APPLIED ORGANOMETALLIC CHEMISTRY
Appl. Organometal. Chem. 2001; **15**: 699–709
DOI: 10.1002/aoc.216

α-Amino acid: an effective ligand for asymmetric catalysis of transfer hydrogenation of ketones

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Ruthenium complexes, prepared by mixing the potassium salt of α-amino acids and $[RuCl_2(arene)]_2$, acted as catalysts for the asymmetric transfer hydrogenation of ketones from 2-propanol in the presence of KOH. For example, the transfer hydrogenation of acetophenone from 2-propanol was catalyzed effectively by the ruthenium complex prepared from potassium L-prolinate and $[RuCl_2(p\text{-cymene})]_2$ to give (*R*)-1-phenylethanol in 72% yield with 81% *ee*. The yields and enantioselectivities of the product were influenced strongly by the structure of the α-amino acidate ligand, arene ligand, and substrate, by the amount of additional base, and by the concentration of the substrates. The best enantiomeric excesses of the products was 92%, when 1-tetralone was subjected to this reaction using a prolinated ruthenium complex bearing *p*-cymene. Furthermore, the potassium salts of dipeptides were tested as a ligand for this transfer hydrogenation. Copyright © 2001 John Wiley & Sons, Ltd.

Keywords: α-amino acid; asymmetric transfer hydrogenation; ruthenium catalyst; chiral alcohol; dipeptide

Received 13 February 2001; accepted 28 March 2001

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Contract/grant sponsor: Doshisha University Research Promotion Fund.
Contract/grant sponsor: Ministry of Education, Japan.
Contract/grant sponsor: Kurata Foundation.
Contract/grant sponsor: Sumitomo Foundation.

INTRODUCTION

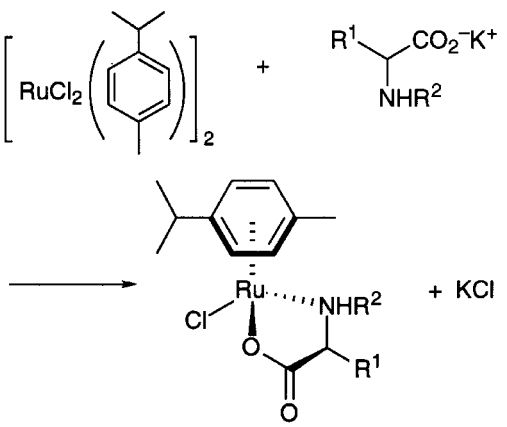
Asymmetric catalysis is one of the best methods for the synthesis of optically active organic compounds, and the structure of chiral ligands is the key factor of determining the asymmetric induction of the catalysis.[1–4] Therefore, many ligands have been prepared and tested. Even though a lot of chiral compounds are usable for obtaining excellent asymmetric induction in catalytic reactions as a ligand, most of them need to be prepared by multiple-step reactions or are not commercially available. Only a few-step transformations of naturally occurring chiral compounds sometimes gave good ligands like amino alcohols,[5–7] tartaric acid derivatives,[8,9] and alkaloids,[10] but the direct use of such compounds as ligands has rarely been successful.

α-Amino acids are chiral materials of the most readily available natural compounds. Although they have frequently been used for the synthesis of optically active compounds as starting materials,[11] their applications as ligands for asymmetric catalysis are limited.[12] We have now determined that α-amino acids are usable as an effective ligand for asymmetric transfer hydrogenation and wish to describe the utilization of α-amino acids as a ligand in this reaction of ketones from alcohols.[13] The asymmetric catalytic reduction of ketones by transfer hydrogenation now receives much attention from the viewpoint of laboratory synthesis because of its mild conditions and ease of operation; for reviews, see Refs 4 and 14–16 and references cited therein; for recent papers, see Refs 17–24. Noyori's group reported the highly efficient transfer hydrogenation of ketones by catalysts

prepared from ruthenium precursors and chiral amino alcohols or diamines.[25–31] Our catalysis reported in this article indicates that the readily obtainable chiral materials, *i.e.* the α-amino acids, are effective as a ligand for this transfer hydrogenation.

RESULTS AND DISCUSSION

Catalyst preparation



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α-Amino acidate–Ru complexes were prepared by the reaction of the α-amino acidate anion with $[RuCl_2(arene)]_2$ according to the literature method.[32] A mixture of a solution of $[RuCl_2(arene)]_2$ in CH_2Cl_2 and a solution of potassium α-amino acidate in water was vigorously stirred, and then dried in vacuo to give a mixture of two diastereomers in the ratio of 82:18, which was determined from the integral ratio of the signals assigned as aromatic protons (^{1}H NMR ($CDCl_3$) major isomer: 5.25 (d), 5.41 (d), 5.45 (d), 5.51 (d); minor isomer: 5.57 (d), 5.60 (d), 5.64 (d), 5.77 (d)). This ratio was somewhat changed by the other preparation methods and/or by several recrystallizations.

These complexes were subjected to the transfer hydrogenation of acetophenone in 2-propanol in the presence of potassium hydroxide. Even though the complex **1a** was produced in a mixture of two diastereomers, their ratio hardly influenced the catalytic activities and selectivities. Therefore, the diastereomeric mixture of the complex was used in this study.

Effects of α-amino acidate ligands

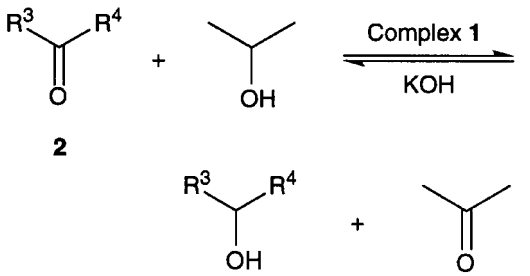

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Table 1 shows the results using various α-amino acidate–Ru complexes **1a–s**. The proline complex **1a** showed the best stereoselectivity among the α-amino acidate–Ru complexes used. The bulkiness of the substituent on the α-amino acidate moieties influenced the catalytic activity and the stereoselectivity. When a substituent on the α-carbon atom was a methyl group the reaction was fast, with only a 5% enantiomeric excess (*ee*). As the substituents became bulkier with *iso*-butyl, *iso*-propyl, and *sec*-butyl, the enantioselectivities of the products also became better, being 16% *ee*, 56% *ee*, and 63% *ee* respectively (entries 3–5), whereas 50% *ee* was obtained using *tert*-leucine (R^1 = *tert*-butyl, entry 6). The complexes **1g** and **1h** prepared from the amino dicarboxylic acid mono potassium salt showed no catalytic activities, but the complexes prepared from the dipotassium salts exhibited some catalytic activities with moderate enantioselectivities. The complexes having an aromatic substituent as R^1 showed good catalytic activities with moderate to good enantioselectivities.

