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Ruthenium-catalyzed oxidative coupling and cyclization between 2-aminobenzyl alcohol and secondary alcohols leading to quinolines

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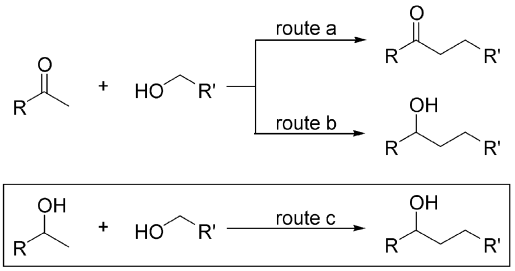
Abstract—2-Aminobenzyl alcohol is oxidatively coupled and cyclized with secondary alcohols in dioxane at 80°C in the presence of a catalytic amount of $RuCl_2(PPh_3)_3$ and KOH along with 1-dodecene as a sacrificial hydrogen acceptor to give the corresponding quinolines in good yields. The cyclization is applicable to a wide range of alkyl(aryl) and alkyl(alkyl) carbinols. The catalytic pathway seems to be proceeded via a sequence involving initial oxidation of both substrates to carbonyl compounds, cross aldol reaction, and cyclodehydration.

1. Introduction

It is known that many quinoline containing compounds exhibit a wide spectrum of pharmacological activities such as antiasthmatic, antiinflammatory and antimalarial.[1] Thus, besides conventional named routes such as Skraup, Döbner-von Miller, Conrad-Limpach, Friedlaender and Pfitzinger syntheses,[2] homogeneous transition metal-catalyzed synthetic methods have also been developed as alternative methods for the construction of quinoline framework because of efficiency of reaction and wide availability of substrates.[3] During the course of our ongoing studies on homogeneous ruthenium-catalysis for the synthesis of N-heterocycles,[4,5] we have also reported on ruthenium-catalyzed synthesis of quinolines via an alkyl group transfer from α-hydrogen containing alkyl amines to anilines[3b,5] (amine exchange reaction[6]) and an oxidative cyclization of 2-aminobenzyl alcohol with ketones[7] (modified Friedlaender quinoline synthesis[8]). The latter was intrinsically based on our recent report, an unusual type of ruthenium-catalyzed transfer hydrogenation between ketones and primary alcohols accompanied by carbon–carbon coupling under KOH, in which alkylated ketones (Scheme 1, route a)[9] or unconventional transfer hydrogenated secondary alcohols (Scheme 1, route b)[10] were preferentially formed according to the molar ratio of primary alcohols to ketones.[11] Furthermore, in connection with this report, we recently disclosed an unprecedented ruthenium-catalyzed coupling between secondary alcohols and primary alcohols which eventually leads to β-alkylation of the former by the latter (Scheme 1, route c).[12] These findings led us to attempt the cyclization of 2-aminobenzyl alcohol with secondary alcohols leading to quinolines since compounds possessing secondary alcohol moiety can be directly subjected to react with 2-aminobenzyl alcohol for quinoline framework without preoxidation of the secondary alcohol to ketone. Herein, we report a successful ruthenium-catalyzed oxidative coupling and subsequent cyclization between 2-aminobenzyl alcohol and secondary alcohols in the presence of KOH and 1-dodecene leading to quinolines.



Scheme 1.

2. Results and discussion

Based on our recent report on ruthenium-catalyzed oxidative cyclization of 2-aminobenzyl alcohol (**1**) with ketones[7] and oxidative coupling between secondary alcohols and primary alcohols,[12] several tentative results for the reaction between **1** and 1-phenylethanol (**2a**) are

