Supplementary Information for

Catalytic Enantioselective 2°-Alkyl and Aryl Addition to Aldehydes and Ketones with Organozinc Reagents Derived from 2°-Alkyl Grignard Reagents or Arylboronic Acids

Manabu Hatano,[a] Riku Gouzu,[b] Tomokazu Mizuno,[a] Hitoshi Abe,[b] Toshihide Yamada,[b]
and Kazuaki Ishihara*[a,c]

[a] *Graduate School of Engineering, Nagoya University, Furo-cho, Chikusa, Nagoya, 464-8603, Japan.*
[b] *Sekisui Medical Co., Ltd, 4-115, Matsuo, Hachimantai, Iwate, 028-7305, Japan*
[c] *Japan Science and Technology Agency (JST), CREST, Furo-cho, Chikusa, Nagoya, 464-8603, Japan.*

E-mail: ishihara@cc.nagoya-u.ac.jp

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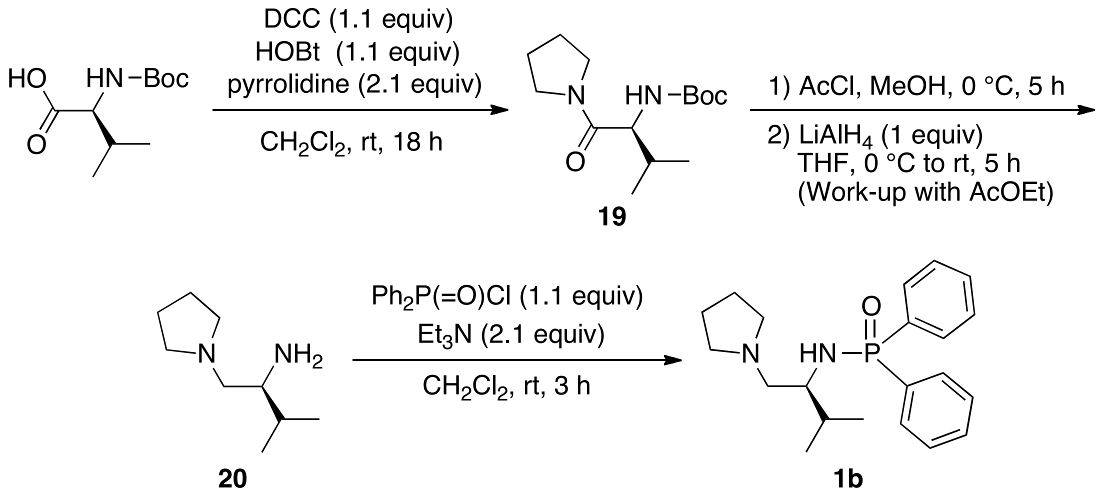
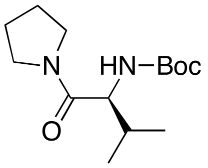
1. General methods. ^{1}H NMR spectra were measured on a JEOL ECS-400 (400 MHz) spectrometer at ambient temperature. Data were recorded as follows: chemical shift in ppm from internal tetramethylsilane on the δ scale, multiplicity (s = singlet; d = doublet; t = triplet; q = quartet; m = multiplet; br = broad), coupling constant (Hz), integration, and assignment. ^{13}C NMR spectra were measured on JEOL ECS-400 (100 MHz) spectrometer. Chemical shifts were recorded in ppm from the solvent resonance employed as the internal standard (deuterochloroform at 77.10 ppm). ^{31}P NMR spectra were measured on a JEOL ECS-400 (161 MHz) spectrometer. Chemical shifts were recorded in ppm from the solvent resonance employed as the internal standard (H_3PO_4 at 0 ppm). ^{19}F NMR spectra were measured on a JEOL ECS-400 (376 MHz) spectrometer. Chemical shifts were recorded in ppm from the solvent resonance employed as the internal standard ($CF_3C_6H_5$ at –63.24 ppm). High resolution mass spectral analyses (HRMS, FAB, EI, ESI) were performed at Chemical Instrument Center, Nagoya University (JEOL JMS-700, QSTAR). IR spectra were determined by a FT-IR spectrometer. High performance liquid chromatography (HPLC) analysis was conducted using Shimadzu LC-10 AD coupled diode array-detector SPD-MA-10A-VP and chiral column of Daicel CHIRALCEL, CHIRALPAK; AD-H, AD-3, OB-H, OD-H. GC analysis was performed with Shimadzu 17A instruments using CP-Cyclodextrin-β-2,3,6-M-19 (i.d. 0.25 mm × 25 m; CHROMPACK; GL Science Inc.) or CHIRALDEX B-DM (i.d. 0.25 mm × 20 m; Tokyo Kasei Kogyo Co., LTD). Centrifugal separator was Kubota Corporation model 2410. All experiments were carried out under an atmosphere of dry nitrogen. For thin-layer chromatography (TLC) analysis throughout this work, Merck TLC plates (silica gel 60G F_{254} 0.25 mm) were used. The products were purified by neutral column chromatography on silica gel (Kanto Chemical Co., Inc. 37560). Visualization was accomplished by UV light (254 nm), anisaldehyde, $KMnO_4$ and phosphomolybdic acid. All dry solvents and reagents were obtained from commercial source and were distilled before use. Et_2Zn (neat) was provided by Tosoh Finechem Corp., Ph_2Zn was purchased from Strem Chemicals, and other organozinc reagents were purchased from Aldrich.

2. Preparation of chiral ligands.[1,2]

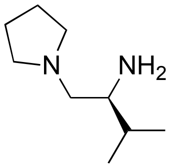


(Preparation of compound **19**) To a solution of *N*-Boc-L-valine (147 g, 0.677 mol) in dry CH_2Cl_2 (3.5 L) was added *N*,*N*'-dicyclohexylcarbodiimide (DCC) (154 g, 0.745 mol) and 1-hydroxybenzotriazole (HOBt) (101 g, 0.745 mol) and pyrrolidine (119 mL, 1.42 mol) at 0 °C. After being stirred for 2 h at the same temperature, the reaction mixture was allowed to warm to ambient temperature and was stirred for 18 h. The reaction was quenched with water (800 mL). The mixture was stirred for 2 h with a formation of white solid. The white solid was filtered and the filtrate was extracted with $CHCl_3$ (1.5 L × 2). The organic layers were dried over anhydrous $MgSO_4$ (110 g), filtered and concentrated *in vacuo*. The crude product was purified by neutral column chromatography on silica gel using *n*-hexane–AcOEt (v/v = 3/1–1/1) as eluent to give **19** (89% yield, 166 g).



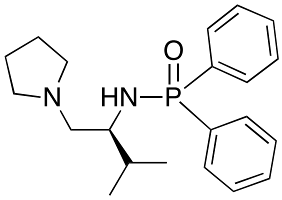
(*S*)-*tert*-Butyl 3-methyl-1-oxo-1-(pyrrolidin-1-yl)butan-2-ylcarbamate (19): ^1H NMR (400 MHz, $CDCl_3$) δ 0.93 (d, J = 10.5 Hz, 3H), 0.96 (d, J = 10.8 Hz, 3H), 1.43 (s, 9H), 1.80-2.04 (m, 5H), 3.10-3.60 (m, 3H), 3.68 (m, 1H), 4.25 (t, J = 8.7 Hz, 1H), 5.27 (d, J = 8.7 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 17.5, 19.5, 24.2, 26.0, 28.4 (3C), 31.5, 45.8, 46.7, 57.0, 79.3, 155.9, 170.7. IR (KBr) 3291, 2971, 2874, 1708, 1637, 1499, 1443, 1250, 1171 cm^{-1}. HRMS (FAB+) calcd for $C_{14}H_{27}N_2O_3$ $[M+H]^+$ 271.2022, found 271.2024.

(Preparation of compound **20**) To a solution of **19** (166 g, 0.614 mol) in MeOH (500 mL) was added dropwise acetyl chloride (750 mL) at 0 °C over 5 h. The reaction mixture was allowed to warm to ambient temperature, and was stirred for 2 h, and then the solution was concentrated *in* *vacuo*. Resultant product in THF (1.8 L) was added dropwise to the 1.8 L of THF solution with lithium aluminum hydride (23.3 g, 0.614 mol) at 0 °C over 4 h. After being stirred at the same temperature for 1 h, AcOEt (240 mL) was added dropwise to the mixture over 30 min with vigorous stirring. Saturated aqueous Na_2SO_4 (45 mL) was then added with vigorous stirring at 0 °C over another 30 min. Na_2SO_4 (100 g) was added. The resultant mixture was heated to 50 °C, and the white suspension was filtered. Wash the white solid with THF (500–1000 mL) at 50 °C, and the white suspension was filtered again (This wash-procedure was repeated for three times.). The combined filtrate was concentrated *in vacuo* (35 °C, 200 Torr). The residue obtained was purified by column chromatography on Cromatorex® NH-DM1020 using *n*-hexane–Et_2O (v/v = 1/1–0/1) as eluent to give the **20** (52% yield, 50 g).