The five-membered ring in proline is considered to produce a rigid asymmetric condition on the ruthenium center, and, therefore, a better enantiomeric excess was obtained using **1a**. Using an (*S*)-indoline-2-carboxylic acid as the amino acid, which also has a five-membered ring, gave **3a** in high yield with good enantioselectivity (entry 21). As these two amino acids are secondary amines, the *N*-substituted amino acids were also used for this reaction (entries 18–20), but the yields and enantiomeric excesses decreased. Further substituents on the nitrogen atom of proline made the reaction very sluggish (entry 22).

We examined the catalytic activity of the prolinol–Ru complex, in which prolinol was prepared by the reduction of proline, and realized that the enantiomeric excess of the product, 1-

Table 1 Enantioselective transfer hydrogenation of acetophenone (**2a**) in 2-propanol catalyzed by ruthenium (II) complexes bearing α-amino acid[a]

	Catalyst (**1**)				1-Phenylethanol (**3a**)		
Entry	R^1	R^2			Yield[b] (%)	% *ee*[c]	Config.[d]
1	—$(CH_2)_3$—		**1a**	(*S*)-Proline	72	81	*R*
2	Me	H	**1b**	(*S*)-Alanine	95	5	*R*
3	*iso*-Pr	H	**1c**	(*S*)-Valine	79	56	*R*
4	*iso*-Bu	H	**1d**	(*S*)-Leucine	64	16	*R*
5	*sec*-Bu	H	**1e**	(*S*)-Isoleucine	72	63	*R*
6	*tert*-Bu	H	**1f**	(*S*)-*tert*-Leucine	60	50	*R*
7	—CH_2CO_2H	H	**1g**	(*S*)-Aspartic acid	0	–	–
8[e]	—CH_2CO_2H	H	**1g**	(*S*)-Aspartic acid	4	58	*R*
9	—$(CH_2)_2CO_2H$	H	**1h**	(*S*)-Glutamic acid	0	–	–
10[e]	—$(CH_2)_2CO_2H$	H	**1h**	(*S*)-Glutamic acid	68	48	*R*
11	—CH_2OH	H	**1i**	(*S*)-Serine	0	–	–
12	—$(CH_2)_4NH_2$	H	**1j**	(*S*)-Lysine	29	∼0	–
13	Ph	H	**1k**	(*R*)-α-Phenylglycine	98	37	*S*
14	Bn	H	**1l**	(*S*)-Phenylalanine	74	28	*R*
15[e]	—$CH_2C_6H_4$-*p*-OH	H	**1m**	(*S*)-Tyrosine	87	57	*R*
16	—CH_2-3-Indole	H	**1n**	(*S*)-Tryptophan	51	66	*R*
17	—CH_2-4-Imidazole	H	**1o**	(*S*)-Histidine	0	–	–
18[e]	Bn	Bn	**1p**	(*S*)-*N*-Benzyl-L-phenylalanine	48	9	*R*
19[e,f]	Bn	Bn	**1p**	(*S*)-*N*-Benzyl-L-phenylalanine	5	16	*R*
20[e]	Bn	Et	**1q**	(*S*)-*N*-Ethyl-L-phenylalanine	11	3	*S*
21	—$CH_2-(o-C_6H_4)$—		**1r**	(*S*)-Indoline-2-carboxylic acid	90	60	*R*
22	—$(CH_2)_3$—, Bn (R^2)		**1s**	(*S*)-*N*-Benzylproline	trace	–	–

[a] The reaction was carried out at room temperature using a 0.1 M solution of acetophenone (2.5 mmol) in 2-propanol for 24 h. Acetophenone:Ru:KOH = 1:0.01:0.01. Catalyst was prepared by Method A (see Experimental section).
[b] Yield was determined by GLC.
[c] Determined by HPLC analysis (see Experimental section).
[d] Determined from the sign of rotation of the isolated product.
[e] Preparation of catalyst: Method B (see Experimental section).
[f] Acetophenone:Ru:KOH = 1:0.01:0.02.

phenylethanol, was 37% (*R*). The difference between proline and prolinol as a ligand was considered to be due to the rigidity of the carbon atom attached to the oxygen in the metallacycle. Namely, this carbon in proline has sp^2 hybridization, whereas that in prolinol has sp^3 hybridization.

Effect of reaction conditions

For this reaction, the use of an equimolar amount of KOH to the ruthenium complex was effective (Table 2). Using two equivalents of KOH decreased the yield and the enantiomeric excess (entry 5), whereas no reaction occurred without KOH (entry 1). KOH is considered to approach complex **1** for the generation of catalytically active species, which may have a structure similar to that noted by Noyori and coworkers.[29] On the other hand, an excess amount of KOH could take away the α-amino acidate ligand from the ruthenium center, resulting in a low catalytic activity and selectivity. When using NEt_3 as a base, no reaction occurred. At 0 °C, the hydrogenation proceeded very slowly (entry 6).

The effect of the concentration of acetophenone was investigated. The reaction at a higher concentration of acetophenone (1.0 M) afforded a lower yield of 1-phenylethanol (49% after 24 h) than that at a lower concentration (72% after 24 h) with almost the same stereoselectivity (79% *ee* and 81% *ee* respectively) (Table 3). Interestingly, during the early stage of this reaction (after 1 h), the enantiomeric excesses were higher in both cases than those after 24 h. Consequently, a low concentration of the substrate **2** was a better choice for this reaction.

This reaction is basically under equilibrium, and

Table 2 Effect of KOH on the asymmetric transfer hydrogenation of acetophenone (**2a**) in 2-propanol catalyzed by ruthenium complex **1a**[a]

Entry	Catalyst (**1a**) (eq. to **2a**)	KOH (eq. to **2a**)	1-Phenylethanol (**3a**)		
			Yield[b] (%)	% *ee*[c]	Config.[c]
1	0.010	None	0	–	–
2	0.030	0.010	73	79	*R*
3	0.030	0.030	98	73	*R*
4	0.010	0.010	72	81	*R*
5	0.005	0.010	6	42	*R*
6[d]	0.010	0.010	3	75	*R*

[a] The reaction was carried out at room temperature using a 0.1 M solution of acetophenone (**2a**, 5.0 mmol) in 2-propanol for 24 h.
[b] Yield was determined by GLC.
[c] Determined by HPLC analysis (see Experimental section).
[d] The reaction was carried out at 0 °C.

the dehydrogenation reactions of alcohols were carried out in order to know which enantiomer reacted easily in the reverse reaction. The solution of the racemic 1-phenylethanol in acetone in the presence of **1a** and KOH was stirred at room temperature. After 72 h, 1-phenylethanol was recovered in 71% yield with 16% *ee* (*S*) by chromatographic analysis. Furthermore, the efficient kinetic resolution of the racemic 1-tetralol with acetone in 2-propanol occurred, and the 87% *ee* of (*S*)-1-tetralol was recovered in 45% yield. In both cases, the (*R*)-configuration alcohols were obtained from the asymmetric transfer hydrogenation (Table 5, *vide infra*) by **1a**. In contrast, during the kinetic resolution of the racemic alcohols, **3a** and **3p**, the (*R*)-configuration alcohols reacted faster than the (*S*)-isomer. Therefore, the reverse reaction, *i.e.* dehydrogenation of the alcohol produced, may reduce the enantiomeric excesses of the product.

