Novel Synthesis of 1,2-Substituted 4-Quinolones

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Abstract An efficient method for the straightforward synthesis of N-functionalized 4-quinolones and 1,2-substituted 4-quinolones from simple 2-aminoacetophenones has been developed.

Key words 2-aminoacetophenone, 4-quinolone, echinopsine

Nitrogen-containing heterocycles are frequently found in a variety of biologically active molecules that can be used in therapeutic areas. Specifically, 4-quinolone derivatives have attracted considerable attention because of their diverse biological activities. Several quinolone compounds, such as oxolinic acid, Ciprofloxacin, Pefloxacin, and Ofloxacin, have emerged as potent antibiotics (Figure 1).

More recently, 4-quinolone derivatives have been explored for their antibacterial, antitumor, antimalarial, antidiabetic, antiviral and HIV-1 integrase inhibition properties. Given the importance of these heterocycles in medical chemistry, the development of synthetic methodology to access 4-quinolone derivatives remains an imperative. To date, numerous methods have been reported for the synthesis of quinolones. The most frequently used approaches are based on various cyclocondensation strategies, such as the Camps, Conrad–Limpach, Gould–Jacobs, and Niementowski cyclizations. Often these synthetic methods are carried out under extremely harsh conditions, including temperatures up to 250 °C or the use of strong acids such as polyphosphoric acid or Eaton’s reagent. As a result, the harsh conditions dramatically limit the substrate scope of these transformations. To develop milder processes for construction of the 4-quinolone framework, much effort has been focused on the development of transition-metal-catalyzed (Pd, Cu, and Au) cyclization methodologies during the past decade. Despite significant progress, transition-metal-catalyzed synthetic methods often require specially designed ligands. Another disadvantage is the need to remove metal-related impurities from products, which is an important issue in the synthesis of pharmaceutical molecules.

Some quinolones have been found to be active as mammalian topoisomerase-II inhibitors, including a series of 3-unsubstituted compounds. 1-Methyl-1,4-dihydroquinolin-4-one, echinopsine, is a nontoxic alkaloid from Echinops species that regulates the function of the parasympathetic autonomous nervous system.

Several 1-alkyl-3-unsubstituted derivatives have been prepared by decarboxylation of the corresponding 3-carboxylic acids. This method usually requires high temperatures and the reported yields are generally low to medium. Some 1-aryl-3-unsubstituted 1,4-dihydroquinolin-4-ones have also been prepared by this method but the yields are also generally low. Thermal rearrangement of 4-methoxy- and 4-ethoxyquinoline derivatives can be used for the synthesis of the corresponding 1-methyl- and 1-ethyl-1,4-dihydroquin-
olino-4-ones, respectively.\textsuperscript{21} This method usually requires high temperatures (300–350 °C) and the yields are again usually low. Lower temperatures and higher yields were reported when the rearrangement was carried out in the presence of the appropriate iodoalkane,\textsuperscript{22} alkyl tosylate,\textsuperscript{23} or trialkyl phosphate.\textsuperscript{23} 1-Alkyl-3-unsubstituted 1,4-dihydroquinolin-4-ones having a primary alkyl group at the 1-position can also be prepared by N-alkylation of the corre-
sponding 1-unsubstituted 1,4-dihydroquinolin-4-ones.