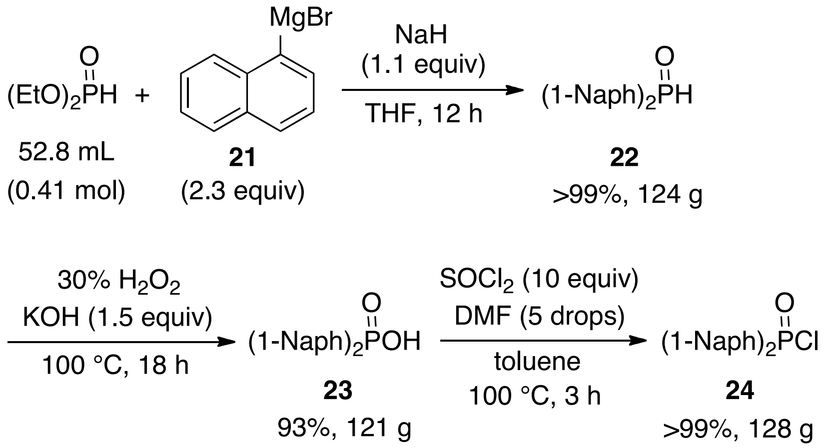


(*S*)-3-Methyl-1-(pyrrolidin-1-yl)butan-2-amine (20): ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.90 (d, *J* = 6.6 Hz, 3H), 0.92 (d, *J* = 6.6 Hz, 3H), 1.30-1.70 (br, 2H), 1.56 (m, 1H), 1.70-1.80 (m, 4H), 2.23 (dd, *J* = 11.4, 3.3 Hz, 1H), 2.30-2.52 (m, 3H), 2.52-2.63 (m, 2H), 2.67 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 17.8, 19.4, 23.5 (2C), 32.2, 54.4 (2C), 55.0, 61.0. IR (neat) 3303, 2958, 2928, 2786, 1714, 1463 cm^{-1}. HRMS (FAB+) calcd for $C_9H_{21}N_2$ $[M+H]^+$ 157.1705, found 157.1706.

(Preparation of compound **1b**) To a solution of **20** (2.34 g, 15 mmol) in THF (40 mL) was added Et_3N (4.43 mL, 31.5 mmol) at room temperature. Diphenylphosphinic chloride (3.15 ml, 16.5 mmol) in THF (40 mL) was added via cannula to the solution at 0 °C. After being stirred for 15 min at 0 °C, the reaction mixture was allowed to warm to ambient temperature and stirred for 3 h. The resulting mixture was cooled in ice bath, and diluted with $CHCl_3$ and water. The product was extracted with $CHCl_3$ and combined organic layer was washed with brine. The combined extracts were dried over $MgSO_4$ and filtered and concentrated *in vacuo*. The crude product was purified by column chromatography on Cromatorex® NH-DM1020 using *n*-hexane–AcOEt as eluent (v/v = 3/1–1/1) to give the corresponding phosphoramide **1b** (92% yield, 4.92 g).



(*S*)-*N*-(3-Methyl-1-(1-pyrrolidinyl)2-butanyl) diphenylphosphinic amide (1b):[1,2] H NMR (400 MHz, $CDCl_3$) δ 0.84 (d, *J* = 6.3 Hz, 3H), 0.91 (d, *J* = 6.3 Hz, 3H), 1.69 (m, 4H), 1.99 (m, 1H), 2.30–2.55 (m, 5H), 2.59 (dd, *J* = 12.6, 7.8 Hz, 1H), 3.15 (m, 1H), 3.27 (m, 1H), 7.38–7.50 (m, 6H), 7.85–7.95 (m, 4H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 17.5, 18.1, 23.6 (2C), 30.3, 54.3 (2C), 55.3, 57.9 (d, J = 5.7 Hz), 128.3 (d, J = 12.4 Hz, 4C), 131.5 (d, J = 2.8 Hz), 131.6 (d, J = 2.8 Hz), 132.1 (d, J = 6.7 Hz, 2C), 132.2 (d, J = 6.7 Hz, 2C), 133.4 (d, J = 125.8 Hz), 133.5 (d, J = 129.6 Hz). ^{31}P NMR (161 MHz, $CDCl_3$) δ 22.8. IR (KBr) 3158, 2957, 2777, 1590, 1458, 1354, 1283, 1179, 1107, 1049 cm^{-1}. $[\alpha]_D^{20} = -9.2$ (*c* 1.00, THF). HRMS (FAB+) calcd for $C_{21}H_{30}N_2OP$ $[M+H]^+$ 357.2096, found 357.2095.



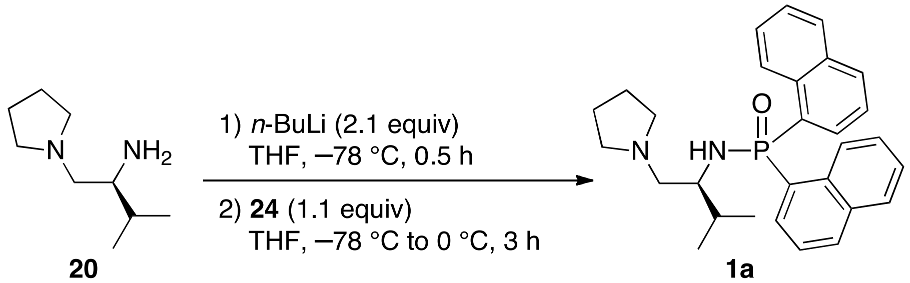
(Preparation of compound **21**) The mixture of magnesium turnings (23.8 g, 0.98 mol) and iodine (ca. 50 mg) was stirred vigorously at room temperature for 2 h. After THF (2 L) was added to the mixture, 1-bromonaphthalene (132 mL, 0.94 mol) was added slowly over 20 min. After the exothermic reaction finished, a black solution of **21** was prepared within 30 min. If necessary, the solution was titrated prior to use against a solution of 1,10-phenanthoroline/*n*-BuLi/*s*-BuOH in benzene.

(Preparation of compound **22**) To a suspension of sodium hydride (60% dispersion in mineral oil, 18.0 g, 0.45 mol) in THF (200 mL) was added dropwise diethyl phosphite (52.8 mL, 0.41 mol) at 0 °C. After being stirred at 0 °C for 30 min, the reaction mixture was cooled to –78 °C. Then, the prepared 1-bromonaphthylmagnesium bromide solution (**21**, 0.94 mol) was added to the suspension at –78 °C. The mixture was allowed to warm to room temperature, and was stirred at that temperature for 12 h. Then, the reaction was quenched at 0 °C with saturated NH_4Cl aqueous solution, where the color of the mixture changed from dark green to bright gray. The mixture was dried over $MgSO_4$ (ca. 200 g). The brown organic phase was filtered, and the solid residue was washed with THF (ca. 500 mL) for three times. The filtrate was concentrated *in vacuo*, and desired compound (**22**) was obtained (124 g, >99% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40-7.65 (m, 6H), 7.80-8.12 (m, 4H), 8.04 (d, J = 8.4 Hz, 2H), 8.31 (d, J = 8.4 Hz, 2H), 9.72 (s, 1H). ^{31}P NMR (161 MHz, $CDCl_3$) δ 18.7.

(Preparation of compound **23**) To a mixture of compound **22** (124 g, 0.41 mol) and 30% H_2O_2

aqueous solution (950 mL) was added dropwise carefully 20 mL of KOH aqueous solution (34.2 g, 0.62 mol) at 0 °C. The mixture was stirred at 0 °C for 30 min, and at room temperature for 1 h. The mixture was heated carefully to 100 °C, and stirred at that temperature for 18 h. Then, the reaction was quenched at 0 °C with 1 *M* HCl aqueous solution to acidify the solution (pH = 1). A white precipitate (**23**) was filtered, washed with *n*-hexane, and dried *in vacuo* (121 g, 93% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.10 (br, 1H), 7.31 (t, *J* = 7.5 Hz, 2H), 7.38 (t, *J* = 7.8 Hz, 2H), 7.42 (t, *J* = 7.2 Hz, 2H), 7.81 (d, *J* = 7.8 Hz, 2H), 7.93 (d, *J* = 8.4 Hz, 2H), 8.14 (d, *J* = 7.2 Hz, 1H), 8.19 (d, *J* = 6.9 Hz, 1H), 8.51 (d, *J* = 8.4 Hz, 2H). ^{31}P NMR (161 MHz, $CDCl_3$) δ 37.5.

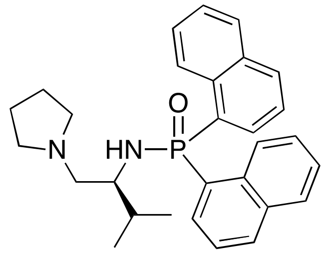
(Preparation of compound **24**) To a mixture of compound **23** (121 g, 0.38 mol) and *N*,*N*-dimethylformamide (5 drops) in toluene (400 mL) was added thionyl chloride (277 mL, 3.8 mol) at room temperature. The mixture was heated to 100 °C, and stirred at that temperature for 3 h. Then, volatiles were removed *in vacuo* at room temperature for 12 h. Compound **24** was obtained in >99% yield (128 g). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.48-7.63 (m, 6H), 7.91-8.00 (m, 2H), 8.04 (d, *J* = 7.2 Hz, 1H), 8.08-8.16 (m, 3H), 8.63-8.72 (m, 2H). ^{31}P NMR (161 MHz, $CDCl_3$) δ 47.0.



