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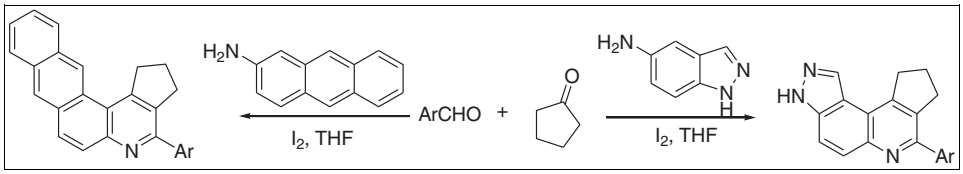
Received November 11, 2011
DOI 10.1002/jhet.1670
Published online 22 November 2013 in Wiley Online Library (wileyonlinelibrary.com).



A mild and efficient method for the synthesis of cyclopenta[*c*]naphtho[2,3-*f*]quinoline and cyclopenta[*c*]pyrazolo[4,3-*f*]quinoline derivatives via an imino Diels–Alder reaction of aromatic aldehyde, anthracen-2-amine, or 1*H*-indazol-5-amine and cyclopentanone catalyzed by iodine is described. This novel procedure has the advantages of mild reaction condition, high yields, and metal-free catalyst.

J. Heterocyclic., **51**, 830 (2014).

INTRODUCTION

Quinoline and its derivatives are privileged heterocyclic scaffold because of their variety of medicinal properties, such as antimicrobial [1], antiproliferative [2], antioxidant [3], and antifungal activity [4], so the synthesis of quinolines has been extensively researched in recent years [5]. Povarov and coworkers [6] have explored an important methodology that provided a convenient access to synthesis of quinoline derivatives from an imino Diels–Alder reaction, which uses Schiff base and electron-rich dienophile as reactants. This reaction is also named as Povarov reaction and is usually catalyzed by various Lewis acids, which is well documented as a review by Kouznetsov in 2009 [7].

This methodology has been improved greatly by Wang and coworkers in 2006 and catalyzed by iodine [8], using aliphatic aldehyde as starting material. Iodine is a novel metal-free Lewis acid, which is used to catalyze various types of organic reactions in recent years [9]. In our previous work, using aromatic aldehyde and 2-naphthylamine as starting materials to produce Schiff base, the dienophiles were expanded to various ketones, such as aliphatic, aromatic, and cyclicketone; they all gave the satisfied results. In connection with our continued research on this iodine-catalyzed Povarov reaction [10], in this article, we would like to report an efficient synthesis of cyclopenta[*c*]naphtho[2,3-*f*]quinoline and cyclopenta[*c*]pyrazolo[4,3-*f*]quinoline derivatives catalyzed by iodine. This novel polycyclic ring skeleton containing both naphthalene or pyrazole and quinoline rings may possess potential bioactive for screening.

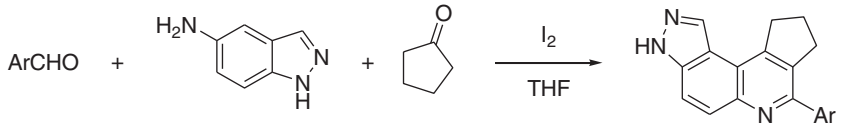
RESULTS AND DISCUSSION

Treatment of aromatic aldehyde **1**, 1*H*-indazol-5-amine **2**, and cyclopentanone **3** in THF in the presence of 5 mol % iodine at reflux condition afforded the corresponding 7-aryl-3,8,9,10-tetrahydrocyclopenta[*c*]pyrazolo[4,3-*f*]quinoline derivatives **4** in high yields (Scheme 1).

In our initial study, the amount of catalyst (I_2) was identified firstly; therefore, the model reaction was conducted using 4-chlorobenzaldehyde (**1a**), 1*H*-indazol-5-amine, and cyclopentanone in the presence of various catalytic amount of iodine. The screening results of the reaction were summarized in Table 1. The 1, 5, and 10 mol% iodine were used to mediate the reaction; 5 mol% I_2 at reflux in THF is sufficient to initiate the reaction (Table 1, entries 4–6). To find the optimum reaction temperature, the reaction was carried out with 5 mol% of I_2 at room temperature, 50°C, and reflux temperature, resulting in the isolation of **4a** in trace amount, 78%, and 86% yields (Table 1, entries 2, 3, and 5), respectively. In addition, CH_3CN, benzene, DMF, and $CHCl_3$ (Table 1, entries 7–10) were also tested as the solvents. In these cases, product **4a** was formed in slightly lower yields.

According to the optimized conditions, various aromatic aldehydes **1** were then subjected to react with **2** and **3** to generate a library of cyclopenta[*c*]pyrazolo [4,3-*f*]quinoline derivatives **4a–l** (Table 2). For aldehyde **1**, the yields of **4** were not sensitive to the electronic properties of the aromatic ring in the presence of electron-withdrawing groups (such as halide) or electron-donating groups (such as alkyl or alkoxy group, Table 2).

Scheme 1. The reaction of **1**, **3**, and 1*H*-indazol-5-amine.



