Pergamon

Tetrahedron: *Asymmetry* 12 (2001) 1677–1682

TETRAHEDRON: *ASYMMETRY*

Palladium-catalyzed asymmetric allylic alkylation using chiral aminophosphine ligands

Takashi Mino,* Yoh-ichi Tanaka, Koji Akita, Kouhei Anada, Masami Sakamoto and Tsutomu Fujita

Department of Materials Technology, Faculty of Engineering, Chiba University, Inage-ku, Chiba 263-8522, Japan

Received 22 February 2001; accepted 5 April 2001

Abstract—Palladium-catalyzed asymmetric allylic alkylation of 1,3-diphenyl-2-propenyl acetate **18** with a dimethyl malonate–BSA–LiOAc system has been successfully carried out in the presence of new chiral aminophosphine ligands **1**–**5** in good yields with good enantioselectivities (up to 85% e.e.).

1. Introduction

Palladium-catalyzed allylic alkylation is a widely used process in organic synthesis,[1] and the development of efficient enantioselective catalysis for this reaction is awaited.[2] Recently, *P*,*N*-bidentate ligands were found to be efficient chirality sources for this reaction.[3] Examples of such aminophosphine ligands are 4-[2-(diphenylphosphino)phenyl]-4,5-dihydro-3*H*-dinaphth[2,1-*c*:1′,2′-*e*]azepine,[4] 1-[2′-(diphenylphosphino)-1′-naphthalenyl]-2-methylpyrrolidine[5] and 1-[2′-(diphenylphosphino)-phenyl]-2-(benzyloxymethyl)pyrrolidine.[6] We have previously reported phosphine–hydrazone bidentate ligands such as 2-diphenylphosphinobenzaldehyde SAMP hydrazone (DPPBA–SAMP).[7]

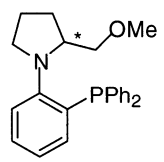
We were interested in aminophosphine ligands which have an ether bond such as a methoxymethyl group. This ether bond was expected to interact with the incoming nucleophile to bring about good stereoselectivity.[8] We designed a DPPBA–SAMP-derived chiral aminophosphine without a hydrazone moiety for application in asymmetric catalysis. Herein, we report palladium-catalyzed asymmetric allylic alkylation using chiral aminophosphine ligands **1**–**5** which were prepared from homochiral 2-methoxymethylpyrrolidine[9] and its derivatives.

2. Results and discussion

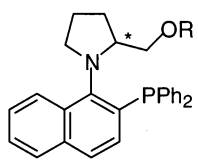
2.1. Preparation of aminophosphine ligands

The synthesis of the chiral aminophosphine ligands (such as (*R*)-1-[2-(diphenylphosphino)phenyl]-2-(methoxymethyl)pyrrolidine (*R*)-**1**) is shown in Scheme 1. Nucleophilic aromatic substitution (SNAr) reactions[9] of the corresponding phosphine oxide such as diphenyl(2-methoxyphenyl)phosphine oxide **6** with lithiated (*R*)-1-(methoxymethyl)pyrrolidine (*R*)-**9** gave the corresponding aminophosphine oxide **10**. The resulting aminophosphine oxide **10** was converted into the desired homochiral aminophosphine ligand (*R*)-**1** in good yield by reduction with trichlorosilane–triethylamine. Aminophosphine ligands (*R*)-**2**[10] and (*R*)-**5** were prepared in the same manner using the corresponding phosphine oxides 1-methoxy-2-diphenylphosphinonaphthalene oxide **7**[11] and 9-methoxy-10-diphenylphosphinophenanthrene oxide **8**.

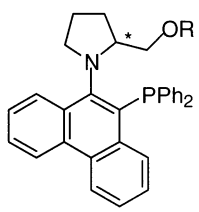
Aminophosphine ligand (*S*)-**3** was prepared in the same manner using (*S*)-2-methoxyethoxymethylpyrrolidine (*S*)-**13**[12] (Scheme 2). This ligand has a methoxyethoxymethyl moiety attached to the pyrrolidine backbone.



1



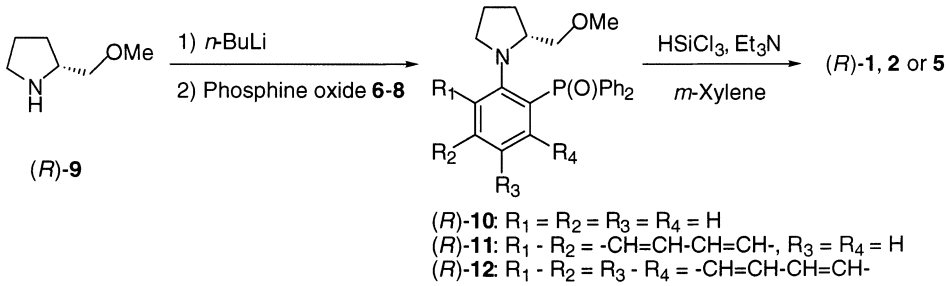
2: R = Me
3: R = $(CH_2)_2OMe$
4: R = $(CH_2CH_2O)_2Me$



