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Chiral 1,2,3,4-tetrahydroquinolinyl-oxazoline ligands for Ru-catalyzed asymmetric transfer hydrogenation of ketones

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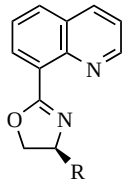
Abstract—Chiral 1,2,3,4-tetrahydroquinolinyl-oxazoline compounds have been synthesized from 8-quinolinecarboxylic acid and enantiomerically pure amino alcohols using a convenient procedure. Asymmetric transfer hydrogenation of aryl ketones with the catalyst prepared in situ from [Ru(*p*-cymene)Cl_2]$_2$ and ligands **2** in 2-propanol in the presence of KOH, afforded the corresponding secondary alcohols in reasonable yields and up to 83% e.e.

1. Introduction

In response to an increasing demand for optically active secondary alcohols in the area of pharmaceuticals and advanced materials,[1] a number of methods for the asymmetric reduction of prochiral ketones have been developed.[2] Transition metal-catalyzed transfer hydrogenation using 2-propanol as the hydrogen source is a practical and versatile method because of the inexpensive reagents and operational simplicity.[3] Notable among the recently developed efficient transition-metal-based chiral reduction catalyst is the Ru(II)–TsDPEN (TsDPEN = *N*-(*p*-tolylsulfonyl)-1,2-diphenyl ethylenediamine) system reported by Noyori and co-workers,[4] who suggested that the presence of an amino group in the ligand plays a key role in obtaining high enantioselectivity.[3b,4d,5] Few other reports also showed a similar 'NH effect'.[6,7] We have recently developed quinolinyl-oxazolines **1** as chiral ligands in asymmetric cyclopropanation,[8] Heck-type hydroarylation[9] and allylic oxidation.[10] In an ongoing effort to study new bisnitrogen ligands with C_1 symmetry, we designed 1,2,3,4-tetrahydroquinolinyl-oxazoline ligands **2**, with the expectance that the new ligands would confirm the importance of the amino group to the high enantioselectivity in ruthenium-catalyzed transfer hydrogenation of ketones. Herein, we wish to describe the synthesis of chiral 1,2,3,4-tetrahydroquinolinyl-oxazolines and their application as ligands in the Ru(II)-catalyzed asymmetric transfer hydrogenation of aromatic ketones.



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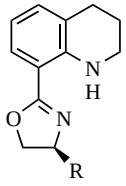

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2. Results and discussion

2.1. Synthesis of 1,2,3,4-tetrahydroquinolinyl-oxazoline ligands

The 1,2,3,4-tetrahydroquinolinyl-oxazoline ligands were synthesized in four steps as shown in Scheme 1. The 8-quinolinecarboxamides **3** were obtained through two straightforward routes, either by converting 8-quinolinecarboxylic acid to the corresponding acyl chloride followed by treatment with the (*S*)-amino alcohol or by ester exchange of ethyl 8-quinolinecarboxylate with (*S*)-amino alcohols in 92–97% yield. 8-Quinolinecarboxamides **3** were reduced to 1,2,3,4-tetrahydroquinolinecarboxamides **4** in 82–89% yield with nickel–aluminum alloy at room temperature. Treatment of **4** with methanesulfonic acid under azeotropic removal of water provided (*S*)-1,2,3,4-tetrahydroquinolinyl-oxazolines **2a–c** in 47–51% yield.

2.2. Ru(II)-catalyzed asymmetric transfer hydrogenation

In the initial experiment, the transfer hydrogenation of acetophenone was chosen as a model reaction. The catalyst (5 mol%) was prepared in situ from [Ru(*p*-

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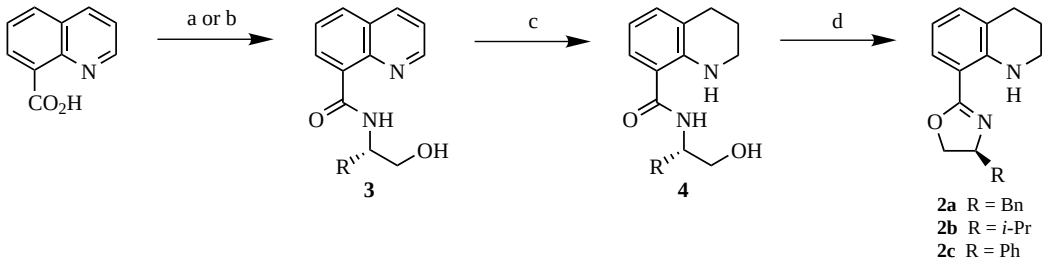