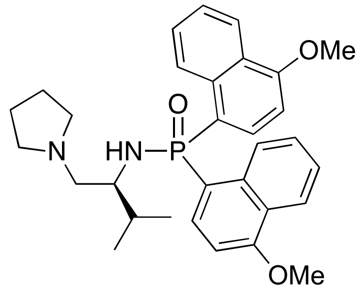
20
(30 g, 192 mmol)

1a
31%, 27 g

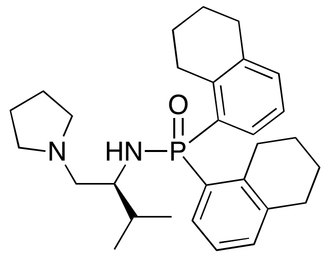
(Preparation of compound **1a**) To a solution of **20** (30 g, 191 mmol) in THF (300 mL) was added *n*-BuLi (1.6 *M* in *n*-hexane, 251 mL) at –78 °C. Compound **24** (70.8 g, 211 mmol) in THF (300 mL) was added slowly via cannula to the solution at –78 °C. After being stirred for 30 min at –78 °C, the reaction mixture was allowed to warm to 0 °C over 3 h. The resulting mixture was cooled in ice bath, and quenched with saturated NH_4Cl aqueous solution. The product was extracted with AcOEt and combined organic layer was washed with brine. The combined extracts were dried over $MgSO_4$ and filtered and concentrated *in vacuo*. The crude product was purified by column chromatography on Cromatorex® NH-DM1020 using *n*-hexane–AcOEt as eluent (v/v = 2/1), and recrystalized in *n*-hexane–AcOEt (v/v = 3/1) to give the corresponding phosphoramide **1a** (31% yield, 27.0 g).



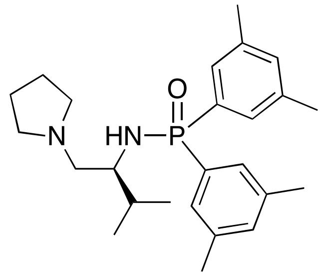
(*S*)-*N*-(3-Methyl-1-(pyrrolidin-1-yl)butan-2-yl)-*P*,*P*-di(naphthalen-1-yl)phosphinic amide (1a):[1,2] ^{1}H NMR (400 MHz, CDCl$_3$) δ 0.87 (d, *J* = 7.2 Hz, 3H), 0.89 (d, *J* = 6.9 Hz, 3H), 1.63 (m, 4H), 2.20-2.65 (m, 7H), 3.40-3.60 (m, 2H), 7.36-7.56 (m, 6H), 7.80-8.02 (m, 5H), 8.21 (dd, *J* = 15.9, 7.2 Hz, 1H), 8.87 (m, 1H), 8.99 (m, 1H). ^{13}C NMR (100 MHz, CDCl$_3$) δ 16.9, 18.6, 23.6 (2C), 31.1, 54.3 (2C), 55.6, 57.1 (d, *J* = 5.7 Hz), 124.4 (d, *J* = 14.4 Hz), 124.5 (d, *J* = 14.4 Hz), 126.2 (d, *J* = 6.7 Hz, 2C), 127.0 (2C), 127.6 (2C), 128.7 (2C), 130.2 (d, *J* = 121.0 Hz), 130.5 (d, *J* = 123.9 Hz), 132.7 (d, *J* = 10.4 Hz), 132.8 (d, *J* = 10.4 Hz), 133.2-134.2 (m, 6C). ^{31}P NMR (161 MHz, CDCl$_3$) δ 28.7. IR (KBr) 3210, 2958, 2782, 1457, 1175, 1158 cm^{-1}. $[\alpha]_D^{20}$ = +20.8 (*c* 1.00, THF). HRMS (FAB+) calcd for $C_{29}H_{34}N_2OP$ $[M+H]^+$ 457.2409, found 457.2405.



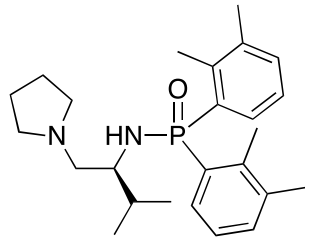
(*S*)-*P*,*P*-Bis(4-methoxynaphthalen-1-yl)-*N*-(3-methyl-1-(pyrrolidin-1-yl)butan-2-yl)phosphinic amide (1c): ^{1}H NMR (400 MHz, CDCl$_3$) δ 0.85 (d, *J* = 7.2 Hz, 3H), 0.87 (d, *J* = 7.2 Hz, 3H), 1.63 (m, 4H), 2.20-2.40 (m, 4H), 2.45-2.62 (m, 3H), 3.45-3.55 (m, 2H), 3.94 (s, 3H), 3.96 (s, 3H), 6.68-6.73 (m, 2H), 7.37-7.52 (m, 4H), 7.90 (dd, *J* = 15.8, 7.8 Hz, 1H), 8.07 (dd, *J* = 15.8, 7.8 Hz, 1H), 8.29 (d, *J* = 8.1 Hz, 2H), 8.84 (d, *J* = 8.7 Hz, 1H), 8.93 (d, *J* = 8.7 Hz, 1H). ^{13}C NMR (100 MHz, CDCl$_3$) δ 16.8, 18.5, 23.5 (2C), 30.8, 54.2 (2C), 55.3, 55.5 (2C), 57.0 (d, *J* = 6.6 Hz), 102.2 (d, *J* = 13.3 Hz), 102.3 (d, *J* = 15.2 Hz), 121.6 (d, *J* = 125.8 Hz), 121.9 (d, *J* = 130.6 Hz), 122.3 (2C), 125.3 (2C), 125.8 (d, *J* = 11.4 Hz), 125.9 (d, *J* = 11.4 Hz), 127.2 (d, *J* = 4.8 Hz, 2C), 127.3 (d, *J* = 3.8 Hz), 127.4 (d, *J* = 3.8 Hz), 134.6-135.2 (m, 4C), 158.5 (d, *J* = 7.6 Hz), 158.6 (d, *J* = 7.6 Hz). ^{31}P NMR (161 MHz, CDCl$_3$) δ 29.1. IR (KBr) 3399, 2959, 1588, 1570, 1509, 1460, 1317, 1092 cm^{-1}. $[\alpha]_D^{20}$ = +22.1 (*c* 1.1, CHCl$_3$). HRMS (FAB+) calcd for $C_{31}H_{38}N_2O_3P$ $[M+H]^+$ 517.2620, found 517.2613.



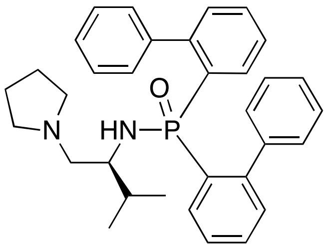
(*S*)-*N*-(3-Methyl-1-(pyrrolidin-1-yl)butan-2-yl)-*P*,*P*-bis(5,6,7,8-tetrahydronaphthalen-1-yl) phosphinic amide (1d): ^{1}H NMR (400 MHz, CDCl$_3$) δ 0.87 (d, *J* = 6.9 Hz, 3H), 0.89 (d, *J* = 6.9 Hz, 3H), 1.40-3.42 (m, 29H), 7.04-7.80 (m, 6H). ^{13}C NMR (100 MHz, CDCl$_3$) δ 16.8, 18.5, 22.4 (2C), 22.7 (2C), 23.5 (2C), 28.1 (d, *J* = 4.8 Hz, 2C), 30.2 (2C), 30.6, 54.3 (2C), 54.9, 57.0 (d, *J* = 6.6 Hz), 124.6 (d, *J* = 14.3 Hz, 2C), 130.6 (d, *J* = 9.5 Hz), 130.7 (d, *J* = 10.5 Hz), 132.5 (d, *J* = 119.2 Hz), 132.6 (d, *J* = 117.2 Hz), 132.8 (2C), 138.1 (d, *J* = 11.4 Hz, 2C), 140.9 (d, *J* = 7.6 Hz), 141.0 (d, *J* = 10.5 Hz). ^{31}P NMR (161 MHz, CDCl$_3$) δ 29.1. IR (KBr) 3231, 2928, 1676, 1439, 1196, 1169, 1087 cm^{-1}. HRMS (FAB+) calcd for $C_{29}H_{42}N_2OP$ [M+H]$^+$ 465.3035, found 465.3030.



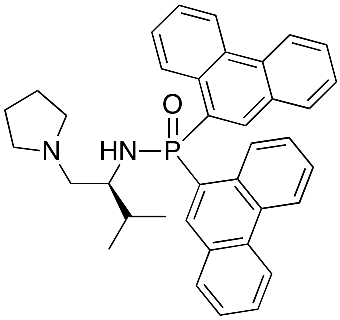
(*S*)-*P*,*P*-Bis(3,5-dimethylphenyl)-*N*-(3-methyl-1-(pyrrolidin-1-yl)butan-2-yl)phosphinic amide (1e): ^{1}H NMR (400 MHz, CDCl$_3$) δ 0.87 (d, *J* = 6.9 Hz, 3H), 0.92 (d, *J* = 6.9 Hz, 3H), 1.71 (m, 4H), 1.99 (m, 1H), 2.32 (s, 12H), 2.33-2.65 (m, 6H) 3.12 (m, 1H), 3.23 (m, 1H), 7.09 (s, 2H), 7.45 (s, 1H), 7.49 (s, 2H), 7.53 (s, 1H). ^{31}P NMR (161 MHz, CDCl$_3$) δ 23.7. IR (KBr) 3206, 2956, 2786, 1599, 1455, 1273, 1183, 1126, 1046 cm^{-1}. HRMS (FAB+) calcd for $C_{25}H_{38}N_2OP$ [M+H]$^+$ 413.2722, found 413.2722.