It is known that amino-substituted acetophenones are valuable precursors for the synthesis of medicinally important substances such as 2-arylquinolin-4(1H)-ones and their analogues.\textsuperscript{24,25} In recent years, interest in these compounds has prompted extensive studies into their properties, such as toxicity to human tumor cell lines and tubulin polymerization inhibition.\textsuperscript{4a,26} The method most widely used to prepare 2-aryl-2,3-dihydroquinolin-4(1H)-ones includes a two-step sequence consisting of base-catalyzed aldol condensation of 2-aminoacetophenones and aldehydes and then acid-catalyzed cyclization of the corresponding 2-aminochalcones thus formed via an intramolecular aza-Mi-
chael reaction.\textsuperscript{25–27} Other groups have also investigated the synthesis of 4-quinolones from 2-aminoacetophenones,\textsuperscript{28} 2-bromoacetophenones,\textsuperscript{28} halophenones,\textsuperscript{15a} and 2-iodo-
anilines,\textsuperscript{29} as well as the reactions of isatoic anhydrides with aryl ketones\textsuperscript{25b} or alkynes\textsuperscript{28b} using transition-metal catalysts. Tambe and co-workers used copper-mediated N-
cyclopropylation on substituted fused or unfused pyridinol systems to generate N-cyclopropyl quinolones in moderate yields (Equation 1).\textsuperscript{31}

Shao et al.\textsuperscript{9h} prepared N-cyclopropyl quinolones from trimethylsilyl substituted substrates and cyclopropyl amine in good yields (Equation 4).

However, especially for structure–activity studies, the need for new methods for the preparation of the 3-unsub-
stituted compounds remains. This is particularly true for 1-
sec-alkyl, 1-tert-alkyl, and 1-aryl-1,4-dihydroquinolin-4-
one.

At the outset, when we attempted the reaction of 1-(2-
cyclopropylaminophenyl)ethanone\textsuperscript{33} with dimethylforma-
mide dimethylacetal (DMFDMA) as both reactant and sol-
vent, the desired product was not observed (Table 1). However, product was formed in 90% yield when para-
toluenesulfonic acid (PTSA, 0.1 mol) in ortho-
-xylene was employed (entry 10). The yields were not improved by us-

ing other acids such as methanesulfonic acid, benzenesul-
fonic acid, camphor sulfonic acid, conc. HCl or sulfuric acid (entries 11–15). A survey of reaction media showed that the use of polar solvents such as DMSO, DMF, and DMA provid-
ed better results than those obtained in either toluene or 1,4-dioxane (entries 16–21).

A series of experiments were then carried out to reveal the crucial role of the reaction temperature (Table 1, entries 4–9). The results showed that increasing reaction tempera-
ture led to higher yields (90% at 130 °C vs. 25% at 100 °C; entries 10 and 5). Investigation of the effect of time on the reaction showed that higher yields can be obtained by pro-
longing the reaction time from 8 to 24 hours (entries 8–10). Thus, optimal conditions used 1a and DMFDMA in the pres-
ence of PTSA in ortho-xylene at 130 °C (entry 10).

With the optimized reaction conditions established, we then studied the scope of the cyclization of DMFDMA with a series of other aminoacetophenones, as shown in Scheme 1. First, we examined the effect of substitution with electron-donating groups and electron-withdrawing groups (EWGS) on the phenyl ring. Both were well tolerated and gave the corresponding quinolones in good to excellent yields (60–90%). All ortho-, meta- and para-substituted
Aminoacetoephones were smoothly transformed into the desired products, which indicates that steric bulk and electronic effects did not significantly alter the reactivity.

To explore substrate scope still further, we next examined variations in the nitrogen substituent R2. When R2 was cyclic (cyclopentyl, cyclohexyl), all substrates examined were smoothly converted into the corresponding quinolones 2h–k (Scheme 2). The method was successfully utilized in the synthesis of echinopsine 2l. Changing R2 to an aryl group led to quinolones 2m–u in good yields. Substrates possessing N-aryl substituents containing either electron-donating or electron-withdrawing groups also reacted efficiently.

We also evaluated the possibility of synthesizing 1,2-disubstituted 4-quinolones 4a directly from 2-aminoacetoephone 1a and benzoyl chloride, using TEA as the catalyst and THF as the solvent. Subsequently, the intermediate was cyclized with DMF and K2CO3 and the desired product 4a was formed in 87% yield (Scheme 3).