1 **2** **3** **4**

Table 1

Yield optimization for **4a** under different conditions.[a]

Entry	Temp. (°C)	I_2 (mol %)	Solvent	Yields (%)[b]
1	Reflux	0	THF	0
2	RT	5	THF	trace
3	50	5	THF	78
4	Reflux	1	THF	82
5	Reflux	5	THF	86
6	Reflux	10	THF	86
7	Reflux	5	CH_3CN	82
8	Reflux	5	Benzene	80
9	80	5	DMF	78
10	Reflux	5	$CHCl_3$	82

[a]Reagents and conditions: 4-chlorobenzaldehyde **1a** (0.281 g, 2.0 mmol), **2** (0.266 g, 2.0 mmol), **3** (0.168 g, 2.0 mmol), solvent (10 mL).
[b]Isolated yields.

This optimized condition was also suitable for anthracen-2-amine **5**, which was selected as a reactant to react with aromatic aldehyde **1** and cyclopentanone **3** (Scheme 2). The desired reactions carried out smoothly and gave cyclopenta[*c*]naphtha[2,3-*f*]quinoline derivatives **6a–l** in high yields (Table 3). The structures of the products **4** and **6** were characterized by ^{1}H NMR, IR, and HRMS; their data are all in good agreement with their structures.

EXPERIMENTAL

Melting points were determined in open capillaries and are uncorrected. IR spectra were recorded on a Tensor 27 spectrometer (Bruker Corporation: Karlsruhe, DE.) in KBr pellet. ^{1}H NMR spectra were obtained from a solution in DMSO-d_6 or $CDCl_3$ with Me_4Si as internal standard using a Bruker-400 spectrometer (Bruker Corporation: Karlsruhe, DE.). HRMS analyses were

Table 2

Synthetic results of **4a–l** catalyzed by iodine in THF.[a]

Entry	Ar	Products	Time (h)	Yields (%)[b]
1	4-ClC_6H_4	**4a**	10	86
2	4-MeC_6H_4	**4b**	14	84
3	4-FC_6H_4	**4c**	8	90
4	4-$MeOC_6H_4$	**4d**	14	82
5	3,4-$Cl_2C_6H_3$	**4e**	8	92
6	2-BrC_6H_4	**4f**	10	86
7	3-$MeOC_6H_4$	**4g**	10	88
8	3-BrC_6H_4	**4h**	12	90
9	Piperonyl	**4i**	14	90
10	3,5-$(MeO)_2C_6H_3$	**4j**	10	82
11	3-ClC_6H_4	**4k**	12	86
12	2-FC_6H_4	**4l**	8	91

[a]Reagents and conditions: **1** (2.0 mmol), **2** (0.266 g, 2.0 mmol), **3** (0.168 g, 2.0 mmol), I_2 (0.1 mmol, 0.026 g), THF (10 mL).
[b]Isolated yields.

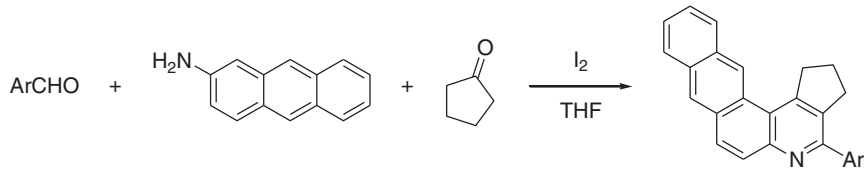
Table 3

Synthetic results of **6a–l** catalyzed by iodine in THF.[a]

Entry	Ar	Products	Time (h)	Yields (%)[b]
1	4-MeC_6H_4	**6a**	18	83
2	4-FC_6H_4	**6b**	12	86
3	3-ClC_6H_4	**6c**	14	80
4	2-ClC_6H_4	**6d**	12	88
5	3,4-$Cl_2C_6H_3$	**6e**	12	90
6	3,4-$(MeO)_2C_6H_3$	**6f**	18	78
7	4-BrC_6H_4	**6g**	16	82
8	3-$MeOC_6H_4$	**6h**	14	86
9	2-BrC_6H_4	**6i**	14	90
10	4-$MeOC_6H_4$	**6j**	16	81
11	3-BrC_6H_4	**6k**	16	79
12	2,3-$Cl_2C_6H_3$	**6l**	12	86

[a]Reagents and conditions: **1** (1.0 mmol), **5** (0.193 g, 1.0 mmol), **3** (0.084 g, 1.0 mmol), I_2 (0.05 mmol, 0.013 g), THF (10 mL).
[b]Isolated yields.

Scheme 2. The reaction of **1**, **3**, and anthracen-2-amine.



1 **5** **3** **6**

carried out using a Bruker-micro-TOF-Q-MS analyzer (Bruker Corporation: Karlsruhe, DE.).

General procedure for the syntheses of cyclopenta[*c*]pyrazolo[4,3-f]quinoline derivatives 4a–l. A dry 50 mL flask was charged with aromatic aldehyde (2.0 mmol), 1*H*-indazol-5-amine (0.266 g, 2.0 mmol), cyclopentanone (0.168 g, 2.0 mmol), I_2 (0.026 g, 0.1 mmol), and THF (10 mL). The reaction mixture was stirred at reflux for 8–14 h. After completion of the reaction as indicated by TLC, a little DMF was added to the mixture until all the yellow solid was dissolved. The generated powder was collected by filtration to give **4** when the mixture was cooled to room temperature.