Several arene ligands were also investigated (Table 4). Noyori and coworkers reported that the arene ligand affected the catalytic activities and enantioselectivities.[25–31] In our case, the complex bearing *p*-cymene gave the best yield and selectivity for the reaction of **2a**. Using benzene, mesitylene, and hexamethylbenzene as an arene ligand of the catalyst resulted in various yields (11–38%) of the product with similar moderate enantiomeric excesses (59–67%).

Reduction of various ketones

Various ketones were used for this transfer hydro-

Table 3 Effect of the concentration of **2a** on the asymmetric transfer hydrogenation of **2a** in 2-propanol[a]

Entry	Conc. of **2a** (M)	1-Phenylethanol (**3a**)		
		Yield (%)[b]	% *ee*[c]	Config.[c]
1[d]	0.10	7	88	*R*
2	0.10	72	81	*R*
3[d]	1.00	8	85	*R*
4	1.00	49	79	*R*

[a] The reaction was carried out at room temperature in 2-propanol for 24 h. Acetophenone:Ru:KOH = 1:0.01:0.01.
[b] Yield was determined by GLC.
[c] Determined by HPLC analysis (see Experimental section).
[d] Reaction time 1 h.

Table 4 Effects of arene ligands in ruthenium complexes on asymmetric transfer hydrogenation of **2a** in 2-propanol[a]

		1-Phenylethanol (**3a**)		
Entry	Arene	Yield (%)[b]	% *ee*[c]	Config.[c]
1	Benzene	11	62	*R*
2	*p*-Cymene	72	81	*R*
3	Mesitylene	13	59	*R*
4	Hexamethylbenzene	38	67	*R*

[a] The reaction was carried out at room temperature using a 0.1 M solution of acetophenone (2.5 mmol) in 2-propanol for 24 h. Acetophenone:Ru:KOH = 1:0.01:0.01.
[b] Yield was determined by GLC.
[c] Determined by HPLC analysis (see Experimental section).

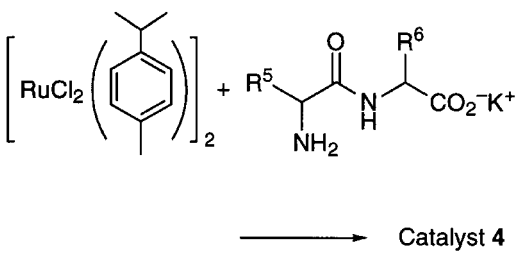
genation (Table 5). The reactivity was sometimes not high, but moderate to good enantiomeric excesses were obtained. Hydrogenation proceeded smoothly at higher temperatures, but the enantioselectivity decreased (entries 2 and 3). For the phenyl alkyl ketones, linear alkyl substituents influenced the yield but not the enantiomeric excesses (around 80% *ee*, entries 1–6). Phenyl alkyl ketones with sterically hindered substituents were reduced to the corresponding alcohols with low enantiomeric excesses (entries 7 and 8). The dialkyl ketone, cyclohexyl methyl ketone, was also able to be reduced in low yield with 64% *ee*. The reaction of the substituted acetophenone (entries 1, 11–15) showed that the enantioselectivity was not significantly affected by the type of substituent (methoxy or chloride at meta or para positions) but *o*-chloroacetophenone was reduced in high yield with low enantiomeric excess (entry 13). The 1-naphthyl and 2-naphthyl methyl ketones were hydrogenated in the same yields with different selectivities. The reduction of the cyclic ketones was very slow, but the highest enantioselectivity was obtained for the reaction of the 1-tetralone.

Employment of the keto esters, such as ethyl 3-oxobutanoate, ethyl 3-oxo-3-phenylpropanoate, ethyl 2-oxopropanoate, and ethyl benzoylformate, resulted in no reaction under standard conditions.

Our attempts to isolate and/or identify the intermediary complex failed. That is, the reaction of a catalyst precursor **1a** with KOH in 2-propanol gave a complex mixture and no hydride was observed from the ^{1}H NMR spectroscopy. Although there is no information about the intermediate, the hydride species might be as an intermediate for this reaction because one equivalent of KOH is required for catalytic acitivity.

Effects of dipeptide ligand

Next, we tried dipeptides as a ligand for this asymmetric transfer hydrogenation. The catalysts were prepared by the mixing of $[RuCl_2(p\text{-cymene})]_2$ and a potassium salt of dipeptide, and used directly.



Asymmetric transfer hydrogenation was done by use of 2-propanol as a solvent in the presence of two equivalents of KOH to ruthenium catalyst (Table 6), whereas no reaction occurred by use of an equimolar amount of KOH to ruthenium catalyst. Basically, R^5 substituents on dipeptide ligands affected the yields of the product. When R^5 is hydrogen, yields of the product were low except when using **4f**, and yields of the product became better by use of the peptides having methyl or isobutyl as R^5. R^6 substituents on the dipeptide ligand influenced the enantioselectivities of the product. In cases of small substituents (R^6), such as hydrogen, methyl, dimethylenecarboxyl, trimethy-

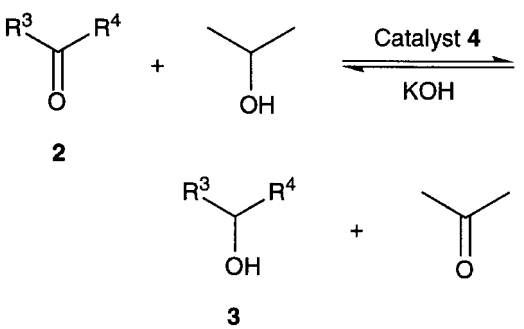
Table 5 Asymmetric transfer hydrogenation of ketones **2** catalyzed by ruthenium complex **1a** in 2-propanol[a]

