Supporting Information

Synthesis of 3,3-disubstituted α-tetralones
by rhodium-catalysed reaction of 1-(2-haloaryl)cyclobutanols

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General Methods. All reactions were carried out under a nitrogen atmosphere unless otherwise noted. Infrared spectra were recorded on a Shimadzu FTIR-8400 spectrometer. $^1$H and $^{13}$C NMR spectra were recorded on a Varian Mercury vx400 ($^1$H at 400 MHz and $^{13}$C at 100 MHz) spectrometer using CHCl$_3$ ($^1$H, $\delta$ = 7.26) and CDCl$_3$ ($^{13}$C, $\delta$ = 77.0) as an internal standard unless otherwise noted. High-resolution mass spectra were recorded on a Thermofisher EXACTIVE (APCI and ESI). Optical rotation was measured by a JASCO P-1020 polarimeter with a sodium lamp. HPLC analysis was performed by 4.6 x 250 mm column. Gel permeation chromatography (GPC) was carried out with a Japan Analytical Industry LC-9204. Recycling preparative HPLC was carried out with a Japan Analytical Industry LC-9110 NEXT SERIES. Flash column chromatography was performed with silica gel 60 N (Kanto). Preparative thin-layer chromatography was performed on silica gel plates with PF254 indicator (Merck).

Materials. 1,4-dioxane was distilled from sodium/benzophenone ketyl. [Rh(OH)(cod)]$_2$ was prepared according to the literature procedure.$^1$ The cyclobutanones were prepared by [2+2] cycloaddition of the corresponding olefins with dichloroketene and subsequent dechlorination with zinc dust in acetic acid.$^2$ Cyclobutanol 1b was prepared according to the literature procedure.$^3$ All other commercially available chemical reagents were used as received without further purification.

1-(2-bromophenyl)-3,3-diphenylcyclobutanol (1a). To a stirred solution of 2-bromoiodobenzene (2.97 g, 10.5 mmol) in THF (15 ml) at –78°C was added i-PrMgBr in THF (0.84 M, 12.5 ml, 10.5 mmol) slowly. After stirring for 2 h, a solution of 3,3-diphenylcyclobutanol (1.55 g, 7.0 mmol) in THF (5 ml) was added dropwise to the reaction mixture at –78°C. The mixture was stirred at room temperature for 11 h, and saturated NH$_4$Cl aq was added. The mixture was extracted with Et$_2$O, washed with water and brine, dried over Na$_2$SO$_4$, and evaporated. Purification by flash column chromatography on silica gel (hexane:AcOEt = 5:1) afforded 1a, which still contained only a small amount of unidentified impurities. After further purification with GPC and recrystallisation (DCM and hexane), 1a was obtained in a pure form (861 mg, 2.27 mmol, 32%). $^1$H NMR: $\delta$ = 2.66 (s, 1H), 3.55 (s, 4H), 7.04-7.11 (m, 2H), 7.15-7.25 (m, 6H), 7.31-7.35 (m, 3H), 7.50-7.56 (m, 3H); $^{13}$C NMR: $\delta$ = 44.3, 48.5, 74.9, 121.7, 125.5, 125.7, 125.9, 126.5, 127.3, 127.6, 128.3, 128.5, 129.1, 134.0, 143.3, 148.9, 149.9; IR (neat): 3553, 2986, 762, 710, 696 cm$^{-1}$; HRMS (APCI)
Calcd for C_{22}H_{19}BrOCl (M + Cl)^− \text{413.0302}, found 413.0311.