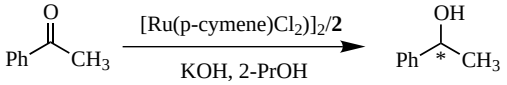
Scheme 1. Synthesis of (*S*)-1,2,3,4-tetrahydroquinolinyl-oxazoline ligands. *Reagents*: (a) $SOCl_2$, then amino alcohol; (b) $EtOH/H^+$, then amino alcohol; (c) Ni–Al, KOH; (d) CH_3SO_3H.

cymene)$Cl_2]_2$ and the chiral ligand **2a** under nitrogen in dry 2-propanol. After introduction of the acetophenone into the catalyst solution, the reduction was performed at 82°C in the presence of potassium hydroxide (2.5 equiv. per Ru atom), giving (*S*)-1-phenylethanol in 43% yield with 12% e.e. (Table 1, entry 1). Similar yield and enantioselectivity were obtained under the same conditions using ligand **2b**. While the ligand **2c**, with a phenyl group on the oxazoline ring, was found to be superior to the ligands **2a** and **2b**, affording the reduction product in 71% yield with 44% e.e. Encouraged with this result, we made efforts to optimize the reaction conditions. The effect of temperature on the enantioselectivity of the reaction was firstly investigated and was found to be a significant variable. When the reaction temperature was changed incrementally from 82 to −20°C, the enantioselectivity increased constantly as the temperature was lowered, although the rate of reaction was reduced (entries 3–6). The highest enantiomeric excess (83% e.e.) was achieved at −20°C. Extension of the reaction time from 21 h to 48 h at −20°C enhanced the yield of the desired product from 46 to 78%, but resulted in an erosion of the asymmetric induction (entry 7). This arises presumably as a result of the known reversibility of the reaction.

To overcome this problem, HCO_2H/Et_3N, which has been reported to promote irreversible transfer hydrogenation in certain catalytic systems,[4e] was used as the hydrogen source, but the reaction proceeded rather slowly even at 60°C and was unselective at all. Using less catalyst (1 mol%) reduced both the e.e. value and the yield of the product (67% e.e. and 23% yield at 25°C). When $RuCl_2(PPh_3)_3$ was used as precatalyst in the reduction of acetophenone at 25°C, racemic 1-phenylethanol was obtained in 60% yield. Replacement of KOH with NaO(*i*-Pr) also led to a drop in the e.e. value to 6%.

Under the optimized conditions, a variety of aromatic ketones have been reduced to the corresponding secondary alcohols with good enantiomeric excess (Table 2). The rate and enantioselectivity of the reaction were found to be affected by the steric and electronic properties of the substrates. The bulk of the R group in the ketone caused a reduction in the rate of the reaction, giving 68% e.e. in 65% yield after 37 h for propiophenone (entry 2). While for isobutyrophenone the rate of reaction was further retarded and the drop in e.e. value was greater still (e.e. = 34%, entry 3). Substitution at the phenyl ring of acetophenone with an electron-donating group gave yields and enantioselectivities that are similar to those obtained with acetophenone (entries 4–6 versus 1). Introduction of chlorine atoms, however, led to lower enantioselectivities, although the yields of the reduction products increased (entries 7–9). Increasing the volume of the aryl group in the starting ketone from phenyl to naphthyl had a slightly negative effect on the enantioselectivity (entry 10). The cyclic substrates tetralone and indanone were also converted under the same conditions to the corresponding alcohols in 79 and 67% e.e., respectively (entries 11 and 12).

Table 1. Reduction of acetophenone catalyzed by Ru(II)-**2** complex[a]



Entry	Ligand	Temp.(°C)	Time (h)	% Yield[b]	% E.e.[c]	Conf.[d]
1	**2a**	82	1	43	12	S
2	**2b**	82	1	40	16	*S*
3	**2c**	82	1	71	44	*S*
4	**2c**	25	2	56	73	*S*
5	**2c**	0	5	50	75	*S*
6	**2c**	−20	21	46	83	*S*
7	**2c**	−20	48	78	78	*S*

[a] Reaction conditions: 5 mol% catalyst, 0.1 M solution of acetophenone in 2-propanol, Ru(II):**2**:KOH = 1:2.2:2.5.
[b] Isolated yield after flash column chromatography on silica gel.
[c] Determined by chiral GC using a capillary column (Supleco β-Dex 120, 30 m).
[d] Determined by comparing the specific rotation value with that in the literature (Ref. 11).