Keywords: 2-aminobenzyl alcohol; cyclization; oxidative coupling; quinolines; ruthenium catalyst; secondary alcohols.
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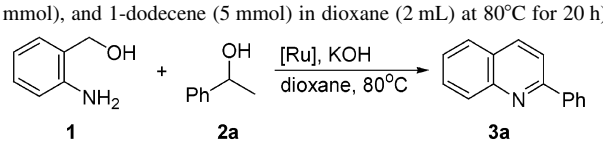
summarized in Table 1. When **1** was allowed to react with equimolar amount of **2a** in the presence of $RuCl_2$-(=CHPh)$(PCy_3)_2$ (1 mol%) along with KOH, 2-phenylquinoline (**3a**) was produced in only 10% yield (Table 1, run 1). However, the addition of 1-dodecene as hydrogen acceptor increased the yield of **3a** to 52% (run 2). It appears that the reaction is similarly accelerated by the addition of 1-dodecene as we have observed that secondary alcohols and primary alcohols are easily coupled in the presence of 1-dodecene.[12,13] Under the catalytic system of run 2 in Table 1, the yield of **3a** increased gradually from 1% (1 h), 19% (5 h), 29% (10 h), 42% (15 h), to 52% (20 h). $RuCl_2(PPh_3)_3$ could be alternatively used as catalyst, **3a** being formed in 53% yield (run 3). By increasing the amount of ruthenium catalyst to 2 mol%, a higher yield (74%) of **3a** was achieved (run 4). However, performing the reaction under more amount of KOH did not give any significant change (run 5).[14] Treatment of equimolar amount of **1** and **2a** is desirable in atom economy point of view since the reaction under the molar ratio of [**2a**]/[**1**]=1.5 results in a slightly increased yield of **3a** (run 6).[15]

Having established reaction conditions, various secondary alcohols **2** were subjected to react with **1** in order to investigate the reaction scope and several representative results are summarized in Table 2. With aryl(methyl) carbinols (**2a**–**2f**) the oxidative coupling and cyclization products were formed in the range of 71–87% yields with the minimal formation of acetophenones on GLC analysis. The product yield was not significantly affected by the position and electronic nature of the substituent on the aromatic ring of **2a**–**2f**. The reaction proceeds likewise with heteroaryl(methyl) carbinols (**2g**–**2i**) to give the corresponding 2-heteroaryl substituted quinolines (**3g**–**3i**) and the quinoline yield was lower than that when aryl(methyl) carbinols were used. 1-(2-Naphthyl)ethanol (**2j**) was also readily oxidatively coupled and cyclized with **1** to afford 2-(2-naphthyl)quinoline (**3j**) in 90% yield. The reaction of 1-phenyl-1-propanol (**2k**), which has only methylene reaction site, with **1** also proceeds to give the corresponding quinoline **3k** in 61% yield. From the reactions between **1** and alkyl(alkyl) carbinols (**2l**–**2p**), the corresponding quinolines (**3l**–**3p**) were also produced in moderate to good yields. In the case of isopropanol (**2l**), the molar ratio of [**2l**]/[**1**]=3 was necessary for the effective formation of **3l**.

Table 1. Optimization of conditions for the reaction of **1** with **2a** (except as noted, all reactions were carried out with **1** (1 mmol), **2a** (1 mmol), KOH (1 mmol), and 1-dodecene (5 mmol) in dioxane (2 mL) at 80°C for 20 h)

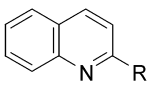
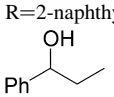
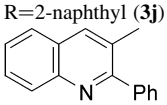
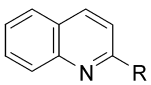
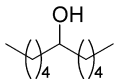
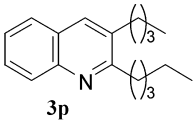
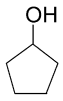
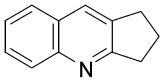
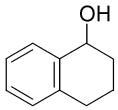
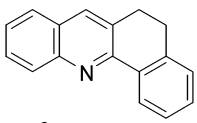


1 **2a** **3a**

Run	Ruthenium catalysts (mol%)	Hydrogen acceptor	Yield (%)[a]
1	$RuCl_2$(=CHPh)$(PCy_3)_2$ (1)	–	10
2	$RuCl_2$(=CHPh)$(PCy_3)_2$ (1)	1-dodecene	52
3	$RuCl_2(PPh_3)_3$ (1)	1-dedecene	53
4	$RuCl_2(PPh_3)_3$ (2)	1-dodecene	74
5[b]	$RuCl_2(PPh_3)_3$ (2)	1-dodecene	74
6[c]	$RuCl_2(PPh_3)_3$ (2)	1-dodecene	78

