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Palladium-catalyzed asymmetric allylic alkylation using (*R*)-2-(methoxymethyl)pyrrolidine-derived aminophosphine ligands

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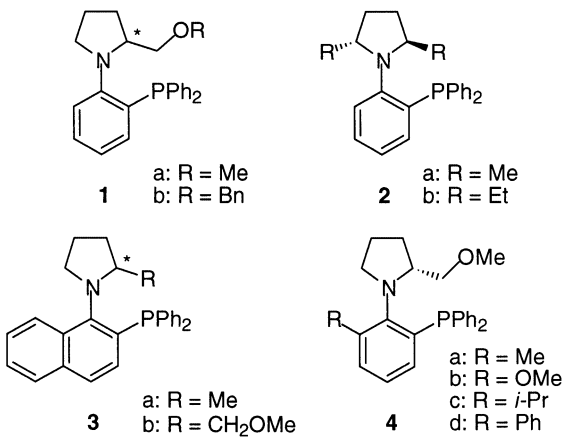
Abstract—Palladium-catalyzed asymmetric allylic alkylation of 1,3-diphenyl-2-propenyl acetate **7a** using a dimethyl malonate–BSA–LiOAc system has been successfully carried out in the presence of new chiral aminophosphine ligands such as **4** in good yields with good enantioselectivities (up to 96% e.e.). © 2001 Elsevier Science Ltd. All rights reserved.

1. Introduction

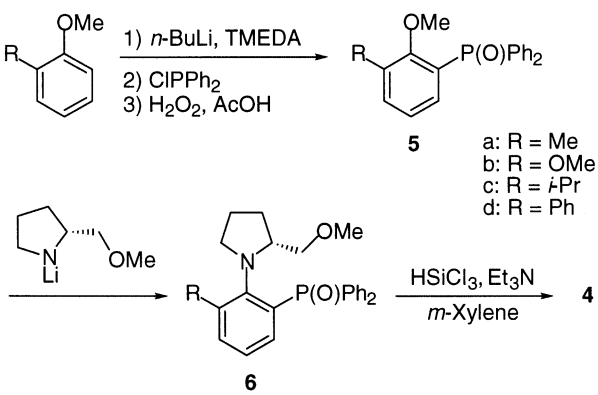
Palladium-catalyzed allylic alkylation is a widely used process in organic synthesis[1] and the development of efficient enantioselective catalysts for this reaction is still awaited.[2] Chiral *P*,*N*-bidentate compounds have been used as ligands for this reaction,[3] and recently several *P*,*N*-bidentate ligands were found to be efficient chiral ligands.[4] The majority of examples utilize an sp^2 nitrogen and ligands possessing an sp^3 nitrogen donor atom have recently been reported. Pyrrolidinyl-containing aminophosphines such as **1**[5] and **2**[6] gave poor e.e.s when applied in the palladium-catalyzed asymmetric allylic alkylation, but pyrrolidinyl-containing naphthyl backbone type aminophosphines of the type **3**[5c,7] act as efficient ligands in the reaction. Herein, we report the synthesis of the new chiral aminophosphines **4** as 6′-substituted analogues of **1a** and their application in palladium-catalyzed asymmetric allylic alkylation.



2. Results and discussion

2.1. Synthesis of aminophosphine ligands 4

The synthesis of chiral aminophosphine ligands **4** is shown in Scheme 1. Phosphine oxides **5** were prepared via the selective *o*-lithiation of the corresponding 2-substituted-1-methoxybenzene with *n*-BuLi–TMEDA and then treatment with chlorodiphenylphosphine followed by oxidation with hydrogen peroxide in acetic acid. Nucleophilic aromatic substitution (SNAr) reaction[8] of



Scheme 1.

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the corresponding phosphine oxides **5** such as 2-methoxy-3-methylphenyldiphenylphosphine oxide **5a** with (*R*)-2-(methoxymethyl)pyrrolidine gave the corresponding aminophosphine oxide **6a**. This aminophosphine oxide was converted into the desired chiral aminophosphine ligand **4a** using trichlorosilane–triethylamine in good yield. The other ligands were easily prepared in the same manner using the corresponding phosphine oxides (Table 1).