1-(2-bromophenyl)-3-methyl-3-phenylcyclobutanol (1c). To a stirred solution of 2-bromiodobenzene (8.55 g, 30.0 mmol) in THF (10 ml) at −78 °C was added i-PrMgBr in THF (1.0 M, 30.0 ml, 30.0 mmol) slowly. After stirring for 2 h, a solution of 3-methyl-3-phenylcyclobutanone (3.20 g, 20.0 mmol) in THF (10 ml) was added dropwise to the reaction mixture at −78 °C. The mixture was stirred at room temperature for 12 h, and saturated NH₄Cl aq was added. The mixture was extracted with Et₂O, washed with water and brine, dried over Na₂SO₄, and evaporated. After purification by flash column chromatography on silica gel (hexane:AcOEt = 5:1) and GPC, 1c was obtained (2.38 g, 7.5 mmol, 38%) as a diastereomer mixture. ¹H NMR: δ = 1.31 (s, 3H*), 1.77 (s, 3H), 2.83-2.87 (m, 1H* + 3H), 3.04-3.12 (m, 4H* + 2H), 7.08-7.40 (m, 7H* + 8H), 7.54-7.56 (m, 1H), 7.58-7.61 (m, 1H*), 7.63-7.65 (m, 1H*); ¹³C NMR: δ = 31.9, 32.2*, 34.8*, 36.4, 47.3, 48.3*, 73.7*, 74.6, 121.5, 122.3*, 124.9, 125.27, 125.30*, 125.4*, 127.3, 127.35*, 127.43, 127.6*, 128.2, 128.3*, 129.0, 129.2*, 133.9, 134.4*, 143.7*, 144.3, 151.1*, 152.0; IR (neat): 3422, 2951, 1026, 754, 729, 698 cm⁻¹; HRMS (APCI) Calcd for C_{17}H_{17}BrOCl (M + Cl)^− 351.0146, found 351.0155.

1-(2-bromophenyl)-3-n-butyl-3-methylcyclobutanol (1d). To a stirred solution of 2-bromiodobenzene (2.15 g, 7.6 mmol) in THF (7 ml) at −78 °C was added i-PrMgBr in THF (0.90 M, 8.5 ml, 7.7 mmol) slowly. After stirring for 2 h, a solution of 3-n-butyl-3-methylcyclobutanone (0.87 g, 6.2 mmol) in THF (3 ml) was added dropwise to the reaction mixture at −78 °C. The mixture was stirred at room temperature for 4 h, and saturated NH₄Cl aq was added. The mixture was extracted with Et₂O, washed with water and brine, dried over Na₂SO₄, and evaporated. After purification by flash column chromatography on silica gel (hexane:AcOEt = 20:1) and GPC, 1d was obtained as a diastereomer mixture. ¹H NMR: δ = 0.86 (t, J = 6.8 Hz, 3H), 0.94 (t, J = 7.2 Hz, 3H*), 0.96 (s, 3H), 1.15-1.38 (m, 9H + 4H*), 1.65-1.69 (m, 2H*), 2.30-2.41 (m, 2H + 2H*), 2.49-2.54 (m, 2H + 2H*), 2.75-2.78 (m, 1H + 1H*), 7.10-7.15 (m, 1H + 1H*), 7.27-7.33 (m, 1H + 1H*), 7.36-7.38 (m, 1H), 7.43-7.45 (m, 1H*), 7.54-7.58 (m, 1H + 1H*); ¹³C NMR: δ = 14.1, 14.2*, 23.2, 23.3*, 26.4, 26.7, 26.8*, 27.0*, 30.4*, 31.2, 42.4*, 43.4, 46.9, 47.0*, 73.9*, 74.3, 121.8, 122.1*, 127.3*, 127.35, 127.43, 127.5*, 128.89, 128.92*, 134.1, 134.2*, 144.6*, 144.8; IR (neat): 3422, 2924, 1003, 754, 727 cm⁻¹; HRMS (APCI) Calcd for C_{15}H_{21}BrOCl (M + Cl)^− 331.0459, found 331.0467.

After purification by recycling preparative HPLC, trans-1d was obtained (217 mg, 0.73 mmol, 12%), and cis-1d was obtained (330 mg, 1.11 mmol, 18%).