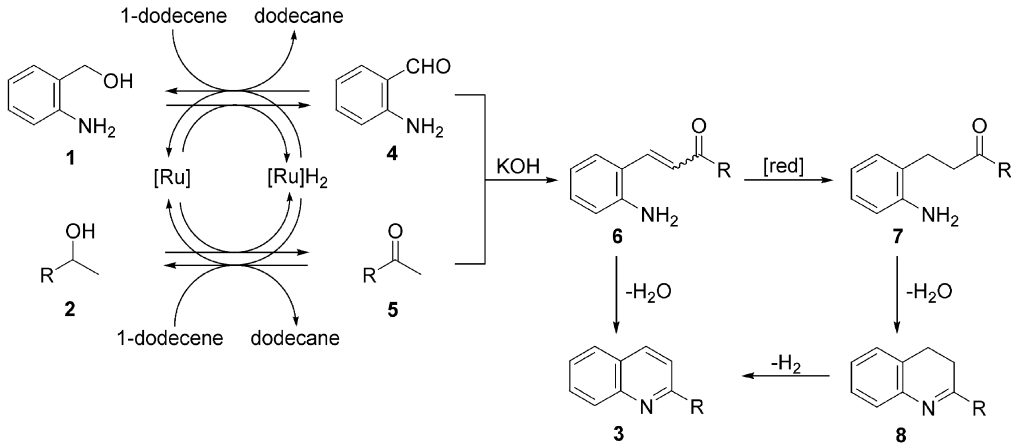
[a] Isolated yield.
[b] KOH (2 mmol).
[c] [**2a**]/[**1**]=1.5.

Table 2. Ruthenium-catalyzed synthesis of quinolines **3** from **1** and **2** (except as noted, all reactions were carried out with **1** (1 mmol), **2** (1 mmol), $RuCl_2(PPh_3)_3$ (0.02 mmol), KOH (1 mmol), and 1-dodecene (5 mmol) in dioxane (2 mL) at 80°C for 20 h)

Secondary alcohols **2**	Quinolines **3**	Yield (%)[a]
		
R=Ph (**2a**)	R=Ph (**3a**)	74
R=4-MeC_6H_4 (**2b**)	R=4-MeC_6H_4 (**3b**)	87
R=3-MeC_6H_4 (**2c**)	R=3-MeC_6H_4 (**3c**)	85
R=2-MeC_6H_4 (**2d**)	R=2-MeC_6H_4 (**3d**)	71
R=4-$MeOC_6H_4$ (**2e**)	R=4-$MeOC_6H_4$ (**3e**)	85
R=4-FC_6H_4 (**2f**)	R=4-FC_6H_4 (**3f**)	82
R=4-pyridyl (**2g**)	R=4-pyridyl (**3g**)	48
R=2-thienyl (**2h**)	R=2-thienyl (**3h**)	73
R=2-furanyl (**2i**)	R=2-furanyl (**3i**)	57
R=2-naphthyl (**2j**)	R=2-naphthyl (**3j**)	90
 **2k**	 **3k**	61
		
R=Me (**2l**)[b]	R=Me (**3l**)	56
R=*i*-Pr (**2m**)	R=*i*-Pr (**3m**)	42
R=phenethyl (**2n**)	R=phenethyl (**3n**)	60[c]
R=pentyl (**2o**)	R=pentyl (**3o**)	43[d]
 **2p**	 **3p**	43
 **2q**	 **3q**	54
 **2r**	 **3r**	69

[a] Isolated yield.
[b] 3 mmol of isopropanol was used.
[c] 3-Benzyl-2-methylquinoline was also formed in 16% yield.
[d] 3-Butyl-2-methylquinoline was also formed in 10% yield.

In the reaction of unsymmetrical alkyl(alkyl) carbinols **2n** and **2o** which have methyl and methylene reaction sites, the corresponding quinolines **3n** and **3o** were obtained as a regioisomeric mixture, favoring oxidative coupling and cyclization at less-hindered methyl position over methylene position. Similar observations have also been made by our recent reports on ruthenium-catalyzed α-alkylation of ketones with trialkylamines[16] and primary alcohols[9] and β-alkylation of secondary alcohols with primary alcohols.[12] It is also known that palladium-catalyzed α-arylation of ketones with aryl halides regioselectively occurs at less-hindered methyl position over α-methylene and -methine.[17] Cyclic carbinols such as cyclopentanol (**2q**) and 1-tetralol (**2r**) were also reacted with **1** to give 2,3-dihydro-1*H*-cyclopenta[*b*]quinoline (**3q**) and 5,6-dihydrobenzo[*c*]acridine (**3r**), respectively.