Table 1. Preparation of aminophosphine ligand **4**

Entry	R	**5**, Yield (%)[a]	**6**, Yield (%)[a]	**4**, Yield (%)[a]
1	Me	**5a**, 71	**6b**, 52	**4a**, 92
2	OMe	**5b**, 94	**6b**, 60	**4b**, 82
3	*i*-Pr	**5c**, 92	**6c**, 17	**4c**, 70
4	Ph	**5d**, 83	**6d**, 22	**4d**, 89

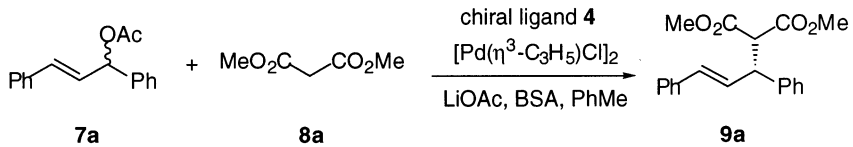
[a] Isolated yields.

2.2. Palladium-catalyzed asymmetric allylic alkylation

The chiral aminophosphine ligands **4** were applied in the palladium-catalyzed asymmetric allylic alkylation of 1,3-diphenyl-2-propenyl acetate **7a** with dimethyl malonate **8a**. This reaction was carried out in the presence of 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 toluene (Scheme 2, Table 2).

While aminophosphine ligands **4** showed similar reactivity, the enantioselectivity varied dramatically (entries 1–4). Using ligand **4b**, the product (*R*)-**9a** was obtained with the best enantioselectivity (85% e.e.) (entry 2). When the reaction was carried out at 50°C, the reaction rate increased but the e.e. decreased to 76% (entry 5). Completing the reaction at 0°C further improved the enantioselectivity of the reaction to afford product with 88% e.e. (entry 6). Although the enantioselectivity was improved to 94% e.e. by further lowering the temperature (−20°C), the reaction rate became slow (entry 7). When the reaction was carried out at −40°C, the product (*R*)-**9a** was obtained in the best enantioselectivity (95% e.e.), but the yield of the reaction was only 6% (entry 8).

We next investigated the palladium-catalyzed asymmetric allylic alkylation of similar allylic esters and/or active methylene compounds using ligand **4b** (Scheme 3, Table 3). When 1,3-diphenyl-2-propenyl pivalate **7b** was used instead of **7a**, the reaction with dimethyl malonate **8a** gave the product (*R*)-**9a** in good yield with



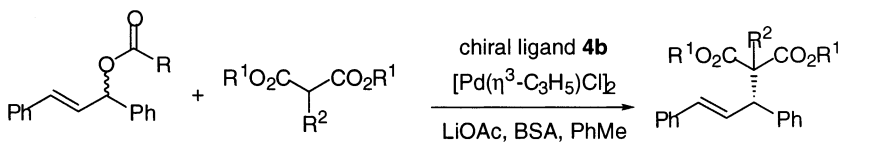
7a **8a** **9a**

Scheme 2.

Table 2. Asymmetric allylic alkylation catalyzed by palladium complexes with ligand **4** in toluene[a]

Entry	Ligand	Temp. (°C)	Reaction time	Yield (%)[b]	E.e. (%)[c]
1	**4a**	Rt	24 h	96	82
2	**4b**	Rt	24 h	97	85
3	**4c**	Rt	24 h	95	80
4	**4d**	Rt	24 h	95	73
5	**4b**	50	1 h	95	76
6	**4b**	0	4 days	95	88
7	**4b**	−20	7 days	94	94
8	**4b**	−40	7 days	6	95

[a] Molar ratio: $[Pd(\eta^3\text{-}C_3H_5)Cl]_2$ (0.02 equiv.), ligand **4** (0.04 equiv.), dimethyl malonate (3.0 equiv.), BSA (3.0 equiv.), LiOAc (0.01 equiv.).
[b] Isolated yields.
[c] The e.e. values were determined by HPLC analysis using a chiral column [Chiralcel OD-H (hexane:*i*-PrOH = 99:1)].



7
a: R = Me
b: R = *t*-Bu

8
a: R^1 = Me, R^2 = H
b: R^1 = Et, R^2 = H
c: R^1 = *t*-Bu, R^2 = H
d: R^1 = Et, R^2 = Me

9
a: R^1 = Me, R^2 = H
b: R^1 = Et, R^2 = H
c: R^1 = *t*-Bu, R^2 = H
d: R^1 = Et, R^2 = Me

Scheme 3.

