Structurally well-defined, recoverable C_3 -symmetric tris(β -hydroxy phosphoramidate) catalyzed enantioselective borane reduction of ketones

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General remarks

Melting points were measured on an XT-4 melting point apparatus and are uncorrected. ^1H NMR spectra were recorded on Varian 200 MHz, Varian 300 MHz and Bruker 400 MHz spectrometer with tetramethylsilane serving as the internal standard. Infrared spectra were obtained on a Nicolet AVATAR 330 FT-IR spectrometer. Mass spectra were obtained on a VG-ZAB-HS (EI) mass spectrometer or APEX II FT-ICRMS (FAB) mass spectrometer. The optical rotations were measured on a Perkin–Elmer 341 LC spectrometer. The enantiomeric excesses of addition products were determined by HPLC analysis on HP 1100 using the Diacel Chiralcel OB column. Toluene, diethyl ether and tetrahydrofuran were distilled with sodium under nitrogen. Methylene chloride were distilled with calcium. Other solvents used were purified and dried by standard procedures. Borane-methyl sulfide complex (2.0 mol/L solution in THF) was purchased from Acros.

Synthesis of trisphosphoramidate 2

A 50 mL flask was charged with *L*-Proline methyl ester (3.1 g, 24 mmol), Et_3N (6.1 g, 6.7 mL, 60 mmol) and CH_2Cl_2 (25 mL). After cooling to -78°C , a solution of POCl_3 (0.61 g, 40 mmol) in CH_2Cl_2 (10 mL) was added slowly to the mixture and stirred for 12h at room temperature. The reaction mixture was washed with water (10 mL $\times$ 3) and sodium hydroxide (2 mol/L, 5 mL $\times$ 2). The organic layer was dried over anhydrous Na_2SO_4 and concentrated in vacuo to give crude product. Purification by column chromatography on silica to afford **2** as a

colorless oil 1.59 g (93 % yield). Colorless oil. $[\alpha]_{\text{D}}^{20} = -260.0$ (c 1.43, CH_2Cl_2); IR: ν 2953, 2878, 1743, 1671, 1435, 1206, 1088, 1021, 994 cm^{-1} ; ^1H NMR (300 MHz, CDCl_3): δ = 4.31 (m, 3H), 3.73 (s, 9H), 3.52 (m, 3H), 3.25 (m, 3H), 2.21 (m, 3H), 1.85 (m, 9H); ^{13}C NMR (75 MHz, CDCl_3): δ = 175.39, 175.36, 59.5, 59.4, 51.7, 46.7, 46.6, 30.9, 30.8, 25.3, 25.2; ^{31}P NMR (121M, CDCl_3): δ = 15.13; HRMS (EI): m/z calcd for $\text{C}_{18}\text{H}_{30}\text{N}_3\text{O}_7\text{P}$: 431.18214;

Found: 431.18204.

Synthesis of trisphosphoramidate 1a

To a 25 mL round bottom flask was charged with LiAlH_4 (1.24 g, 32.6 mmol) and THF (20 mL). After cooling to 0°C , a solution of trisphosphoramidate **2** (0.78 g, 1.8 mmol) in THF (5 mL) was added slowly. The mixture was stirred at room temperature for 36 h. The reaction was quenched with saturated NH_4Cl (4.0 mL) and extracted with ethyl acetate (20 mL $\times$ 3). The organic phase was dried over anhydrous sodium sulfate. After concentration by rotatory evaporation, the product was purified by column chromatography on silica gel (CH_2Cl_2 : MeOH = 10:1 V/V) to afford **1a** as a colorless oil 0.14 g (22 % yield). Colorless oil. $[\alpha]_{\text{D}}^{20} = -14.5$ (c 1.43, CH_2Cl_2); IR: ν 3353, 2953, 2873, 1461, 1205, 1147, 1088, 1041, 734 cm^{-1} ; ^1H NMR (300 MHz, CDCl_3): δ = 4.32 (brs, 3H), 3.73 (s, 3H), 3.67-3.25 (m, 6H), 3.18 (m, 6H), 2.07-1.63 (m, 12H); ^{13}C NMR (75 MHz, CDCl_3): δ = 66.0, 60.6, 60.5, 46.9, 46.8, 29.4, 29.2, 25.2, 25.1; ^{31}P NMR (121M, CDCl_3): δ = 19.65; HRMS (FAB): m/z calcd for $\text{C}_{15}\text{H}_{31}\text{N}_3\text{O}_4\text{P}$: 348.20465; Found: 348.2046 $[\text{M}+\text{H}^+]$.