Entry	Substrate **2**			Alcohol **3**		
		R^3	R^4	Yield (%)[b]	% *ee*[c]	Config.[d]
1	**2a**	Ph	Me	72	81	*R*
2	**2b**	Ph	Et	30	87	*R*
3[e]	**2b**	Ph	Et	69	79	*R*
4[f]	**2b**	Ph	Et	83	77	*R*
5	**2c**	Ph	*n*-Pr	21[g]	88	*R*
6[h]	**2c**	Ph	*n*-Pr	47[g]	85	*R*
7	**2d**	Ph	*iso*-Pr	27[g]	63	*R*
8	**2e**	Ph	*tert*-Bu	64	19	–
9	**2f**	Ph	Cyclohexyl	38[g]	75	*R*
10	**2g**	Cyclohexyl	Me	23[g]	64	–
11	**2h**	*m*-$MeOC_6H_4$	Me	74	68	*R*
12	**2i**	*p*-$MeOC_6H_4$	Me	37	62	*R*
13	**2j**	*o*-ClC_6H_4	Me	98	32	*R*
14	**2k**	*m*-ClC_6H_4	Me	76	76	*R*
15	**2l**	*p*-ClC_6H_4	Me	81	61	*R*
16	**2m**	1-Naphthyl	Me	64[g]	82	*R*
17	**2n**	2-Naphthyl	Me	63[g]	58	*R*
18	**2o**	1-Indanone		6	43	–
19	**2p**	1-Tetralone		8	92	*R*
20[e]	**2p**	1-Tetralone		37	92	*R*

[a] The reaction was carried out at room temperature using a 0.1 M solution of acetophenone (2.5 mmol) in 2-propanol for 24 h. Acetophenone:Ru:KOH = 1:0.01:0.01.
[b] Yield was determined by GLC.
[c] Determined by HPLC analysis (see Experimental section).
[d] Determined from the sign of rotation of the isolated product.
[e] At 50 °C for 5 h.
[f] At 50 °C.
[g] Isolated yield.
[h] Reaction time 72 h.

lene, only racemic products were obtained. Overall, the level of enantiomeric induction was low. Probably, this is due to the structure of the ruthenium complex, which may be coordinated by carboxylate and the nitrogen atom of the amine to form an eight-membered metallacycle.

2-Methyl-1-phenyl-1-propanone and 1-tetralone were tested for this transfer hydrogenation using **4l, 4m** and **4n** as a catalyst (Table 7). The yields and the stereoselectivities were not high. These results showed that the dipeptides used are not good ligands for this reaction.



CONCLUSION

The asymmetric transfer hydrogenation of ketones from 2-propanol was achieved by use of an α-amino acidate ruthenium catalyst. This reaction is considered to be the first efficient catalysis directly using an α-amino acid as a ligand. On the other hand, dipeptide ligands are not good ligands for this catalysis.

Table 6 Effect of dipeptide ligands in ruthenium complexes[a]

Entry	4				1-Phenylethanol		
		R^5	R^6		Yield (%)[b]	% *ee*[c]	Config.[c]
1	**4a**	H	*iso*-Pr	Glycyl-L-valine	22	27	*S*
2	**4b**	H	*iso*-Bu	Glycyl-L-leucine	33	22	*S*
3	**4c**	H	*sec*-Bu	Glycyl-L-isoleucine	19	41	*S*
4	**4d**	H	—$(CH_2)_2CO_2H$	Glycyl-L-glutamic acid	9	*racemic*	–
5	**4e**	H	—$(CH_2)_3$—	Glycyl-L-proline	6	*racemic*	–
6	**4f**	H	Bn	Glycyl-L-phenylalanine	>99	33	*S*
7	**4g**	H	—CH_2—C_6H_4-*p*-OH	Glycyl-L-tyrosine	63	41	*S*
8	**4h**	H	—CH_2-3-Indole	Glycyl-L-tryptophan	29	41	*S*
9	**4i**	H	—CH_2-4-Imidazole	Glycyl-L-histidine	Trace	–	–
10	**4j**	*iso*-Bu	H	L-Leucylglycine	90	*racemic*	–
11	**4k**	*iso*-Bu	Me	L-Leucyl-L-alanine	78	*racemic*	–
12	**4l**	*iso*-Bu	—CH_2—C_6H_4-*p*-OH	L-Leucyl-L-tyrosine	89	29	*S*
13	**4m**	Me	—CH_2—C_6H_4-*p*-OH	L-Alanyl-L-tyrosine	>99	43	*S*
14	**4n**	Me	—CH_2-3-Indole	L-Alanyl-L-tryptophan	>99	39	*S*
15	**4o**	Me	Me	L-Alanyl-L-alanine	91	*racemic*	–
16	**4p**	D,L-Me	Bn	D,L-Alanyl-L-phenylalanine	84	29	*S*

[a] The reaction was carried out at room temperature using a 0.1 M solution of acetophenone (2.5 mmol) in 2-propanol for 24 h. Acetophenone:[**4**]:KOH = 1:0.01:0.02.
[b] Yield was determined by GLC.
[c] Determined by HPLC analysis using a Daicel Chiralcel OD-H column (eluent, 95:5 hexane/2-propanol; flow rate, 0.30 ml min^{-1}; UV 254 nm.).

EXPERIMENTAL

General

All solvents were dried by standard methods and distilled under argon.[33] Commercially available compounds were used without further purification. $RuCl_3 \cdot nH_2O$ was purchased from Mitsuwa Chemicals. All other chemicals, including the substrates and amino acids, were purchased from Wako Pure Chemical Industries, Ltd, Tokyo Kasei Kogyo Co., Ltd, Nacalai Tesque, Inc., or Aldrich. $[RuCl_2(p\text{-cymene})]_2$, $[RuCl_2(\text{benzene})]_2$, $[RuCl_2(\text{mesitylene})]_2$, and $[RuCl_2(\text{hexamethylbenzene})]_2$ were prepared by procedures according to the literature.[34] All products were identified by ^1H NMR analysis by comparison with that of purchased authentic samples.

^1H NMR spectra were measured on a JEOL JNM-A400 (400 MHz) spectrometer using tetramethylsilane as the internal standard. IR spectra were measured on a JEOL IR810 spectrometer. Optical rotations were recorded on a Horiba SEPA-200 spectrophotometer. The gas chromatography analyses were performed using a Shimadzu GC-14A. Liquid chromatographic analyses were conducted using a Hitachi L-7100 (Daicel Chiralcel OD-H, 4.6 mm × 0.25 m) and a Shimadzu LC-6A (Daicel Chiralcel OJ-R, 4.6 mm × 0.15 m) attached with an RID-6A refractive index detector.