(*S*)-*P*,*P*-Bis(2,3-dimethylphenyl)-*N*-(3-methyl-1-(pyrrolidin-1-yl)butan-2-yl)phosphinic amide (1f): ^{1}H NMR (400 MHz, CDCl$_3$) δ 0.87 (d, *J* = 6.9 Hz, 3H), 0.91 (d, *J* = 6.9 Hz, 3H), 1.67 (m, 4H), 2.18-2.62 (m, 19H), 3.09 (m, 1H), 3.37 (m, 1H), 7.03-7.36 (m, 4H), 7.58 (m, 1H), 7.82 (m, 1H). ^{31}P NMR (161 MHz, CDCl$_3$) δ 29.8. IR (KBr) 3217, 2953, 2780, 1451, 1193, 1168, 1143, 1090 cm^{-1}. $[\alpha]_D^{23}$ = +33.6 (*c* 1.00, THF). HRMS (FAB+) calcd for $C_{25}H_{38}N_2OP$ $[M+H]^+$ 413.2722, found 413.2722.



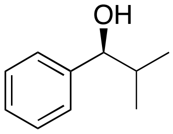
(*S*)-*P*,*P*-Di([1,1'-biphenyl]-2-yl)-*N*-(3-methyl-1-(pyrrolidin-1-yl)butan-2-yl)phosphinic amide (1g): ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.74 (d, *J* = 6.9 Hz, 3H), 0.81 (d, *J* = 6.9 Hz, 3H), 1.47 (m, 4H), 1.82-2.04 (m, 2H), 2.17-2.23 (m, 6H), 3.49 (m, 1H), 6.88-7.40 (m, 16H), 7.40-7.62 (m, 2H). IR (KBr) 3367, 2961, 2934, 2791, 2764, 1462, 1412, 1204, 1136, 1038 cm^{-1}. HRMS (FAB+) calcd for $C_{33}H_{38}N_2OP$ $[M+H]^+$ 509.2722, found 509.2727.



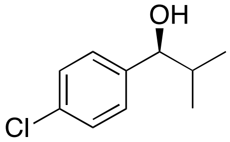
(*S*)-*N*-(3-Methyl-1-(pyrrolidin-1-yl)butan-2-yl)-*P*,*P*-di(phenanthren-9-yl)phosphinic amide (1h): ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.85 (d, *J* = 6.9 Hz, 3H), 0.91 (d, *J* = 6.9 Hz, 3H), 1.67 (m, 4H), 2.16-2.77 (m, 7H), 3.60 (m, 2H), 7.36-9.06 (m, 18H). ^{31}P NMR (161 MHz, $CDCl_3$) δ 28.8. IR (KBr) 3210, 2958, 2790, 1448, 1196, 1047 cm^{-1}. $[\alpha]_D^{24}$ = +8.0 (*c* 0.8, THF). HRMS (FAB+) calcd for $C_{37}H_{38}N_2OP$ $[M+H]^+$ 557.2722, found 557.2711.

3. General procedure for the catalytic enantioselective addition of di(2°-alkyl)zinc reagents to aldehydes (Tables 1 and 2).

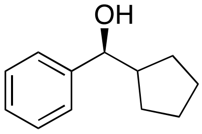
A well-dried Pyrex Schlenk tube was charged with **1a** (22.8 mg, 0.05 mmol) and the di(2°-alkyl)zinc reagent (0.44 *M* in Et_2O) (3.4 mL, 1.5 mmol) at room temperature under a nitrogen atmosphere. Et_2O was removed under reduced pressure to generate the solvent free di(2°-alkyl)zinc reagent containing **1a** in situ. After the removal of Et_2O, toluene (0.4 mL) was added when (*c*-Hex)$_2$Zn was used. Aldehyde **2** (0.5 mmol) was added to the mixture at room temperature. The resulting mixture was stirred at room temperature for 2 h. Ether or EtOAc (10 mL) and sat. NH_4Cl aqueous solution (10 mL) was poured into the mixture at 0 °C. The product was extracted with ether (10 mL × 3) and washed with brine (10 mL). The combined extracts were dried over $MgSO_4$. The organic phase was concentrated under reduced pressure and the crude product was purified by neutral silica gel column chromatography (eluent: *n*-hexane/Et_2O or *n*-pentane/Et_2O) to give the desired products (**3**). The enantiomeric purity was determined by GC or HPLC on a chiral column. The products (**3a**,**b**,**d**–**j**,**l**,**m**,**o**,**p**,**r**–**w**) and their derivatives (**4**–**8**) have been fully characterized in a previous report.[2]



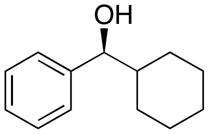
(*S*)-2-Methyl-1-phenylpropan-1-ol (3a):[2] ^1H NMR (400 MHz, $CDCl_3$) δ 0.79 (d, *J* = 6.9 Hz, 3H), 1.00 (d, *J* = 6.9 Hz, 3H), 1.85 (s, 1H), 1.96 (octet, *J* = 6.9 Hz, 1H), 4.36 (m, 1H), 7.20-7.39 (m, 5H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 18.3, 19.0, 35.3, 80.1, 126.6 (2C), 127.4, 128.2 (2C), 143.6. IR (neat) 3390, 2958, 2927, 2871, 1454, 1022 cm^{-1}. HRMS (EI) calcd for $C_{10}H_{14}O$ $[M]^+$ 150.1045, found 150.1052. $[\alpha]_D^{20}$ = –46.8 (94% ee, *c* 1.0, Et_2O) (lit.[3] $[\alpha]_D^{20}$ = –48.4 (95% ee (*S*), *c* 1.34, Et_2O)). Chiral GC CP-Cyclodextrin-β-2,3,6-M-19, 110 °C, t_R = 36.5 min (minor, *R*), 38.0 min (major, *S*).



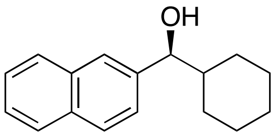
(*S*)-1-(4-Chlorophenyl)-2-methylpropan-1-ol (3c):[4] ^1H NMR (400 MHz, $CDCl_3$) δ 0.80 (d, *J* = 6.9 Hz, 3H), 0.97 (d, *J* = 6.9 Hz, 3H), 1.56 (br, 1H), 1.92 (octet, *J* = 6.9 Hz, 1H), 4.36 (m, 1H), 7.25 (d, *J* = 8.7 Hz, 2H), 7.31 (d, *J* = 8.7 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 18.1, 18.8, 35.3, 79.2, 127.9 (2C), 128.3 (2C), 133.0, 142.0. IR (neat) 3389, 2960, 2872, 1596, 1489, 1409, 1089, 1013 cm^{-1}. HRMS (EI) calcd for $C_{10}H_{13}ClO$ $[M]^+$ 184.0655, found 184.0652. $[\alpha]_D^{20}$ = –31.2 (80% ee, *c* 1.0, $CHCl_3$) (lit.[5] $[\alpha]_D^{21}$ = +38.9 (95% ee (*R*), *c* 1.15, $CHCl_3$)). Chiral GC CP-Cyclodextrin-β-2,3,6-M-19, 140 °C, t_R = 17.8 min (minor, *R*), 18.4 min (major, *S*).



(*S*)-Cyclopentyl(phenyl)methanol (3k):[6] ^1H NMR (400 MHz, $CDCl_3$) δ 1.05-1.80 (m, 7H), 1.88 (m, 1H), 1.94 (br, 1H), 2.21 (sextet, *J* = 7.8 Hz, 1H), 4.39 (d, *J* = 8.1 Hz, 1H), 7.22-7.40 (m, 5H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 25.4, 25.5, 29.4, 29.5, 47.6, 79.2, 126.5 (2C), 127.5, 128.3 (2C), 144.4. IR (neat) 3391, 2953, 2866, 1490, 1024 cm^{-1}. HRMS (EI) calcd for $C_{12}H_{16}O$ $[M]^+$ 176.1201, found 176.1204. $[\alpha]_D^{20}$ = –44.4 (>99% ee, *c* 0.9, $CHCl_3$) (lit.[6] $[\alpha]_D^{20}$ = –40.0 (78% ee (*S*), *c* 0.8, $CHCl_3$)). Chiral HPLC analysis; OD-H, *n*-hexane/*i*-PrOH = 19/1, 0.5 mL/min, t_R = 16.3 min (major, *S*), 17.4 min (minor, *R*).



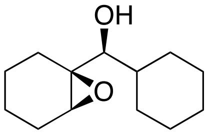
(*S*)-Cyclohexyl(phenyl)methanol (3n):[7] ^{1}H NMR (400 MHz, CDCl$_3$) δ 0.85-2.10 (m, 12H), 4.37 (m, 1H), 7.20-7.40 (m, 5H). ^{13}C NMR (100 MHz, CDCl$_3$) δ 26.0, 26.1, 26.4, 28.9, 29.3, 45.1, 79.4, 126.7 (2C), 127.4, 128.2 (2C), 143.6. IR (KBr) 3409, 2917, 1444, 1323, 1071, 1009 cm^{-1}. HRMS (FAB+) calcd for $C_{13}H_{18}NaO$ $[M+Na]^+$ 213.1255, found 213.1259. $[\alpha]_D^{20} = -18.4$ (90% ee, *c* 1.0, CHCl$_3$) (lit.[7] $[\alpha]_D = +17.0$ (85% ee (*R*), *c* 0.60, CHCl$_3$)). Chiral GC CHIRALDEX B-DM, 130 °C, t_R = 26.1 min (major, *S*), 28.3 min (minor, *R*).