General procedure for synthesis of trisphosphoramides **1b-1d**

To a 25 mL round bottom flask was charged with trisphosphoramide **2** (0.73 g, 1.7 mmol) and THF (5 mL) under nitrogen. After cooling to 0 °C, a solution of methyl magnesium bromide (3 mol/L, 15 mmol, 5 mL) was added slowly. The mixture was stirred at 0 °C for 4 h. The reaction was quenched with saturated NH₄Cl (4.0 mL) and extracted with dichloromethane (20 mL × 3). The organic phase was dried over anhydrous sodium sulfate. After concentration by rotatory evaporation, a pale yellow oil was obtained. Purification by recrystallization from

petroleum ether and ethyl acetate to afford pure product **1b** 0.43 g (59 % yield). Colorless solid, m.p. 218-220 °C. $[\alpha]_D^{20} = -59.4$ (*c* 1.10, CH₂Cl₂); IR: ν 3332, 2971, 2879, 1414, 1379, 1222, 1119, 1072, 1032, 949 cm⁻¹; ¹H NMR (300 MHz, CDCl₃): δ = 5.97 (s, 3H), 3.68 (m, 3H), 3.26 (m, 6H), 3.18 (m, 6H), 2.11 (m, 3H), 1.89-1.66 (m, 9H), 1.21 (s, 9H), 1.11 (s, 9H); ¹³C NMR (75 MHz, CDCl₃): δ = 72.4, 69.41, 69.36, 48.4, 48.3, 30.5, 30.4, 27.2, 25.2, 25.1, 22.6; ³¹P NMR (121 MHz, CDCl₃): δ = 22.56; MS (ESI): *m/z* 432.2 [M+H⁺]. Anal. Calcd. for C₂₁H₄₂N₃O₄P: C, 58.45; H, 9.81; N, 9.74. Found: C, 58.10; H, 9.73; N, 9.69.

1c: 52 % yield. Colorless solid, m.p. 208-209 °C. $[\alpha]_D^{20} = -32.1$ (*c* 0.96, CH₂Cl₂); IR: ν 3330, 2967, 2937, 2879, 1463, 1421, 1167, 1056, 1035, 960 cm⁻¹; ¹H NMR (400 MHz, CDCl₃): δ = 5.45 (s, 3H), 3.84 (m, 3H), 3.20 (m, 6H), 2.07 (m, 3H), 1.77 (m, 3H), 1.75-1.63 (m, 12H), 1.23 (m, 6H), 0.92 (m, 18H); ¹³C NMR (100 MHz, CDCl₃): δ = 75.3, 66.64, 66.60, 48.44, 48.38, 29.1, 29.0, 28.9, 27.0, 25.31, 25.25, 7.4; ³¹P NMR (121 MHz, CDCl₃): δ = 22.36; MS (ESI): *m/z* 516.3 [M+H⁺]. Anal. Calcd. for C₂₇H₅₄N₃O₄P: C, 62.88; H, 10.55; N, 8.15.

Found: C, 63.01; H, 10.46; N, 7.83.