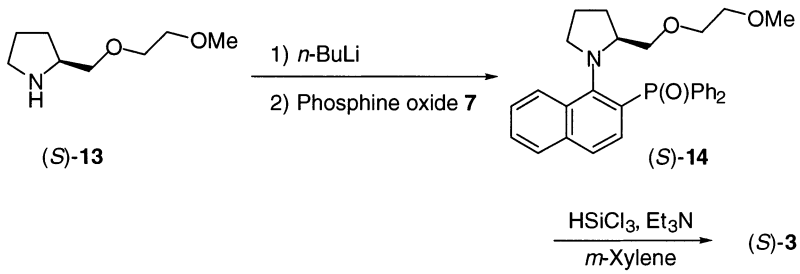
5

* Corresponding author. Tel.: +81 43 290 3385; fax: +81 43 290 3401; e-mail: tmino@planet.tc.chiba-u.ac.jp

0957-4166/01/$ - see front matter
PII: S0957-4166(01)00310-X



Scheme 1.



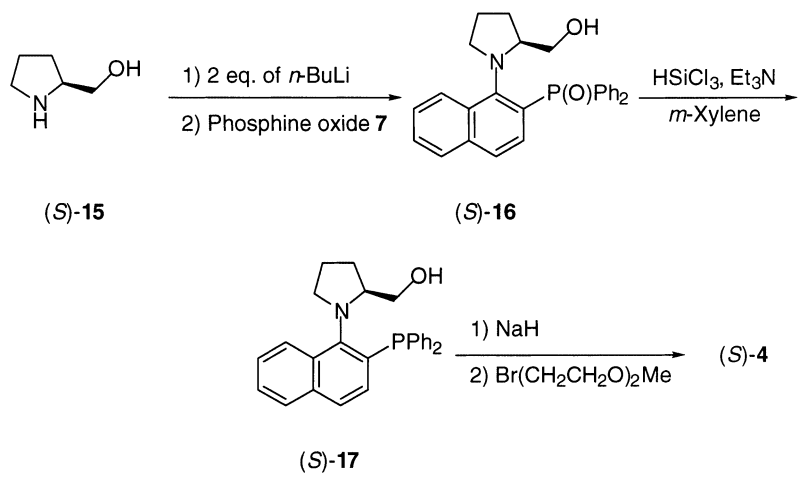
Scheme 2.

The synthesis of chiral aminophosphine ligand (*S*)-**4** is shown in Scheme 3. An aminoalcohol phosphine (*S*)-**17** was prepared in the same manner using L-prolinol (*S*)-**15** and phosphine oxide **7**. The ligand (*S*)-**4** was prepared by alkylation of the hydroxyl group in (*S*)-**17** with 1-bromo-2-(methoxyethoxy)ethane. This ligand has a methoxyethoxyethoxymethyl moiety attached to the pyrrolidine backbone.

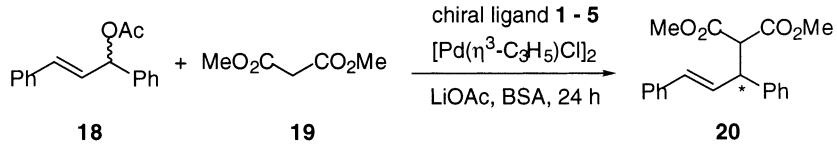
2.2. Palladium-catalyzed asymmetric allylic alkylation

The chiral aminophosphine ligands **1**–**5** were used as catalysts in the palladium-catalyzed asymmetric allylic alkylation of 1,3-diphenyl-2-propenyl acetate **18** with dimethyl malonate **19**.[13] This reaction was carried out under our previously reported conditions[7] (2 mol% of $[Pd(\eta^3\text{-}C_3H_5)Cl]_2$, 4 mol% of chiral ligand, and a mixture of *N*,*O*-bis(trimethylsilyl)acetamide (BSA) and 2 mol% of LiOAc in THF) (Scheme 4, Table 1).

Using ligand (*R*)-**1**, the product **20** was obtained in excellent yield (93%), but the enantiomeric excess was low (39% e.e.) (entry 1). However, using ligand (*R*)-**2** which has a naphthyl backbone, the product **20** was obtained with higher enantioselectivity (74% e.e.) (entry 3). When the reaction was carried out using (*R*)-**2** in toluene, the yield increased from 92 to 94% and the e.e. increased from 74 to 76% (entry 3 versus 4). Completing the reaction at −20°C further improved the enantioselectivity to 83% e.e. (entry 9). When the reaction was carried out using ligand (*S*)-**3** instead of (*R*)-**2** in THF, the yield and the e.e. increased slightly (entry 3 versus 10). Indicating that a methoxyethoxymethyl group of the pyrrolidine side chain in ligand (*S*)-**4** interacts slightly with the incoming nucleophile.