Preparation of amino acidate–ruthenium complexes

Method A

This is a typical procedure for the preparation of α-amino acidate–Ru complexes. A solution of potassium (*S*)-2-pyrrolidinecarboxylate in water (2.5 ml, 0.50 mmol), which was prepared by mixing L-(−)-proline (0.23 g, 2.0 mmol) and KOH (0.11 g, 2.0 mmol) in water (10 ml), was added dropwise to a solution of $[RuCl_2(p\text{-cymene})]_2$ (0.15 g, 0.25 mmol) in CH_2Cl_2 (2.5 ml). After stirring for 1 h, solvent was removed *in vacuo* to give an orange solid. This solid was used for catalytic reaction without further purification.

Method B

A solution of potassium α-amino acidate in water was prepared by mixing amino acid (2.0 mmol) and KOH (0.22 g, 4.0 mmol) in water (10 ml). This solution (2.5 ml) was added to a solution of $[RuCl_2(p\text{-cymene})]_2$ (0.15 g, 0.25 mmol) in CH_2Cl_2 (2.5 ml), and the mixture was stirred for 1 h. The

Table 7 Enantioselective transfer hydrogenation of ketones catalyzed by **4l–n**[a]

Entry	Substrate		Catalyst	Alcohol		
	R^3	R^4		Yield (%)[b]	% *ee*[c]	Config.[c]
1	Ph	*iso*-Pr	**4l**	5	24	*S*
2	Ph	*iso*-Pr	**4m**	88	23	*S*
3	Ph	*iso*-Pr	**4n**	61	25	*S*
4	1-Tetralone		**4l**	57	41	*S*
5	1-Tetralone		**4m**	65	24	*S*
6	1-Tetralone		**4n**	57	43	*S*

[a] The reaction was carried out at room temperature using a 0.1 M solution of acetophenone (2.5 mmol) in 2-propanol for 24 h. Acetophenone:catalyst:KOH = 1:0.01:0.02.
[b] Yield was determined by GLC.
[c] Determined by HPLC analysis using a Daicel Chiralcel OD-H column.

solid materials obtained by concentration of the above mixture were used directly for catalytic reaction.

Method C
A solution of potassium salt of dipeptide in water was prepared by mixing dipeptide (2.0 mmol) and KOH (0.22 g, 4.0 mmol) in water (20 ml). This solution (5.0 ml) was added to a solution of $[RuCl_2(p\text{-cymene})]_2$ (0.15 g, 0.25 mmol) in CH_2Cl_2 (5.0 ml), and the mixture was stirred for 1 h. The solid materials obtained by concentration of the above mixture were used directly for catalytic reaction.

Asymmetric transfer hydrogenation: typical procedure

The reaction was typically performed as follows. A solution of acetophenone (600 mg, 5.0 mmol) in 2-propanol (49.5 ml) and a solution of KOH in 2-propanol (0.10 mol dm^{-3}, 0.50 ml, 5.0×10^{-2} mmol) were mixed and degassed by five freeze–thaw cycles. This was introduced into an 80 ml Schlenk tube containing ruthenium complex **1a** (23 mg, 5.0×10^{-2} mmol) under argon atmosphere. The resulting mixture was stirred for 24 h at room temperature. This solution was neutralized by adding 1.0 M hydrochloric acid, and the solvent was removed under reduced pressure. To the residue were added water and ethyl acetate. The organic layer was separated, washed with brine, dried over $MgSO_4$, and concentrated. Purification by column chromatography (silica gel 200, hexane:ethyl acetate = 4:1) gave the desired product 1-phenylethanol (440 mg) in 72% yield with 81% *ee* (Daicel Chiralcel OD-H or OJ-R).

1-Phenylethanol (3a)
^{1}H NMR ($CDCl_3$) δ 1.49 (3H, d, $J = 6.4$), 1.95 (1H, s), 4.88 (1H, q, $J = 6.4$), 7.25–7.38 (5H, m). IR (NaCl) 3300, 3020, 2960, 2900, 2850, 1590, 1485, 1450, 1365, 1200, 1070, 1025, 1005, 950, 890, 750, 695 cm^{-1}. (*R*)-**3a** of 83% *ee*: $[\alpha]_D^{23}$ 44.0 (*c* 1.0, CH_2Cl_2) (lit.[35] (*R*)-**3a** of 96% *ee*: $[\alpha]_D$ 48.6 (*c* 0.9–1.1, CH_2Cl_2)); Daicel Chiralcel OD-H, hexane/2-propanol = 19, 0.30 ml min^{-1}, UV 254 nm; $t_R = 24.2$ (*R*) and 27.3 min (*S*) or Daicel Chiralcel OJ-R, methanol/H_2O = 2/3, 0.50 ml min^{-1}, UV 254 nm; $t_R = 49.8$ (*S*) and 58.2 min (*R*).

1-Phenyl-1-propanol (3b)
^{1}H NMR ($CDCl_3$) δ 0.92 (3H, t, $J = 7.0$), 1.69–1.88 (2H, m), 1.91 (1H, d, $J = 2.4$), 4.59 (1H, dt, $J = 7.0$ and 2.4), 7.25–7.37 (5H, m). IR (NaCl) 3300, 3030, 3005, 2940, 2900, 2850, 1595, 1485, 1445, 1370, 1320, 1190, 1085, 1035, 1005, 970, 910, 890, 750, 695 cm^{-1}. (*R*)-**3b** of 87% *ee*: $[\alpha]_D^{23}$ 42.0 (*c* 1.0, $CHCl_3$) (lit.[36] (*R*)-**3b** of 96% *ee*: $[\alpha]_D$ 49.0 (*c* 1.0, $CHCl_3$)); Daicel Chiralcel OD-H, hexane/2-propanol = 99, 0.30 ml min^{-1}, UV 254 nm; $t_R = 33.0$ (*R*) and 35.3 min (*S*).

1-Phenyl-1-butanol (3c)
^{1}H NMR ($CDCl_3$) δ 0.93 (3H, t, $J = 7.0$), 1.24–1.49 (2H, m), 1.63–1.84 (2H, m), 1.89 (1H, s) 4.67 (1H, t, $J = 7.0$), 7.24–7.37 (5H, m). IR (NaCl) 3325, 3160, 3030, 2950, 2910, 2860, 1945, 1880, 1800, 1600, 1490, 1450, 1375, 1305, 1200, 1105, 1060, 1025, 985, 955, 915, 900, 855, 820, 760, 700 cm^{-1}. (*R*)-**3c** of 85% *ee*: $[\alpha]_D^{23}$ 45.6 (*c* 2.74, $CHCl_3$) (lit.[36] (*R*)-**3c** of 94% *ee*: $[\alpha]_D$ 50.6 (*c* 1, $CHCl_3$)); Daicel

Chiralcel OD-H, hexane/ethanol = 99, 0.30 ml min^{-1}, UV 254 nm; t_R = 33.5 (*R*) and 37.8 min (*S*).