1d: 49 % yield. Colorless solid, m.p. >260 °C decompose. $[\alpha]_D^{20} = -105.4$ (*c* 1.18, CH₂Cl₂); IR: ν 3309, 1445, 1396, 1171, 1103, 1090, 1055, 771, 701 cm⁻¹; ¹H NMR (400 MHz, CDCl₃): δ = 7.61 (dd, *J* = 1.3, 7.2 Hz, 6H) 7.42-7.30 (m, 24H), 7.11 (s, 3H), 4.62 (m, 3H), 2.77 (m, 3H), 2.09 (m, 9H), 1.49 (m, 3H), 1.13 (m, 3H); ¹³C NMR (75 MHz, CDCl₃): δ = 145.8, 144.1, 128.9, 128.3, 127.9, 127.2, 127.1, 127.0, 80.9, 67.3, 67.2, 47.5, 47.4, 30.44, 30.38, 23.9, 23.8; ³¹P NMR (121 MHz, CDCl₃): δ = 23.92; MS (ESI): *m/z* 804.3 [M+H⁺]. Anal. Calcd. for C₅₁H₅₄N₃O₄P: C, 76.19; H, 6.77; N, 5.23. Found: C, 75.56; H, 6.89; N, 5.04.

Typical procedure for the borane reduction of prochiral ketones

BH₃·Me₂S (0.3 mL, 2 mol/L) was added by syringe to a solution of chiral ligand (0.025 mmol) in dry THF (1.5 mL) under nitrogen at room temperature. The mixture was stirred at 70 °C for 30 min. A solution of acetophenone (0.5 mmol) in dry THF (0.5 mL) was added dropwise over a period of 45 min at 70 °C. After 1 h, the reaction mixture was cooled and quenched by dropwise addition of water (5 mL). The alcohol product was isolated by

extraction with dichloromethane (5 mL $\times$ 3). The organic phase was dried over anhydrous sodium sulfate. After concentration by rotatory evaporation, the product was purified by column chromatography on silica gel (petroleum ether-ethyl acetate 5:1) to afford the corresponding secondary alcohol. The enantiomeric excess was determined by HPLC with chiral columns.

(R)-1-Phenylethanol¹

94 % yield. 95 % ee determined by HPLC analysis (Daicel Chiralcel OB column, hexane: 2-propanol = 90: 10, 1.0 mL/min, 254 nm). Retention time: $t_{\text{major}} = 8.54$ and $t_{\text{minor}} = 6.53$ min. $[\alpha]_{\text{D}}^{20} = +39.8$ (c 1.6, CH_2Cl_2). ^1H NMR (300 MHz, CDCl_3): $\delta = 7.29\text{--}7.20$ (m, 4H), 4.74 (q, $J = 6.3$ Hz, 1H), 2.92 (brs, 1H), 1.40 (d, $J = 6.3$ Hz, 3H); ^{13}C NMR (75 MHz, CDCl_3): $\delta = 145.7, 128.2, 127.1, 125.3, 70.0, 25.0$. lit.¹ $[\alpha]_{\text{D}}^{25} = +44.5$ (c 1.0, MeOH); 98.4 % ee.

(R)-1-(4-Fluorophenyl)-ethanol²

95 % yield. 95 % ee determined by HPLC analysis (Daicel Chiralcel OB column, hexane: 2-propanol = 98: 2, 1.0 mL/min, 254 nm). Retention time: $t_{\text{major}} = 16.60$ and $t_{\text{minor}} = 15.23$ min. $[\alpha]_{\text{D}}^{20} = +34.1$ (c 2.0, CH_2Cl_2). ^1H NMR (300 MHz, CDCl_3): $\delta = 7.30$ (m, 2H), 7.02 (m, 2H), 4.82 (q, $J = 6.3$ Hz, 1H), 2.61 (brs, 1H), 1.38 (d, $J = 6.3$ Hz, 3H); ^{13}C NMR (75 MHz, CDCl_3): $\delta = 162.0$ (d, $J = 243.3$ Hz), 141.5 (d, $J = 3.0$ Hz), 127.0 (d, $J = 7.7$ Hz), 126.9, 115.1 (d, $J = 21.5$ Hz), 69.6, 25.1. lit.² $[\alpha]_{\text{D}}^{21} = +38.7$ (c 1.309, MeOH), 98 % ee.