Scheme 3.



18 19 20

Scheme 4.

Table 1. Asymmetric allylic alkylation catalyzed by palladium complexes with ligands **1**–**5**

Entry	Ligand	Solv.	Temp. (°C)	Yield (%)[a]	E.e. (%)[b]	Conf. of **20**[c]
1	(*R*)-**1**	THF	rt	93	39	*R*
2	(*R*)-**1**	PhMe	rt	97	40	*R*
3	(*R*)-**2**	THF	rt	92	74	*R*
4	(*R*)-**2**	PhMe	rt	94	76	*R*
5	(*R*)-**2**	MeCN	rt	94	60	*R*
6	(*R*)-**2**	CH_2Cl_2	rt	95	64	*R*
7	(*R*)-**2**	DMF	rt	95	64	*R*
8[d]	(*R*)-**2**	PhMe	0	99	79	*R*
9[e]	(*R*)-**2**	PhMe	−20	88	83	*R*
10	(*S*)-**3**	THF	rt	96	79	*S*
11	(*S*)-**3**	PhMe	rt	93	76	*S*
12	(*S*)-**3**	Ether	rt	97	79	*S*
13[e]	(*S*)-**3**	THF	−20	22	85	*S*
14	(*S*)-**4**	PhMe	rt	86	76	*S*
15	(*R*)-**5**	PhMe	rt	95	57	*R*

[a] Isolated yields.
[b] Determined by HPLC analysis using a chiral column (Chiralcel OD).
[c] Determined by optical rotation.
[d] This reaction was carried out for 96 h.
[e] This reaction was carried out for 7 days.

Although the enantioselectivity was improved to 85% e.e. by further decreasing the temperature (−20°C), the reaction rate reduced (entry 13). Using (*S*)-**4** as a ligand, the yield was decreased slightly without a decrease in enantioselectivity (entry 11 versus 14). Using ligand (*R*)-**5** which has a phenanthrenyl backbone instead of a naphthyl backbone, the e.e. decreased from 76 to 57% (entry 4 versus 15).

2.3. The mechanism for asymmetric induction with chiral aminophosphine ligands

The mechanism for asymmetric induction with this type of ligand is rationalized on the basis of the stereochemical results obtained. The (*R*)-1-(methoxymethyl)-pyrrolidine derived ligand (*R*)-**2** would provide a five-membered chelate by coordination of the rather more electron-donating nitrogen group and phosphorus group to the palladium catalyst.[14] In the conformational equilibrium of sterically favored π-allylpalladium complexes **21a** and **21b**, complex **21b** would be formed preferentially because of greater steric interference between the methoxymethyl group of the ligand and the allylic compound in **21a** (Scheme 5).[5,15] This interference was more effective than the case of methyl group and benzyloxymethyl group. Therefore, the nucleophile would attack the allylic terminus in **21b** *trans* to the better π-acceptor, which is the phosphine group in the present case, from the back side of the palladium catalyst in the π-allyl system as designated in **21b**, affording **20**.

3. Conclusion

We showed the palladium-catalyzed asymmetric allylic alkylation of 1,3-diphenyl-2-propenyl acetate **18** with dimethyl malonate **19** using chiral aminophosphine ligands **1**–**5** with good e.e.

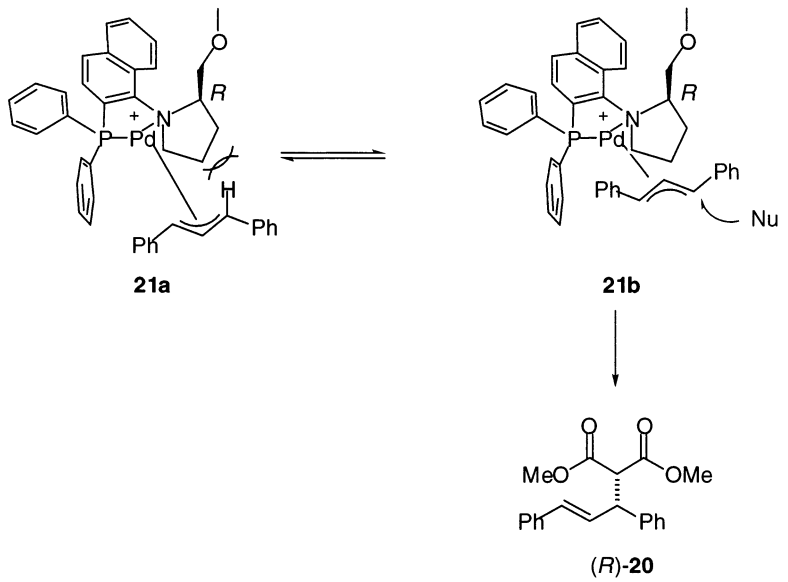
4. Experimental

4.1. General methods

Melting points were measured on a Shibata micromelting point apparatus. NMR spectra were recorded on a JEOL LA-400 system or a Bruker DPX-300 system with TMS as an internal standard. Mass spectra were recorded on a JEOL JMS-HX110. Optical rotations were measured on a JASCO DIP-370.