7-(4-Chlorophenyl)-3,8,9,10-tetrahydrocyclopenta[c]pyrazolo[4,3-f]quinoline 4a. m.p. 283–285°C; ^{1}H NMR (DMSO-d_6, 400 MHz): δ_H 2.26–2.30 (m, 2H, CH_2), 3.26–3.31 (m, 2H, CH_2), 3.49–3.52 (m, 2H, CH_2), 7.59 (d, J = 8.4 Hz, 2H, ArH), 7.88 (d, J = 9.2 Hz, 1H, ArH), 7.94 (d, J = 8.4 Hz, 3H, ArH), 8.48 (s, 1H, ArH), 13.63 (s, 1H, NH). IR (KBr): *v* 3192, 3053, 2949, 2918, 1589, 1563, 1536, 1492, 1436, 1401, 1376, 1349, 1303, 1292, 1092, 1016, 959, 850, 818, 786, 736 cm^{-1}. HRMS (ESI, *m/z*): Calcd for $C_{19}H_{15}ClN_3$ $[M+H]^+$ 320.0955, found 320.0956.

7-(p-Tolyl)-3,8,9,10-tetrahydrocyclopenta[c]pyrazolo[4,3-f]quinoline 4b. m.p. 287–289°C; ^{1}H NMR (DMSO-d_6, 400 MHz): δ_H 2.24–2.28 (m, 2H, CH_2), 2.39 (s, 3H, CH_3), 3.26 (t, J = 7.2 Hz, 2H, CH_2), 3.47–3.51 (m, 2H, CH_2), 7.33 (d, J = 7.6 Hz, 2H, ArH), 7.74–7.81 (m, 2H, ArH), 7.86 (d, J = 8.8 Hz, 1H, ArH), 7.91–7.96 (m, 1H, ArH), 8.47 (s, 1H, ArH), 13.62 (s, 1H, NH). IR (KBr): *v* 3186, 3135, 3095, 3035, 2981, 2921, 2867, 1666, 1610, 1561, 1536, 1510, 1432, 1408, 1379, 1346, 1313, 1181, 1161, 1091, 953, 905, 822, 787, 738 cm^{-1}. HRMS (ESI, *m/z*): Calcd for $C_{20}H_{17}N_3Na$ $[M+Na]^+$ 300.1501, found 300.1533.

***7-(4-Fluorophenyl)-3,8,9,10-tetrahydrocyclopenta[c]*pyrazolo[4,3-*f*]quinoline 4c**. m.p. 258–259°C; ^{1}H NMR (DMSO-d_6, 400 MHz): δ_H 2.24–2.34 (m, 2H, CH_2), 3.25–3.29 (m, 2H, CH_2), 3.48–3.52 (m, 2H, CH_2), 7.33–7.38 (m, 2H, ArH), 7.87 (d, J = 8.8 Hz, 1H, ArH), 7.92–7.97 (m, 3H, ArH), 8.48 (s, 1H, ArH), 13.64 (s, 1H, NH). IR (KBr): *v* 3193, 3146, 3111, 2934, 1669, 1602, 1567, 1537, 1509, 1434, 1411, 1385, 1346, 1218, 1157, 1093, 956, 842, 740 cm^{-1}. HRMS (ESI, *m/z*): Calcd for $C_{19}H_{15}FN_3$ $[M+H]^+$ 304.1250, found 304.1291.

7-(4-Methoxyphenyl)-3,8,9,10-tetrahydrocyclopenta[c]pyrazolo[4,3-f]quinoline 4d. m.p. 279–281°C; ^{1}H NMR (DMSO-d_6, 400 MHz): δ_H 2.25–2.29 (m, 2H, CH_2), 3.27 (t, J = 7.2 Hz, 2H, CH_2), 3.47–3.51 (m, 2H, CH_2), 3.84 (s, 3H, CH_3O), 7.08 (d, J = 8.8 Hz, 2H, ArH), 7.84–7.93 (m, 4H, ArH), 8.46 (s, 1H, ArH), 13.60 (s, 1H, NH). IR (KBr): *v* 3178, 3093, 2980, 2915, 1605, 1560, 1536, 1509, 1461, 1418, 1380, 1347, 1307, 1255, 1174, 1095, 1032, 950, 838, 819, 784, 746 cm^{-1}. HRMS (ESI, *m/z*): Calcd for $C_{20}H_{18}N_3O$ $[M+H]^+$ 316.1450, found 316.1491.

7-(3,4-Dichlorophenyl)-3,8,9,10-tetrahydrocyclopenta[c]pyrazolo[4,3-f]quinoline 4e. m.p. >300°C; ^{1}H NMR (DMSO-d_6, 400 MHz): δ_H 2.25–2.29 (m, 2H, CH_2), 3.26–3.30 (m, 2H, CH_2), 3.47 (s, 2H, CH_2), 7.78 (d, J = 8.4 Hz, 1H, ArH), 7.88–7.96 (m, 3H, ArH), 8.13 (d, J = 1.6 Hz, 1H, ArH), 8.47 (s, 1H, ArH), 13.67 (s, 1H, NH). IR (KBr): *v* 3186, 2968, 2911, 2848, 1588, 1536, 1471, 1438, 1397, 1350, 1294, 1133, 1097, 1032, 965, 931, 846, 818, 749, 728 cm^{-1}. HRMS (ESI, *m/z*): Calcd for $C_{19}H_{14}Cl_2N_3$ $[M+H]^+$ 354.0565, found 354.0555.