Quinolones 4 were useful synthetic precursors; for example, the corresponding 3-functionalized quinolones can be readily generated by using well-documented amination34, cyanation35, Heck5a,36, Sonogashira37, and Suzuki–Miyaura14e,38 reactions from 3-halogenated quinolones prepared by direct halogenation of products 4.14e,38b

In summary, we have developed an efficient method for the straightforward synthesis of N-functionalized 4-quinolones and 1,2-substituted 4-quinolones from 2-aminoacetoephones. By using this method, N-alkyl and N-aryl aminoacetoephones can be successfully transformed into the corresponding 4-quinolones. This approach provides one of the simplest methods for the synthesis of this class of compounds, and a wide range of multisubstituted 4-quinolones can be generated accordingly.

**Preparation of 1-Cyclopropyl-1H-quinolin-4-one (2a); Typical Procedure**

A mixture of 1-(2-cyclopropylamino-phenyl)ethane 1 (1.0 gm, 5.71 mmol), dimethylformamide dimethylacetal (2.0 mL), and PTSA (100 mg, 0.571 mmol) in o-xylene (30 mL) was heated to reflux for 24 h. After completion of reaction (monitored by TLC), the reaction mixture was allowed to cool and then diluted with o-xylene (10 mL). Water (20 mL) was added and the organic phase was separated. The aqueous layer was then extracted further with o-xylene (10 mL) and the combined organic extracts were washed with brine, dried over sodium sulfate, filtered and concentrated under reduced pressure to give 2a.

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**Table 1 Optimization of One-Pot Tandem Reaction Conditions of 2a**

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<th>Entry</th>
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<th>Catalyst</th>
<th>Temp (°C)</th>
<th>Time (h)</th>
<th>Yield (%)</th>
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<td>80</td>
<td>24</td>
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<tr>
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Yield: 950 mg (90%); yellow solid; mp 79.8–81.4 °C.

IR (KBr): 3488, 1610, 1620, 1565, 1485, 1299, 762 cm⁻¹.

1H NMR (400 MHz, CDCl₃): δ = 1.03–1.12 (q, 2 H), 1.23–1.30 (q, 2 H), 3.36–3.42 (m, 1 H), 6.23 (d, J = 7.92 Hz, 1 H), 7.37–7.41 (m, 1 H), 7.66–7.70 (m, 2 H), 7.91 (d, J = 8.6 Hz, 1 H), 8.42 (dd, J₁ = 0.84, J₂ = 0.88 Hz, 1 H).

13C NMR (100 MHz, CDCl₃): δ = 8.19, 33.61, 109.89, 116.91, 123.75, 126.67, 131.96, 141.51, 142.51, 178.33.

Anal. Calcd for C₁₂H₁₁NO: C, 77.81; H, 5.99; N, 7.56; Found: C, 77.80; H, 5.97; N, 7.53.

6-Chloro-1-cyclopropyl-1H-quinolin-4-one (2c)

Yield: 445 mg (85%); white solid; mp 168.4–174.1 °C.

IR (KBr): 3075, 3012, 1630, 1582, 1473, 1287, 1144, 823 cm⁻¹.

1H NMR (300 MHz, CDCl₃): δ = 1.03–1.09 (q, 2 H), 1.26–1.33 (q, 2 H), 3.35–3.42 (m, 1 H), 6.24 (d, J = 7.8 Hz, 1 H), 7.60 (dd, J₁ = 2.4, J₂ = 2.4 Hz, 1 H), 7.67 (d, J = 7.8 Hz, 1 H), 7.85 (d, J = 9.0 Hz, 1 H), 8.39 (d, J = 2.4 Hz, 1 H).

13C NMR (75 MHz, CDCl₃): δ = 8.31, 33.80, 110.25, 118.10, 126.09, 128.69, 130.08, 132.27, 140.02, 142.68, 177.6.

Anal. Calcd for C₁₂H₁₀ClNO: C, 60.61; H, 4.59; N, 6.38; Found: C, 60.66; H, 4.57; N, 6.40.