Scheme 2.

As to the reaction pathway, it seems to proceed via a sequence involving initial oxidations of both substrates to carbonyl compounds **4** and **5**, cross aldol reaction under KOH to afford α,β-unsaturated ketone **6**, and cyclodehydration (Scheme 2). The initial oxidations of alcohols to carbonyl compounds, which proceed via oxidative addition of ruthenium to O–H bond and subsequent β-hydrogen elimination, are well documented in transition metal-catalyzed transfer hydrogenations.[11] As has been observed in our recent report,[12] 1-dodecene seems to act as a sacrificial hydrogen acceptor oxidizing $[Ru]H_2$ generated in the initial oxidation stage to [Ru]. An alternative route for **3** involves a sequence such as reduction of **6** to saturated ketone **7**, cyclodehyderation to form 3,4-dihydroquinoline **8** and dehydrogenation.[18]

In summary, we have demonstrated that 2-aminobenzyl alcohol can be oxidatively coupled and cyclized with an array of secondary alcohols under the conditions of $RuCl_2(PPh_3)_3$/KOH/1-dodecene/dioxane/80°C to afford quinolines in moderate to good yields. The present reaction will be useful for the direct quinoline formation from 2-aminobenzyl alcohol and secondary alcohols without preoxidation of the secondary alcohols to ketones.

3. Experimental

^1H and ^{13}C NMR (400 and 100 MHz) spectra were recorded on a Bruker Avance Digital 400 spectrometer using TMS as an internal standard. Melting points were determined on a Thomas–Hoover capillary melting point apparatus and were uncorrected. Mass spectra were obtained on a Shimadzu QP-1000 spectrometer. GLC analyses were carried out with Shimadzu GC-17A (FID) equipped with CBP10-S25-050 column (Shimadzu, a silica fused capillary column, 0.33 mm×25 m, 0.25 μm film thickness) using N_2 as carrier gas. The isolation of pure products was carried out via column (silica gel 60, 70–230 mesh, Merck) and thin layer (silica gel 60 GF_{254}, Merck) chromatography. Secondary alcohols **2b–2j** were prepared by reduction of the corresponding ketones with $LiAlH_4$. $RuCl_2(PPh_3)_3$ was prepared by the reported method.[19] Commercially available organic and inorganic compounds were used without further purification.

3.1. Typical procedure for ruthenium-catalyzed oxidative coupling and cyclization between 2-aminobenzyl alcohol and secondary alcohols

A mixture of 2-aminobenzyl alcohol (0.123 g, 1 mmol), 1-phenylethanol (0.122 g, 1 mmol), $RuCl_2(PPh_3)_3$ (0.019 g, 0.02 mmol), 1-dodecene (0.842 g, 5 mmol) and KOH (0.056 g, 1 mmol) in dioxane (2 mL) was placed in a 5 mL screw-capped vial. The system was allowed to react at 80°C for 20 h. The reaction mixture was filtered through a short silica gel column (ethyl acetate) to eliminate inorganic salts. Removal of the solvent left a crude mixture, which was separated by thin layer chromatography (silica gel, ethyl acetate–hexane mixture) to give quinoline (0.151 g, 74%).

3.1.1. 2-Phenylquinoline (3a). Solid (hexane); mp 84–85°C (lit.[20] 83–84°C); ^1H NMR (400 MHz, $CDCl_3$) δ 7.41–7.52 (m, 4H), 7.67–7.71 (m, 1H), 7.76 (d, J=8.0 Hz, 1H), 7.80 (d, J=8.5 Hz, 1H), 8.12–8.18 (m, 4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 118.9, 126.2, 127.1, 127.4, 127.5, 128.7, 129.2, 129.5, 129.6, 136.7, 139.6, 148.2, 157.2; MS m/z (relative intensity) 205 (M^+, 100).

3.1.2. 2-(4-Methylphenyl)quinoline (3b). Solid (hexane); mp 80–81°C (lit.[21] 81–82°C); ^1H NMR (400 MHz, $CDCl_3$) δ 2.41 (s, 3H), 7.31 (d, J=8.0 Hz, 2H), 7.46–7.50 (m, 1H), 7.67–7.71 (m, 1H), 7.76–7.82 (m, 2H), 8.05 (d, J=8.0 Hz, 2H), 8.15 (t, J=8.0 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.3, 118.8, 126.0, 127.0, 127.4, 129.5, 129.6, 136.6, 136.8, 139.3, 148.2, 157.2; MS m/z (relative intensity) 219 (M^+, 100).