7-(2-Bromophenyl)-3,8,9,10-tetrahydrocyclopenta[c]pyrazolo[4,3-f]quinoline 4f. m.p. 246–248°C; ^{1}H NMR (DMSO-d_6, 400 MHz): δ_H 2.25–2.31 (m, 2H, CH_2), 2.89 (s, 2H, CH_2), 3.53 (d, J = 7.2 Hz, 2H, CH_2), 7.41–7.48 (m, 2H, ArH), 7.53 (t, J = 7.2 Hz, 1H, ArH), 7.78 (d, J = 8.0 Hz, 1H, ArH), 7.90 (s, 2H, ArH), 8.50 (s, 1H, ArH), 13.67 (s, 1H, NH). IR (KBr): *v* 3210, 3160, 3125, 3052, 2906, 2849, 1665, 1573, 1540, 1476, 1461, 1431, 1385, 1349, 1307, 1290, 1176, 1162, 1099, 1044, 1018, 957, 910, 849, 820, 788, 756, 735 cm^{-1}. HRMS (ESI, *m/z*): Calcd for $C_{19}H_{15}BrN_3$ $[M+H]^+$ 364.0449, found 364.0416.

7-(3-Methoxyphenyl)-3,8,9,10-tetrahydrocyclopenta[c]pyrazolo[4,3-f]quinoline 4g. m.p. 221–223°C; ^{1}H NMR (DMSO-d_6, 400 MHz): δ_H 2.24–2.31 (m, 2H, CH_2), 3.28 (t, J = 7.2 Hz, 2H, CH_2), 3.49–3.52 (m, 2H, CH_2), 3.85 (s, 3H, CH_3O), 7.04–7.05 (m, 1H, ArH), 7.45 (d, J = 6.8 Hz, 3H, ArH), 7.88 (d, J = 9.2 Hz, 1H, ArH), 7.94 (d, J = 10.4 Hz, 1H, ArH), 8.48 (s, 1H, ArH), 13.64 (s, 1H, NH). IR (KBr): *v* 3186, 3136, 3097, 3040, 2938, 1600, 1564, 1538, 1484, 1449, 1430, 1380, 1344, 1333, 1268, 1232, 1177, 1153, 1026, 956, 927, 856, 834, 788, 765, 734, 702 cm^{-1}. HRMS (ESI, *m/z*): Calcd for $C_{20}H_{18}N_3O$ $[M+H]^+$ 316.1450, found 316.1444.

7-(3-Bromophenyl)-3,8,9,10-tetrahydrocyclopenta[c]pyrazolo[4,3-f]quinoline 4h. m.p. 282–284°C; ^{1}H NMR (DMSO-d_6, 400 MHz): δ_H 2.34–2.40 (m, 2H, CH_2), 3.28 (t, J = 7.6 Hz, 4H, $2CH_2$), 3.63–3.67 (m, 1H, NH), 7.61–7.64 (m, 1H, ArH), 7.86 (d, J = 8.0 Hz, 1H, ArH), 7.93 (d, J = 8.0 Hz, 1H, ArH), 8.06 (d, J = 9.2 Hz, 1H, ArH), 8.15 (s, 1H, ArH), 8.19 (d, J = 9.2 Hz, 1H, ArH), 8.70 (s, 1H, ArH). IR (KBr): *v* 3177, 3036, 3013, 2983, 2836, 1625, 1581, 1547, 1456, 1419, 1375, 1352, 1340, 1294, 1275, 1181, 1075, 956, 919, 875, 853, 792, 716, 704 cm^{-1}. HRMS (ESI, *m/z*): Calcd for $C_{19}H_{15}BrN_3$ $[M+H]^+$ 364.0449, found 364.0443.

7-Piperonyl-3,8,9,10-tetrahydrocyclopenta[c]pyrazolo[4,3-f]quinoline 4i. m.p. 259–261°C; ^{1}H NMR (DMSO-d_6, 400 MHz): δ_H 2.25–2.30 (m, 2H, CH_2), 3.27 (t, J = 7.2 Hz, 2H, CH_2), 3.49 (t, J = 7.6 Hz, 2H, CH_2), 6.11 (s, 2H, CH_2), 7.06 (d, J = 8.0 Hz, 1H, ArH), 7.40 (d, J = 8.4 Hz, 1H, ArH), 7.47 (s, 1H, ArH), 7.86 (d, J = 9.2 Hz, 1H, ArH), 7.91 (d, J = 9.2 Hz, 1H, ArH), 8.46 (s, 1H, ArH), 13.63 (s, 1H, NH). IR (KBr): *v* 3176, 3129, 3090, 3037, 2983, 2907, 2862, 2813, 1584, 1561, 1532, 1504, 1493, 1445, 1390, 1331, 1261, 1239, 1176, 1143, 1107, 1038, 956, 929, 863, 822, 785, 739 cm^{-1}. HRMS (ESI, *m/z*): Calcd for $C_{20}H_{16}N_3O_2$ $[M+H]^+$ 330.1243, found 330.1218.

7-(3,5-Dimethoxyphenyl)-3,8,9,10-tetrahydrocyclopenta[c]pyrazolo[4,3-f]quinoline 4j. m.p. 270–272°C; ^{1}H NMR (DMSO-d_6, 400 MHz): δ_H 2.27 (t, J = 7.2 Hz, 2H, CH_2), 3.26–3.29 (m, 2H, CH_2), 3.48–3.51 (m, 2H, CH_2), 3.83 (s, 6H, $2CH_3O$), 6.60 (s, 1H, ArH), 7.01 (s, 2H, ArH), 7.87 (d, J = 9.2 Hz, 1H, ArH), 7.94 (d, J = 10.0 Hz, 1H, ArH), 8.47 (s, 1H, ArH), 13.64 (s, 1H, NH). IR (KBr): *v* 3196, 3144, 3102, 2995, 2933, 2844, 1673, 1591, 1538, 1457, 1427, 1380, 1361, 1327, 1284, 1205, 1157, 1095, 1066, 1051, 978, 940, 830, 791, 739, 706 cm^{-1}. HRMS (ESI, *m/z*): Calcd for $C_{21}H_{20}N_3O_2$ $[M+H]^+$ 346.1556, found 346.1544.