(*S*)-Cyclohexyl(naphthalen-2-yl)methanol (3q):[8] ^{1}H NMR (400 MHz, CDCl$_3$) δ 0.90-1.82 (m, 10H), 1.94 (d, *J* = 2.7 Hz, 1H), 2.02 (m, 1H), 4.55 (dd, *J* = 7.2, 3.3 Hz, 1H), 7.42-7.51 (m, 3H), 7.73 (s, 1H), 7.80-7.86 (m, 3H). ^{13}C NMR (100 MHz, CDCl$_3$) δ 26.0, 26.1, 26.4, 28.8, 29.3, 44.7, 79.3, 124.7, 125.4, 125.6, 126.0, 127.6, 127.8, 127.9, 132.8, 133.0, 141.0. IR (neat) 3389, 3054, 2925, 2851, 1449, 1020 cm^{-1}. HRMS (EI) calcd for $C_{17}H_{20}O$ $[M]^+$ 240.1514, found 240.1521. $[\alpha]_D^{20} = -32.0$ (95% ee, *c* 1.0, THF) (lit.[8] $[\alpha]_D^{20} = +14.51$ (82% ee, *c* 0.255, THF)). Chiral HPLC analysis; OD-H, *n*-hexane/*i*-PrOH = 19/1, 0.5 mL/min, t_R = 33.3 min (major, *S*), 42.4 min (minor, *R*).

4. Synthesis of a 2,3-epoxyalcohol (Eq. 5).

Vanadyl acetylacetonate (2.0 mg, 0.0075 mmol) and *tert*-butyl hydroperoxide (5.5 *M* in decane, 68 μL, 0.375 mmol) were added to a dichloromethane solution (1 mL) of **3w** (48.6 mg, 0.25 mmol) at 0 °C. After the mixture was kept at 0 °C for 2 h, the solvent was removed and the crude mixture was purified by silica gel column chromatography (eluent: *n*-hexane/ether = 6/1), to give the titled compound (**8**) (52.7 mg, >99%, *syn*/*anti* = 96/4).



7-Oxabicyclo[4.1.0]heptan-1-yl)(cyclohexyl)methanol (8): *syn*-isomer ^{1}H NMR (400 MHz, CDCl$_3$) δ 1.09-1.93 (m, 18H), 1.99 (m, 1H), 2.14 (br, 1H), 3.22 (d, *J* = 2.7 Hz, 1H), 3.40 (d, *J* = 4.2 Hz, 1H). ^{13}C NMR (100 MHz, CDCl$_3$) δ 19.8, 20.2, 24.2, 25.3, 26.3, 26.4, 26.6, 26.9, 30.2, 40.2, 55.8, 61.3, 75.6. IR (neat) 3464, 2928, 2852, 1448, 1115, 1025 cm^{-1}. HRMS (ESI+) calcd for $C_{13}H_{22}NaO_2$ $[M+Na]^+$ 233.1517, found 233.1521. *anti*-isomer ^{1}H NMR (400

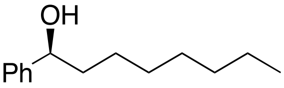
MHz, $CDCl_3$) δ 0.80-2.25 (m, 20H), 2.89 (d, *J* = 8.1 Hz, 1H), 3.04 (d, *J* = 2.4 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 19.7, 19.9, 22.4, 24.4, 25.8, 26.1, 26.4, 29.1, 29.3, 40.4, 58.2, 62.0, 81.4. IR (neat) 3452, 2927, 2852, 1448, 1087, 1026 cm^{-1}. HRMS (ESI+) calcd for $C_{13}H_{22}NaO_2$ $[M+Na]^+$ 233.1517, found 233.1521.

5. General procedure for the catalytic enantioselective addition of di(2°-alkyl)zinc reagents to ketones (Table 3).

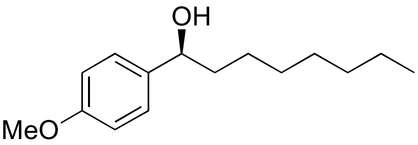
A well-dried Pyrex Schlenk tube was charged with **1a** (22.8 mg, 0.05 mmol) and the di(2°-alkyl)zinc reagent (0.44 *M* in Et_2O) (3.4 mL, 1.5 mmol) at room temperature under a nitrogen atmosphere. Et_2O was removed under reduced pressure to generate the solvent free di(2°-alkyl)zinc reagent containing **1a** in situ. After the removal of Et_2O, toluene (0.4 mL) was added when $(c\text{-Hex})_2Zn$ was used, and the mixture was cooled to 0 °C. Ketone (**9**) (0.5 mmol) was added to the mixture (In the case of **9b**, **9b** was added dropwise at 0 °C over 12 h). The resulting mixture was stirred at 0 °C for 24 h. Ether or EtOAc (10 mL) and sat. NH_4Cl aqueous solution (10 mL) was poured into the mixture at 0 °C. The product was extracted with ether (10 mL × 3) and washed with brine (10 mL). The combined extracts were dried over $MgSO_4$. The organic phase was concentrated under reduced pressure and the crude product was purified by neutral silica gel column chromatography (eluent: *n*-hexane/Et_2O = 20/1–8/1) to give the desired product (**10**). To determine the enantioselectivity by GC or HPLC on a chiral column, compound **10** was readily transformed to the corresponding acetate derivative by using Ac_2O/Et_3N/DMAP in CH_2Cl_2. The products (**10a–d**) have been fully characterized in a previous report.[2]

6. General procedure for the catalytic enantioselective long *n*-alkyl chain addition to aldehydes (Table 4).[9]

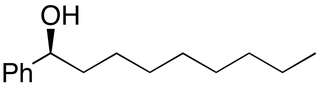
A well-dried Pyrex Schlenk tube was charged with **1a** (22.8 mg, 0.05 mmol) and the salt free R_2Zn reagent (0.4–0.6 *M* Et_2O solution) (1.5 mmol) at room temperature under a nitrogen atmosphere. Et_2O was removed under reduced pressure to generate the solvent free R_2Zn reagent containing **1a** in situ. Aldehyde (0.5 mmol) was added to the mixture at room temperature. The resulting mixture was stirred at room temperature for 2 h. Ether or EtOAc (10 mL) and sat. NH_4Cl aqueous solution (10 mL) was poured into the mixture at 0 °C. The product was extracted with ether (10 mL × 3) and washed with brine (10 mL). The combined extracts were dried over $MgSO_4$. The organic phase was concentrated under reduced pressure and the crude product was purified by neutral silica gel column chromatography (eluent: *n*-hexane/Et_2O) to give the desired products (**12**). The enantiomeric purity was determined by GC on a chiral column.



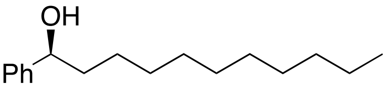
(*S*)-1-phenyloctan-1-ol (12a):[10] ^{1}H NMR (400 MHz, CDCl$_3$) δ 0.86 (t, *J* = 6.9 Hz, 3H), 1.18-1.87 (m, 13H), 4.66 (m, 1H), 7.24-7.37 (m, 5H). ^{13}C NMR (100 MHz, CDCl$_3$) δ 14.1, 22.7, 25.9, 29.2, 29.5, 31.8, 39.1, 74.7, 125.9 (2C), 127.5, 128.4 (2C), 144.9. IR (neat) 3357, 2955, 2925, 2855, 1455, 1025 cm^{-1}. HRMS (FAB+) calcd for $C_{14}H_{22}NaO$ $[M+Na]^+$ 229.1568, found 229.1564. $[\alpha]_D^{20} = -14.0$ (92% ee, *c* 1.0, CHCl$_3$) (lit.[10] $[\alpha]_D^{27} = -18.3$ (42% ee (*S*), *c* 0.8, CHCl$_3$)). Chiral GC CHIRALDEX β-DM, 140 °C, t_R = 18.5 min (major, *S*), 19.8 min (minor, *R*).



(*S*)-1-(4-methoxyphenyl)octan-1-ol (12b):[11] ^{1}H NMR (400 MHz, CDCl$_3$) δ 0.87 (t, *J* = 7.2 Hz, 3H), 1.17-1.42 (m, 10H), 1.74 (m, 2H), 1.72 (br, 1H), 3.81 (s, 3H), 4.62 (t, *J* = 5.7 Hz, 1H), 6.89 (d, *J* = 8.7 Hz, 2H), 7.55 (d, *J* = 7.8 Hz, 2H). ^{13}C NMR (100 MHz, CDCl$_3$) δ 14.2, 22.7, 26.0, 29.3, 29.6, 31.9, 39.0, 55.3, 74.3, 113.8 (2C), 127.2 (2C), 137.2, 158.9. IR (neat) 3359, 2927, 2855, 1612, 1513, 1465, 1248, 1174, 1038 cm^{-1}. HRMS (FAB+) calcd for $C_{15}H_{24}O_2$ $[M]^+$ 236.1776, found 236.1769. $[\alpha]_D^{20} = -19.2$ (94% ee, *c* 1.0, CHCl$_3$). Chiral HPLC analysis; OD-H, *n*-hexane/*i*-PrOH = 95/5, 1.0 mL/min, t_R = 8.5 min (minor, *R*), 9.6 min (major, *S*).