(R)-1-(4-Nitrophenyl)-ethanol²

95 % yield. 98 % ee determined by HPLC analysis (Daicel Chiralcel OB column, hexane: 2-propanol = 95: 5, 1.0 mL/min, 254 nm). Retention time: $t_{\text{major}} = 25.63$ and $t_{\text{minor}} = 24.32$ min. $[\alpha]_{\text{D}}^{20} = +27.1$ (c 2.2, CH_2Cl_2). ^1H NMR (300 MHz, CDCl_3): $\delta = 8.19$ (m, 2H), 7.55 (m, 2H), 5.00 (q, $J = 6.6$ Hz, 1H), 2.45 (brs, 1H), 1.53 (d, $J = 6.6$ Hz, 3H); ^{13}C NMR (75 MHz, CDCl_3): $\delta = 153.1, 147.1, 126.1, 123.7, 69.4, 25.4$. lit.² $[\alpha]_{\text{D}}^{21} = +31.0$ (c 1.225, MeOH), 98.7 % ee.

(R)-1-(4-Methoxyphenyl)-ethanol²

92 % yield. 93 % ee determined by HPLC analysis (Daicel Chiralcel OB column, hexane: 2-propanol = 95: 5, 1.0 mL/min, 254 nm). Retention time: $t_{\text{major}} = 25.16$ and $t_{\text{minor}} = 20.12$ min. $[\alpha]_{\text{D}}^{20} = +49.4$ (c 2.3, CH_2Cl_2). ^1H NMR (300 MHz, CDCl_3): $\delta = 7.24$ (m, 2H), 6.83 (m, 2H), 4.76 (q, $J = 6.6$ Hz, 1H), 3.76 (s, 1H), 2.65 (brs, 1H), 1.41 (d, $J = 6.6$ Hz, 3H); ^{13}C NMR (75 MHz, CDCl_3): $\delta = 158.7, 138.0, 126.5, 113.6, 69.6, 55.1, 24.9$. lit.² $[\alpha]_{\text{D}}^{21} = +41.0$ (c 1.069, MeOH), 99.6 % ee.

(S)- α -(Trifluoromethyl)-benzenemethanol³

99 % yield. 95 % ee determined by HPLC analysis (Daicel Chiralcel OJ column, hexane: 2-propanol = 90: 10, 1.0 mL/min, 254 nm). Retention time: $t_{\text{major}} = 15.82$ and $t_{\text{minor}} = 13.51$ min. $[\alpha]_{\text{D}}^{20} = +28.4$ (c 1.3, CHCl_3). ^1H NMR (300 MHz, CDCl_3): $\delta = 7.47\text{--}7.40$ (m, 5H), 4.98 (d, $J = 4.2$ Hz, 1H), 2.95 (s, 1H); ^{13}C NMR (75 MHz, CDCl_3): $\delta = 133.9, 129.5, 128.6, 127.4, 124.2$ (q, $J = 280$ Hz), 72.8 (q, $J = 31.5$ Hz). lit.³ $[\alpha]_{\text{D}}^{22} = +8.6$ (c 4.25, C_6H_6).

(R)-1-(4-Bromophenyl)-propanol⁴

96 % yield. 91 % ee determined by HPLC analysis (Daicel Chiralcel OB column, hexane: 2-propanol = 97: 3, 0.5 mL/min, 254 nm). Retention time: $t_{\text{major}} = 19.26$ and $t_{\text{minor}} = 18.46$ min. $[\alpha]_{\text{D}}^{20} = +16.8$ (c 2.1, CH_2Cl_2). ^1H NMR (300 MHz, CDCl_3): $\delta = 7.42$ (m, 2H), 7.11 (m, 2H), 4.42 (t, $J = 6.6$ Hz, 1H), 3.06 (brs, 1H), 1.67 (m, 2H), 0.83 (t, $J = 7.5$ Hz, 3H); ^{13}C NMR (75 MHz, CDCl_3): $\delta = 143.3, 131.2, 127.6, 120.9, 74.9, 31.6, 9.8$. lit.⁴ (*R*)-(+)-isomer, 50 % ee.