2-Methyl-1-phenyl-1-propanol (3d)
^{1}H NMR ($CDCl_3$) δ 0.80 (3H, d, J = 6.6), 1.00 (3H, d, J = 6.6), 1.87 (1H, d, J = 2.8), 1.92–2.00 (1H, m), 4.36 (1H, heptet of d, J = 6.6, 2.8), 7.24–7.36 (5H, m). IR (NaCl) 3050, 3020, 2900, 1600, 1488, 1465, 1445, 1375, 1360, 1165, 1120, 1010, 745, 700 cm^{-1}. (*R*)-**3d** of 63% *ee*: $[\alpha]_D^{23}$ 26.3 (*c* 0.8, diethyl ether) (lit.[37] (*R*)-**3d** of 73% *ee*: $[\alpha]_D$ 34.8 (*c* 1.0, diethyl ether)); Daicel Chiralcel OD-H, hexane/2-propanol = 19, 0.50 ml min^{-1}, UV 254 nm; t_R = 12.0 (*R*) and 14.1 min (*S*).

2,2-Dimethyl-1-phenyl-1-propanol (3e)
^{1}H NMR ($CDCl_3$) δ 0.92 (9H, s), 1.88 (1H, d, J = 2.8), 4.40 (1H, d, J = 2.8), 7.25–7.32 (5H, m). IR (NaCl) 3410, 3040, 3010, 2940, 2890, 2850, 1600, 1580, 1485, 1470, 1445, 1390, 1380, 1360, 1350, 1300, 1230, 1195, 1175, 1150, 1080, 1045, 1025, 1005, 930, 915, 895, 830, 780, 735, 700 cm^{-1}. 19% *ee* by Daicel Chiralcel OD-H, hexane/2-propanol = 19, 0.50 ml min^{-1}, UV 254 nm; t_R = 11.9 and 16.6 min.

Cyclohexylphenylmethanol (3f)
^{1}H NMR ($CDCl_3$) δ 0.87–1.28 (5H, m), 1.35–1.38 (1H, m), 1.56–1.67 (3H, m), 1.74–1.78 (1H, m), 1.92–2.00 (2H, m), 4.35 (1H, d, J = 7.6), 7.24–7.36 (5H, m). IR (NaCl) 3350, 3040, 3010, 2910, 2840, 2650, 1600, 1490, 1445, 1385, 1345, 1300, 1260, 1195, 1080, 1065, 1015, 955, 910, 890, 870, 845, 820, 760, 700, 670 cm^{-1}. (*R*)-**3f** of 75% *ee*: $[\alpha]_D^{23}$ 23.3 (*c* 3.0, benzene) (lit.[38] (*S*)-**3f** $[\alpha]_D$ −28.27 (*c* 3.29, benzene)); Daicel Chiralcel OD-H, hexane/2-propanol = 9, 0.50 ml min^{-1}, UV 254 nm; t_R = 10.2 (*R*) and 12.0 min (*S*).

1-Cyclohexylethanol (3g)
^{1}H NMR ($CDCl_3$) δ 0.91–1.31 (6H, m), 1.16 (3H, d, J = 6.4), 1.38 (1H, s), 1.66–1.87 (5H, m), 3.55 (1H, q, J = 6.4). IR (NaCl) 3320, 2950, 2910, 2830, 1445, 1370, 1310, 1260, 1185, 1150, 1125, 1095, 1085, 1060, 1040, 940, 890, 870, 855, 830 cm^{-1}. 1-Cyclohexylethyl 2-naphthoate: ^{1}H NMR ($CDCl_3$) δ 1.07–1.31 (6H, m), 1.35 (3H, d, J = 6.4), 1.61–1.91 (5H, m), 5.06 (1H, q, J = 6.4), 7.52–7.60 (2H, m), 7.88 (2H, d, J = 8.4), 7.97 (1H, d, J = 8.0), 8.07 (1H, dd, J = 8.4, 1.6), 8.60 (1H, s). IR (NaCl) 3040, 2960, 2910, 2840, 1710, 1625, 1595, 1575, 1505, 1460, 1445, 1350, 1320, 1275, 1225, 1195, 1130, 1090, 1055, 1030, 955, 925, 890, 865, 825, 780, 760 cm^{-1}. 64% *ee* by Daicel Chiralcel OD-H, hexane/2-propanol = 99, 0.30 ml min^{-1}, UV 254 nm; t_R = 16.3 and 18.8 min.

1-(3-Methoxyphenyl)ethanol (3h)
^{1}H NMR ($CDCl_3$) δ 1.50 (3H, d, J = 6.4), 1.89 (1H, s), 3.82 (3H, s), 4.88 (1H, q, J = 6.4), 6.80–6.83 (1H, m), 6.94–6.96 (2H, m), 7.25–7.29 (1H, m). IR (NaCl) 3350, 2970, 2830, 1595, 1485, 1450, 1430, 1365, 1315, 1250, 1190, 1155, 1105, 1070, 1045, 1020, 920, 855, 785, 720, 720 cm^{-1}. (*R*)-**3h** of 68% *ee*: $[\alpha]_D^{23}$ 27.0 (*c* 1.0, MeOH) (lit.[39] (*R*)-**3h** of 97% *ee*: $[\alpha]_D$ 35.0 (*c* 1.0, MeOH)); Daicel Chiralcel OD-H, hexane/2-propanol = 9, 0.50 ml min^{-1}, UV 254 nm; t_R = 14.9 (*R*) and 16.7 min (*S*).

1-(4-Methoxyphenyl)ethanol (3i)
^{1}H NMR ($CDCl_3$) δ 1.48 (3H, d, J = 6.4), 1.82 (1H, s), 3.80 (3H, s), 4.86 (1H, q, J = 6.4), 6.87–6.90 (2H, m), 7.26–7.32 (2H, m). IR (NaCl) 3350, 2970, 2830, 2050, 1885, 1605, 1580, 1505, 1455, 1365, 1300, 1240, 1175, 1085, 1035, 895, 830 cm^{-1}. (*R*)-**3i** of 62% *ee*: $[\alpha]_D^{23}$ 34.3 (*c* 1.17, $CHCl_3$) (lit.[35] (*R*)-**3i** of 89% *ee*: $[\alpha]_D$ 47.2 (*c* 0.9–1.1, $CHCl_3$)); Daicel Chiralcel OD-H, hexane/2-propanol = 99, 0.50 ml min^{-1}, UV 220 nm; t_R = 45.3 (*R*) and 51.0 min (*S*).

