3 Hz, 3H), 1.37–1.47 (m, 2H), 1.52–1.60 (m, 2H), 1.72–1.78 (m, 2H), 1.96 (s, 1H), 2.04–2.14 (m, 1H), 2.22 (s, 3H), 6.94 (s, 1H), 7.23–7.25 (m, 1H), 7.37–7.42 (m, 3H), 7.48–7.53 (m, 5H), 7.69 (d, J=7.2 Hz, 2H), 7.99 (d, J=8.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 13.8, 14.8, 16.5, 21.8, 21.9, 27.9, 36.9, 86.2, 122.2, 122.9, 128.1, 128.4, 128.9, 129.0, 129.7, 130.7, 131.4, 133.9, 135.3, 136.2, 138.1, 140.3, 147.3, 147.6, 154.5, 154.9; HRMS calcd for $C_{31}H_{31}ClNO^+$ $[M+H]^+$: 468.2089, found: 448.2079. IR: 3398.5, 3058.7, 2958.6, 2927.3, 2870.7, 1550.4, 1489.6 cm^{-1}.

4.2.11. 8-Methyl-1,4-diphenyl-2,3-dipropyl-3H-cyclopenta[c]quinolin-3-ol ***3k***. ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.60 (t, J=6.8 Hz, 3H), 0.83 (t, J=7.3 Hz, 4H), 1.39–1.47 (m, 1H), 1.54–1.60 (m, 2H), 1.72–1.78 (m, 1H), 1.99 (s, 1H), 2.07–2.12 (m, 1H), 2.15 (s, 3H), 2.19–2.25 (m, 1H), 6.89 (s, 1H), 7.26–7.27 (m, 1H), 7.37–7.49 (m, 8H), 7.70 (d, J=6.4 Hz, 2H), 7.98 (d, J=8.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 13.8, 14.8, 16.5, 21.7, 27.9, 36.8, 86.2, 122.4, 123.2, 127.8, 128.1, 128.3, 128.6, 129.1, 129.3, 129.5, 131.2, 134.9, 136.2, 136.7, 139.4, 140.4, 147.6, 147.9, 154.1, 154.3; HRMS calcd for $C_{31}H_{32}NO^+$ $[M+H]^+$: 434.2478, found: 434.2471. IR: 3356.1, 3057.0, 2958.8, 2930.1, 2871.0, 1552.3, 1492.3, 1442.8, 1377.5 cm^{-1}.

4.2.12. 4-(4-Chlorophenyl)-8-methyl-1-phenyl-2,3-dipropyl-3H-cyclopenta[c]quinolin-3-ol ***3l***. ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.59 (t, J=7.2 Hz, 3H), 0.83 (t, J=7.6 Hz, 3H), 1.39–1.44 (m, 2H), 1.51–1.56 (m, 1H), 1.60–1.67 (m, 1H), 1.72–1.80 (m, 1H), 2.07–2.11 (m, 1H), 2.15 (s, 3H), 2.19–2.24 (m, 2H), 6.87 (s, 1H), 7.25–7.26 (m, 2H), 7.36–7.39 (m, 1H), 7.43 (d, J=8.4 Hz, 1H), 7.46–7.50 (m, 3H), 7.74 (d, J=8.0 Hz, 2H), 7.96 (d, J=8.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 14.0, 14.9, 16.5, 21.9, 22.0, 28.0, 36.3, 86.3, 122.5, 123.3, 128.0, 128.1, 128.2, 128.8, 129.4, 130.7, 131.0, 131.6, 134.6, 135.3, 136.3, 136.7, 139.5, 147.7, 148.4, 153.3, 154.5; HRMS calcd for $C_{31}H_{31}ClNO^+$ $[M+H]^+$: 468.2089, found: 468.2080. IR: 3342.7, 2959.1, 2929.8, 2870.7, 1591.4, 1551.2, 1490.9, 1441.7 cm^{-1}.