3.1.3. 2-(3-Methylphenyl)quinoline (3c).[22] Viscous oil; ^1H NMR (400 MHz, $CDCl_3$) δ 2.43 (s, 3H), 7.23 (d, J=7.5 Hz, 1H), 7.37 (t, J=7.5 Hz, 1H), 7.42–7.46 (m, 1H), 7.65–7.77 (m, 3H), 7.89 (d, J=7.5 Hz, 1H), 7.98 (s, 1H), 8.07 (d, J=8.5 Hz, 1H), 8.17 (d, J=8.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.5, 118.9, 124.6, 126.0, 127.0, 127.3, 128.1, 128.6, 129.4, 129.5, 130.0, 136.5, 138.3, 139.5, 148.1, 157.4; MS m/z (relative intensity) 219 (M^+, 100).

3.1.4. 2-(2-Methylphenyl)quinoline (3d).[23] Viscous oil; ^1H NMR (400 MHz, $CDCl_3$) δ 2.40 (s, 3H), 7.21–7.32 (m, 3H),

7.41–7.54 (m, 3H), 7.71 (t, J=7.5 Hz, 1H), 7.81 (d, J=8.5 Hz, 1H), 8.15–8.18 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 20.2, 122.3, 125.9, 126.3, 126.6, 127.4, 128.4, 129.4, 129.5, 129.6, 130.8, 135.9, 136.0, 140.6, 147.7, 160.1; MS m/z (relative intensity) 219 (M^+, 30), 218 (100).

3.1.5. 2-(4-Methoxyphenyl)quinoline (3e). Solid (hexane); mp 117–118°C (lit.[23] 122–123°C); ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.82 (s, 3H), 7.01 (d, J=9.0 Hz, 2H), 7.45 (t, J=7.5 Hz, 1H), 7.67 (t, J=7.5 Hz, 1H), 7.74 (t, J=7.8 Hz, 2H), 8.07–8.14 (m, 4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 55.2, 114.1, 118.4, 125.8, 127.3, 128.8, 129.4, 129.5, 130.4, 132.1, 136.5, 148.2, 156.7, 160.7.

3.1.6. 2-(4-Fluorophenyl)quinoline (3f).[24] Solid (hexane); mp 92–93°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.13–7.17 (m, 2H), 7.44–7.48 (m, 1H), 7.65–7.73 (m, 3H), 8.06–8.14 (m, 4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 115.6 (d, J=21.3 Hz), 118.4, 126.2, 126.9, 127.4, 129.3 (d, J=7.8 Hz), 129.5, 129.6, 135.6 (d, J=2.9 Hz), 135.7, 148.1, 156.0, 163.7 (d, J=247.3 Hz); MS m/z (relative intensity) 223 (M^+, 100).

3.1.7. 2-(4-Pyridyl)quinoline (3g).[25] Solid (hexane); mp 91–92°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.56–7.60 (m, 1H), 7.74–7.79 (m, 1H), 7.85 (d, J=8.0 Hz, 1H), 7.89 (d, J=8.5 Hz, 1H), 8.08 (d, J=5.0 Hz, 2H), 8.19 (d, J=8.5 Hz, 1H), 8.27 (d, J=8.5 Hz, 1H), 8.79 (s, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 118.3, 121.6, 127.2, 127.5, 127.8, 129.9, 130.1, 137.2, 146.7, 148.2, 150.1, 154.2.

3.1.8. 2-(2-Thienyl)quinoline (3h). Solid (hexane); mp 126°C (lit.[26] 125–127°C); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.14 (t, J=4.5 Hz, 1H), 7.44–7.48 (m, 2H), 7.66–7.77 (m, 4H), 8.07–8.10 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 117.6, 125.8, 126.0, 127.1, 127.4, 128.0, 128.5, 129.2, 129.8, 136.6, 145.3, 148.0, 152.3; MS m/z (relative intensity) 211 (M^+, 100).