Table 2. Transfer hydrogenation of ketones catalyzed by Ru(II)-**2c** complex[a]

Entry	Substrate	Time (h)	% Yield[b]	% E.e.	Conf.[c]
1	C_6H_5COMe	21	46	83[d]	S
2	C_6H_5COEt	37	65	68[d]	*S*
3	$C_6H_5CO(i\text{-}Pr)$	69	44	34[e]	*S*
4	$p\text{-}MeC_6H_4COMe$	64	40	75[d]	*S*
5	$o\text{-}MeC_6H_4COMe$	69	59	83[d]	*S*
6	$p\text{-}MeOC_6H_4COMe$	75	30	72[e]	*S*
7	$o\text{-}ClC_6H_4COMe$	48	81	50[f]	*S*
8	$p\text{-}ClC_6H_4COMe$	64	78	50[g]	*S*
9	$2,3,4\text{-}Cl_3C_6H_2COMe$	9	88	46[g]	nd[j]
10	2-Acetonaphthone	64	76	67[h]	*S*
11	Tetralone	37	36	79[i]	*S*
12	Indanone	64	76	67[i]	*S*

[a] The reaction was conducted at −20°C with the catalyst (5 mol%) in a 2-propanol solution of the ketone (concentration 0.1 M), Ru(II):**2c**:KOH = 1:2.2:2.5.
[b] Isolated yield after flash column purification on silica gel.
[c] Determined by comparing specific rotation values (Refs. 11–14).
[d] Chiral GC (Supelco β-Dex 120 capillary column).
[e] Chiral GC (Supelco γ-Dex 225 capillary column).
[f] Chiral HPLC (Chiracel OD column, *n*-hexane/2-PrOH = 98:2, 0.8 mL/min).
[g] Chiral HPLC (Chiracel OD column, *n*-hexane/2-PrOH = 99:1, 0.8 mL/min).
[h] Chiral HPLC (Chiracel OB column, *n*-hexane/2-PrOH = 98:2, 0.8 mL/min).
[i] Chiral HPLC (Chiracel OB column, *n*-hexane/2-PrOH = 90:10, 0.5 mL/min).
[j] Not determined.

To determine the role of the amino group in the ligands **2**, we tested the ligand **1c** (R = Ph) in the transfer hydrogenation of acetophenone at 25°C, resulting (*S*)-1-phenyethanol in 39% yield with a poor enantioselectivity (15% e.e.). This is in sharp contrast with e.e. value obtained with **2c**, and therefore shows that the NH in the ligands **2** indeed plays a crucial role in asymmetric transfer hydrogenations. According to the reaction mechanism suggested by Noyori,[4d,5] Ru(II)-catalyzed transfer hydrogenation takes place via metallic hydride, which delivers hydrogen through the six-membered cyclic transition state **5**. The carbonyl oxygen of the ketone interacts with the amino group of the coordinated ligand through hydrogen bonding. This bifunctional metal/ligand catalyst increases the affinity of the substrate for the active site of the catalyst and therefore induces enantioselectivity. The sense of asymmetric induction is primarily based on the chirality of the Ru(II) complex, which differentiates the enantiofaces of prochiral carbonyl compounds. The Ru center in the Ru(II) complex of ligand (*S*)-**2c** has (*R*)-configuration (Fig. 1).[15] Transfer hydrogenation via (*R*)-$\mathbf{5}_S$ affords (*S*)-ArCH(OH)R, while the diastereomeric structure (*R*)-$\mathbf{5}_R$ leads to (*R*)-ArCH(OH)R. Differentiation between these two diastereomeric transition states is actually caused by various steric and electronic factors. The preference for (*R*)-$\mathbf{5}_S$ is due perhaps to the CH/π interaction[5,16] between the arene ligand of the complex and the aryl group in the substrate.

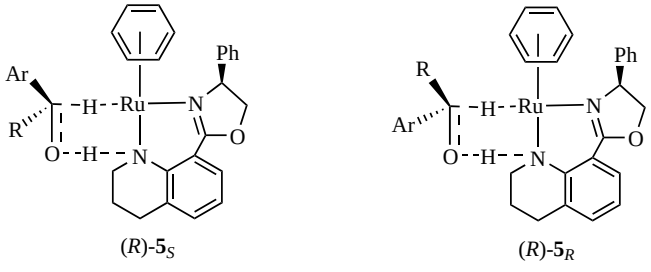


Figure 1.