4.2. Synthesis of 9-methoxy-10-diphenylphosphinophenanthrene 8

To a mixture of 9-methoxyphenanthrene (0.313 g, 1.5 mmol), TMEDA (0.23 mL, 1.52 mmol) and ether (4 mL) was added dropwise *n*-BuLi in hexane (1.56 M, 1.5 mL, 2.3 mmol) over 10 min and the mixture was stirred at rt for 2 h. Chlorodiphenylphosphine (0.27 mL, 1.5



Scheme 5.

mmol) was added and the resulting mixture was stirred for a further 2 h. Then it was diluted with ether and quenched with aq. HCl (2 M, 30 mL). The organic layer was washed with aq. Na_2CO_3 (2 M, 30 mL), brine, dried over $MgSO_4$, and concentrated under reduced pressure. The residue was dissolved in AcOH (7.5 mL) and aq. H_2O_2 (30%, 0.25 mL) was added. The mixture was gradually heated to 80°C over 20, and stirred at 80°C for 2 h. After being cooled to rt, the mixture was diluted with benzene (15 mL) and added 2 M aq. NaOH (40 mL) at 0°C. The water layer was extracted with ether and the combined extracts were washed with water, dried over $MgSO_4$, and concentrated under reduced pressure. The residue was purified by silica-gel chromatography (elution with *n*-hexane/EtOAc = 1/3) (0.507 g, 1.24 mmol, 83%); mp 142–143°C; ^{1}H NMR (300 MHz, $CDCl_3$): δ 3.21 (s, 3H), 7.38–7.82 (m, 14H), 8.08 (d, J = 8.1 Hz, 1H), 8.64 (d, J = 8.3 Hz, 1H), 8.71 (d, J = 8.3 Hz, 1H), 9.00 (d, J = 8.4 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 63.46, 116.38, 117.71, 123.02–132.69 (m, Ar), 134.87 (d, J = 1.7 Hz), 135.57, 136.99; ^{31}P NMR (121 MHz, $CDCl_3$): δ 29.19; FAB-MS (m/z) 409 (M^++H, 100); HRMS (FAB) calcd for $C_{27}H_{22}O_2P$ (M^++H) 409.1357, found 409.1371.

4.3. Synthesis of aminophosphine oxide: general procedure

To a solution of amine (1.03 mmol) in THF (1 mL) at −80°C was added slowly *n*-BuLi in hexane (0.71 mL, 1.1 mmol, 1.56 M) at −80°C over 10 min. The mixture was allowed to warm to rt and stirred for 2 h. The phosphine oxide (1.0 mmol) was added at 0°C, and the mixture stirred for a further 20 h at rt. The mixture was diluted with ether and quenched with satd NH_4Cl. The organic layer was washed with brine, dried over $MgSO_4$, and concentrated under reduced pressure. The residue was purified by silica-gel chromatography.

4.3.1. (*R*)-1-[2′-(Diphenylphosphinyl)phenyl]-2-(methoxymethyl)pyrrolidine (*R*)-10. Yield 68%; mp 49–50°C; $[\alpha]_D^{25} = -71$ (*c* 0.10, $CHCl_3$); ^{1}H NMR (400 MHz, $CDCl_3$): δ 1.39–1.50 (m, 2H), 1.61–1.69 (m, 1H), 1.77–1.94 (m, 1H), 2.63 (t, J = 8.9 Hz, 1H), 2.72 (q, J = 7.1 Hz, 1H), 3.03 (dd, J = 3.7 and 9.2 Hz, 1H), 3.12 (s, 3H), 3.45–3.56 (m, 1H), 3.63–3.77 (m, 1H), 6.81 (dq, J = 1.3 and 3.8 Hz, 1H), 6.94 (t, J = 7.4 Hz, 1H), 7.18–7.39 (m, 12H); ^{13}C NMR (75 MHz, $CDCl_3$); 23.66, 29.02, 56.28, 58.73, 60.70, 74.65, 122.21, 128.06–133.20 (m, Ar), 135.47, 154.42; ^{31}P NMR (121 MHz, $CDCl_3$): δ 27.24; FAB-MS (m/z) 392 (M^++H, 64); HRMS (FAB) calcd for $C_{24}H_{27}NO_2P$ (M^++H) 392.1779, found 392.1742.