7-(3-Chlorophenyl)-3,8,9,10-tetrahydrocyclopenta[c]pyrazolo[4,3-f]quinoline 4k. m.p. 200–201°C; ^{1}H NMR (DMSO-d_6, 400 MHz): δ_H 2.25–2.29 (m, 2H, CH_2), 3.27 (t, J = 7.2 Hz, 2H, CH_2), 3.48 (s, 2H, CH_2), 7.52–7.58 (m, 2H, ArH), 7.84–7.93 (m, 4H, ArH), 8.48 (s, 1H, ArH), 13.67 (s, 1H, NH). IR (KBr): *v* 3346, 3193, 3146, 3105, 2966, 2940, 2843, 1597, 1562, 1538, 1431, 1379, 1346, 1333, 1262, 1090, 961, 927, 879, 854, 816, 788, 779, 737, 720 cm^{-1}. HRMS (ESI, *m/z*): Calcd for $C_{19}H_{15}ClN_3$ $[M+H]^+$ 320.0955, found 320.0947.

7-(2-Fluorophenyl)-3,8,9,10-tetrahydrocyclopenta[c]pyrazolo[4,3-f]quinoline 4l. m.p. 133–134°C; ^{1}H NMR (DMSO-d_6, 400 MHz): δ_H 2.27 (t, J = 7.2 Hz, 2H, CH_2), 2.98–3.02 (m, 2H, CH_2), 3.52 (s, 2H, CH_2), 7.37 (t, J = 8.4 Hz, 2H, ArH), 7.54

(d, $J = 5.6$ Hz, 1H, ArH), 7.61 (t, $J = 7.2$ Hz, 1H, ArH), 7.90 (s, 2H, ArH), 8.50 (s, 1H, ArH), 13.66 (s, 1H, NH). IR (KBr): *v* 3194, 3147, 3106, 2926, 1665, 1616, 1571, 1555, 1538, 1493, 1450, 1379, 1348, 1297, 1271, 1254, 1217, 1191, 1105, 1084, 957, 914, 856, 819, 769 cm^{-1}. HRMS (ESI, *m/z*): Calcd for $C_{19}H_{15}FN_3$ $[M + H]^+$ 304.1250, found 304.1256.

General procedure for the syntheses of cyclopenta[*c*] naphtho[2,3-*f*]quinoline derivatives 6a–l. A dry 50 mL flask was charged with aromatic aldehyde (1.0 mmol), anthracen-2-amine (0.193 g, 1.0 mmol), cyclopentanone (0.084 g, 1.0 mmol), I_2 (0.013 g, 0.05 mmol), and THF (10 mL). The reaction mixture was stirred at reflux for 12–18 h. After completion of the reaction as indicated by TLC, a little DMF was added to the mixture until all the yellow solid was dissolved. The generated powder was collected by filtration to give **6** when the mixture was cooled to room temperature.

4-(p-Tolyl)-2,3-dihydro-1H-cyclopenta[c]naphtho[2,3-f] quinoline 6a. m.p: 274–276°C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ_H 2.29–2.36 (m, 2H, CH_2), 2.45 (s, 3H, CH_3), 3.30–3.34 (m, 2H, CH_2), 3.91–3.95 (m, 2H, CH_2), 7.34 (d, $J = 8.0$ Hz, 2H, ArH), 7.57–7.61 (m, 2H, ArH), 7.83 (d, $J = 8.0$ Hz, 2H, ArH), 7.97 (d, $J = 2.4$ Hz, 2H, ArH), 8.06–8.09 (m, 1H, ArH), 8.12–8.15 (m, 1H, ArH), 8.41 (s, 1H, ArH), 9.17 (s, 1H, ArH). IR (KBr): *v* 2977, 2933, 2913, 2844, 1551, 1482, 1433, 1384, 1346, 1320, 1262, 1182, 1016, 889, 833, 818, 750, 639 cm^{-1}. HRMS (ESI, *m/z*): Calcd for $C_{27}H_{21}NNa$ $[M + Na]^+$ 382.1572, found 382.1580.

4-(4-Fluorophenyl)-2,3-dihydro-1H-cyclopenta[c]naphtho [2,3-f]quinoline 6b. m.p: 237–238°C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ_H 2.29–2.36 (m, 2H, CH_2), 3.26–3.30 (s, 2H, CH_2), 3.89–3.93 (m, 2H, CH_2), 7.19–7.24 (m, 2H, ArH), 7.58–7.60 (m, 2H, ArH), 7.90–8.00 (m, 4H, ArH), 8.06–8.08 (m, 1H, ArH), 8.11–8.14 (m, 1H, ArH), 8.41 (s, 1H, ArH), 9.14 (s, 1H, ArH). IR (KBr): *v* 3049, 2954, 2916, 1600, 1553, 1506, 1481, 1432, 1421, 1385, 1344, 1320, 1297, 1263, 1222, 1155, 1098, 1011, 889, 847, 818, 747, 635, 611 cm^{-1}. HRMS (ESI, *m/z*): Calcd for $C_{26}H_{18}FNNa$ $[M + Na]^+$ 386.1321, found 386.1324.