4.2.13. 1-(4-Chlorophenyl)-8-methyl-4-phenyl-2,3-dipropyl-3H-cyclopenta[c]quinolin-3-ol ***3m***. ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.60 (t, J=6.4 Hz, 3H), 0.83 (t, J=6.8 Hz, 3H), 1.38–1.48 (m, 2H), 1.54–1.60 (m, 2H), 1.72–1.78 (m, 1H), 1.95 (br, 1H), 2.06–2.14 (m, 1H), 2.19–2.26 (m, 1H), 2.49 (s, 3H), 7.12–7.16 (m, 2H), 7.28–7.36 (m, 3H), 7.46–7.48 (m, 4H), 7.71 (d, J=6.4 Hz, 2H), 8.00 (d, J=8.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 13.9, 14.9, 16.5, 21.5, 21.8, 28.0, 36.9, 86.2, 123.4, 128.3, 128.7, 129.1, 129.6, 129.7, 130.0, 131.1, 131.4, 132.8, 137.2, 138.1139.1, 140.1, 147.5, 148.3, 155.0, 155.6; HRMS calcd for $C_{31}H_{31}ClNO^+$ $[M+H]^+$: 468.2089, found: 468.2082. IR: 3376.2, 3057.2, 2959.3, 2930.5, 2871.1, 1616.8, 1560.9, 1493.7, 1418.9 cm^{-1}.

4.2.14. 8-Chloro-1,4-diphenyl-2,3-dipropyl-3H-cyclopenta[c]quinolin-3-ol ***3n***. ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.60 (t, J=6.8 Hz, 3H), 0.84 (t, J=7.3 Hz, 3H), 1.42–1.47 (m, 1H), 1.56–1.62 (m, 2H), 1.74–1.80 (m, 1H), 1.97 (br, 1H), 2.04–2.15 (m, 1H), 2.21–2.25 (m, 1H), 7.09–7.10 (m, 1H), 7.26–7.30 (m, 2H), 7.41–7.53 (m, 7H), 7.71–7.72 (m, 2H), 8.02 (d, J=8.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 13.9, 14.9, 16.6, 21.8, 28.0, 36.9, 86.3, 120.2, 123.1, 128.3, 128.7, 129.0, 129.1, 129.2, 130.0, 131.2, 131.5, 133.2, 135.9, 139.1, 140.0, 147.8, 148.1, 155.1, 155.6; HRMS calcd for $C_{30}H_{29}ClNO^+$ $[M+H]^+$: 454.1932, found: 454.1930. IR: 3361.7, 3052.3, 2959.3, 2930.5, 2817.2, 1543.9, 1485.6, 1464.6, 1377.3 cm^{-1}.

4.2.15. 8-Chloro-2,3-diethyl-4-phenyl-1-p-tolyl-3H-cyclopenta[c]quinolin-3-ol ***3o***. ^{1}H NMR (400 MHz, $CDCl_3$): δ 0.35 (t, J=7.3 Hz, 3H),

1.06 (t, J=7.3 Hz, 3H), 1.67–1.70 (m, 2H), 1.82–1.87 (m, 1H), 2.01 (s, 1H), 2.15–2.21 (m, 1H), 2.29–2.34 (m, 1H), 2.50 (s, 3H), 7.16–7.19 (m, 2H), 7.30–7.38 (m, 3H), 7.48–7.50 (m, 4H), 7.75 (d, J=7.3 Hz, 2H), 8.02 (d, J=8.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 7.48, 13.2, 18.5, 21.4, 27.4, 87.0, 123.0, 123.3, 128.2, 128.5, 129.0, 129.6, 129.7, 129.9, 131.0, 131.3, 132.7, 136.5, 138.0, 139.0, 140.0, 147.4, 148.4, 155.4, 155.8; HRMS calcd for $C_{29}H_{27}ClNO^+$ $[M+H]^+$: 440.1776, found: 440.1765. IR: 3371.2, 2967.5, 2932.8, 2875.0, 1542.7, 1484.9, 1457.3, 1379.2 cm^{-1}.

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Supplementary data

Supplementary data associated with this article can be found in the online version, at http://dx.doi.org/10.1016/j.tet.2012.08.093. These data include MOL files and InChiKeys of the most important compounds described in this article.

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