4.3.2. (*R*)-1-[2′-(Diphenylphosphinyl)-1′-naphthalenyl]-2-(methoxymethyl)pyrrolidine (*R*)-11. Yield 85%; mp 106–108°C; $[\alpha]_D^{25} = -244$ (*c* 0.11, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.56 (br, 1H), 1.73–1.88 (m, 2H), 2.03–2.22 (br, 1H), 2.77 (br, 1H), 3.02 (s, 3H), 3.03–3.10 (m, 2H), 3.23 (br-s, 1H), 4.30 (br-s, 1H), 7.17 (dd, J = 8.6 and 12.6 Hz, 1H), 7.40–7.62 (m, 9H), 7.68–7.81 (m, 4H), 7.86 (d, J = 7.8 Hz, 1H), 8.11–8.14 (br, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 25.11, 29.88, 53.88, 58.93, 63.99, 76.12, 125.87, 126.35, 128.09, 128.55–135.95 (m, Ar), 137.44, 152.34; ^{31}P NMR (121 MHz, $CDCl_3$): δ 26.49; FAB-MS (m/z) 442 (M^++H, 100); HRMS (FAB) calcd for $C_{28}H_{29}NO_2P$ (M^++H) 442.1936, found 442.1934.

4.3.3. (*R*)-1-[10′-(Diphenylphosphinyl)-9′-phenanthrenyl]-2-(methoxymethyl)pyrrolidine (*R*)-12. Yield 83%; mp 101–102°C; $[\alpha]_D^{25} = -224$ (*c* 0.135, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.28 (br, 1H), 1.65–1.77 (br-m, 2H), 1.98 (br-s, 1H), 2.60 (br, 1H), 2.98 (s, 3H), 3.13–3.24 (m, 2H), 3.43 (br-s, 1H), 4.39 (br-s, 1H), 7.04–7.13 (m, 1H), 7.27–7.47 (m, 7H), 7.54–7.78 (m, 6H), 7.98 (d, J = 8.5 Hz, 1H), 8.11 (d, J = 8.3 Hz, 1H), 8.55 (d, J = 8.3

Hz, 1H), 8.72 (d, $J=8.3$ Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 24.53, 29.31, 52.84, 59.00, 65.08, 75.46, 122.74, 123.73, 125.74, 126.13, 126.59, 126.45, 128.43–134.64 (m, Ar), 137.02, 138.40, 151.83; ^{31}P NMR (121 MHz, $CDCl_3$): δ 26.46; FAB-MS (m/z) 492 (M^++H, 86); HRMS (FAB) calcd for $C_{32}H_{31}NO_2P$ (M^++H) 492.2092, found 492.2072.

4.3.4. (*S*)-1-[2′-(Diphenylphosphinyl)-1′-naphthalenyl]-2-[(2″-methoxyethoxy)methyl]pyrrolidine (*S*)-14. Yield 33%; mp 94–95°C; $[\alpha]_D^{25}=+206$ (c 1.0, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.43–1.90 (m, 3H), 2.17–2.24 (m, 2H), 2.84–3.29 (m, 7H), 3.24 (s, 3H), 4.29 (br, 1H), 7.17 (dd, $J=8.6$ and 12.6 Hz, 1H), 7.40–7.61 (m, 9H), 7.70–7.88 (m, 5H), 8.12 (br, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 24.67, 29.55, 54.04, 58.91, 63.45, 69.94, 71.73, 74.14, 125.94, 127.65, 128.14–135.49 (m, Ar), 137.04, 152.08; ^{31}P NMR (121 MHz, $CDCl_3$): δ 26.61; FAB-MS (m/z) 486 (M^++H, 8); HRMS (FAB) calcd for $C_{30}H_{33}NO_3P$ (M^++H) 486.2198, found 486.2160.

4.4. Synthesis of (*S*)-1-[2′-(diphenylphosphinyl)-1′-naphthalenyl]-2-(hydroxymethyl)pyrrolidine (*S*)-16

To a solution of L-prolinol (*S*)-**15** (0.104 g, 1.03 mmol) in THF (1 mL) at −80°C was added slowly n-BuLi in hexane (1.56 M, 1.41 mL, 2.2 mmol) over 10 min, and the mixture was stirred at rt for 2 h. Phosphine oxide **7** (0.359 g, 1.0 mmol) was added at 0°C and stirring was continued for 20 h at rt. The mixture was diluted with ether and quenched with satd NH_4Cl. The organic layer was washed with brine, dried over $MgSO_4$, and concentrated under reduced pressure. The residue was purified by silica-gel chromatography (elution with n-hexane/acetone/EtOAc = 10/4/1) (75%); mp 218–220°C; $[\alpha]_D^{25}=+12.5$ (c 1.0, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.59–1.85 (m, 4H), 2.12–2.19 (m, 2H), 3.00–3.08 (m, 1H), 3.30–3.39 (m, 1H), 3.63 (dd, $J=4.5$ and 12.3 Hz, 1H), 3.95 (br, 1H), 6.75–6.79 (br-m, 1H), 7.07 (dd, $J=8.6$ and 12.7 Hz, 1H), 7.41–7.72 (m, 10H), 7.79–7.86 (m, 2H), 7.93 (d, $J=8.0$ Hz, 1H), 7.97 (d, $J=8.4$ Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 26.16, 28.17, 55.08, 63.24, 67.77, 124.77, 125.96, 126.35, 127.67, 128.23–132.34 (m, Ar), 137.82, 153.50; ^{31}P NMR (121 MHz, $CDCl_3$): δ 27.28; FAB-MS (m/z) 428 (M^++H, 100); HRMS (FAB) calcd for $C_{27}H_{27}NO_2P$ (M^++H) 428.1779, found 428.1768.