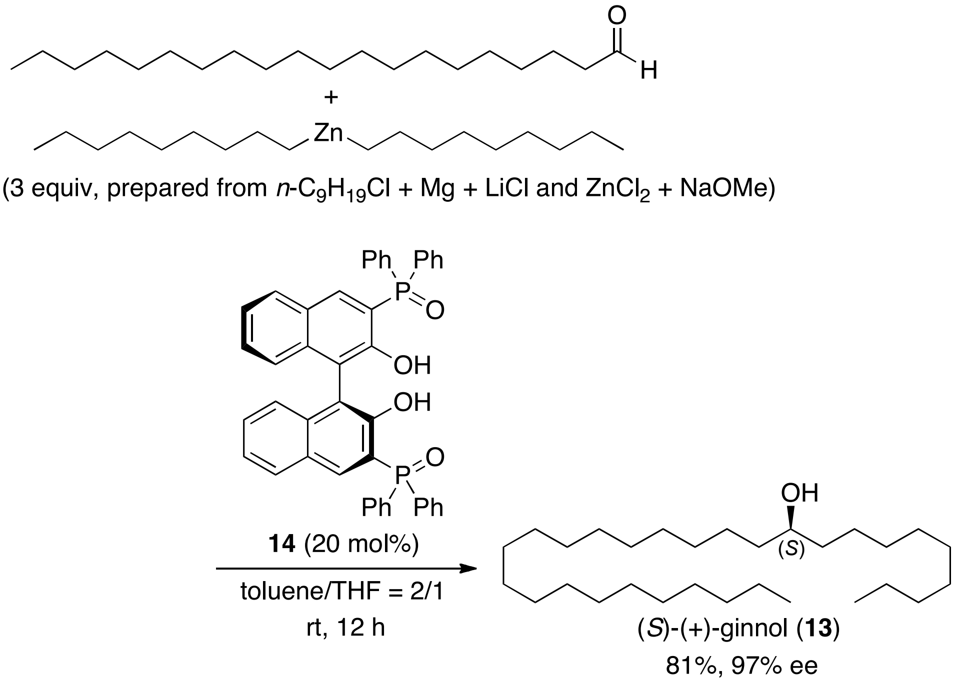


(*S*)-1-Phenylnonan-1-ol (12c):[12] ^{1}H NMR (400 MHz, CDCl$_3$) δ 0.79 (t, *J* = 6.0 Hz, 3H), 1.10-1.37 (m, 12H), 1.50-1.80 (m, 2H), 1.97 (br, 1H), 4.54 (t, *J* = 6.0 Hz, 1H), 7.15-7.31 (m, 5H). ^{13}C NMR (100 MHz, CDCl$_3$) δ 14.1, 22.7, 25.8, 29.3, 29.5, 29.6, 31.9, 39.1, 74.7, 125.9 (2C), 127.4, 128.4 (2C), 144.9. IR (neat) 3357, 2925, 2854, 1455, 1026 cm^{-1}. HRMS (EI) calcd for $C_{15}H_{24}O$ $[M]^+$ 220.1827, found 220.1830. $[\alpha]_D^{20} = -23.5$ (96% ee, *c* 2.0, CHCl$_3$) (lit.[13] $[\alpha]_D^{18} = +26.6$ (94% ee (*R*), *c* 1.65, CHCl$_3$)). Chiral GC CHIRALDEX β–DM, 140 °C, t_R = 29.9 min (major, *S*), 33.0 min (minor, *R*).



(*S*)-1-Phenylundecan-1-ol (12d):[14] ^{1}H NMR (400 MHz, CDCl$_3$) δ 0.97 (t, *J* = 7.2 Hz, 3H), 1.15-1.45 (m, 16H), 1.60-1.85 (m, 2H), 1.87 (br, 1H), 4.65 (t, *J* = 6.9 Hz, 1H), 7.20-7.40 (m, 5H). ^{13}C NMR (100 MHz, CDCl$_3$) δ 14.2, 22.7, 25.9, 29.3, 29.6 (2C), 29.7 (2C), 31.9, 39.1, 74.9, 125.9 (2C), 127.5, 128.5 (2C), 144.9. IR (neat) 3357, 2924, 2853, 1455, 1027 cm^{-1}. HRMS (EI) calcd for $C_{17}H_{28}O$ $[M]^+$ 248.2140, found 248.2138. $[\alpha]_D^{20} = -21.2$ (95% ee, *c* 3.0, CHCl$_3$) (lit.[14] $[\alpha]_D^{25} = +16.3$ (76% ee (*R*), *c* 2.2, CHCl$_3$)). Chiral GC CHIRALDEX β-DM, 150 °C, t_R = 47.1 min (major, *S*), 50.3 min (minor, *R*).

7. Catalytic enantioselective synthesis of (*S*)-(+)-ginnol (Scheme 1).



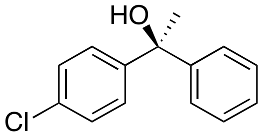
A well-dried Pyrex Schlenk tube was charged with **14** (68.7 mg, 0.10 mmol) and the salt free (n-C_9H_{19})$_2$Zn reagent (0.44 *M* Et_2O solution) (3.4 mL, 1.5 mmol) at room temperature under a nitrogen atmosphere. Et_2O was removed under reduced pressure to generate the solvent free (n-C_9H_{19})$_2$Zn reagent containing **14** in situ. Toluene (1.5 mL) and THF (0.7 mL) were then added, and the mixture was stirred at room temperature for 1 h. Icosanal (148.3 mg, 0.5 mmol) was added. The resulting mixture was stirred at room temperature for 12 h. After hydrolysis with 10 mL of saturated NH_4Cl aqueous solution, the product was extracted with ethyl acetate (10 mL × 3) and washed with brine (10 mL). The combined extracts were dried over $MgSO_4$. The organic phase was concentrated under reduced pressure and the crude product was purified by neutral silica gel column chromatography (eluent: *n*-hexane/Et_2O) to give ginnol (172.5 mg, 81% yield).

^{1}H NMR (400 MHz, $CDCl_3$) δ 0.88 (t, *J* = 6.9 Hz, 6H), 1.20-135 (m, 48H), 1.42 (m, 4H), 1.56 (s, 1H), 3.58 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.2 (2C), 22.7 (2C), 25.7 (2C), 29.3, 29.4, 29.8 (16C), 32.0 (2C), 37.6 (2C), 72.1. IR (KBr) 3449, 2917, 2850, 1467, 1561, 1101 cm^{-1}. HRMS (EI) calcd for $C_{29}H_{58}$ $[M{-}H_2O]^+$ 406.4539, found 406.4535. $[\alpha]_D^{20}$ = +1.8 (>99% ee, *c* 2.0, $CHCl_3$) [lit.[15] $[\alpha]_D^{20}$ = +2.18 (*c* 1.1, $CHCl_3$) for (*S*)-ginnol]. Enantioselectivity was confirmed by HPLC analysis of the diastereotopic (*R*)-MTPA-esters of the resulting ginnol. Chiral HPLC, Daicel chiralpack AD-3 × 2 at 4 °C, *n*-hexane/*i*-PrOH = 2,000/1, flow rate = 0.1 mL/min, t_R =

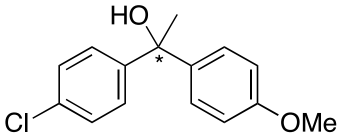
100.3 min [major, (*S*)-derivative], 103.5 min [minor, (*R*)-derivative].

8. General procedure for the catalytic enantioselective arylzinc addition to ketones with arylboronic acids as an aryl source (Tables 5 and 6).

A solution of arylboronic acid (1.5 mmol) in toluene (3 mL) in Pyrex Schlenk tube was stirred at room temperature for 10 min. The solution was heated under azeotropic reflux conditions with the removal of water. Water was removed through a pressure-equalized addition funnel that contained a cotton plug and 4 Å molecular sieves (pellets) and functioned as a Soxhlet extractor. After heating for 3 h at reflux temperature (bath temp.; 140 °C), the reaction mixture was allowed to cool to ambient temperature. After the removal of volatiles under reduced pressure (<5 Torr), the corresponding triarylboroxine (**16**)[16] was obtained in situ and could be used without purification. Et_2Zn (1.1 *M* in toluene) (4.1 mL, 4.5 mmol), and toluene (2 mL) were added at room temperature under a nitrogen atmosphere. The mixture was stirred at 60 °C for 12 h. Ligand **1a** (45.6 mg, 0.10 mmol) was added to the mixture and the solution was stirred for 10 min. Ketone **9** (1.0 mmol) was then added. The resulting mixture was stirred at room temperature for 24 h. After hydrolysis with 10 mL of sat. NH_4Cl aqueous solution, the product was extracted with ether (10 mL × 3) and washed with brine (10 mL). The combined extracts were dried over $MgSO_4$. The organic phase was concentrated under reduced pressure and the crude product was purified by neutral silica gel column chromatography (eluent: *n*-hexane/Et_2O) to give the desired products (**17**). The enantiomeric purity was determined by HPLC on a chiral column.

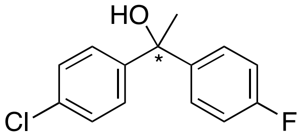


(*S*)-1-(4-Chlorophenyl)-1-phenylethanol (**17a**):[17] ^1H NMR (400 MHz, $CDCl_3$) δ 1.92 (s, 3H), 2.31 (s, 1H), 7.23-7.43 (m, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 30.7, 75.8, 125.8 (2C), 127.2, 127.3 (2C), 128.2 (2C), 128.3 (2C), 132.7, 146.6, 147.5. IR (neat) 3419, 2979, 1489, 1446, 1398, 1093, 1013 cm^{-1}. HRMS (DART) calcd for $C_{14}H_{12}Cl$ $[M–OH]^+$ 215.0628, found 215.0625. $[\alpha]_D^{24}$ = +9.1 (94% ee, *c* 1.8, $CHCl_3$) (lit.[18] $[\alpha]_D^{22}$ = +14.8 (98% ee (*S*), *c* 6.5, $CHCl_3$). Chiral HPLC analysis; OB-H, *n*-hexane/*i*-PrOH = 90/10, 0.5 mL/min, t_R = 18.7 min (minor, *R*), 20.8 min (major, *S*).