3.1.9. 2-(2-Furanyl)quinoline (3i).[7] Solid (hexane); mp 88–90°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.48–6.54 (m, 1H), 7.13–7.18 (m, 1H), 7.42 (t, J=7.5 Hz, 1H), 7.53–7.74 (m, 4H), 8.04 (d, J=8.6 Hz, 1H), 8.12 (d, J=8.0 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 109.9, 112.0, 117.2, 126.0, 126.9, 127.4, 129.1, 129.6, 136.4, 143.9, 147.9, 148.8, 153.5; MS m/z (relative intensity) 195 (M^+, 100).

3.1.10. 2-(2-Naphthyl)quinoline (3j). Solid (hexane); mp 162–163°C (lit.[27] 163°C); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.49–7.53 (m, 3H), 7.70–7.75 (m, 1H), 7.79 (d, J=8.0 Hz, 1H), 7.86–7.88 (m, 1H), 7.96–7.98 (m, 3H), 8.18–8.23 (m, 2H), 8.35 (dd, J=8.6, 2.0 Hz, 1H), 8.59 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 119.1, 125.0, 126.3, 126.7, 127.1, 127.2, 127.5, 127.7, 128.5, 128.8, 129.7, 133.4, 133.8, 136.7, 136.9, 148.3, 157.1; MS m/z (relative intensity) 255 (M^+, 100).

3.1.11. 3-Methyl-2-phenylquinoline (3k).[28] Pale yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.41 (s, 3H), 7.38–7.48 (m, 4H), 7.55–7.58 (m, 2H), 7.60–7.64 (m, 1H), 7.71 (d, J=8.0 Hz, 1H), 7.93 (s, 1H), 8.13 (d, J=8.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 20.5, 126.2, 126.5, 127.4, 128.0, 128.1, 128.6, 128.7, 129.0, 129.1, 136.6, 140.7, 146.4, 160.3; MS m/z (relative intensity) 219 (M^+, 50), 218 (100).

3.1.12. 2-Methylquinoline (3l).[29] Pale yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.73 (s, 3H), 7.25 (d, J=8.5 Hz, 1H), 7.46 (t, J=7.5 Hz, 1H), 7.66 (t, J=7.8 Hz, 1H), 7.74 (d, J=8.0 Hz, 1H), 8.01 (t, J=7.3 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 25.3, 121.9, 125.6, 126.4, 127.4, 128.5, 129.3, 136.1, 147.8, 158.9.

3.1.13. 2-Isopropylquinoline (3m).[30] Pale yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.39 (d, J=7.0 Hz, 6H), 3.26 (hept, J=7.0 Hz, 1H), 7.32 (d, J=8.5 Hz, 1H), 7.46 (t, J=7.5 Hz, 1H), 7.66 (t, J=7.3 Hz, 1H), 7.75 (d, J=8.0 Hz, 1H), 8.06 (d, J=8.6 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 22.5, 37.3, 119.1, 125.6, 126.9, 127.4, 128.9, 129.2, 136.3, 147.7, 167.6.

3.1.14. 2-Phenethylquinoline (3n).[29] Pale yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.12–3.16 (m, 2H), 3.25–3.29 (m, 2H), 7.14–7.18 (m, 2H), 7.21–7.27 (m, 4H), 7.43 (t, J=7.5 Hz, 1H), 7.65 (t, J=7.5 Hz, 1H), 7.71 (d, J=8.0 Hz, 1H), 7.95 (d, J=8.5 Hz, 1H), 8.08 (d, J=8.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 35.7, 40.8, 121.4, 125.6, 125.8, 126.6, 127.4, 128.2, 128.4, 128.7, 129.2, 136.0, 141.3, 147.8, 161.6.

3.1.15. 3-Benzyl-2-methylquinoline. This regioisomer was isolated as a mixture with the starting 4-phenyl-2-butanol, and the yield was calculated from the peak areas of the clearly separated protons in ^{1}H NMR spectrum; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.64 (s, 3H, CH_3), 4.13 (s, 2H, CH_2).