4.5. General procedure for reduction of aminophosphine oxides

To a mixture of phosphine oxide (0.3 mmol), triethylamine (0.34 mL, 1.2 mmol) and m-xylene (2 mL) was added trichlorosilane (0.24 mL, 1.2 mmol) at 0°C under an argon atmosphere. The reaction mixture was stirred under reflux for 6 h. After being cooled to rt, the mixture was diluted with ether and quenched with 2 M aq. NaOH. The organic layer was washed with brine, dried over $MgSO_4$, and concentrated under reduced pressure. The residue was purified by silica-gel chromatography (elution with n-hexane/EtOAc = 6/1).

4.5.1. (*R*)-1-[2′-(Diphenylphosphino)phenyl]-2-(methoxymethyl)pyrrolidine (*R*)-1. Yield 87%; mp 60–62°C; $[\alpha]_D^{20}=+8.2$ (c 1.00, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.54–1.86 (m, 3H), 2.01–2.16 (m, 1H), 2.63 (t, $J=8.9$ Hz, 1H), 2.72 (q, $J=7.1$ Hz, 1H), 3.03 (dd, $J=3.7$ and 9.2 Hz, 1H), 3.12 (s, 3H), 3.45–3.56 (m, 1H), 3.63–3.77 (m, 1H), 6.81 (dq, $J=1.3$ and 3.8 Hz, 1H), 6.94 (t, $J=7.4$ Hz, 1H), 7.18–7.39 (m, 12H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 24.48, 30.23, 56.03 (d, $J=8.4$ Hz), 59.27, 60.92 (d, $J=2.5$ Hz), 75.82, 121.62 (d, $J=2.8$ Hz), 123.92, 128.53–134.85 (m, Ar), 135.45 (d, $J=10.9$ Hz), 138.16 (d, $J=12.6$ Hz), 138.56 (d, $J=11.9$ Hz), 153.99 (d, $J=19.6$ Hz); ^{31}P NMR (121 MHz, $CDCl_3$): δ −12.14; FAB-MS (m/z) 376 (M^++H, 64); HRMS (FAB) calcd for $C_{24}H_{27}NOP$ (M^++H) 376.1830, found 376.1813.

4.5.2. (*R*)-1-[2′-(Diphenylphosphino)-1′-naphthalenyl]-2-(methoxymethyl)pyrrolidine (*R*)-2. Yield 100%; mp 105–106°C; $[\alpha]_D^{20}=-12.3$ (c 1.0, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$): δ 2.00 (br, 3H), 2.39 (br, 1H), 2.89 (br, 1H), 3.09 (s, 3H), 3.22 (br, 3H), 4.08 (br, 1H), 7.06 (br, 1H), 7.14–7.38 (m, 11H), 7.47 (br, 2H), 7.60 (d, $J=8.5$ Hz, 1H), 7.85 (br, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 25.05, 30.11, 54.32, 58.59 (d, $J=12.4$ Hz), 63.09, 123.85, 124.85, 125.78–133.81 (m, Ar), 135.56, 138.55, 139.08; ^{31}P NMR (121 MHz, $CDCl_3$): δ −16.22; FAB-MS (m/z) 426 (M^++H, 57); HRMS (FAB) calcd for $C_{28}H_{29}NOP$ (M^++H) 426.1987, found 426.1976.

4.5.3. (*S*)-1-[2′-(Diphenylphosphino)-1′-naphthalenyl]-2-[(2″-methoxyethoxy)methyl]pyrrolidine (*S*)-3. Yield 85%; mp 97–98°C; $[\alpha]_D^{25}=+125$ (c 1.00, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.99–2.09 (m, 3H), 2.26–2.38 (m, 1H), 2.83 (br, 1H), 3.10–3.31 (m, 7H), 3.26 (s, 3H), 4.08 (br-s, 1H), 7.04 (br-s, 1H), 7.29 (br, 10H), 7.43–7.46 (m, 2H), 7.60 (d, $J=8.5$ Hz, 1H) 7.83 (br, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 25.02, 30.19, 54.29, 58.94, 62.98, 70.12, 71.72, 75.07, 124.05, 125.74, 126.02–133.85 (m, Ar), 135.88, 138.50; ^{31}P NMR (121 MHz, $CDCl_3$): δ −16.31; FAB-MS (m/z) 470 (M^++H, 0.4); HRMS (FAB) calcd for $C_{30}H_{33}NO_2P$ (M^++H) 470.2249, found 470.2210.