In summary, we have demonstrated that ruthenium complexes of 1,2,3,4-tetrahydroquinolinyl-oxazolines are efficient catalysts for the enantioselective transfer hydrogenation of aromatic ketones. The presence of the amine function in the Ru(II)-**2** complexes is important for obtaining high enantioselectivity. Further optimization of this new type of ligand is currently in progress.

3. Experimental

3.1. General

Melting points were measured with a Yanaco MP-500 apparatus and uncorrected. ^{1}H NMR spectra were recorded on a Bruker AMX-300AC instrument using TMS as an internal standard in $CDCl_3$. IR spectra were obtained as KBr plates or film on a Nicdet magna-IR550 FT-IR spectrophotometer. Mass spectra were measured on a VG-7070E spectrometer (EI, 70 eV). Elemental analyses were carried out on a Yanaco CHN CORDER MT-3 analyser. High resolution mass spectra were measured using APEX2 spectrometer (FAB). Optical rotations measurements were obtained on a Perkin–Elmer 241 rotation apparatus. CH_2Cl_2 was distilled over CaH_2. $CHCl_3$ was distilled over $CaSO_4$. 2-Propanol was treated with sodium and degassed.

3.2. General procedure for the synthesis of 8-quinolinecarboxamides 3

In a double-necked round-bottomed flask, a mixture of ethyl 8-quinolinecarboxylate (15.4 mmol), the (*S*)-amino alcohol (18.5 mmol), KCN (5.2 mmol) and toluene (50 mL) was heated under reflux temperature under nitrogen for 3 days. After cooling to rt, the reaction mixture was washed with water and brine and dried over anhydrous $MgSO_4$. The solvent was evaporated under reduced pressure and the crude product was purified by column chromatography on silica gel with petroleum ether/EtOAc (1:1) to give product **3a** in 97% yield, **3b** in 92% yield and **3c** in 93% yield, respectively.[17] The procedure for another route is reported in the literature.[8]

3.3. Synthesis of tetrahydroquinolinecarboxamides 4

3.3.1. General procedure for the synthesis of *N*-[(1*S*)-1-benzyl-2-hydroxyethyl]-(1,2,3,4-tetrahydroquinolin-8-yl)-carboxamide 4a. To a mixture of **3a** (2.24 g, 8.1 mmol), methanol (50 mL) and 1 M aqueous KOH (24 mL) was added Ni–Al alloy (3.9 g) in portions over 30 min. The mixture was stirred at room temperature for 8 h and the methanol was removed under reduced pressure. The residue was filtered through a pad of Celite and washed with $CHCl_3$. Layers were separated and the aqueous layer was extracted twice with $CHCl_3$. The organic phase was dried over anhydrous Na_2SO_4. Evaporation of solvent and purification by column chromatography on silica gel with petroleum ether/EtOAc (1:1) afforded **4a** as a white solid (3.11 g, 82%). Mp 118–119°C. $[\alpha]_D^{25}=+30.9$ (*c* 1.0, $CHCl_3$). ^1H NMR: 1.82–1.97 (m, 2H), 2.75 (t, $J=6.0$ Hz, 2H), 2.88–3.06 (m, 2H), 3.36 (t, $J=5.4$ Hz, 2H), 3.62–3.82 (m, 2H), 4.24–4.36 (m, 1H), 6.38 (d, $J=6.6$ Hz, 1H), 6.43 (t, $J=7.8$ Hz, 1H), 6.94 (d, $J=7.2$ Hz, 2H), 7.20–7.38 (m, 5H). IR: 3418, 3365, 3302, 2955, 2851, 1626, 1530, 1511, 1462, 1360, 1276, 1186, 1052, 1014 cm^{-1}. MS (*m*/*e*,%): 310 (36, M^+), 160 (100), 132 (11), 130 (24), 104 (38), 91 (32). Anal. calcd for $C_{19}H_{22}N_2O_2$: C, 73.10; H, 6.73; N, 10.24. Found: C, 73.55; H, 7.09; N, 10.03%.