trans-1d: ¹H NMR: δ = 0.86 (t, J = 6.8 Hz, 3H), 1.14-1.30 (m, 6H), 1.35 (s, 3H), 2.31-2.35 (m, 2H), 2.49-2.53 (m, 2H), 2.74 (s, 1H), 7.10-7.14 (m, 1H), 7.27-7.32 (m, 1H), 7.36-7.38 (m, 1H), 7.54-7.57 (m, 1H); ¹³C NMR: δ = 14.1, 23.2, 26.4, 26.7, 31.2, 43.4, 46.9, 74.3, 121.8, 127.36, 127.43, 128.9, 134.1, 144.8; IR (neat): 3422, 2924, 1001, 754, 727 cm⁻¹; HRMS (APCI) Calcd for C_{15}H_{23}BrOCl (M + Cl)^− 331.0459, found 331.0464.
cis-1d: $^1$H NMR: $\delta = 0.94$ (t, $J = 7.2$ Hz, 3H), 0.96 (s, 3H), 1.25-1.38 (m, 4H), 1.65-1.69 (m, 2H), 2.37-2.41 (m, 2H), 2.50-2.54 (m, 2H), 2.78 (s, 1H), 7.11-7.15 (m, 1H), 7.28-7.32 (m, 1H), 7.43-7.45 (m, 1H), 7.56-7.58 (m, 1H); $^{13}$C NMR: $\delta = 14.2$, 23.3, 26.8, 27.0, 30.4, 42.4, 47.0, 73.9, 122.1, 127.3, 127.5, 128.9, 134.2, 144.6; IR (neat): 3422, 2926, 1005, 907, 754, 727 cm$^{-1}$; HRMS (APCI) Calcd for C$_{15}$H$_{21}$BrOCl (M + Cl)$^+$ 331.0459, found 331.0471.

1-(2-bromophenyl)-3-tert-butyloxy-cyclobutanol (1e). To a stirred solution of 2-bromoiodobenzene (3.97 g, 14.0 mmol) in THF (15 ml) at $-78$ °C was added $i$-PrMgBr in THF (0.91 M, 15.4 ml, 14.0 mmol) slowly. After stirring for 2 h, a solution of 3-tert-butyloxy-cyclobutanolone (1.64 g, 11.7 mmol) in THF (15 ml) was added dropwise to the reaction mixture at $-78$ °C. The mixture was stirred at room temperature for 9 h, and saturated NH$_4$Cl aq was added. The mixture was extracted with Et$_2$O, washed with water and brine, dried over Na$_2$SO$_4$, and evaporated. After purification by flash column chromatography on silica gel (hexane:AcOEt = 20:1) and GPC, 1e was obtained (1.17 g, 3.94 mmol, 29%) as a diasteromer mixture. $^1$H NMR: $\delta = 0.78$ (s, 9H), 0.93 (s, 3H*), 0.94 (s, 9H*), 1.44 (s, 3H), 2.08-2.11 (m, 2H), 2.43-2.46 (m, 2H*), 2.60-2.63 (m, 2H*), 2.75-2.81 (m, 3H + 1H*), 7.09-7.16 (m, 1H + 1H*), 7.27-7.34 (m, 1H + 1H*), 7.37-7.40 (m, 1H), 7.55-7.58 (m, 1H + 1H*), 7.59-7.61 (m, 1H*); $^{13}$C NMR: $\delta = 24.3$, 24.4*, 25.0, 25.2*, 28.7*, 33.9, 35.3*, 37.2, 42.1, 42.8*, 7.18*, 73.0, 121.8, 122.6*, 127.2, 127.27*, 127.35, 127.5*, 128.85, 128.95*, 134.2, 134.5*, 144.2, 144.4*; IR (neat): 3447, 2961, 1159, 1020, 750, 725 cm$^{-1}$ HRMS (APCI) Calcd for C$_{15}$H$_{21}$BrOCl (M + Cl)$^+$ 331.0459, found 331.0466.