4.5.4. (*R*)-1-[10′-(Diphenylphosphino)-9′-phenanthrenyl]-2-(methoxymethyl)pyrrolidine (*R*)-5. Yield 66%; mp 70–72°C; $[\alpha]_D^{25}=-88$ (c 0.25, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.99 (br, 1H), 2.12–2.21 (m, 2H), 2.39–2.48 (m, 1H), 2.96 (br-s, 3H), 3.09–3.25 (m, 2H), 3.55–3.73 (m, 2H), 4.05–4.17 (m, 1H), 7.01–7.06 (m, 1H), 7.08–7.54 (m, 11H), 7.55–7.76 (m, 3H), 7.85–8.34 (br-m, 2H), 8.64 (d, $J=8.2$ Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 24.09, 29.70, 55.58, 58.58, 64.98, 122.65, 125.61 (d, $J=9.4$ Hz), 126.67, 127.12, 127.88, 128.15–133.17 (m, Ar), 138.38; ^{31}P NMR (121 MHz, $CDCl_3$): δ −17.97; FAB-MS (m/z) 476 (M^++H, 34); HRMS (FAB) calcd for $C_{32}H_{29}NO_2P$ (M^+−H) 474.1987, found 474.1955.

4.5.5. (*S*)-1-[2′-(Diphenylphosphino)-1′-naphthalenyl]-2-(hydroxymethyl)pyrrolidine (*S*)-17. Yield 66%; mp 183–184°C; $[\alpha]_D^{25}=+206$ (c 1.0, $CHCl_3$); ^{1}H NMR (300 MHz, $CDCl_3$): δ 1.87–1.96 (m, 2H), 2.20–2.27 (m, 2H), 2.37–2.43 (m, 1H), 3.21 (q, $J=8.0$ Hz, 1H), 3.39 (t, $J=11.8$ Hz, 1H), 3.72 (d, $J=12.0$ Hz, 1H), 3.98 (t, $J=5.9$ Hz, 1H), 4.41 (dt, $J=2.9$ and 12.5 Hz, 1H), 7.00 (dd,

$J=3.1$ and 8.2 Hz, 1H), 7.23–7.38 (m, 10H), 7.45–7.51 (m, 2H), 7.65 (d, $J=8.5$ Hz, 1H), 7.86–7.91 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 25.91, 28.54, 54.55, 63.02, 65.11, 123.70, 125.77, 126.22, 127.14, 128.48–134.50 (m, Ar), 136.18; ^{31}P NMR (121 MHz, $CDCl_3$): δ −17.07; FAB-MS (m/z) 412 (M^++H, 0.4); HRMS (FAB) calcd for $C_{27}H_{27}NOP$ (M^++H) 412.1830, found 412.1833.

4.6. Synthesis of (*S*)-1-[2′-(diphenylphosphino)-1′-naphthalenyl]-2-[(2″-methoxyethoxyethoxy)methyl]pyrrolidine (*S*)-4

NaH (60% dispersion in oil, 0.18 mmol, 0.50 g) was washed with hexane, and DMF (1 mL) was added. To the suspension of NaH in DMF was added phosphine **9** (0.45 mmol, 9.185 g) at 0°C. The mixture was stirred for 3 h at rt, treated with methoxyethoxyethyl bromide (1.87 mmol, 0.25 mL), and stirring was continued for 20 h at rt. The mixture was diluted with ether and quenched with satd NH_4Cl. The organic layer was washed with brine, dried over $MgSO_4$, and concentrated under reduced pressure. The residue was purified by silica-gel chromatography (elution with *n*-hexane/EtOAc = 6/1) (45%); mp 60–61°C; $[\alpha]_D^{20}=+108$ (c 0.102, $CHCl_3$); ^1H NMR (300 MHz, $CDCl_3$): δ 1.68–2.00 (m, 1H), 1.97 (br-s, 3H), 2.37 (br-s, 1H), 2.82–3.56 (m, 11H), 3.32 (s, 3H), 4.07 (br-s, 1H), 7.04 (br-s, 1H), 7.21–7.37 (m, 10H), 7.43–7.46 (m, 2H), 7.58 (d, $J=8.5$ Hz, 1H), 7.77–8.32 (m, 2H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 25.04, 30.17, 54.27, 58.98, 63.03, 70.29, 70.40, 71.91, 75.03, 124.63 (d, $J=6.6$ Hz), 125.63–138.49 (m, Ar); ^{31}P NMR (121 MHz, $CDCl_3$): δ −16.37; FAB-MS (m/z) 514 (M^++H, 42); HRMS (FAB) calcd for $C_{32}H_{37}NO_3P$ (M^++H) 514.2511, found 514.2490.