Table 3. Asymmetric allylic alkylation catalyzed by palladium complexes with ligand **4b**[a,b]

Entry	R	R^1	R^2	Temp. (°C)	Yield (%)[c]	E.e. (%)[c]	Config.
1	Me	Me	H	−20	94	94[d]	*R*
2	*t*-Bu	Me	H	−20	97	96[d]	*R*
3	Me	Et	H	−20	91	96[e]	*R*
4	Me	*t*-Bu	H	−20	81	72[f]	*R*
5	Me	Et	Me	0	95	95[g]	*S*[h]

[a] Molar ratio: $[Pd(\eta^3\text{-}C_3H_5)Cl]_2$ (0.02 equiv.), ligand **4b** (0.04 equiv.), **8** (3.0 equiv.), BSA (3.0 equiv.), LiOAc (0.01 equiv.)
[b] This reaction was carried out for 7 days.
[c] Isolated yields.
[d] The e.e. values were determined by HPLC analysis using a chiral column [Chiralcel OD-H (hexane:*i*-PrOH = 99:1)].
[e] The e.e. value was determined by HPLC analysis using a chiral column [Chiralcel OJ (hexane:*i*-PrOH = 95:5)].
[f] The e.e. value was determined by HPLC analysis using a chiral column [Chiralpak AD-H (hexane:*i*-PrOH = 97:3)].
[g] The e.e. value was determined by HPLC analysis using a chiral column [Chiralcel OD-H+OD (hexane:*i*-PrOH = 199:1)].
[h] See Ref. 9.

96% e.e. (entry 2). The reactions with diethyl malonate **8b** and diethyl methylmalonate **8d** gave the corresponding products in good yields with high enantioselectivities (entries 3 and 5). But when using di-*t*-butyl malonate **8c** instead of **8a**, the reaction gave the corresponding product (*R*)-**9c** with moderate enantioselectivity of 72% (entry 4).

2.3. The mechanism for the asymmetric induction with chiral aminophosphine ligands

The mechanism for the asymmetric induction with this type of ligand is rationalized on the basis of the stereochemical results obtained and the analysis of X-ray structure of (*R*)-**4b**.

The X-ray crystal structure of (*R*)-**4b** in Fig. 1 shows that the more stable structure has *a*R-type conformation about the C(Ar)–N bond (Scheme 4). The (*R*)-2-(methoxymethyl)pyrrolidine derived ligand (*R*)-**4b** would provide a five-membered chelate by coordination of the rather more electron-donating nitrogen group and phosphorus group to the palladium centre.[10] In the conformational equilibrium of sterically favoured π-

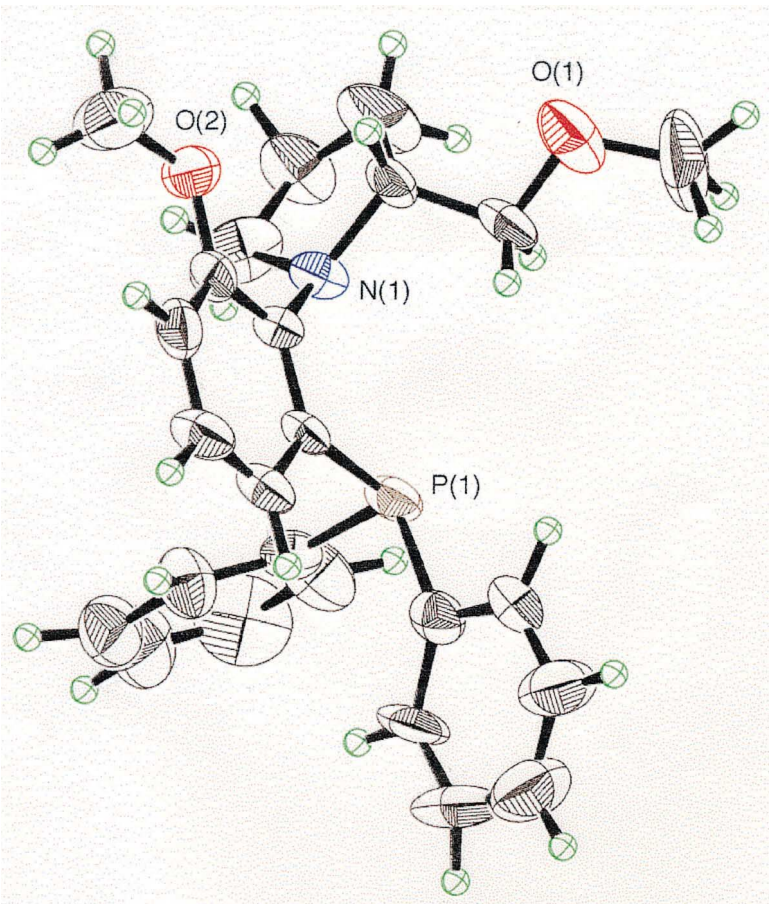
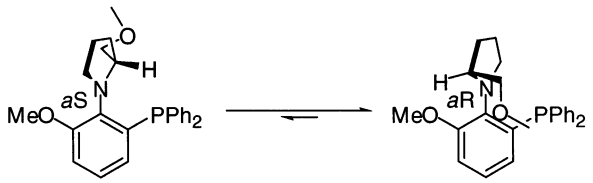