3.3.2. *N*-[(1*S*)-1-Isopropyl-2-hydroxyethyl]-(1,2,3,4-tetrahydroquinolin-8-yl)-carboxamide 4b. White solid, 88% yield. Mp 149–150.5°C. $[\alpha]_D^{25}=-59.0$ (*c* 1.0, $CHCl_3$). ^1H NMR: 1.0 (d, $J=4.5$ Hz, 3H), 1.02 (d, $J=4.5$ Hz, 3H), 1.84–1.96 (m, 2H), 1.94–2.08 (m, 1H), 2.77 (t, $J=6.0$ Hz, 2H), 3.37 (t, $J=5.7$ Hz, 2H), 3.68–3.83 (m, 2H), 3.85–3.96 (m, 1H), 6.19 (d, $J=9.0$ Hz, 1H), 6.46 (t, $J=7.2$ Hz, 1H), 7.00 (d, $J=6.6$ Hz, 1H), 7.17 (d, $J=7.5$ Hz, 1H). IR: 3388, 3306, 2982, 2923, 2888, 1616, 1584, 1532, 1513, 1472, 1406, 1354, 1275, 1185, 1068 cm^{-1}. MS (*m*/*e*,%): 262 (25, M^+), 160 (100), 132 (6), 130 (15), 104 (23). Anal. calcd for $C_{15}H_{22}N_2O_2$: C, 68.70; H, 8.39; N, 11.69. Found: C 68.68; H, 7.93; N, 11.58%.

3.3.3. *N*-[(1*S*)-1-Phenyl-2-hydroxyethyl]-(1,2,3,4-tetrahydroquinolin-8-yl)-carboxamide 4c. Reaction temperature was 60°C. Yellow solid, 89% yield. Mp 119–120°C. $[\alpha]_D^{25}=+97.0$ (*c* 1.04, $CHCl_3$). ^1H NMR: 1.88 (t, $J=5.7$ Hz, 2H), 2.76 (t, $J=6.3$ Hz, 2H), 3.34 (t, $J=5.7$ Hz, 2H), 3.96 (d, $J=4.8$ Hz, 2H), 5.17 (q, $J=6.6$ Hz, 1H), 6.46 (t, $J=7.5$ Hz, 1H), 6.74 (d, $J=6.3$ Hz, 1H), 7.00 (d, $J=7.2$ Hz, 1H), 7.25 (d, $J=7.5$ Hz, 1H), 7.28–7.42 (m, 5H). IR: 3345, 2923, 2845, 1618, 1584, 1531, 1509, 1461, 1361, 1271, 1263, 1195, 1036 cm^{-1}. MS (*m*/*e*,%): 296 (26, M^+), 160 (100), 132 (7), 130 (17), 104 (33). Anal. calcd for $C_{18}H_{20}N_2O_2$: C, 72.97; H, 6.76; N, 9.46. Found: C, 73.30; H, 6.49; N, 9.63%.

3.4. Synthesis of tetrahydroquinolinyl-oxazoline ligands 2

3.4.1. General procedure for the synthesis of (4*S*)-4,5-dihydro-4-benzyl-2-(1,2,3,4-tetrahydroquinolin-8-yl)-oxazole 2a. Compound **4a** (2.9 g, 9.45 mmol) was dissolved in dry CH_2Cl_2 (150 mL) in a round-bottomed flask fitted with a Sohxlet extraction apparatus into which was placed CaH_2 powder. Methanesulfonic acid (5.4 mL) was then added to the flask. The resulting mixture was heated under reflux for 2 days and diluted with CH_2Cl_2 (150 mL), washed with aqueous $NaHCO_3$, water and brine. After drying over anhydrous K_2CO_3 and concentration, the crude product was purified by flash column chromatography on silica gel with EtOAc containing 0.5% Et_3N to provide **2a** (1.4 g, 51%). Yellow oil. $[\alpha]_D^{25}=+43.5$ (*c* 2.0, $CHCl_3$). ^1H NMR: 1.64–2.04 (m, 2H), 2.64–2.98 (m, 2H), 2.70–2.90 (m, 2H), 3.40–3.64 (m, 3H), 4.04–4.30 (m, 2H), 6.45 (t, $J=4.8$ Hz, 1H), 7.05 (d, $J=4.0$ Hz, 1H), 7.18–7.36 (m, 5H), 7.69–7.84 (m, 2H). IR: 3372, 3061, 3026, 2931, 2887, 2844, 1676, 1602, 1589, 1513, 1465, 1414, 1363, 1250, 1181, 1145, 1030 cm^{-1}. MS (*m*/*e*, %): 292 (8, M^+), 201 (16), 177 (79), 160 (100), 158 (27), 132 (17), 130 (36), 104 (47), 91 (60). HRMS calcd for $C_{19}H_{20}N_2O$: 292.1570. Found: 292.1568.