4.7. General procedure for the palladium-catalyzed allylic alkylation

To a mixture of $[Pd(\eta^3\text{-}C_3H_5)Cl]_2$ (0.01 mmol, 0.004 g), chiral aminophosphine ligand (0.02 mmol), and LiOAc (0.01 mmol, 0.001 g) in a solvent (1 mL) was added BSA (1.5 mmol, 0.37 mL), racemic 1,3-diphenyl-2-propenyl acetate **18** (0.5 mmol, 0.126 g), and dimethyl malonate **19** (1.5 mmol, 0.17 mL) at rt under an argon atmosphere. After stirring the mixture for 24 h, the reaction mixture was diluted with ether and water. The organic layer was washed with brine and dried over $MgSO_4$. The filtrate was concentrated under reduced pressure and the residue was purified by column chromatography.

Acknowledgements

We thank the Ogura group (Chiba University) for generously sharing their Bruker DPX-300 system.

References

1. (a) Tsuji, J.; Minami, I. *Acc. Chem. Res.* **1987**, *20*, 140–145; (b) Trost, B. M.; Verhoeven, T. R. In *Comprehensive Organometallic Chemistry*; Wilkinson, G.; Stone, F. G. A.; Abel, E. W., Eds.; Pergamon: Oxford, 1982; Vol. 8, p. 799; (c) Trost, B. M. *Acc. Chem. Res.* **1980**, *13*, 385–393.
2. (a) Pfaltz, A.; Lautens, M. In *Comprehensive Asymmetric Catalysis*; Jacobsen, E. N.; Pfaltz, A.; Yamamoto, H., Eds.; Springer: Tokyo, 1999; Vol. 2, p. 833; (b) Trost, B. M.; Van Vranken, D. L. *Chem. Rev.* **1996**, *96*, 395–422; (c) Williams, J. M. J. *Synlett* **1996**, 705–710; (d) Pfaltz, A. *Acc. Chem. Res.* **1993**, *26*, 339–345; (e) Hayashi, T. In *Catalytic Asymmetric Synthesis*; Ojima, I., Ed.; VCH: New York, 1993; p. 325; (f) Consiglio, G.; Waymouth, R. M. *Chem. Rev.* **1989**, *89*, 257–276 and references cited therein.
3. Fache, F.; Schulz, E.; Tommasino, M. L.; Lemaire, M. *Chem. Rev.* **2000**, *100*, 2159–2231 and references cited therein.
4. (a) Wimmer, P.; Widhalm, M. *Monatch. Chem.* **1996**, *127*, 669–681; (b) Wimmer, P.; Widhalm, M. *Tetrahedron: Asymmetry* **1995**, *6*, 657–660.
5. Hattori, T.; Komuro, Y.; Hashizaka, N.; Takahashi, H.; Miyano, S. *Enantiomer* **1997**, *2*, 203–213.
6. (a) Suzuki, Y.; Abe, I.; Hiroi, K. *Heterocycles* **1999**, *50*, 89–94; (b) Hiroi, K.; Suzuki, Y.; Abe, I. *Tetrahedron: Asymmetry* **1999**, *10*, 1173–1188.
7. (a) Mino, T.; Shiotsuki, M.; Yamamoto, N.; Suenaga, T.; Sakamoto, M.; Fujita, T.; Yamashita, M. *J. Org. Chem.* **2001**, *66*, 1795–1797; (b) Mino, T.; Imiya, W.; Yamashita, M. *Synlett* **1997**, 583–584.
8. (a) Enders, D. In *Asymmetric Synthesis*; Morrison, J. D., Ed.; Academic Press: Orlando, FL, 1984; Vol. 3, p. 275; (b) Hayashi, T.; Yamamoto, A.; Hagihara, T.; Ito, Y. *Tetrahedron Lett.* **1986**, *27*, 191–194.
9. Enders, D.; Klatt, M. *Synthesis* **1996**, 1403–1418.
10. (*S*)-**2** has been synthesized previously. See: Miyano, S.; Hattori, T.; Komuro, Y.; Kumobayashi, H. *Jpn. Kokai Tokkyo Koho* H09241277 (*Chem. Abstr.* **1997**, *127*, 302486h).
11. Hattori, T.; Sakamoto, J.; Hayashizaka, N.; Miyano, S. *Synthesis* **1994**, 199–202.
12. Nakayama, K.; Thompson, W. J. *J. Am. Chem. Soc.* **1990**, *112*, 6936–6942.
13. Mino, T.; Tanaka, Y.; Sakamoto, M.; Fujita, T. *Heterocycles* **2000**, *53*, 1485–1488.
14. Ganter, C.; Wagner, T. *Chem. Ber.* **1995**, *128*, 1157–1161.
15. Sprinz, J.; Kiefer, M.; Helmchen, G. *Tetrahedron Lett.* **1994**, *35*, 1523–1526.