Figure 1. X-Ray crystal structure of (*R*)-**4b**.



Scheme 4.

allylpalladium complexes **10a** and **10b**, the palladium complex **10b** would be preferentially formed because of the existence of steric interference between the phenyl groups of the ligand and the allylic compound in **10a** (Scheme 5).[7,11] Therefore, the nucleophile would attack the allylic terminal in **10b** *trans* to the better π-acceptor (which is the phosphine group in this case) from the back side of the palladium catalyst in the π-allyl system as in **10b**, affording (*R*)-**9a**.

3. Conclusion

We have achieved the palladium-catalyzed asymmetric allylic alkylation of 1,3-diphenyl-2-propenyl acetate **7** with malonate esters **8** in good enantiomeric excess (up to 96% e.e.) using the novel chiral aminophosphine ligands **4**.

4. Experimental

4.1. General methods

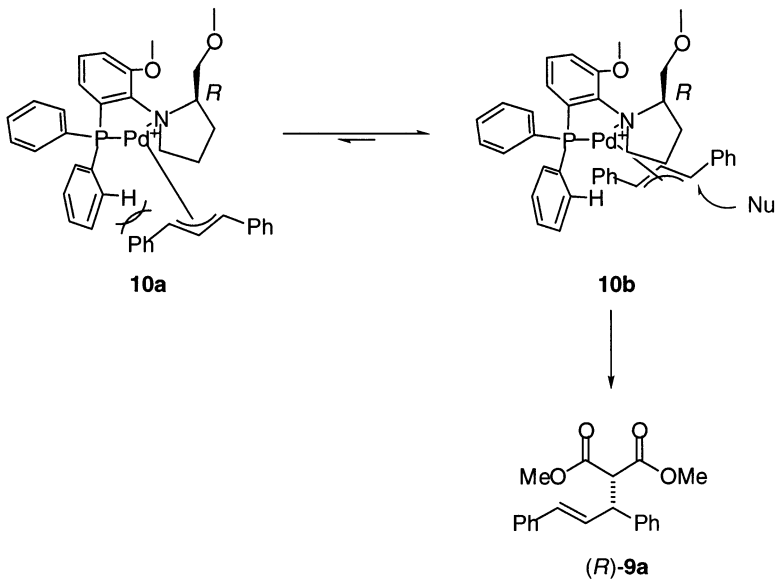
Melting points were measured on a Shibata micromelting point apparatus. NMR spectra were recorded on a JEOL LA-400 system or a Bruker DPX-300 system with TMS as an internal standard. Mass spectra were recorded on a JEOL JMS-HX110. Optical rotations were measured on a JASCO DIP-370.