3-(2-bromophenyl)-1-tert-butoxy-carbonyl-azetidin-3-ol (1f). To a stirred solution of 2-bromoiodobene (843 mg, 3.0 mmol) in THF (5 ml) at $-78$ °C was added $i$-PrMgBr in THF (0.90 M, 3.3 ml, 3.0 mmol) slowly. After stirring for 2 h, a solution of 1-Boc-3-azetidinone (316 mg, 1.9 mmol) in THF (2 ml) was added dropwise to the reaction mixture at $-78$ °C. The mixture was stirred at room temperature for 3 h, and saturated NH$_4$Cl aq was added. The mixture was extracted with Et$_2$O, washed with water and brine, dried over Na$_2$SO$_4$, and evaporated. After purification by chromatography on silica gel (hexane:AcOEt = 2:1), 1f was obtained (433 mg, 1.32 mmol, 66%); $^1$H NMR: $\delta = 1.45$ (s, 9H), 2.98 (s, 1H), 4.23-4.26 (m, 2H), 4.50-4.53 (m, 2H), 7.19-7.23 (m, 1H), 7.35-7.37 (m, 2H), 7.60-7.62 (m, 1H); $^{13}$C NMR: $\delta = 28.4$, 61.5, 73.6, 79.8, 121.9, 127.7, 127.8, 130.1, 134.2, 140.3, 156.3; IR (neat): 3350, 2961, 1678, 1433, 1111, 748 cm$^{-1}$; HRMS (APCI) Calcd for C$_{14}$H$_{18}$BrNO$_3$Cl (M + Cl)$^+$ 362.0153, found 362.0163.

1-(2-bromo-5-methoxyphenyl)-3,3-diphenyl-cyclobutanol (1g). To a stirred solution of 2-iodo-4-methoxybromobenzene (1.40 g, 4.5 mmol), prepared according to the literature procedure, in THF (6 ml) at $-78$ °C was added $i$-PrMgBr in THF (0.84 M,
5.4 ml, 4.5 mmol) slowly. After stirring for 2 h, a solution of 3,3-diphenylcyclobutanone (0.67 g, 3.0 mmol) in THF (4 ml) was added dropwise to the reaction mixture at –78 °C. The mixture was stirred at room temperature for 11 h, and saturated NH₄Cl aq was added. The mixture was extracted with Et₂O, washed with water and brine, dried over Na₂SO₄, and evaporated. After purification by chromatography on silica gel (hexane:AcOEt = 5:1) and GPC, 1g was obtained (404 mg, 0.99 mmol, 33%). ¹H NMR: δ = 2.74 (s, 1H), 3.53 (s, 4H), 3.74 (s, 3H), 6.63-6.66 (m, 1H), 6.87-6.88 (m, 1H), 7.05-7.09 (m, 1H), 7.15-7.24 (m, 5H), 7.33 (t, J = 7.6 Hz, 2H), 7.42 (d, J = 8.8 Hz, 1H), 7.49-7.51 (m, 2H); ¹³C NMR: δ = 44.2, 48.4, 55.5, 74.7, 111.8, 114.0, 114.2, 125.5, 125.7, 125.9, 126.5, 128.3, 128.4, 134.6, 144.3, 148.9, 149.8, 158.8; IR (neat): 3545, 2939, 1464, 1292, 1228, 1026, 745, 694 cm⁻¹; HRMS (APCI) Calcd for C₂₃H₂₁BrO₂Cl (M + Cl)⁻ 443.0408, found 443.0418.

1-(2-bromo-5-trifluoromethylphenyl)-3,3-diphenylcyclobutanol (1h). To a stirred solution of 2-iodo-4-trifluoromethylbromobenzene (2.63 g, 7.5 mmol), prepared according to the literature procedure ⁵, in THF (10 ml) at –78 °C was added i-PrMgBr in THF (0.96 M, 7.8 ml, 7.5 mmol) slowly. After stirring for 2 h, a solution of 3,3-diphenylcyclobutanone (1.11 g, 5.0 mmol) in THF (5 ml) was added dropwise to the reaction mixture at –78 °C. The mixture was stirred at room temperature for 13 h, and saturated NH₄Cl aq was added. The mixture was extracted with Et₂O, washed with water and brine, dried over Na₂SO₄, and evaporated. After purification by flash column chromatography on silica gel (hexane:AcOEt = 5:1) and GPC, 1h was obtained (327 mg, 0.73 mmol, 15%); ¹H NMR: δ = 2.67 (br, 1H), 3.58 (s, 4H), 7.07-7.12 (m, 1H), 7.19-7.27 (m, 5H), 7.34-7.39 (m, 3H), 7.52-7.57 (m, 3H), 7.68 (d, J = 8.4 Hz, 1H); ¹³C NMR = 44.3, 48.2, 74.7, 123.6 (q, J = 270.1 Hz), 124.7 (q, J = 3.7 Hz), 125.68, 125.71, 125.74, 125.8, 126.3, 128.4, 128.5, 129.6 (q, J = 32.9 Hz), 134.6, 144.1, 148.5, 149.2; IR (neat): 3566, 3024, 1329, 1167, 1124, 1082, 694 cm⁻¹; HRMS (APCI) Calcd for C₂₃H₁₈BrF₃OCl (M + Cl)⁻ 481.0176, found 481.0183.