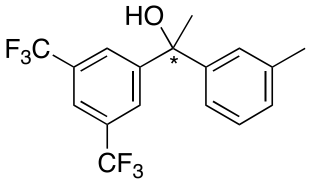


1-(4-Chlorophenyl)-1-(4-methoxyphenyl)ethanol (17b):[19] ^1H NMR (400 MHz, $CDCl_3$) δ 1.89 (s, 3H), 2.34 (s, 1H), 3.78 (s, 3H), 6.83 (d, *J* = 8.7 Hz, 2H), 7.23-7.36 (m, 6H). ^{13}C NMR (100

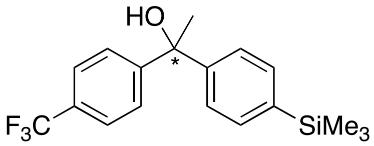
MHz, $CDCl_3$) δ 31.2, 55.5, 75.9, 113.8 (2C), 127.4 (2C), 127.6 (2C), 128.4 (2C), 132.8, 140.0, 147.2, 158.9. IR (neat) 3436, 2973, 1609, 1511, 1489, 1251, 1178, 1091, 1032, 1012 cm^{-1}. HRMS (FAB+) calcd for $C_{15}H_{15}ClO_2$ $[M]^+$ 262.0761, found 262.0763. $[\alpha]_D^{25}$ = +18.9 (92% ee, *c* 2.1, $CHCl_3$). Chiral HPLC analysis; OB-H, *n*-hexane/*i*-PrOH = 90/10, 0.5 mL/min, t_R = 35.5 min (minor), 43.0 min (major).



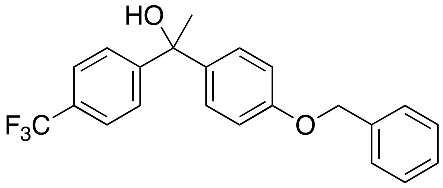
1-(4-Chlorophenyl)-1-(4-fluorophenyl)ethanol (17c):[20] ^1H NMR (400 MHz, $CDCl_3$) δ 1.92 (s, 3H), 2.15 (s, 1H), 6.99 (t, *J* = 8.7 Hz, 2H), 7.25-7.37 (m, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 31.1, 75.7, 115.2 (d, $J_{C–F}$ = 21.0 Hz, 2C), 127.4 (2C), 127.7 (d, $J_{C–F}$ = 8.6 Hz, 2C), 128.5 (2C), 133.1, 143.4, 146.4, 162.0 (d, $J_{C–F}$ = 245.0 Hz). ^{19}F NMR (376 MHz, $CDCl_3$) δ –116.1. IR (neat) 3407, 2978, 1601, 1508, 1489, 1229, 1160, 1094, 1013 cm^{-1}. HRMS (DART) calcd for $C_{14}H_{11}ClF$ $[M–OH]^+$ 233.0533, found 233.0538. $[\alpha]_D^{25}$ = +32.0 (95% ee, *c* 2.0, $CHCl_3$). Chiral HPLC analysis; OD-H, *n*-hexane/*i*-PrOH = 99/1, 0.5 mL/min, t_R = 38.7 min (major), 40.9 min (minor).



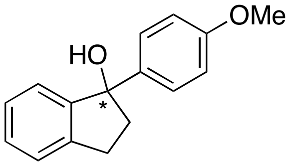
1-(3,5-Bis(trifluoromethyl)phenyl)-1-(*m*-tolyl)ethanol (17d): ^1H NMR (400 MHz, $CDCl_3$) δ 1.96 (s, 3H), 2.34 (s, 3H), 2.36 (s, 1H), 7.11 (d, *J* = 7.8 Hz, 1H), 7.17 (d, *J* = 7.8 Hz, 1H), 7.21-7.26 (m, 2H), 7.75 (s, 1H), 7.89 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.7, 30.9, 75.9, 121.0 (m), 123.5 (q, $J_{C–F}$ = 270.8 Hz, 2C), 123.0, 126.1 (2C), 126.6, 128.7, 128.8, 131.5 (q, $J_{C–F}$ = 32.4 Hz, 2C), 138.6, 146.2, 151.0. ^{19}F NMR (376 MHz, $CDCl_3$) δ –62.6. IR (neat) 3435, 2983, 2929, 1468, 1374, 1279, 1179, 1135 cm^{-1}. HRMS (FAB+) calcd for $C_{17}H_{14}F_6O$ $[M]^+$ 348.0949, found 348.0935. $[\alpha]_D^{21}$ = +29.8 (97% ee, *c* 2.1, $CHCl_3$). Chiral HPLC analysis; OD-H, *n*-hexane/*i*-PrOH = 95/5, 0.5 mL/min, t_R = 11.9 min (minor), 16.9 min (major).



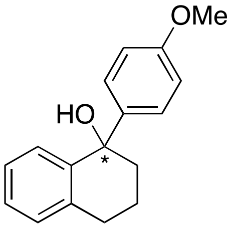
1-(4-(Trifluoromethyl)phenyl)-1-(4-(trimethylsilyl)phenyl)ethanol (17e):[21] ^1H NMR (400 MHz, $CDCl_3$) δ 0.25 (s, 9H), 1.94 (s, 3H), 2.36 (s, 1H), 7.37 (d, *J* = 8.1 Hz, 2H), 7.49 (d, *J* = 8.1 Hz, 2H), 7.52 (d, *J* = 8.7 Hz, 2H), 7.54 (d, *J* = 8.7 Hz, 2H). NMR (100 MHz, $CDCl_3$) δ –1.0 (3C), 30.7, 76.1, 124.3 (q, $J_{C–F}$ = 270.8 Hz), 125.2 (4C), 126.3 (2C), 129.1 (q, $J_{C–F}$ = 31.5 Hz), 133.6 (2C), 139.8, 147.6, 152.0. ^{19}F NMR (376 MHz, $CDCl_3$) δ –62.9. IR (KBr) 3419, 2955, 1619, 1410, 1326, 1167, 1133, 1073, 1015 cm^{-1}. HRMS (FAB+) calcd for $C_{18}H_{21}F_3OSi$ $[M]^+$ 338.1314, found 338.1814. $[\alpha]_D^{21}$ = +20.5 (92% ee, *c* 2.0, $CHCl_3$). Chiral HPLC analysis; AS-H, *n*-hexane/*i*-PrOH = 98/2, 0.5 mL/min, t_R = 15.0 min (major), 16.5 min (minor).



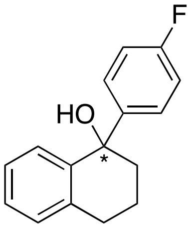
1-(4-(Benzyloxy)phenyl)-1-(4-(trifluoromethyl)phenyl)ethanol (17f): ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.82 (s, 3H), 2.62 (s, 1H), 4.97 (s, 2H), 6.87 (d, *J* = 8.7 Hz, 2H), 7.23 (d, *J* = 8.7 Hz, 2H), 7.26 (t, *J* = 6.9 Hz, 1H), 7.31 (t, *J* = 6.9 Hz, 2H), 7.37 (d, *J* = 6.9 Hz, 2H), 7.44 (d, *J* = 8.1 Hz, 2H), 7.50 (d, *J* = 8.1 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 30.7, 70.0, 75.7, 114.6 (2C), 124.3 (q, $J_{C–F}$ = 270.8 Hz), 125.1 (d, $J_{C–F}$ = 3.8 Hz, 2C), 126.2 (2C), 127.3 (2C), 127.5 (2C), 128.1, 128.7 (2C), 128.9 (q, $J_{C–F}$ = 31.5 Hz), 136.9, 139.6, 152.3, 158.0. ^{19}F NMR (376 MHz, $CDCl_3$) δ –62.7. IR (neat) 3437, 2979, 1608, 1510, 1328, 1246, 1167, 1124, 1072, 1015 cm^{-1}. HRMS (FAB+) calcd for $C_{22}H_{19}F_3O_2$ $[M]^+$ 372.1337, found 372.1337. $[\alpha]_D^{21}$ = +23.2 (90% ee, *c* 2.0, $CHCl_3$). Chiral HPLC analysis; OD-H, *n*-hexane/*i*-PrOH = 95/5, 0.5 mL/min, t_R = 43.7 min (minor), 51.9 min (major).



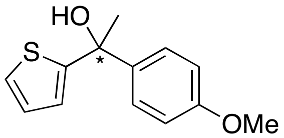
1-(4-Methoxyphenyl)-2,3-dihydro-1*H*-inden-1-ol (17g):[22] ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.15 (s, 1H), 2.40-2.53 (m, 2H), 2.91 (m, 1H), 3.14 (m, 1H), 3.81 (s, 3H), 6.86 (d, *J* = 9.3 Hz, 2H), 7.12 (d, *J* = 7.8 Hz, 1H), 7.23 (ddd, *J* = 7.2, 6.3, 1.5 Hz, 1H), 7.27-7.35 (m, 4H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 30.1, 45.1, 55.6, 85.5, 113.7 (2C), 124.3, 125.3, 127.2 (2C), 127.3, 128.7, 138.8, 144.3, 148.3, 158.8. IR (neat) 3422, 2936, 2836, 1610, 1510, 1457, 1301, 1248, 1176, 1034 cm^{-1}. HRMS (FAB+) calcd for $C_{16}H_{16}O_2$ $[M]^+$ 240.1150, found 240.1143. $[\alpha]_D^{24}$ = +27.7 (84% ee, *c* 2.0, $CHCl_3$). Chiral HPLC analysis; OD-H, *n*-hexane/*i*-PrOH = 95/5, 0.5 mL/min, t_R = 22.8 min (minor), 35.9 min (major).