4.2. Typical procedure for the preparation of phosphine oxides 5

To a mixture of 2-substituted-1-methoxybenzene (10.0 mmol), TMEDA (1.51 mL, 10.0 mmol) and ether (25 mL), was added dropwise *n*-BuLi in hexane (9.2 mL, 14.7 mmol, 1.66 M) over 10 min. The mixture was stirred at rt for 2 h then treated with chlorodiphenylphosphine (1.8 mL, 10.0 mmol) and the resulting mixture was stirred for a further 2 h. The mixture was diluted with ether and quenched with 2 M aqueous HCl. The organic layer was washed with 2 M aqueous Na_2CO_3, brine, dried over $MgSO_4$ and concentrated under reduced pressure. The residue was dissolved in AcOH (50 mL) and treated with 30% aqueous H_2O_2 (1.5 mL) then gradually heated to 80°C over 20 min, and stirred at 80°C for 2 h. The mixture was cooled to rt and diluted with benzene (100 mL) then treated with 2 M aqueous NaOH 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).

4.2.1. 2-Methoxy-3-methylphenyldiphenylphosphine oxide 5a. Yield 71%; mp 151–153°C; ^{1}H NMR ($CDCl_3$) δ: 2.31 (s, 3H), 3.42 (s, 3H), 7.05 (dt, J = 2.6 and 7.6 Hz, 1H), 7.20–7.28 (m, 1H), 7.36–7.56 (m, 7H), 7.66–7.78 (m, 4H); ^{31}P NMR ($CDCl_3$) δ: 27.89; FAB-MS m/z (rel. intensity): 323 (M^++1, 100); HRMS (FAB-MS) m/z calcd for $C_{20}H_{19}O_2P$+H 323.1201, found 323.1223.

4.2.2. 2,3-Dimethoxyphenyldiphenylphosphine oxide 5b. Yield 94%; mp 109–110°C; ^{1}H NMR ($CDCl_3$) δ: 3.29 (s, 3H), 3.85 (s, 3H), 7.09–7.19 (m, 2H), 7.26–7.3 (m, 1H), 7.39–7.55 (m, 6H), 7.69–7.81 (m, 4H); ^{31}P NMR ($CDCl_3$) δ: 27.60; FAB-MS m/z (rel. intensity): 339 (M^++1, 100); HRMS (FAB-MS) m/z calcd for $C_{20}H_{19}O_3P$+H 339.1150, found 339.1125.



Scheme 5.

4.2.3. 3-Isopropyl-2-methoxyphenyldiphenylphosphine oxide 5c. Yield 92%; mp 111–114°C; ^{1}H NMR ($CDCl_3$) δ: 1.23 (d, J=6.9 Hz, 6H), 3.29 (sept, J=6.9 Hz, 1H), 3.53 (s, 3H), 7.07–7.18 (m, 2H), 7.41–7.56 (m, 7H), 7.66–7.78 (m, 4H); ^{31}P NMR ($CDCl_3$) δ: 28.02; FAB-MS m/z (rel. intensity): 351 (M^++1, 100); HRMS (FAB-MS) m/z calcd for $C_{22}H_{23}O_2P$+H 351.1514, found 351.1497.

4.2.4. 2-Methoxy-3-phenylphenyldiphenylphosphine oxide 5d. Yield 83%; mp 119–121°C; ^{1}H NMR ($CDCl_3$) δ: 2.76 (s, 3H), 7.13–7.62 (m, 14H), 7.73–7.85 (m, 4H); ^{31}P NMR ($CDCl_3$) δ: 27.92; FAB-MS m/z (rel. intensity): 385 (M^++1, 100); HRMS (FAB-MS) m/z calcd for $C_{25}H_{21}O_2P$+H 385.1357, found 385.1356.