(*R*)-1-(4-Chlorophenyl)-ethanol²

95 % yield. 94 % ee determined by HPLC analysis (Daicel Chiralcel OB column, hexane: 2-propanol = 95:5, 1.0 mL/min, 254 nm). Retention time: $t_{\text{major}} = 8.50$ and $t_{\text{minor}} = 7.82$ min. $[\alpha]_{\text{D}}^{20} = +47.2$ (c 1.8, CH_2Cl_2). ^1H NMR (300 MHz, CDCl_3): $\delta = 7.33$ -7.27 (m, 4H), 4.84 (q, $J = 6.6$ Hz, 1H), 2.18 (brs, 1H), 1.47 (d, $J = 6.6$ Hz, 3H); ^{13}C NMR (75 MHz, CDCl_3): $\delta = 144.2, 133.0, 128.5, 126.7, 69.6, 25.2$. lit.² $[\alpha]_{\text{D}}^{21} = +39.8$ (c 1.064, MeOH), 97.8 % ee.

(*R*)-1-(3,5-Nitrophenyl)-ethanol⁵

94 % yield. 95 % ee determined by HPLC analysis (Daicel Chiralcel AD column, hexane: 2-propanol = 95: 5, 1.0 mL/min, 254 nm). Retention time: $t_{\text{major}} = 23.36$ and $t_{\text{minor}} = 25.66$ min. $[\alpha]_{\text{D}}^{20} = +22.0$ (c 2.5, CH_2Cl_2). ^1H NMR (300 MHz, CDCl_3): $\delta = 8.96$ (d, $J = 2.1$ Hz, 1H), 8.62 (d, $J = 2.1$ Hz, 2H), 5.17 (m, 1H), 2.27 (d, $J = 3.9$ Hz, 1H), 1.62 (d, $J = 6.6$ Hz, 3H); ^{13}C NMR (75 MHz, CDCl_3): $\delta = 150.3, 148.6, 125.8, 117.6, 68.7, 25.7$. lit.⁵ $[\alpha]_{\text{D}}^{20} = +25.9$ (c 1.0, CHCl_3), 98 % ee.

(*R*)-1-(4-Bromophenyl)-ethanol²

96 % yield. 95 % ee determined by HPLC analysis (Daicel Chiralcel OB column, hexane: 2-propanol = 95: 5, 1.0 mL/min, 254 nm). Retention time: $t_{\text{major}} = 9.09$ and $t_{\text{minor}} = 8.41$ min. $[\alpha]_{\text{D}}^{20} = +36.0$ (c 1.7, CH_2Cl_2). ^1H NMR (300 MHz, CDCl_3): $\delta = 7.41$ (m, 1H), 7.14 (m, 2H), 4.73 (dd, $J = 6.3, 6.3$ Hz, 1H), 3.03 (brs, 1H), 1.40 (m, 3H); ^{13}C NMR (75 MHz, CDCl_3): $\delta = 144.6, 131.3, 127.0, 120.9, 69.4, 25.0$. lit.² $[\alpha]_{\text{D}}^{21} = +32.9$ (c 1.39, MeOH), 99.3 % ee.

(*R*)-1-(2-Naphthyl)-ethanol⁶

94 % yield. 94 % ee determined by HPLC analysis (Daicel Chiralcel OB column, hexane: 2-propanol = 90: 10, 1.0 mL/min, 254 nm). Retention time: $t_{\text{major}} = 10.64$ and $t_{\text{minor}} = 9.68$ min. $[\alpha]_{\text{D}}^{20} = +38.1$ (c 1.5, CH_2Cl_2). ^1H NMR (300 MHz, CDCl_3): $\delta = 7.72$ (m, 4H), 7.39 (m, 3H), 4.84 (q, $J = 6.3$ Hz, 1H), 3.09 (brs, 1H), 1.43 (d, $J = 6.6$ Hz, 3H); ^{13}C NMR (75 MHz, CDCl_3): $\delta = 143.1, 133.1, 132.7, 128.0, 127.8, 127.5, 125.9, 125.5, 123.7, 123.6, 70.1, 24.9$. lit.⁶ $[\alpha]_{\text{D}}^{20} = +21.56$ (c 5, EtOH), 52% optical yield.