1-Cyclopropyl-7-methoxy-1H-quinolin-4-one (2d)

Yield: 419 mg (80%); yellow solid; mp 78.1–82.4 °C.

IR (KBr): 3010, 1614, 1569, 1460, 1016, 827 cm⁻¹.

1H NMR (300 MHz, CDCl₃): δ = 1.05–1.09 (q, 2 H), 1.23–1.30 (q, 2 H), 3.36–3.42 (m, 1 H), 6.20 (d, J = 7.92 Hz, 1 H), 7.66 (d, J = 7.92 Hz, 1 H), 7.97 (d, J = 5.92 Hz, 1 H), 8.14 (d, J = 9.12 Hz, 1 H).

13C NMR (100 MHz, CDCl₃): δ = 8.27, 33.83, 109.72, 112.69, 118.52, 126.42, 138.23, 142.73, 153.55, 156.05, 176.76.

Anal. Calcd for C₁₃H₁₃NO₂: C, 72.54; H, 6.09; N, 6.51; Found: C, 72.55; H, 6.07; N, 6.53.

1-Cyclopropyl-6-methyl-1H-quinolin-4-one (2e)

Yield: 421 mg (80%); yellow solid; mp 96.4–100.7 °C.

IR (KBr): 3032, 3008, 1633, 1604, 1582, 1488, 1341, 1296, 1154, 835 cm⁻¹.

Scheme 2 Synthesis of N-substituted-4-quinolone derivatives

Yield: 396 mg (76%); yellow solid; mp 195.6–197.2 °C.

IR (KBr): 3100, 3027, 1633, 1610, 1589, 1477, 1259, 971, 893, 824 cm⁻¹.
1H NMR (300 MHz, CDCl3): δ = 1.05–1.07 (q, 2 H), 1.23–1.27 (q, 2 H), 2.47 (s, 3 H), 3.35–3.40 (m, 1 H), 6.21 (d, J = 7.8 Hz, 1 H), 7.49 (d, J = 7.8 Hz, 1 H), 7.65 (d, J = 7.8 Hz, 1 H), 7.80 (d, J = 8.7 Hz, 1 H), 8.23 (s, 1 H).

13C NMR (75 MHz, CDCl3): δ = 8.16, 20.95, 33.63, 109.65, 116.17, 126.11, 126.65, 133.42, 133.70, 139.65, 142.13, 178.29.


1-Cyclopentyl-1H-quinolin-4-one (2j)

Yield: 440 mg (84%); yellow solid; mp 104.6–107.8 °C.

IR (KBr): 3076, 2963, 1625, 1606, 1579, 1488, 1354, 1210, 1179, 838 cm−1.

1H NMR (300 MHz, CDCl3): δ = 1.80–1.93 (m, 6 H), 2.25–2.29 (m, 2 H), 4.94 (m, 1 H), 6.31 (d, J = 7.8 Hz, 1 H), 7.36 (d, J = 7.2 Hz, 1 H), 7.60–7.70 (m, 3 H), 8.48 (d, J = 7.8 Hz, 1 H).

13C NMR (75 MHz, CDCl3): δ = 24.05, 32.29, 60.61, 110.10, 115.43, 123.49, 127.27, 127.57, 132.01, 138.22, 140.73, 177.94.

Anal. Calcd for C31H28N2O: C, 79.84; H, 7.09; N, 6.57; Found: C, 78.85; H, 7.10; N, 6.54.

6-Chloro-1-cyclopentyl-1H-quinolin-4-one (2k)

Yield: 448 mg (86%); white solid; mp 141.7–143.2 °C.

IR (KBr): 3079, 2954, 2877, 1626, 1585, 1483, 1326, 1008, 845, 823 cm−1.