1-(2-bromo-4,5-dimethylphenyl)-3,3-diphenylcyclobutanol (1i). To a stirred solution of 4,5-dibromo-o-xylene (950 mg, 3.6 mmol) in THF (6 ml) at –78 °C was added i-PrMgCl in THF (0.82 M, 4.4 ml, 3.6 mmol) slowly. After stirring for 3 h, a solution of 3,3-diphenylcyclobutanone (665 mg, 3.0 mmol) in THF (4 ml) was added dropwise to the reaction mixture at –78 °C. The mixture was stirred at room temperature for 17 h, and saturated NH₄Cl aq was added. The mixture was extracted with Et₂O, washed with water and brine, dried over Na₂SO₄, and evaporated. After purification by chromatography on silica gel (hexane:AcOEt = 5:1) and GPC, 1i was obtained (82 mg, 0.20 mmol, 7%); ¹H NMR: δ = 2.19 (s, 3H), 2.21 (s, 3H), 2.63 (br, 1H), 3.56 (s, 4H), 7.07-7.11 (m, 2H), 7.18-7.28 (m, 5H), 7.34-7.39 (m, 3H), 7.54-7.57 (m, 2H); ¹³C NMR: δ = 18.9, 19.2, 44.3, 48.6, 74.6, 118.0, 125.4, 125.6, 125.9, 126.5, 128.2, 128.4, 128.8, 134.6, 135.6, 137.8, 140.6, 148.9, 150.1; IR (neat): 3566, 2980, 2359, 1447, 1265, 1088, 733, 700 cm⁻¹; HRMS (APCI) Calcd for C₂₄H₂₂BrO₂Cl (M + Cl)⁻ 441.0615, found 441.0627.
4b. A mixture containing \( \text{[Rh(OH)(cod)]}_2 \) (2.2 mg, 5.0 μmol, 5.0 mol%), DPPB (4.7 mg, 11 μmol, 11 mol%), \( \text{K}_3\text{PO}_4 \) (23.3 mg, 0.11 mmol), \( \text{PhBr} \) (18.8 mg, 0.12 mmol) and 1b (30.0 mg, 0.10 mmol) in 1,4-dioxane (0.50 ml) was stirred at 120 °C for 24 h. After being cooled to room temperature, the reaction mixture was diluted with water and extracted with AcOEt (three times). The combined organic phase was washed with \( \text{H}_2\text{O} \) and brine, dried over MgSO\(_4\) and evaporated. The residue was purified by preparative thin-layer chromatography of silica gel (hexane:AcOEt = 10:1) to afford 4b.

A typical procedure for the rhodium-catalysed reaction of 1a: A mixture containing \( \text{[Rh(OH)(cod)]}_2 \) (2.3 mg, 5.0 μmol, 5.0 mol%), DPPB (4.7 mg, 11 μmol, 11 mol%), \( \text{K}_3\text{PO}_4 \) (23.3 mg, 0.11 mmol) and 1a (37.9 mg, 0.10 mmol) in 1,4-dioxane (0.50 ml) was stirred at 120 °C for 15 h. After being cooled to room temperature, the reaction mixture was diluted with \( \text{H}_2\text{O} \) and extracted with AcOEt (three times). The combined organic phase was washed with \( \text{H}_2\text{O} \) and brine, dried over MgSO\(_4\) and evaporated. The residue was purified by preparative thin-layer chromatography of silica gel (hexane:AcOEt = 10:1) to afford 2a (28.7 mg, 0.096 mmol, 96%)