1-(2-Chlorophenyl)ethanol (3j)
^{1}H NMR ($CDCl_3$) δ 1.49 (3H, d, J = 6.4), 2.03 (1H, s), 5.29 (1H, q, J = 6.4), 7.18–7.22 (1H, m), 7.26–7.34 (2H, m), 7.59 (1H, dd, J = 8.0, 1.6). IR (NaCl) 3300, 3060, 2970, 2920, 1920, 1800, 1590, 1570, 1470, 1430, 1365, 1260, 1200, 1130, 1090, 1070, 1050, 1035, 1010, 945, 900, 750, 690 cm^{-1}. (*R*)-**3j** of 32% *ee*: $[\alpha]_D^{23}$ 19.4 (*c* 0.124, $CHCl_3$) (lit.[40] (*S*)-**3j** of 90% *ee*: $[\alpha]_D$ −56.5 (*c* 0.0463, $CHCl_3$)); Daicel Chiralcel OD-H, hexane/2-propanol = 166, 0.50 ml min^{-1}, UV 254 nm; t_R = 26.1 (*R*) and 27.7 min (*S*).

1-(3-Chlorophenyl)ethanol (3k)
^{1}H NMR ($CDCl_3$) δ 1.48 (3H, d, J = 6.4), 1.98 (1H, s), 4.87 (1H, q, J = 6.4), 7.20–7.31 (3H, m), 7.37 (1H, s). IR (NaCl) 3300, 3060, 2970, 2920, 2875, 1935, 1870, 1705, 1595, 1570, 1470, 1425, 1365, 1335, 1255, 1200, 1110, 1075, 1010, 910, 880, 810, 785, 695 cm^{-1}. (*R*)-**3k** of 76% *ee*: $[\alpha]_D^{23}$ 30.8 (*c* 1.8, acetone) (lit.[41] (*R*)-**3k** of 100% *ee*: $[\alpha]_D$ 38.6 (*c* 1.50, acetone)); Daicel Chiralcel OD-H, hexane/2-propanol = 199, 0.30 ml min^{-1}, UV 254 nm; t_R = 47.5 (*R*) and 50.3 min (*S*).

1-(4-Chlorophenyl)ethanol (3l)
^{1}H NMR ($CDCl_3$) δ 1.47 (3H, d, J = 6.4), 1.90 (1H, s), 4.88 (1H, q, J = 6.4), 7.26–7.33 (4H, m). IR (NaCl) 3300, 2970, 2920, 1900, 1710, 1645, 1595,

1575, 1490, 1445, 1400, 1365, 1330, 1290, 1200, 1085, 1010, 895, 830, 775, 720 cm^{-1}. (*R*)-**31** of 61% *ee*: $[\alpha]_D^{23}$ 29.0 (*c* 1.0, diethyl ether) (lit.[35] (*R*)-**31** of 91% *ee*: $[\alpha]_D$ 46.1 (*c* 0.9–1.1, diethyl ether)); Daicel Chiralcel OD-H, hexane/2-propanol = 99, 0.50 ml min^{-1}, UV 254 nm; t_R = 19.8 (*R*) and 22.1 min (*S*).

1-(1-Naphthyl)ethanol (3m)
^{1}H NMR ($CDCl_3$) δ 1.68 (3H, d, *J* = 6.6), 1.94 (1H, s), 5.99 (1H, q, *J* = 6.6), 7.47–7.55 (3H, m), 7.69 (1H, d, *J* = 7.2), 7.88 (1H, d, *J* = 7.99), 7.87–7.89 (1H, m), 8.13 (1H, d, *J* = 8.4). IR (NaCl) 3300, 3060, 3020, 2920, 2850, 2650, 1920, 1810, 1600, 1580, 1490, 1450, 1335, 1275, 1210, 1150, 1115, 1065, 1040, 1000, 960, 910, 880, 870, 850, 800, 770, 735 cm^{-1}. (*R*)-**3m** of 82% *ee*: $[\alpha]_D^{23}$ 67.0 (*c* 1.0, diethyl ether) (lit.[42] (*R*)-**3m** of 99% *ee*: $[\alpha]_D$ 82.1 (*c* 1.0, diethyl ether)); Daicel Chiralcel OD-H, hexane/2-propanol = 9, 0.50 ml min^{-1}, UV 254 nm; t_R = 17.0 (*R*) and 26.2 min (*S*).

1-(2-Naphthyl)ethanol (3n)
^{1}H NMR ($CDCl_3$) δ 1.58 (3H, d, *J* = 6.4), 1.97 (1H, s), 5.06 (1H, q, *J* = 6.4), 7.45–7.51 (3H, m), 7.80–7.84 (4H, m). IR (Nujol) 3280, 1590, 1270, 1160, 1120, 1070, 1020, 950, 900, 860, 825, 740 cm^{-1}. (*R*)-**3n** of 58% *ee*: $[\alpha]_D^{23}$ 26.6 (*c* 5.0, ethanol) (lit.[43] (*S*)-**3n** $[\alpha]_D$ −41.9 (*c* 4.92, ethanol)); Daicel Chiralcel OJ-R, methanol/H_2O = 1.5, 0.30 ml min^{-1}, UV 254 nm; t_R = 61.7 (*S*) and 73.6 min (*R*).

1-Indanol (3o)
^{1}H NMR ($CDCl_3$) δ 1.78 (1H, s), 1.90–1.99 (1H, m), 2.45–2.53 (1H, m), 2.78–2.86 (1H, m), 3.02–3.10 (1H, m), 5.24 (1H, t, *J* = 5.6), 7.22–7.29 (3H, m), 7.41–7.42 (1H, m). IR (KBr) 3100, 2900, 1940, 1905, 1600, 1580, 1470, 1440, 1310, 1210, 1160, 1145, 1090, 1050, 1040, 975, 945, 930, 875, 845, 825, 730 cm^{-1}. 43% *ee* by Daicel Chiralcel OD-H, hexane/2-propanol = 49, 0.50 ml min^{-1}, UV 254 nm; t_R = 25.7 and 28.9 min.

1-Tetralol (3p)
^{1}H NMR ($CDCl_3$) δ 1.73–1.82 (2H, m), 1.87–2.02 (3H, m), 2.68–2.76 (1H, m), 2.79–2.86 (1H, m), 4.77 (1H, t, *J* = 5.2), 7.09–7.12 (1H, m), 7.18–7.25 (2H, m), 7.41–7.44 (1H, m). IR (NaCl) 3300, 3060, 3010, 2920, 2850, 2650, 1920, 1810, 1600, 1580, 1490, 1450, 1335, 1280, 1200, 1150, 1115, 1065, 1040, 1000, 960, 910, 880, 870, 850, 800, 770, 735 cm^{-1}. (*R*)-**3p** of 92% *ee*: $[\alpha]_D^{23}$ −31.4 (*c* 1.4, $CHCl_3$) (lit.[44] (*S*)-**3p** of 98% *ee*: $[\alpha]_D$ 34.4 (*c* 1.01, $CHCl_3$)); Daicel Chiralcel OD-H, hexane/2-propanol = 249, 0.30 ml min^{-1}, UV 220 nm; t_R = 63.9 (*R*) and 70.0 min (*S*).