4-(3-Chlorophenyl)-2,3-dihydro-1H-cyclopenta[c]naphtho [2,3-f]quinoline 6c. m.p: 194–195°C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ_H 2.29–2.37 (m, 2H, CH_2), 3.27–3.31 (s, 2H, CH_2), 3.89–3.92 (m, 2H, CH_2), 7.42–7.48 (m, 2H, ArH), 7.58–7.61 (m, 2H, ArH), 7.78 (d, $J = 7.2$ Hz, 1H, ArH), 7.92–8.00 (m, 3H, ArH), 8.06–8.08 (m, 1H, ArH), 8.11–8.13 (m, 1H, ArH), 8.40 (s, 1H, ArH), 9.14 (s, 1H, ArH). IR (KBr): *v* 3045, 2956, 1593, 1540, 1473, 1438, 1418, 1387, 1366, 1331, 1321, 1299, 1266, 1257, 1232, 1163, 1079, 996, 956, 903, 884, 819, 803, 789, 744, 732 cm^{-1}. HRMS (ESI, *m/z*): Calcd for $C_{26}H_{19}ClN$ $[M + H]^+$ 380.1206, found 380.1195.

4-(2-Chlorophenyl)-2,3-dihydro-1H-cyclopenta[c]naphtho [2,3-f]quinoline 6d. m.p: 216–217°C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ_H 2.35 (t, $J = 7.6$ Hz, 2H, CH_2), 3.04 (s, 2H, CH_2), 3.96 (t, $J = 7.2$ Hz, 2H, CH_2), 7.40–7.44 (m, 2H, ArH), 7.52 (d, $J = 6.4$ Hz, 2H, ArH), 7.59–7.62 (m, 2H, ArH), 7.98 (dd, $J = 9.2$ Hz, $J' = 2.4$ Hz, 2H, ArH), 8.07–8.10 (m, 1H, ArH), 8.14–8.16 (m, 1H, ArH), 8.43 (s, 1H, ArH), 9.20 (s, 1H, ArH). IR (KBr): *v* 3049, 2966, 2847, 1619, 1556, 1475, 1433, 1376, 1323, 1299, 1280, 1253, 1173, 1142, 952, 937, 892, 877, 820, 744 cm^{-1}. HRMS (ESI, *m/z*): Calcd for $C_{26}H_{19}ClN$ $[M + H]^+$ 380.1206, found 380.1204.

4-(3,4-Dichlorophenyl)-2,3-dihydro-1H-cyclopenta[c]naphtho [2,3-f]quinoline 6e. m.p: 233–235°C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ_H 2.30–2.37 (m, 2H, CH_2), 3.26–3.29 (m, 2H, CH_2), 3.89 (t, $J = 7.2$ Hz, 2H, CH_2), 7.58–7.61 (m, 3H, ArH), 7.76 (d, $J = 8.0$ Hz, 1H, ArH), 7.91 (d, $J = 9.2$ Hz, 1H, ArH), 7.99 (d, $J = 9.2$ Hz, 1H, ArH), 8.07–8.13 (m, 3H, ArH), 8.40 (s, 1H, ArH), 9.12 (s, 1H, ArH). IR (KBr): *v* 3047, 2960, 2931, 2892, 2843, 1546, 1469, 1436, 1421, 1381, 1357, 1302, 1281, 1265, 1246, 1130, 1059, 1028, 934, 895, 877, 824, 751 cm^{-1}. HRMS (ESI, *m/z*): Calcd for $C_{26}H_{18}Cl_2N$ $[M + H]^+$ 414.0816, found 414.0801.

4-(3,4-Dimethoxyphenyl)-2,3-dihydro-1H-cyclopenta[c] naphtho[2,3-f]quinoline 6f. m.p: 213–214°C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ_H 2.29–2.36 (m, 2H, CH_2), 3.33 (t, $J = 7.2$ Hz, 2H, CH_2), 3.91 (t, $J = 7.2$ Hz, 2H, CH_2), 3.97 (s, 3H, CH_3O), 4.03 (s, 3H, CH_3O), 7.01 (d, $J = 8.4$ Hz, 1H, ArH), 7.46 (dd, $J = 7.6$ Hz, $J' = 1.6$ Hz, 1H, ArH), 7.57–7.60 (m, 3H, ArH), 7.98 (s, 2H, ArH), 8.06–8.14 (m, 2H, ArH), 8.41 (s, 1H, ArH), 9.14 (s, 1H, ArH). IR (KBr): *v* 3086, 3044, 2991, 2951, 2930, 2867, 2833, 1599, 1586, 1551, 1512, 1481, 1461, 1415, 1389, 1330, 1287, 1231, 1178, 1140, 1114, 1026, 956, 888, 829, 807, 757 cm^{-1}. HRMS (ESI, *m/z*): Calcd for $C_{28}H_{33}NO_2Na$ $[M + Na]^+$ 428.1626, found 428.1683.