2a: \( ^1\text{H NMR: } \delta = 3.46 \text{ (s, 2H), 3.78 \text{ (s, 2H), 7.11-7.16 \text{ (m, 2H), 7.19-7.33 \text{ (m, 10H), 7.45-7.49 \text{ (m, 1H), 7.91-7.94 \text{ (m, 1H); } ^{13}\text{C NMR: } \delta = 42.3, 48.6, 51.0, 126.4, 126.8, 128.5, 128.9, 132.4, 134.1, 142.1, 145.9, 197.0; IR (neat): 3024, 1676, 758, 694 cm}^{-1}; \text{HRMS (APCI) Calcd for C}_{22}\text{H}_{19}\text{O (M}^+ + \text{H) 299.1430, found 299.1421.} \)

2c: \( ^1\text{H NMR: } \delta = 1.42 \text{ (s, 3H), 2.87 \text{ (d, J = 16.4 Hz, 1H), 3.16-3.25 \text{ (m, 2H), 3.48 \text{ (d, J = 16.4 Hz, 1H), 7.17 \text{ (t, J = 7.2 Hz, 1H), 7.26-7.30 \text{ (m, 5H), 7.35 \text{ (d, J = 8.0 Hz, 2H), 7.46-7.50 \text{ (m, 1H); } ^{13}\text{C NMR: } \delta = 29.5, 40.7, 42.8, 51.3, 125.5, 126.3, 126.7, 126.8, 128.5, 129.1, 131.9, 133.9, 142.3, 146.4, 197.7; IR (neat): 2920, 1678, 1285, 1028, 768, 698 cm}^{-1}; \text{HRMS (APCI) Calcd for C}_{17}\text{H}_{17}\text{O (M}^+ + \text{H) 237.1274, found 237.1268.} \)

2d: \( ^1\text{H NMR: } \delta = 0.86-0.89 \text{ (m, 3H), 1.01 \text{ (s, 3H), 1.23-1.38 \text{ (m, 6H), 2.44-2.49 \text{ (m, 1H), 2.52-2.56 \text{ (m, 1H), 2.77 \text{ (d, J = 16.4 Hz, 1H), 2.91 \text{ (d, J = 16.4 Hz, 1H), 7.22 \text{ (d, J = 7.6 Hz, 1H), 7.30 \text{ (t, J = 7.6 Hz, 1H), 7.46-7.50 \text{ (m, 1H), 7.99-8.01 \text{ (m, 1H); } ^{13}\text{C NMR: } \delta = 14.0, 23.3, 24.9, 25.9, 36.3, 40.9, 41.9, 51.1, 126.5, 126.6, 129.3, 132.0, 133.7, 142.6, 198.7; IR (neat): 2928, 1682, 1288, 760 cm}^{-1}; \text{HRMS (APCI) Calcd for C}_{15}\text{H}_{21}\text{O (M}^+ + \text{H) 217.1587, found 217.1582.} \)

2e: \( ^1\text{H NMR: } \delta = 0.92 \text{ (s, 3H), 0.99 \text{ (s, 9H), 2.51-2.71 \text{ (m, 3H), 3.19 \text{ (d, J = 16.4 Hz, 1H), 7.22-7.30 \text{ (m, 2H), 7.45-7.49 \text{ (m, 1H), 7.97-8.00 \text{ (m, 1H); } ^{13}\text{C NMR: } \delta = 18.5, 25.2, 35.7, 36.5, 41.0, 46.1, 126.3, 126.4, 129.7, 131.8, 133.6, 143.1, 199.7; IR (neat): 2964, 1682, 1296, 756 cm}^{-1}; \text{HRMS (APCI) Calcd for C}_{13}\text{H}_{21}\text{O (M}^+ + \text{H) 217.1587, found 217.1582.} \)
Asymmetric synthesis of (+)-2d. A mixture containing [Rh(OH)(cod)]₂ (2.2 mg, 5.0 μmol, 5.0 mol%), (R)-tol-BINAP (7.4 mg, 11 μmol, 11 mol%), K₃PO₄ (23.3 mg, 0.11 mmol), and cis-1d (29.7 mg, 0.10 mmol) in 1,4-dioxane (0.50 ml) was stirred at 120 °C for 24 h. After being cooled to room temperature, the reaction mixture was diluted with water and extracted with AcOEt (three times). The combined organic phase was washed with H₂O and brine, dried over MgSO₄ and evaporated. The residue was purified by preparative thin-layer chromatography of silica gel (hexane:AcOEt = 10:1) to afford (+)-2d (15.7 mg, 0.072 mmol, 72%). The enantiomeric excess was determined to be 87% by chiral HPLC [Daicel CHIRALPAK® AS-H column, hexane:i-PrOH = 98:2, 0.4 ml/min, retention times: t₁ = 6.7 min (major); t₂ = 7.0 min (minor)].