3.1.16. 2-Pentylquinoline (3o).[31] Pale yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.90 (t, J=6.8 Hz, 3H), 1.29–1.44 (m, 4H), 1.77–1.85 (m, 2H), 2.96 (t, J=8.0 Hz, 2H), 7.27 (d, J=8.5 Hz, 1H), 7.43–7.47 (m, 1H), 7.64–7.68 (m, 1H), 7.74 (d, J=8.5 Hz, 1H), 8.04 (t, J=9.3 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.9, 22.5, 29.7, 31.7, 39.3, 121.3, 125.5, 126.6, 127.4, 128.7, 129.2, 136.1, 147.8, 163.0.

3.1.17. 3-Butyl-2-methylquinoline.[31] Pale yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.98 (t, J=7.3 Hz, 3H), 1.41–1.50 (m, 2H), 1.63–1.70 (m, 2H), 2.72 (s, 3H), 2.75 (t, J=7.5 Hz, 2H), 7.44 (t, J=7.3 Hz, 1H), 7.58–7.63 (m, 1H), 7.71 (d, J=8.0 Hz, 1H), 7.82 (s, 1H), 7.99 (d, J=8.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.9, 22.6, 23.1, 31.8, 32.5, 125.6, 126.8, 127.3, 128.2, 128.4, 134.3, 134.4, 146.3, 158.6.

3.1.18. 3-Butyl-2-pentylquinoline (3p).[32] Pale yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.92 (t, J=7.0 Hz, 3H), 0.98 (t, J=7.5 Hz, 3H), 1.37–1.50 (m, 6H), 1.63–1.70 (m, 2H), 1.77–1.84 (m, 2H), 2.77 (t, J=7.8 Hz, 2H), 2.97 (t, J=8.0 Hz, 2H), 7.40–7.43 (m, 1H), 7.57–7.61 (m, 1H), 7.69 (d, J=8.0 Hz, 1H), 7.82 (s, 1H), 8.02 (d, J=8.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.9, 14.0, 22.5, 22.6, 29.4, 32.0, 32.1, 32.6, 35.8, 125.4, 126.8, 127.2, 128.2, 128.4, 134.0, 134.7, 146.5, 162.2.

3.1.19. 2,3-Dihydro-1*H*-cyclopenta[*b*]quinoline (3q).[33] Pale yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.16–2.24 (m, 2H), 3.08 (t, J=7.4 Hz, 2H), 3.16 (t, J=7.6 Hz, 2H), 7.43–7.47 (m, 1H), 7.59–7.63 (m, 1H), 7.72 (d, J=8.2 Hz, 1H), 7.87 (s, 1H), 8.01 (d, J=8.4 Hz, 1H); ^{13}C NMR

(100 MHz, $CDCl_3$) δ 23.6, 30.5, 34.6, 125.5, 127.3, 127.4, 128.3, 128.5, 130.3, 135.6, 147.5, 167.9.

3.1.20. 5,6-Dihydrobenzo[*c*]acridine (3r). Solid (hexane); mp 63–65°C (lit.[34] 65°C); ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.93–2.97 (m, 2H), 3.02–3.06 (m, 2H), 7.20–7.24 (m, 1H), 7.31–7.35 (m, 1H), 7.38–7.44 (m, 2H), 7.59–7.63 (m, 1H), 7.67 (d, J=8.0 Hz, 1H), 7.83 (s, 1H), 8.12 (d, J=8.0 Hz, 1H), 8.56–8.58 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 28.3, 28.7, 125.9, 126.8, 127.2, 127.8, 127.9, 128.5, 129.3, 129.6, 130.5, 133.6, 134.6, 139.3, 147.5, 153.3; MS *m*/*z* (relative intensity) 231 (M^+, 100).

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13. In Ref. [12], the reaction rate toward coupling between secondary alcohols and primary alcohols (Scheme 1, route c) was dramatically enhanced by the addition of 1-dodecene. This seemed to be considered as a facile regeneration of [Ru] from [Ru]H_2 generated in the initial oxidation stages by reducing 1-dodecene to dodecane (see Scheme 2).
14. It is also known that strong bases are used as cocatalysts to promote transition metal-catalyzed transfer hydrogenation. However, in the present reaction, KOH seems to act as a base for aldol reaction as well as a promotor for transfer hydrogenation.
15. In contrast to this result, the molar ratio [ketones]/[**1**] in oxidative cyclization of **1** with ketones (Ref. 7) was critical for the effective formation of quinolines since superfluous ketones are partially consumed by transfer hydrogenation of ketones by **1**.
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