(*R*)-1-(2-Bromophenyl)-ethanol⁷

91 % yield. 83 % ee determined by HPLC analysis (Daicel Chiralcel OB column, hexane: 2-propanol = 95: 5, 1.0 mL/min, 254 nm). Retention time: $t_{\text{major}} = 8.30$ and $t_{\text{minor}} = 6.58$ min. $[\alpha]_{\text{D}}^{20} = +50.8$ (c 2.4, CH_2Cl_2). ^1H NMR (300 MHz, CDCl_3): $\delta = 7.51$ (m, 2H), 7.29 (m, 1H), 7.07 (m, 1H), 5.16 (q, $J = 6.3$ Hz, 1H), 3.09 (brs, 1H), 1.40 (d, $J = 6.3$ Hz, 3H); ^{13}C NMR (75 MHz, CDCl_3): $\delta = 144.5, 132.4, 128.5, 127.7, 126.6, 121.5, 68.9, 23.5$. lit.⁷ $[\alpha]_{\text{D}}^{28} = +48$ (c 1.7, CHCl_3), 92 % ee.

(R)-1-(2-Methoxyphenyl)-ethanol⁸

94% yield. 87% ee determined by HPLC analysis (Daicel Chiralcel OB column, hexane: 2-propanol = 90: 10, 1.0 mL/min, 254 nm). Retention time: $t_{\text{major}} = 10.67$ and $t_{\text{minor}} = 7.02$ min. $[\alpha]_{\text{D}}^{20} = +53.0$ (c 1.5, CH₂Cl₂). ¹H NMR (300 MHz, CDCl₃): $\delta = 7.35\text{--}7.20$ (m, 2H), 6.97–6.83 (m, 2H), 5.07 (q, $J = 6.3$ Hz, 1H), 3.81 (s, 1H), 2.94 (brs, 1H), 1.49 (d, $J = 6.3$ Hz, 3H); ¹³C NMR (75 MHz, CDCl₃): $\delta = 156.3, 133.4, 128.0, 125.9, 120.6, 110.2, 66.0, 55.1, 22.8$. lit.⁸ $[\alpha]_{\text{D}}^{20} = +32.3$ (c 2.0, CHCl₃), 94 % ee.

(S)-2-Bromo-1-phenylethanol⁹

95 % yield. 97 % ee determined by HPLC analysis (Daicel Chiralcel OD column, hexane: 2-propanol = 90:10, 0.5 mL/min, 254 nm). Retention time: $t_{\text{major}} = 19.12$ and $t_{\text{minor}} = 21.87$ min. $[\alpha]_{\text{D}}^{20} = +42.3$ (c 1.5, CH₂Cl₂). ¹H NMR (300 MHz, CDCl₃): $\delta = 7.33$ (m, 4H), 4.88 (dd, $J = 3.3, 8.7$ Hz, 1H), 3.62–3.48 (m, 2H), 2.71 (brs, 1H); ¹³C NMR (75 MHz, CDCl₃): $\delta = 140.3, 128.6, 128.4, 125.9, 73.7, 40.0$. lit.⁹ $[\alpha]_{\text{D}}^{25} = +39.0$ (c 1.0, CHCl₃), 87 % ee.

(R)-2-Methyl-1-phenylpropanol¹⁰

92 % yield. 43 % ee determined by HPLC analysis (Daicel Chiralcel OD column, hexane: 2-propanol = 98:2, 0.5 mL/min, 254 nm). Retention time: $t_{\text{major}} = 27.37$ and $t_{\text{minor}} = 29.12$ min. $[\alpha]_{\text{D}}^{20} = +22.1$ (c 2.2, CH₂Cl₂). ¹H NMR (300 MHz, CDCl₃): $\delta = 7.33\text{--}7.20$ (m, 5H), 4.28 (d, $J = 6.9$ Hz, 1H), 2.21 (d, $J = 8.4$ Hz, 1H), 1.90 (m, 1H), 0.97 (d, $J = 6.9$ Hz, 3H), 0.75 (d, $J = 6.9$ Hz, 3H); ¹³C NMR (75 MHz, CDCl₃): $\delta = 143.6, 128.0, 127.2, 126.5, 79.8, 35.1, 18.9, 18.2$. lit.¹⁰ $[\alpha]_{\text{D}}^{20} = +8$ (c 5, Et₂O), 16.8 % ee.