4.3. Typical procedure for the preparation of aminophosphine oxides 6

To a solution of (*R*)-2-(methoxymethyl)pyrrolidine (1.03 mmol) in THF (1 mL) was added slowly *n*-BuLi in hexane (0.71 mL, 1.1 mmol, 1.56 M) at −80°C for 10 min, and the resulting mixture stirred at rt for 2 h. The mixture was cooled to 0°C and phosphine oxide **5** (1.0 mmol) was added. The mixture was allowed to warm to rt and stirred at rt for 20 h. The mixture was diluted with ether and quenched with satd aqueous 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)-6′-methylphenyl]-2-(methoxymethyl)pyrrolidine 6a. Yield 52%; mp 84–86°C; $[\alpha]_D^{25}$=−115 (c 0.20, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ: 1.48–1.72 (m, 3H), 1.87–2.03 (m, 1H), 2.31 (s, 3H), 2.35–3.80 (m, 5H), 3.09 (s, 3H), 6.89–7.05 (m, 2H), 7.29–7.36 (m, 1H), 7.37–7.54 (m, 6H), 7.56–7.87 (m, 4H); ^{13}C NMR ($CDCl_3$) δ: 19.7 (d, Jcp=1.1 Hz), 24.1, 29.3, 55.0, 58.6, 61.9, 75.3, 109.8 (d, Jcp=1.7 Hz), 120.9, 124.6–139.5 (m, Ar), 150.9, 155.9 (d, Jcp=6.0 Hz); ^{31}P NMR ($CDCl_3$) δ: 26.22; FAB-MS m/z (rel. intensity): 406 (M^++1, 100); HRMS (FAB-MS) m/z calcd for $C_{25}H_{28}NO_2P$+H 406.1936, found 406.1918.

4.3.2. (*R*)-1-[2′-(Diphenylphosphinyl)-6′-methoxylphenyl]-2-(methoxymethyl)pyrrolidine 6b. Yield 60%; mp 138–140°C; $[\alpha]_D^{25}$=−66.4 (c 0.11, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ: 1.41–1.58 (m, 3H), 1.87–2.04 (m, 1H), 2.22 (br-s, 1H), 2.49–2.80 (br-m, 2H), 3.00 (dd, J=4.2 and 9.2 Hz, 1H), 3.13 (s, 3H), 3.73 (br-s, 1H), 3.81 (s, 3H), 6.76 (ddd, J=1.8, 7.3 and 13.4 Hz, 1H), 7.03–7.17 (m, 2H), 7.38–7.34 (m, 6H), 7.69–7.85 (m, 4H); ^{13}C NMR ($CDCl_3$) δ: 24.2, 29.6, 53.0, 55.2, 58.7, 61.8, 75.4, 116.1 (d, Jcp=2.1 Hz), 125.9–136.4 (m, Ar), 142.5, 159.1 (d, Jcp=11.4 Hz); ^{31}P NMR ($CDCl_3$) δ: 25.34; FAB-MS m/z (rel. intensity): 422 (M^++1, 100); HRMS (FAB-MS) m/z calcd for $C_{25}H_{28}NO_3P$+H 422.1885, found 422.1856.

4.3.3. (*R*)-1-[2′-(Diphenylphosphinyl)-6′-isopropylphenyl]-2-(methoxymethyl)pyrrolidine 6c. Yield 17%; $[\alpha]_D^{25}$=−93.6 (c 0.14, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ: 0.93–1.36 (br, 1H (maj)), 1.20 (d, J=6.8 Hz, 6H), 1.63 (br-s, 2H and 1H (maj)), 1.92–2.11 (m, 1H), 2.34 (br-s, 1H (min)), 2.57–2.81 (br-m, 1H and 1H (min)), 2.88 (br-s, 1H (min)), 3.00–3.28 (br-m, 2H), 3.11 (s, 3H), 3.28–3.59 (br-m, 1H), 4.46 (br-s, 1H (min)), 6.96 (br-s, 1H), 7.12 (br-s, 1H), 7.32–7.91 (br-m, 11H); ^{13}C NMR ($CDCl_3$) δ: 23.6, 24.0, 24.7, 27.6, 28.6 (min), 30.2 (maj), 52.2 (min), 55.0 (maj), 58.7, 62.2 (min), 63.6 (maj), 75.6, 124.9–136.4 (m, Ar), 150.2–152.2 (m, Ar); ^{31}P NMR ($CDCl_3$) δ: 26.08 (maj), 27.80 (min); FAB-MS m/z (rel. intensity): 434 (M^++1, 100); HRMS (FAB-MS) m/z calcd for $C_{27}H_{32}NO_2P$+H 434.2249, found 434.2240.