4-(4-Bromophenyl)-2,3-dihydro-1H-cyclopenta[c]naphtho [2,3-f]quinoline 6g. m.p: 268–269°C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ_H 2.35 (t, $J = 7.2$ Hz, 2H, CH_2), 3.30 (t, $J = 7.6$ Hz, 2H, CH_2), 3.92–3.96 (m, 2H, CH_2), 7.59–7.62 (m, 2H, ArH), 7.66 (d, $J = 8.4$ Hz, 2H, ArH), 7.82 (d, $J = 8.0$ Hz, 2H, ArH), 7.96–8.02 (m, 2H, ArH), 8.07–8.10 (m, 1H, ArH), 8.13–8.15 (m, 1H, ArH), 8.42 (s, 1H, ArH), 9.17 (s, 1H, ArH). IR (KBr): *v* 2944, 2916, 2878, 1583, 1549, 1478, 1432, 1420, 1384, 1319, 1260, 1070, 1008, 959, 890, 837, 822, 752 cm^{-1}. HRMS (ESI, *m/z*): Calcd for $C_{26}H_{19}BrN$ $[M + H]^+$ 424.0701, found 424.0682.

4-(3-Methoxyphenyl)-2,3-dihydro-1H-cyclopenta[c]naphtho [2,3-f]quinoline 6h. m.p: 150–152°C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ_H 2.30–2.33 (m, 2H, CH_2), 3.29–3.33 (m, 2H, CH_2), 3.90 (d, $J = 7.2$ Hz, 2H, CH_2), 3.92 (s, 3H, CH_3O), 7.01 (d, $J = 8.0$ Hz, 1H, ArH), 7.42–7.49 (m, 3H, ArH), 7.58–7.60 (m, 2H, ArH), 7.97 (s, 2H, ArH), 8.05–8.08 (m, 1H, ArH), 8.11–8.13 (m, 1H, ArH), 8.40 (s, 1H, ArH), 9.14 (s, 1H, ArH). IR (KBr): *v* 3051, 2949, 2834, 1580, 1554, 1539, 1486, 1462, 1436, 1420, 1388, 1365, 1320, 1265, 1234, 1147, 1091, 1043, 994, 953, 884, 820, 791, 743, 693 cm^{-1}. HRMS (ESI, *m/z*): Calcd for $C_{27}H_{22}NO$ $[M + H]^+$ 376.1701, found 376.1721.

4-(2-Bromophenyl)-2,3-dihydro-1H-cyclopenta[c]naphtho [2,3-f]quinoline 6i. m.p: 206–208°C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ_H 2.32–2.39 (m, 2H, CH_2), 2.88–3.02 (m, 2H, CH_2), 3.94–3.98 (m, 2H, CH_2), 7.30–7.34 (m, 1H, ArH), 7.46–7.50 (m, 2H, ArH), 7.59–7.62 (m, 2H, ArH), 7.71 (d, $J = 8.4$ Hz, 1H, ArH), 7.94–8.02 (m, 2H, ArH), 8.07–8.10 (m, 1H, ArH), 8.14–8.16 (m, 1H, ArH), 8.43 (s, 1H, ArH), 9.20 (s, 1H, ArH). IR (KBr): *v* 3051, 2964, 2846, 1619, 1596, 1557, 1473, 1424, 1375, 1323, 1300, 1172, 1142, 1069, 1027, 952, 893, 877, 820, 744 cm^{-1}. HRMS (ESI, *m/z*): Calcd for $C_{26}H_{19}BrN$ $[M + H]^+$ 424.0701, found 424.0705.

4-(4-Methoxyphenyl)-2,3-dihydro-1H-cyclopenta[c]naphtho [2,3-f]quinoline 6j. m.p: 235–236°C; ^{1}H NMR ($CDCl_3$, 400 MHz): δ_H 2.30–2.34 (m, 2H, CH_2), 3.29–3.33 (m, 2H, CH_2), 3.90–3.93 (m, 5H, $CH_2 + CH_3O$), 7.06 (d, $J = 8.4$ Hz, 2H, ArH), 7.57–7.59 (m, 2H, ArH), 7.90 (d, $J = 8.8$ Hz, 2H, ArH), 7.96 (d, $J = 4.0$ Hz, 2H, ArH), 8.06–8.08 (m, 1H, ArH), 8.11–8.14 (m, 1H, ArH), 8.40 (s, 1H, ArH), 9.15 (s, 1H, ArH). IR (KBr): *v* 3054, 3007, 2956, 2926, 2836, 1605, 1549, 1509, 1480, 1437, 1417, 1388, 1370, 1320, 1307, 1250, 1174, 1111,

1032, 886, 832, 742 cm^{-1}. HRMS (ESI, *m/z*): Calcd for $C_{27}H_{22}NO$ $[M+H]^+$ 376.1701, found 376.1694.

4-(3-Bromophenyl)-2,3-dihydro-1H-cyclopenta[c]naphtho[2,3-f]quinoline 6k. m.p: 198–200°C; ^1H NMR ($CDCl_3$, 400 MHz): δ_H 2.29–2.36 (m, 2H, CH_2), 3.27–3.30 (m, 2H, CH_2), 3.88–3.91 (m, 2H, CH_2), 7.37–7.41 (m, 1H, ArH), 7.57–7.60 (m, 3H, ArH), 7.83 (d, $J = 7.6$ Hz, 1H, ArH), 7.96 (dd, $J = 9.2$ Hz, $J' = 1.6$ Hz, 2H, ArH), 8.05–8.08 (m, 1H, ArH), 8.10–8.13 (m, 2H, ArH), 8.40 (s, 1H, ArH), 9.13 (s, 1H, ArH). IR (KBr): *v* 3046, 2942, 1590, 1552, 1539, 1471, 1438, 1419, 1387, 1365, 1345, 1332, 1321, 1296, 1267, 1258, 1164, 1070, 995, 955, 884, 820, 789, 738, 707 cm^{-1}. HRMS (ESI, *m/z*): Calcd for $C_{26}H_{19}BrN$ $[M+H]^+$ 424.0701, found 424.0696.