Acknowledgements We thank Dr Takayuki Yamashita for the helpful discussions during the course of this study. This work was partially supported by Doshisha University's Research Promotion Fund and a grant to RCAST at Doshisha University from the Ministry of Education, Japan. The author (T.O.) also acknowledges the Kurata Foundation and the Sumitomo Foundation for their financial support.

REFERENCES

1. Ojima I (ed). *Catalytic Asymmetric Synthesis*. VCH: New York, 1993.
2. Morrison DJ (ed). *Asymmetric Synthesis*, vol. 5. Academic Press: Orlando, 1985.
3. Noyori R. *Asymmetric Catalysis in Organic Synthesis*. John Wiley & Sons: New York, 1994.
4. Jacobsen EN, Pfaltz A, Yamamoto H (eds). *Comprehensive Asymmetric Catalysis*. Springer: Berlin, 1999.
5. Oguni A, Omi T. *Tetrahedron Lett.* 1984; **25**: 2823.
6. Soai K, Ookawa A, Kaba T, Ogawa K. *J. Am. Chem. Soc.* 1987; **109**: 7111.
7. Soai K, Yokoyama S, Hayasaka T. *J. Org. Chem.* 1991; **56**: 4264.
8. Katsuki T, Sharpless KB. *J. Am. Chem. Soc.* 1980; **102**: 5974.
9. Gao Y, Hanson RM, Klunder JM, Ko SY, Masamune H, Sharpless KB. *J. Am. Chem. Soc.* 1987; **109**: 5765.
10. Jacobsen EN, Markó I, Mungall WS, Schröder G, Sharpless KB. *J. Am. Chem. Soc.* 1988; **110**: 1968.
11. Coppola GM, Schuster HF. *Asymmetric Synthesis. Construction of Chiral Molecules Using Amino Acids*. Wiley: New York, 1987.
12. Mori A, Abe H, Inoue S. *Appl. Organomet. Chem.* 1995; **9**: 189.
13. Ohta T, Nakahara SI, Shigemura Y, Hattori K, Furukawa I. *Chem. Lett.* 1998; 491 (preliminary communication).
14. Zassinovich G, Mestroni G, Gladiali S. *Chem. Rev.* 1992; **92**: 1051.
15. De Graauw CF, Peters JA, van Bekkum H, Huskens J. *Synthesis* 1994; 1007.
16. Palmer MJ, Wills M. *Tetrahedron: Asymmetry* 1999; **10**: 2045.
17. Mashima K, Abe T, Tani K. *Chem. Lett.* 1998; 1199.
18. Arikawa Y, Ueoka M, Matoba K, Nishibayashi Y, Hidai M, Uemura S. *J. Organomet. Chem.* 1999; **572**: 163.
19. Mao J, Baker DC. *Org. Lett.* 1999; **1**: 841.
20. Murata K, Okano K, Miyagi M, Iwane H, Noyori R, Ikariya T. *Org. Lett.* 1999; **1**: 1119.
21. Gao J-X, Xu P-P, Yi X-D, Yang C-B, Zhang H, Cheng S-H, Wan H-L, Tsai K-R, Ikariya T. *J. Mol. Catal. A. Chem.* 1999; **147**: 105.
22. Gao J-X, Yi X-D, Xu P-P, Tang C-L, Wan H-L, Ikariya T. *J. Organomet. Chem.* 1999; **592**: 290.

23. Petra DGI, Kamer PCJ, Spek AL, Schoemaker HE, von Leeuwen PWNM. *J. Org. Chem.* 2000; **65**: 3010.
24. Alonso DA, Nordin SJM, Roth P, Tarnai T, Andersson PG, Thommen M, Pittelkow U. *J. Org. Chem.* 2000; **65**: 3116.
25. Hashiguchi S, Fujii A, Takehara J, Ikariya T, Noyori R. *J. Am. Chem. Soc.* 1995; **117**: 7562.
26. Takehara J, Hashiguchi S, Fujii A, Inoue S, Ikariya T, Noyori R. *J. Chem. Soc. Chem. Commun.* 1996; 233.
27. Fujii A, Hashiguchi S, Uematsu N, Ikariya T, Noyori R. *J. Am. Chem. Soc.* 1996; **118**: 2521.
28. Uematsu N, Fujii A, Hashiguchi S, Ikariya T, Noyori R. *J. Am. Chem. Soc.* 1996; **118**: 4916.
29. Haack K-J, Hashiguchi S, Fujii A, Ikariya T, Noyori R. *Angew. Chem. Int. Ed. Engl.* 1997; **36**: 285.
30. Hashiguchi S, Fujii A, Haack K-J, Matsumura K, Ikariya T, Noyori R. *Angew. Chem. Int. Ed. Engl.* 1997; **36**: 288.
31. Noyori R, Hashiguchi S. *Acc. Chem. Res.* 1997; **30**: 97.
32. Dersnah DF, Baird MC. *J. Organomet. Chem.* 1977; **127**: C55.
33. Perrin DD, Armarego WLF. *Purification of Laboratory Chemicals*, 3rd edn. Pergamon: Oxford, 1988.
34. Bennett MA, Smith AK. *J. Chem. Soc. Dalton Trans.* 1974; 233.
35. Hayashi T, Matsumoto Y, Ito Y. *J. Am. Chem. Soc.* 1989; **111**: 3426.
36. Janssen AJM, Klunder AJH, Zwanenburg B. *Tetrahedron* 1991; **47**: 7645.
37. Niwa S, Soai K. *J. Chem. Soc. Perkin Trans. 1* 1991; 2717.
38. Ojima I, Kogure T, Kumagai M, Horiuchi S, Sato T. *J. Organomet. Chem.* 1976; **122**: 83.
39. Chen C-P, Prasad K, Repic O. *Tetrahedron Lett.* 1991; **32**: 7175.
40. Carter MB, Schiøtt B, Gutiérrez A, Buchwald SL. *J. Am. Chem. Soc.* 1994; **116**: 11 667.
41. Ogawa S, Furukawa N. *J. Org. Chem.* 1991; **56**: 5723.
42. Theisen PD, Heathcock CH. *J. Org. Chem.* 1988; **53**: 2374.
43. Collyer TA, Kenyon J. *J. Chem. Soc.* 1940; 676.
44. Palmer M, Walsgrove T, Wills M. *J. Org. Chem.* 1997; **62**: 5226.