4.3.4. (*R*)-1-[2′-(Diphenylphosphinyl)-6′-phenylphenyl]-2-(methoxymethyl)pyrrolidine 6d. Yield 22%; mp 57–59°C; $[\alpha]_D^{25}$=−165 (c 0.11, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ: 1.03–1.17 (m, 1H) 1.17–1.42 (m, 2H) 1.47–1.64 (m, 1H), 1.96–2.44 (br-m, 1H), 2.66 (dd, J=3.6 and 8.9 Hz, 1H), 2.82 (q, J=7.5 Hz, 1H), 2.95 (s, 3H), 3.00–3.25 (br-m, 1H), 3.78 (br, 1H), 7.00–7.18 (m, 2H), 7.25–7.55 (m, 12H), 7.65–7.75 (m, 2H), 7.75–7.85 (m. 2H); ^{13}C NMR ($CDCl_3$) δ: 23.4, 29.2, 56.5, 58.6, 59.9, 75.0, 123.0–142.9 (m, Ar), 150.7 (d, Jcp=4.4 Hz); ^{31}P NMR ($CDCl_3$) δ: 27.39; FAB-MS m/z (rel. intensity): 468 (M^++1, 100); HRMS (FAB-MS) m/z calcd for $C_{30}H_{30}NO_2P$+H 468.2092, found 468.2091.

4.4. Typical procedure for the preparation of aminophosphine ligands 4

To a mixture of phosphine oxide **6** (0.3 mmol) and triethylamine (0.34 mL, 1.2 mmol) in *m*-xylene (2 mL) was added trichlorosilane (0.24 mL, 1.2 mmol) at 0°C under an Ar atmosphere. The reaction mixture was stirred under reflux for 6 h then cooled to rt, diluted with ether and quenched with 2 M aqueous NaOH solution. 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).

4.4.1. (*R*)-1-[2′-(Diphenylphosphino)-6′-methylphenyl]-2-(methoxymethyl)pyrrolidine 4a. Yield 92%; $[\alpha]_D^{25}$=−56.0 (c 0.11, $CHCl_3$); ^{1}H NMR (CD_2Cl_2) δ: 1.67–1.86 (m, 3H), 2.05 (br-s, 1H), 2.26 (s, 3H), 2.64 (br-s, 1H), 2.83 (q, J=7.7 Hz, 1H), 3.03 (d, J=5.3 Hz, 1H), 3.08–3.30 (m, 1H), 3.10 (s, 3H), 3.59 (br-s, 1H), 6.70 (br-s, 1H), 6.99 (t, J=7.5 Hz, 1H), 7.17 (d, J=7.4 Hz, 1H), 7.20–7.36 (m, 10H); ^{13}C NMR (CD_2Cl_2) δ: 19.0 (d, Jcp=1.5 Hz), 24.9, 30.3, 52.9, 58.8, 61.7, 77.1, 126.2, 128.6–128.7 (m, Ar), 131.9, 133.4, 134.1, 134.4, 134.7, 137.7, 139.2, 139.7, 142.2, 150.6 (d, Jcp=14.6 Hz); ^{31}P NMR ($CDCl_3$) δ: −15.55; FAB-MS m/z (rel. intensity): 390 (M^++1, 50); HRMS (FAB-MS) m/z calcd for $C_{25}H_{28}NOP$+H 390.1987, found 390.2018.

4.4.2. (*R*)-1-[2′-(Diphenylphosphino)-6′-methoxyphenyl]-2-(methoxymethyl)pyrrolidine 4b. Yield 82%; mp 87–89°C; $[\alpha]_D^{25}$=−40.0 (c 0.10, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ: 1.56–1.73 (m, 3H), 1.96–2.13 (m, 1H), 2.41 (br-s, 1H), 2.75 (q, J=7.2 Hz, 1H), 3.03 (t, J=9.2 Hz, 1H), 3.16–3.24 (m, 1H), 3.18 (s, 3H), 3.63–3.74 (m, 1H), 3.79 (s, 3H), 6.39 (ddd, J=1.2, 2.8 and 7.6 Hz, 1H), 6.88 (d, J=7.9 Hz, 1H), 7.06 (t, J=7.9 Hz, 1H), 7.22–7.37 (m,

10H); ^{13}C NMR ($CDCl_3$) δ: 24.6, 30.1, 52.4, 55.0, 58.8, 61.5, 76.9 (d, Jcp = 4.9 Hz), 112.4, 124.8, 126.0, 126.6 (d, Jcp = 0.8 Hz), 128.1–128.3 (m), 133.9, 134.2 (d, Jcp = 5.2 Hz), 134.5, 138.4, 138.6, 139.0, 139.2, 140.8, 141.1, 142.4 (d, Jcp = 4.5 Hz), 158.0 (d, Jcp = 3.5 Hz); ^{31}P NMR ($CDCl_3$) δ: −15.38; FAB-MS m/z (rel. intensity): 406 (M^++1, 40); HRMS (FAB-MS) m/z calcd for $C_{25}H_{28}NO_2P$+H 406.1936, found 406.1950.