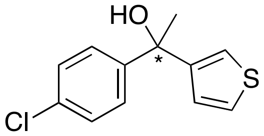
1-(4-Methoxyphenyl)-1,2,3,4-tetrahydronaphthalen-1-ol (17h):[23] ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.76 (m, 1H), 1.99 (m, 1H), 2.09-2.15 (m, 2H), 2.35 (s, 1H), 2.85-2.93 (m, 2H), 3.79 (s, 3H), 6.83 (d, J = 8.7 Hz, 2H), 7.08-7.22 (m, 4H), 7.24 (d, J = 8.7 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 19.7, 29.8, 41.4, 55.2, 75.1, 113.0 (2C), 126.4, 127.4, 127.6 (2C), 128.8, 128.9, 137.6, 141.2, 142.2, 158.2. IR (neat) 3465, 2937, 2836, 1609, 1510, 1248, 1177, 1036 cm^{-1}. HRMS (FAB+) calcd for $C_{17}H_{18}O_2$ $[M]^+$ 254.1307, found 254.1311. $[\alpha]_D^{22}$ = –20.4 (98% ee, c 2.4, $CHCl_3$). Chiral HPLC analysis; OD-H, n-hexane/i-PrOH = 95/5, 0.5 mL/min, t_R = 19.0 min (minor), 33.1 min (major).



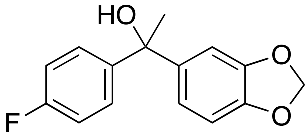
1-(4-Fluorophenyl)-1,2,3,4-tetrahydronaphthalen-1-ol (17i): ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.78 (m, 1H), 1.90-2.38 (m, 4H), 2.80-3.00 (m, 2H), 6.96 (t, J = 8.7 Hz, 2H), 7.02 (d, J = 7.5 Hz, 1H), 7.10-7.35 (m, 5H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 19.7, 29.9, 41.7, 75.2, 114.6 (d, J_{C-F} = 21.0 Hz, 2C), 126.7, 127.8, 128.2 (d, J_{C-F} = 7.6 Hz, 2C), 128.9, 129.1, 137.7, 141.9, 144.8, 161.7 (d, J_{C-F} = 244.1 Hz). ^{19}F NMR (376 MHz, $CDCl_3$) δ –117.3. IR (neat) 3420, 2938, 1603, 1507, 1224, 1158, 1081, 1015 cm^{-1}. HRMS (FAB+) calcd for $C_{16}H_{15}FO$ $[M]^+$ 242.1107, found 240.1107. $[\alpha]_D^{25}$ = –24.9 (96% ee, c 2.0, $CHCl_3$). Chiral HPLC analysis; OD-H, n-hexane/i-PrOH = 97/3, 0.5 mL/min, t_R = 16.7 min (minor), 27.8 min (major).



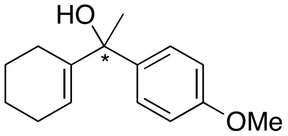
1-(4-Methoxyphenyl)-1-(thiophen-2-yl)ethanol (17j):[24] ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.00 (s, 3H), 2.48 (s, 1H), 3.81 (s, 3H), 6.87 (d, J = 8.5 Hz, 2H), 6.87-6.89 (m, 1H), 6.93 (dd, J= 5.1, 3.6 Hz, 1H), 7.23 (dd, J = 5.1, 0.9 Hz, 1H), 7.41 (d, J = 8.2 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 32.6, 55.6, 74.9, 113.7 (2C), 124.3, 125.2, 126.8, 126.9 (2C), 139.8, 154.0, 159.0. IR (neat) 3451, 2974, 2932, 1609, 1511, 1299, 1249, 1179, 1031 cm^{-1}. HRMS (FAB+) calcd for $C_{13}H_{14}O_2S$ $[M]^+$ 234.0715, found 234.0706. $[\alpha]_D^{25}$ = +3.2 (93% ee, c 2.0, $CHCl_3$) (lit.[24] $[\alpha]_D^{25}$ = +4.91 (92% ee, c 1.0, $CHCl_3$)). Chiral HPLC analysis; AD-H, n-hexane/i-PrOH = 95/5, 0.5 mL/min, t_R = 38.5 min (major), 41.9 min (minor).



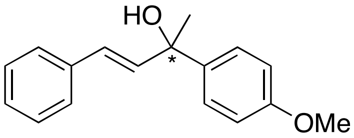
1-(4-Chlorophenyl)-1-(thiophen-3-yl)ethanol (17k): ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.88 (s, 3H), 2.76 (s, 1H), 6.94 (dd, *J* = 5.1, 1.5 Hz, 1H), 7.15 (dd, *J* = 3.0, 1.5 Hz, 1H), 7.24 (dd, *J* = 5.1, 2.1 Hz, 1H), 7.27 (d, *J* = 8.7 Hz, 2H), 7.34 (d, *J* = 8.7 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 31.3, 74.4, 126.5, 126.8, 127.2 (2C), 128.4 (2C), 132.9, 146.2, 149.4. IR (neat) 3407, 2977, 2931, 1490, 1400, 1371, 1230, 1166, 1093, 1013 cm^{-1}. HRMS (DART) calcd for $C_{12}H_{10}ClS$ $[M–OH]^+$ 221.0192, found 221.0197. $[\alpha]_D^{25}$ = +27.4 (90% ee, *c* 1.9, $CHCl_3$). Chiral HPLC analysis; OD-H, *n*-hexane/*i*-PrOH = 95/5, 0.5 mL/min, t_R = 20.5 min (major), 25.2 min (minor).



1-(Benzo[*d*][1,3]dioxol-5-yl)-1-(4-fluorophenyl)ethanol (17l): ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.83 (s, 3H), 2.65 (s, 1H), 5.85 (s, 2H), 6.69 (dd, *J* = 8.7, 0.9 Hz, 1H), 6.80-6.84 (m, 2H), 6.93 (t, *J* = 7.8, 0.9 Hz, 2H), 7.31 (dd, *J* = 7.8, 5.4 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 31.1, 75.7, 101.0, 107.0, 107.7, 114.8 (d, $J_{C–F}$ = 21.0 Hz, 2C), 119.0, 127.5 (d, $J_{C–F}$ = 8.6 Hz, 2C), 142.1, 143.9 (d, $J_{C–F}$ = 2.9 Hz), 146.4, 147.5, 161.7 (d, $J_{C–F}$ = 244.1 Hz). ^{19}F NMR (376 MHz, $CDCl_3$) δ –116.5. IR (neat) 3437, 2979, 2985, 1602, 1505, 1487, 1433, 1240, 1039 cm^{-1}. HRMS (FAB+) calcd for $C_{15}H_{13}FO_3$ $[M]^+$ 260.0849, found 260.0849. $[\alpha]_D^{23}$ = +6.7 (90% ee, *c* 2.2, $CHCl_3$). Chiral HPLC analysis; OD-H, *n*-hexane/*i*-PrOH = 95/5, 0.5 mL/min, t_R = 34.6 min (minor), 39.9 min (major).



1-(Cyclohex-1-en-1-yl)-1-(4-methoxyphenyl)ethanol (17m): ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.53-1.59 (m, 4H), 1.62 (s, 3H), 1.70-1.95 (m, 3H), 2.10-2.12 (m, 2H), 3.80 (s, 3H), 5.88 (m, 1H), 6.85 (d, *J* = 9.3 Hz, 2H), 7.33 (d, *J* = 9.3 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 22.4, 23.0, 24.7, 25.3, 28.8, 55.3, 77.3, 113.4 (2C), 121.4, 126.7 (2C), 139.1, 142.7, 158.4. IR (neat) 3465, 2930, 1610, 1511, 1299, 1248, 1179, 1035 cm^{-1}. HRMS (FAB+) calcd for $C_{15}H_{20}O_2$ $[M]^+$ 232.1463, found 232.1471. $[\alpha]_D^{22}$ = –4.6 (77% ee, *c* 2.0, $CHCl_3$). Chiral HPLC analysis; OD-H, *n*-hexane/*i*-PrOH = 95/5, 0.5 mL/min, t_R = 17.4 min (major), 19.0 min (minor).



2-(4-Methoxyphenyl)-4-phenylbut-3-en-2-ol (17n):[25] ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.69 (s, 3H), 2.49 (s, 1H), 3.72 (s, 3H), 6.45 (d, J = 16.0 Hz, 1H), 6.58 (d, J = 16.0 Hz, 1H), 6.83 (d, J = 8.7 Hz, 2H), 7.18 (t, J = 7.2 Hz, 1H), 7.24 (d, J = 7.2 Hz, 2H), 7.33 (d, J = 7.2 Hz, 2H), 7.39 (dt, J = 8.7 Hz, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 29.6, 55.1, 74.2, 113.5 (2C), 126.5 (2C), 126.6 (2C), 127.3, 127.5, 128.5 (2C), 136.6, 136.8, 138.8, 158.5. IR (neat) 3434, 2972, 1610, 1510, 1248, 1178, 1032 cm^{-1}. HRMS (FAB+) calcd for $C_{17}H_{18}O_2$ $[M]^+$ 254.1307, found 254.1303. $[\alpha]_D^{24}$ = –7.1 (80% ee, c 2.1, $CHCl_3$). Chiral HPLC analysis; OD-H, n-hexane/i-PrOH = 95/5, 0.5 mL/min, t_R = 50.8 min (major), 56.4 min (minor)

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