Transformation of (+)-2d to (+)-5d. The CH₂Cl₂ (1.0 ml), propane-1,3-dithiol (40.0 μL, 0.40 mmol) and boron trifluoride diethyl etherate (48.0 μl, 0.38 mmol) were added to the (-)-2d (31.5 mg, 0.14 mmol) in the schlenk and the mixture was stirred for 14 h at 23°C. The reaction mixture was quenched with 2 M
aq. NaOH and extracted with Et₂O. The organic layer was washed with water and brine, dried over MgSO₄ and evaporated. The residue was purified preparative thin-layer chromatography of silica gel (hexane:AcOEt = 20:1) to give dithiane. A solution of this dithiane in EtOH (1.0 mL) was added to a suspension of Raney-Ni (1 g) in MeOH (1.00 mL) and stirred for 10 h at room temperature. The mixture was filtered over celite. Hexane was added and the organic layer washed with water and brine, and evaporated. The residue was purified preparative thin-layer chromatography of silica gel (hexane only) to give (+)-5d. (14.7 mg, 0.073 mmol, 52 % over 2 steps). [α]D = +1.2.

**Asymmetric synthesis of (–)-2d.** A mixture containing [Rh(OH)(cod)]₂ (2.2 mg, 5.0 μmol, 5.0 mol%), (R)-tol-BINAP (7.4 mg, 11 μmol, 11 mol%), K₃PO₄ (23.3 mg, 0.11 mmol), and trans-1d (29.7 mg, 0.10 mmol) in 1,4-dioxane (0.50 ml) was stirred at 120 °C for 24 h. After being cooled to room temperature, the reaction mixture was diluted with water and extracted with AcOEt (three times). The combined organic phase was washed with H₂O and brine, dried over MgSO₄ and evaporated. The residue was purified by preparative thin-layer chromatography of silica gel (hexane:AcOEt = 10:1) to afford (–)-2d (15.0 mg, 0.069 mmol, 69%). The enantiomeric excess was determined to be 81% by chiral HPLC [Daicel CHIRALPAK® AS-H column, hexane:i-PrOH = 98:2, 0.4 ml/min, retention times: t₁ = 7.4 min (minor); t₂ = 7.0 min (major)].

**Transformation of (–)-2d to (–)-5d.** The CH₂Cl₂ (1.0 ml), propane-1,3-dithiol (40.0 μL, 0.40 mmol) and boron trifluoride diethyl etherate (48.0 μL, 0.38 mmol) were added to the (–)-2d (30.0 mg, 0.13 mmol) in the shrenk and the mixture was stirred for 14 h at 23°C. The reaction mixture was quenched with 2 M aq. NaOH and extracted with Et₂O. The organic layer was washed with water and brine, dried over MgSO₄ and evaporated. The residue was purified preparative thin-layer chromatography of silica gel (hexane:AcOEt = 20:1) to give dithiane. A solution of this dithiane in EtOH (1.0 mL) was added to a suspension of Raney-Ni (1 g) in EtOH (1.0 mL) and stirred for 10 h at room temperature. The mixture was filtered over celite. Hexane was added and the organic layer washed with water and brine, and evaporated. The residue was purified preparative thin-layer chromatography of silica gel (hexane only) to give (–)-5d. (11.8 mg, 0.059 mmol, 45 % over 2 steps). [α]D = -1.3.

**References**

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Electronic Supplementary Material (ESI) for Chemical Communications
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