1H NMR (300 MHz, CDCl3): δ = 1.85–1.93 (m, 6 H), 2.25–2.27 (m, 2 H), 4.87–4.88 (m, 1 H), 6.29 (d, J = 8.1 Hz, 1 H), 7.54–7.61 (m, 2 H), 7.65 (d, J = 7.8 Hz, 1 H), 8.45 (d, J = 1.5 Hz, 1 H).

13C NMR (75 MHz, CDCl3): δ = 24.03, 32.28, 60.98, 110.36, 117.31, 126.56, 126.83, 129.78, 132.25, 138.36, 139.15.

Anal. Calcd for C31H28ClN2O: C, 67.88; H, 5.70; N, 6.55; Found: C, 67.86; H, 5.67; N, 6.57.

1-Methyl-1H-quinolin-4-one (2i)

Yield: 373 mg (70%); white solid; mp 144.6–148.1 °C.

IR (KBr): 3061, 3017, 1625, 1576, 1493, 1237, 759 cm−1.

1H NMR (400 MHz, CDCl3): δ = 3.81 (s, 3 H), 6.28 (d, J = 7.6 Hz, 1 H), 7.41 (t, J = 3.4 Hz, 2 H), 7.52 (d, J = 7.6 Hz, 1 H), 7.71 (t, J = 7.8 Hz, 1 H), 8.48 (d, J = 8.0 Hz, 1 H).

13C NMR (100 MHz, CDCl3): δ = 40.61, 110.15, 115.23, 123.77, 127.06, 127.13, 132.20, 140.67, 143.62, 178.32.

Anal. Calcd for C9H10ClNO: C, 75.45; H, 5.70; N, 8.80; Found: C, 75.43; H, 5.68; N, 8.81.

1-(4-Chloro-phenyl)-1H-quinolin-4-one (2h)

Yield: 884 mg (85%); yellow solid; mp 177.2–181.5 °C.

IR (KBr): 3045, 3022, 1622, 1606, 1590, 1476, 1367, 1285, 1236, 760 cm−1.

1H NMR (400 MHz, CDCl3): δ = 6.38 (d, J = 7.6 Hz, 1 H), 6.98 (d, J = 8.4 Hz, 1 H), 7.40–7.35 (m, 3 H), 7.59–7.49 (m, 4 H), 8.46 (dd, J1 = 0.8 Hz, J2 = 9.8 Hz, 1 H).

13C NMR (100 MHz, CDCl3): δ = 110.54, 116.99, 124.10, 126.60, 126.74, 129.01, 130.61, 130.04, 135.59, 139.81, 141.20, 142.41, 178.23.

Anal. Calcd for C26H16ClN2O: C, 70.46; H, 3.94; N, 5.48; Found: C, 70.47; H, 3.92; N, 5.46.

1-(4-Bromo-phenyl)-6-methyl-1H-quinolin-4-one (2n)

Yield: 454 mg (88%); white solid; mp 145.3–148.4 °C.

IR (KBr): 3021, 1630, 1610, 1583, 1483, 1289, 1201, 823 cm−1.
IR (KBr): 3030, 1584, 1486, 1286, 830, 808, 765, 695 cm⁻¹.

1H NMR (400 MHz, CDCl₃): δ = 2.45 (s, 3 H), 6.36 (d, J = 7.6 Hz, 1 H), 6.89 (d, J = 8.8 Hz, 1 H), 7.29 (d, J = 8.4 Hz, 2 H), 7.34 (dd, J₁ = 2.0 Hz, J₂ = 8.0 Hz, 1 H), 7.52 (d, J = 7.6 Hz, 1 H), 7.73 (d, J = 8.4 Hz, 2 H), 8.26 (s, 1 H).

13C NMR (100 MHz, CDCl₃): δ = 20.89, 110.25, 116.91, 123.45, 126.05, 126.45, 129.24, 133.46, 133.55, 134.17, 139.20, 140.44, 141.99, 178.18.