3.4.2. (4*S*)-4,5-Dihydro-4-isopropyl-2-(1,2,3,4-tetrahydroquinolin-8-yl)oxazole 2b. Pale yellow oil, 47% yield. $[\alpha]_D^{25}=+27.7$ (*c* 2.35, $CHCl_3$). ^1H NMR: 0.88–1.04 (m, 6H), 1.67–1.84 (m, 1H), 1.85–1.96 (m, 2H), 2.77 (t, $J=5.4$ Hz, 2H), 3.36–3.48 (m, 2H), 4.02–4.12 (m, 1H), 4.28–4.36 (m, 2H), 6.43 (t, $J=7.5$ Hz, 1H), 7.02 (d, $J=7.2$ Hz, 1H), 7.70 (dd, $J=1.5$ Hz, 7.2 Hz, 1H), 7.78 (m, 1H). IR: 3371, 2872, 2843, 1677, 1602, 1589, 1513, 1465, 1414, 1364, 1251, 1181, 1144 cm^{-1}. MS (*m*/*e*,%): 244 (9, M^+), 177 (100), 160 (62), 158 (22), 132 (8), 130 (29), 104 (34). HRMS calcd for $C_{15}H_{20}N_2O$: 244.1570. Found: 244.1568.

3.4.3. (4*S*)-4,5-Dihydro-4-phenyl-2-(1,2,3,4-tetrahydroquinolin-8-yl)oxazole 2c. Pale yellow oil, 47% yield. $[\alpha]_D^{25}=+46.8$ (*c* 1.73, $CHCl_3$). ^1H NMR: 1.80–2.02 (m, 2H), 2.77 (t, $J=6.3$ Hz, 2H), 3.41 (t, $J=4.8$ Hz, 2H), 4.17–4.28 (m, 1H), 4.35–4.43 (m, 2H), 6.44 (t, $J=7.5$ Hz, 1H), 7.04 (d, $J=7.2$ Hz, 1H), 7.26–7.50 (m, 5H), 7.64–7.80 (m, 2H). IR: 3373, 2945, 2885, 2843, 1677, 1602, 1588, 1513, 1465, 1248, 1181, 1143 cm^{-1}. MS (*m*/*e*,%): 278 (8, M^+), 177 (58), 160 (40), 132 (29), 130 (25), 106 (100), 104 (47), 91 (11). HRMS calcd for $C_{18}H_{18}N_2O$: 278.1413. Found: 278.1415.

3.5. General procedure for enantioselective Ru(II)-catalyzed transfer hydrogenation

In a Schlenk tube, a solution of $[Ru(p\text{-cymene})Cl_2]_2$ (0.025 mmol) and ligand **2c** (0.11 mmol) in degassed 2-propanol (5 mL) was heated to 82°C for 1 h under nitrogen. After cooling to room temperature, a solution of acetophenone (1 mmol) in 2-propanol (2 mL) was added. The mixture was stirred for 10 min and then cooled to −20°C, KOH (2.5 mmol) in 2-propanol (2 mL) was added and the resulting mixture was stirred for additional 21 h. The reaction mixture was filtered through a pad of silica gel (washing with EtOAc). Concentration and purification by flash column chromatography on silica gel afforded (*S*)-1-phenylethanol in 46% yield with 83% e.e.