4-(2,3-Dichlorophenyl)-2,3-dihydro-1H-cyclopenta[C]naphtho[2,3-f]quinoline 6l. m.p: 263–264°C; ^1H NMR ($CDCl_3$, 400 MHz): δ_H 2.35 (t, $J = 7.2$ Hz, 2H, CH_2), 2.88–3.00 (m, 2H, CH_2), 3.93–3.97 (m, 2H, CH_2), 7.36 (t, $J = 7.6$ Hz, 1H, ArH), 7.42 (d, $J = 7.6$ Hz, 1H, ArH), 7.57 (d, $J = 7.6$ Hz, 1H, ArH), 7.59–7.62 (m, 3H, ArH), 7.92 (d, $J = 9.2$ Hz, 1H, ArH), 8.00 (d, $J = 9.2$ Hz, 1H, ArH), 8.07–8.09 (m, 1H, ArH), 8.42 (s, 1H, ArH), 9.19 (s, 1H, ArH). IR (KBr): *v* 3044, 2950, 2845, 1621, 1556, 1485, 1457, 1409, 1377, 1330, 1324, 1258, 1212, 1173, 1158, 1145, 1063, 1042, 879, 779, 741, 701 cm^{-1}. HRMS (ESI, *m/z*): Calcd for $C_{26}H_{18}Cl_2N$ $[M+H]^+$ 414.0816, found 414.0821.

CONCLUSION

In conclusion, we found a mild and efficient method for the synthesis of cyclopenta[*c*]naphtho[2,3-*f*]quinoline and cyclopenta[*c*]pyrazolo[4,3-*f*]quinoline derivatives via three-component reactions of aromatic aldehyde, anthracen-2-amine or 1*H*-indazol-5-amine, and cyclopentanone catalyzed by iodine. The features of this procedure are mild reaction conditions, high yields, operational simplicity, and metal-free catalyst.

Acknowledgments. We are grateful to the National Natural Science foundation of China (20802061), the Priority Academic Program Development of Jiangsu Higher Education Institutions, Qing Lan Project (08QLT001, 10QLD008) and Graduate Foundation (CXLX12_0984) of Jiangsu Education Committee for financial support.

REFERENCES AND NOTES

[1] (a) Eswaran, S.; Adhikari, A. V.; Shetty, N. S. Eur J Med Chem 2009, 44, 4637; (b) Bhatt, H. G.; Agrawal, Y. K. Med Chem Res 2010, 19, 392.

[2] Mor, M.; Bordi, F.; Carmi, C.; Vezzosi, S.; Lodola, A.; Petronini, P. G.; Alfieri, R.; Cavazzoni, A. Preparation of quinazoline and quinoline compounds as irreversible EGFR inhibitors with antiproliferative activity. PCT Int Appl WO 2010076764 A1 8 Jul 2010; Chem Abstr 2010, 153, 145526.

[3] Kuzmin, V. A.; Mazaletskaya, L. I.; Nekipelova, T. D.; Khodot, E. N. Russ Chem Bull 2008, 57, 2405.

[4] Manivel, P.; Roopan, S. M.; Kumar, R. S.; Khan, F. N. J Chilean Chem Soc 2009, 54, 183.

[5] (a) Michel, B. W.; Steffens, L. D.; Sigman, M. S. J Am Chem Soc 2011, 133, 8317; (b) Shi, D. Q.; Niu, L. H.; Yao, H.; Jiang, H. J Heterocycl Chem 2009, 46, 237; (c) Li, M.; Hou, Y. L.; Wen, L. R.; Gong, F. M. J Org Chem 2010, 75, 8522; (d) Wang, X. S.; Li, Q.; Zhou, J.; Tu, S. J. J Heterocycl Chem 2009, 46, 1222; (e) Luo, Y.; Pan, X. L.; Wu, J. Org Lett 2011, 13, 1150; (f) Chen, Y.; Tu, S. J.; Jiang, B.; Shi, F. J Heterocycl Chem 2007, 44, 1201.

[6] Povarov, L. S. Russ Chem Rev 1967, 36, 656.

[7] Kouznetsov, V. V. Tetrahedron 2009, 65, 2721.

[8] Lin, X. F.; Cui, S. L.; Wang, Y. G. Tetrahedron Lett 2006, 47, 3127.

[9] (a) Shen, S. S.; Xu, X. P.; Ji, S. J. Chinese J Org Chem 2009, 29, 806; (b) Wang, H. S.; Miao, J. Y.; Zhao, L. F. Chinese J Org Chem 2005, 25, 615; (c) Zhang, Z. H.; Liu Q. B. Prog Chem 2006, 18, 271.

[10] (a) Wang, X. S.; Li, Q.; Wu, J. R.; Tu, S. J. J Comb Chem 2009, 11, 433; (b) Wang, X. S.; Li, Q.; Yao, C. S.; Tu, S. J. Eur J Org Chem 2008, 3513.