1-(4-Bromo-phenyl)-1H-quinolin-4-one (2q)
Yield: 832 mg (80%); white solid; mp 161.5–164.7 °C.

IR (KBr): 3056, 2840, 1617, 1581, 1431, 1332, 1225, 1081 cm⁻¹.

1H NMR (400 MHz, CDCl₃): δ = 3.86 (s, 3 H), 6.36 (d, J = 8.0 Hz, 1 H), 6.92 (d, J = 7.5 Hz, 1 H), 7.30 (t, J = 7.6 Hz, 1 H), 7.39 (d, J = 6.3 Hz, 2 H), 7.56–7.60 (m, 4 H), 8.27 (s, 1 H).

13C NMR (75 MHz, CDCl₃): δ = 110.57, 116.98, 123.56, 124.10, 126.51, 126.75, 129.31, 132.04, 133.62, 140.34, 141.13, 142.31, 178.21.

Anal. Calcd for C₁₅H₁₀BrNO: C, 67.67; H, 3.79; N, 10.52. Found: C, 67.72; H, 3.74; N, 10.49.

1-(4-Methoxy-phenyl)-1H-quinolin-4-one (2r)
Yield: 426 mg (82%); yellow solid; mp 163.5–167.1 °C.

IR (KBr): 3056, 2840, 1617, 1581, 1431, 1332, 1225, 1081 cm⁻¹.

1H NMR (400 MHz, CDCl₃): δ = 3.86 (s, 3 H), 6.36 (d, J = 8.0 Hz, 1 H), 6.92 (d, J = 2.0 Hz, 1 H), 6.98 (t, J = 7.6 Hz, 1 H), 7.04–7.10 (m, 2 H), 7.60 (d, J = 7.6 Hz, 2 H), 8.46 (d, J = 7.2 Hz, 1 H).

13C NMR (100 MHz, CDCl₃): δ = 111.21, 115.21, 124.59, 125.82, 126.62, 127.05, 127.32, 130.47, 142.42, 178.29.


Preparation of 1-Cyclopropyl-2-phenyl-1H-quinolin-4-one (4a)
To a mixture of 1-(2-cyclopropylaminophenyl)ethanone 1 (1.0 g, 5.71 mmol) and triethylamine (2.88 g, 28.5 mmol) in THF (10 mL) at 25 °C, benzoyl chloride (0.802 g, 5.71 mmol) was added and the mixture was heated to reflux for 4 h. After completion of reaction (as monitored by TLC), the THF was removed under reduced pressure and the residue was purified by silica gel column chromatography eluting with EtOAc/n-hexane to obtain 4a.

1-Cyclopropyl-2-phenyl-1H-quinolin-4-one (4a)
Yield: 650 mg (87%); white solid; mp 170.1–172.4 °C.
IR (KBr): 3049, 3009, 1617, 1597, 1478, 1462, 1408, 1311, 1271, 1138, 1043, 775, 758, 709 cm⁻¹.
1H NMR (400 MHz, CDCl₃): δ = 0.57–0.58 (q, 2 H), 0.91–0.95 (q, 2 H), 3.32–3.35 (m, 1 H), 6.32 (s, 1 H), 7.38 (t, J = 7.6 Hz, 1 H), 7.47–7.54 (m, 5 H), 7.68–7.72 (m, 1 H), 7.96 (d, J = 8.8 Hz, 1 H), 8.44 (dd, J₁ = 1.2, J₂ = 1.2 Hz, 2 H).

13C NMR (100 MHz, CDCl₃): δ = 12.92, 32.37, 113.32, 117.82, 123.53, 126.41, 126.77, 128.36, 128.52, 129.20, 131.67, 136.96, 143.12, 155.45, 178.19.

Anal. Calcld for C₂₈H₂₃NO: C, 82.73; H, 5.79; N, 5.36. Found: C, 82.74; H, 5.76; N, 5.34.

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Supporting Information

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