Acknowledgements

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References

1. *Chirality in Industry: The Commercial Manufacture and Applications of Optically Active Compounds*; Collins, A. N.; Sheldrake, G. N.; Crosby, J., Eds.; John Wiley & Sons: Chichester, 1992.
2. (a) *Catalytic Asymmetric Synthesis*; Ojima, I. Ed.; VCH: New York, 1993; (b) Noyori, R. *Asymmetric Catalysis in Organic Synthesis*; John Wiley & Sons: New York, 1994; (c) *Comprehensive Asymmetric Catalysis*; Jacobsen, E. N.; Pfaltz, A.; Yamamoto, H., Eds.; Springer: Berlin, 1999; Vols. I–III.
3. For reviews, see: (a) Noyori, R.; Hashiguchi, S. *Acc. Chem. Res.* **1997**, *30*, 97; (b) Zassinovich, G.; Mestroni, G.; Gladiali, S. *Chem. Rev.* **1992**, *92*, 1051.
4. (a) Hashiguchi, S.; Fujii, A.; Takehara, J.; Ikariya, T.; Noyori, R. *J. Am. Chem. Soc.* **1995**, *117*, 7562; (b) Takehara, J.; Hashiguchi, S.; Fujii, A.; Inoue, S.; Noyori, R. *Chem. Commun.* **1996**, 233; (c) Gao, J.-X.; Ikariya, T.; Noyori, R. *Organometallics* **1996**, *15*, 1087; (d) Haack, K.-J.; Hashiguchi, S.; Fujii, A.; Ikariya, T.; Noyori, R. *Angew. Chem., Int. Ed. Engl.* **1997**, *36*, 285; (e) Fujii, A.; Hashiguchi, S.; Uematsu, N.; Ikariya, T.; Noyori, R. *J. Am. Chem. Soc.* **1996**, *118*, 2521; (f) Matsumura, K.; Hashiguchi, S.; Ikariya, T.; Noyori, R. *J. Am. Chem. Soc.* **1997**, *119*, 8738; (g) Murata, K.; Ikariya, T.; Noyori, R. *J. Org. Chem.* **1999**, *64*, 2186; (h) Uematsu, N.; Fujii, A.; Hashiguchi, S.; Ikariya, T.; Noyori, R. *J. Am. Chem. Soc.* **1996**, *118*, 4916; (i) Hashiguchi, S.; Fujii, A.; Haack, K.-J.; Matsumura, K.; Ikariya, T.; Noyori, R. *Angew. Chem., Int. Ed. Engl.* **1997**, *36*, 288.
5. Yamakawa, M.; Ito, H.; Noyori, R. *J. Am. Chem. Soc.* **2000**, *122*, 1466.
6. Gamez, P.; Fache, F.; Lemaire, M. *Tetrahedron: Asymmetry* **1995**, *6*, 705.
7. Jiang, Y.-T.; Jiang, Q.-Z.; Zhang, X.-M. *J. Am. Chem. Soc.* **1998**, *120*, 3817.
8. Wu, X.-Y.; Li, X.-H.; Zhou, Q.-L. *Tetrahedron: Asymmetry* **1998**, *9*, 4143.
9. (a) Wu, X.-Y.; Xu, H.-D.; Zhou, Q.-L.; Chan, A. S. C. *Tetrahedron: Asymmetry* **2000**, *11*, 1255; (b) Wu, X.-Y.; Xu, H.-D.; Tang, F.-Y.; Zhou, Q.-L. *Tetrahedron: Asymmetry* **2001**, *12*, 2565.
10. Li, Z.-P.; Wu, X.-Y.; Zhou, Q.-L. *Chin. J. Chem.* **2001**, *19*, 40.
11. Chen, G.-H.; Hsu, J.-L.; Yang, W.-B.; Fang, J.-M.; Lee, G.-H.; Liu, Y.-H.; Wang, Y. *J. Chin. Chem. Soc.* **1999**, *46*, 797.
12. Hirao, A.; Itsuno, S.; Owa, M.; Nagami, S.; Mochizuki, H.; Zoorov, H. H. A.; Niakahama, S.; Yamazaki, N. *J. Chem. Soc., Perkin Trans. 1* **1981**, 900.
13. Carter, M. B.; Gutierrez, A.; Buchwald, S. L. *J. Am. Chem. Soc.* **1994**, *116*, 11667.
14. Collyer, T. A.; Kenyon, J. *J. Chem. Soc.* **1940**, 676.
15. (a) Lecomte, C.; Dusausoy, Y.; Protas, J.; Tirouflet, J.; Dormond, A. *J. Organomet. Chem.* **1974**, *73*, 67; (b) Stanley, K.; Baird, M. C. *J. Am. Chem. Soc.* **1975**, *97*, 6598; (c) Evans, D. A.; Nelson, S. G.; Gagne, M. R.; Muci, A. R. *J. Am. Chem. Soc.* **1993**, *115*, 9800.
16. (a) Nishio, M.; Hirota, M. *Tetrahedron* **1989**, *45*, 7201; (b) Nishio, M.; Hirota, M.; Umezawa, Y. *The CH/π Interaction, Evidence, Nature, and Consequences*; Wiley-VCH: New York, 1998.
17. For identification of 8-quinolinylcarboxamides **3**, see: Ref. 8.