4.4.3. (*R*)-1-[2′-(Diphenylphosphino)-6′-isopropylphenyl]-2-(methoxymethyl)pyrrolidine 4c. Yield 74%; $[\alpha]_D^{25}$ = −46.4 (c 0.11, $CHCl_3$); ^{1}H NMR (CD_2Cl_2) δ: 1.00–1.50 (m, 6H), 1.63–1.97 (m, 3H), 1.97–2.18 (m, 1H (maj)), 2.18–2.38 (m, 1H (min)), 2.47–2.60 (m, 1H (maj)), 2.69–2.83 (m, 1H (maj)), 2.94–3.33 (m, 3H (maj) and 7H (min)), 3.13 (s, 3H (maj)), 3.45–3.66 (m, 1H), 4.00–4.03 (m, 1H (min)), 6.63–6.72 (m, 1H (maj)), 6.77–6.86 (m, 1H (min)), 7.04–7.14 (m, 1H), 7.14–7.38 (m, 11H); ^{13}C NMR (CD_2Cl_2) δ: 24.0 (maj), 24.7 (maj), 24.8 (maj), 25.4 (br, min, 3C), 27.6 (min), 28.1 (maj), 29.9 (min), 30.1 (min), 30.6 (maj), 54.4 (maj), 55.0 (d, Jcp = 6.5 Hz (min)), 58.8 (maj), 63.2 (d, Jcp = 15.5 Hz (min)), 63.7 (maj), 76.7 (min), 77.3 (d, Jcp = 7.4 Hz, (maj)), 126.6–151.5 (m, Ar); ^{31}P NMR (CD_2Cl_2) δ: −16.27 (min), −15.93 (maj); FAB-MS m/z (rel. intensity): 418 (M^++1, 27); HRMS (FAB-MS) m/z calcd for $C_{27}H_{32}NOP$+H 418.2300, found 418.2313.

4.4.4. (*R*)-1-[2′-(Diphenylphosphino)-6′-phenylphenyl]-2-(methoxymethyl)pyrrolidine 4d. Yield 89%; $[\alpha]_D^{25}$ = −6.7 (c 0.11, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ: 1.21–1.64 (m, 3H), 1.64–1.81 (m, 1H), 2.47 (t, J = 9.2 Hz, 1H), 2.74 (dd, J = 3.9 and 9.1 Hz, 1H), 2.94 (s, 3H), 2.98–3.18 (m, 2H), 3.63 (br, 1H), 6.93 (ddd, J = 1.8, 3.3 and 7.5 Hz, 1H), 7.08 (t, J = 7.5 Hz, 1H), 7.18 (dd, J = 1.7 and 7.5 Hz, 1H), 7.24–7.39 (m, 15 H); ^{13}C NMR ($CDCl_3$) δ: 24.0, 29.7, 55.6 (d, Jcp = 11.2 Hz), 58.6, 59.7, 76.1, 124.7, 127.0, 128.0–142.1 (m, Ar), 149.7 (d, Jcp = 22.5 Hz); ^{31}P NMR ($CDCl_3$) δ: −14.22; FAB-MS m/z (rel. intensity): 450 (M^+−1, 40); HRMS (FAB-MS) m/z calcd for $C_{30}H_{30}NOP$+H 452.2143, found 452.2130.

4.5. 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 **4** (0.02 mmol), and LiOAc (0.01 mmol) in solvent (1 mL) was added BSA (1.5 mmol, 0.37 mL) and racemic allylic ester **7** (0.5 mmol) at rt under an Ar atmosphere. After stirring for 30 min, nucleophile **8** (1.5 mmol) was added and stirring was continued at the desired temperature for the time indicated in Table 3. 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 with a rotary evaporator and the residue was purified by column chromatography.

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