(R)-1-Phenylbutanol¹¹

91 % yield. 83 % ee determined by HPLC analysis (Daicel Chiralcel OB column, hexane: 2-propanol = 95: 5, 1.0 mL/min, 254 nm). Retention time: $t_{\text{major}} = 9.68$ and $t_{\text{minor}} = 10.46$ min. $[\alpha]_{\text{D}}^{20} = +38.5$ (c 1.8, CH₂Cl₂). ¹H NMR (300 MHz, CDCl₃): $\delta = 7.39\text{--}7.22$ (m, 5H), 4.63 (t, $J = 6.9$ Hz, 1H), 2.20 (brs, 1H), 1.72–1.61 (m, 2H), 1.47–1.22 (m, 2H), 0.91 ($J = 7.4$ Hz, 1H, 3H); ¹³C NMR (75 MHz, CDCl₃): $\delta = 144.9, 128.3, 127.4, 125.8, 74.3, 41.1, 18.9, 13.9$. lit.¹¹ $[\alpha]_{\text{D}}^{20} = +23.9$ (c 4.18, C₆H₆), 55% optical yield.

(R)-trans-1-(4-Propylcyclohexyl)-ethanol¹²

88 % yield. 63 % ee determined by HPLC analysis of phenyl isocyanate derivative (Daicel Chiralcel OD column, hexane: 2-propanol = 90: 10, 1.0 mL/min, 230 nm). Retention time: $t_{\text{major}} = 29.15$ and $t_{\text{minor}} = 13.75$ min. $[\alpha]_{\text{D}}^{20} = -1.2$ (c 2.6, CH₂Cl₂). ¹H NMR (300 MHz, CDCl₃): $\delta = 3.54$ (m, 1H), 1.80–1.65 (m, 5H), 1.38–1.30 (m, 3H), 1.16 (m, 6H), 1.12–0.80 (m, 7H); ¹³C NMR (75 MHz, CDCl₃): $\delta = 72.1, 45.2, 39.6, 37.3, 32.9, 32.8, 28.5, 28.2, 20.4, 19.9, 14.3$. lit.¹² $[\alpha]_{\text{D}}^{20} = -1.9$ (c 1.1, CHCl₃), 99 % ee.

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Copies of HPLC spectra.of secondary alcohols:

rac-1-(4-fluorophenyl)ethanol

1-(4-fluorophenyl)ethanol

rac-1-(4-nitrophenyl)ethanol

1-(4-nitrophenyl)ethanol

rac-1-(4-methoxyphenyl)ethanol

1-(4-methoxyphenyl)ethanol

rac-1-(4-bromophenyl)propanol

1-(4-bromophenyl)propanol

rac-1-(4-chlorophenyl)ethanol

1-(4-chlorophenyl)ethanol

rac-1-(3,5-dinitrophenyl)ethanol

1-(3,5-dinitrophenyl)ethanol

rac-1-(4-bromophenyl)ethanol

1-(4-bromophenyl)ethanol

rac-1-(2-naphthyl)ethanol

1-(2-naphthyl)ethanol

rac-1-(2-bromophenyl)ethanol

1-(2-bromophenyl)ethanol

rac-1-(2-methoxyphenyl)ethanol

1-(2-methoxyphenyl)ethanol

rac-2-bromo-1-phenylethanol

2-bromo-1-phenylethanol

rac-2-methyl-1-phenylpropanol

2-methyl-1-phenylpropanol

rac-1-phenylbutanol

1-phenylbutanol

rac-*trans*-1-(4-propylcyclohexyl)ethyl carbanilic acid ester

trans-1-(4-propylcyclohexyl)ethyl carbanilic acid ester

rac- α -(trifluoromethyl)-benzenemethanol

α -(trifluoromethyl)-benzenemethanol

Copies of ^1H NMR and ^{13}C NMR new compounds

300ft040930-01C

Pulse Sequence: s2pu1

175.389
175.357

77.428
77.000
76.580

59.457
59.378

51.717

46.689
46.641

30.907
30.819
25.323
25.236

Unit File Data Parameters
 NAME h29028
 EXPNO 1
 PROCNO 1

F2 - Acquisition Parameters

Date_ 20051122
 Time 16.52
 INSTRUM ARX400
 PROBHD 5 mm Multinu
 PULPROG zg
 TD 32768
 SOLVENT CDC13
 NS 32
 DS 0
 SWH 6578.947 Hz
 FIDRES 0.200774 Hz
 AQ 2.4904180 sec
 RG 128
 DW 76.000 usec
 DE 95.00 usec
 TE 300.0 K
 D1 2.0000000 sec
 P1 3.00 usec
 DE 95.00 usec
 SF01 400.1325540 MHz
 NUCLEUS 1H

F2 - Processing parameters

SI 16384
 SF 400.1300126 MHz
 WDW no
 SSB 0
 LB 0.00 Hz
 GB 0
 PC 4.00

1D NMR plot parameters

CX 20.00 cm
 F1P 10.000 ppm
 F1 4001.30 Hz
 F2P -0.500 ppm
 F2 -200.07 Hz
 PPMCM 0.52500 ppm/cm
 HZCM 210.06825 Hz/cm

Current Data Parameters
 NAME c29028
 EXPNO 1
 PROCNO 1

F2 - Acquisition Parameters

Date_ 20051122
 Time 16.56
 INSTRUM ARX400
 PROBHD 5 mm Multinu
 PULPROG zgpg
 TO 32768
 SOLVENT CDCl3
 NS 380
 DS 2
 SMH 25000.000 Hz
 FIDRES 0.762939 Hz
 AQ 0.6554100 sec
 RG 32768
 DM 20.000 usec
 DE 25.00 usec
 TE 300.0 K
 D12 0.0002000 sec
 DL5 24.00 dB
 CPDPRG waltz16
 P31 100.00 usec
 D1 1.50000000 sec
 P1 4.00 usec
 DE 25.00 usec
 SF01 100.6233283 MHz
 NUCLEUS 13C
 D11 0.03000000 sec

F2 - Processing parameters

SI 32768
 SF 100.6127754 MHz
 NDM EM
 SSB 0
 LB 0.50 Hz
 GB 0
 PC 1.00

1D NMR plot parameters

CX 20.00 cm
 F1P 200.000 ppm
 F1 20122.56 Hz
 F2P -5.000 ppm
 F2 -503.06 Hz
 PPMCM 10.25000 ppm/cm
 HZCM 1031.28101 Hz/cm

F2 - Acquisition Parameters

Date_	20051122
Time	16.44
INSTRUM	ARX400
PROBHD	5 mm Multinu
PULPROG	zg
TD	32768
SOLVENT	CDCl3
NS	32
DS	0
SWH	6578.947 Hz
FIDRES	0.200774 Hz
AQ	2.4904180 sec
RG	256
DW	76.000 usec
DE	95.00 usec
TE	300.0 K
D1	2.00000000 sec
P1	3.00 usec
DE	95.00 usec
SF01	400.1325540 MHz
NUCLEUS	1H

F2 - Processing parameters

SI	16384
SF	400.1300126 MHz
WDW	no
SSB	0
LB	0.00 Hz
GB	0
PC	4.00

1D NMR plot parameters

CX	20.00 cm
F1P	10.000 ppm
F1	4001.30 Hz
F2P	-0.500 ppm
F2	-200.07 Hz
PPMCM	0.52500 ppm/cm
HZCM	210.06825 Hz/cm