Truncated cinchona alcaloids as catalysts in enantioselective monobenzoylation of meso 1,2-diols

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Electronic Supplementary Information

General.
Liquids were distilled under N₂ from CaH₂ in an H-tube prior to use. Molecular sieves (4Å) were activated by heating at 160 °C under high vacuum for 12 hours. NOTE: Diamines 5 and 7 slowly reacted when dissolved in CH₂Cl₂ to give the corresponding chloromethylene chloride salt.¹ Solvents were purified by filtration on drying columns using Solvtek© system. Chemicals were purchased from Aldrich, Fluka, Acros, Lancaster, TCI organics or Buchler GmbH and used without further purification unless noted. Reactions and manipulations involving organometallic or moisture sensitive compounds were carried out under N₂ atmosphere and glassware was previously dried by heating under high vacuum as necessary. Celite 545 was used as filtering material. Yields refer to homogeneous material purified by crystallisation or Flash column chromatography using Brunschwig silica gel 60 Å (32-63 mesh) or Acros neutral Alumina (50-200 micron). Proton and carbon NMR spectra were recorded on Bruker AMX-500, AMX-400 or AMX-300 FT spectrometers using an internal deuterium lock. Chemical shifts are quoted in parts per million (ppm) downfield of TMS. Coupling constants J are quoted in Hz. Carbon NMR and DEPT-135 spectra were recorded with broad band proton decoupling. IR spectra were recorded on a Perkin-Elmer Spectrum One spectrophotometer. Analytical HPLC was performed using an Agilent 1100 series. Electron impact (EI) mass spectra were obtained using Varian CH-4 or SM-1 instruments operating at 40-70eV and for Electrospray ionization (ESI) HRMS analyses were measured on a VG analytical 7070E instrument. Optical rotations were measured at 20°C on a Perkin Elmer 241 polarimeter using a quartz cell (l = 10 cm) with a Na high pressure lamp (λ = 589 nm). Melting points were determined on a Büchi 510 apparatus and are
(2S,4S,5R)-N,N-Dimethyl-2-aminomethyl-5-ethenyl-quinuclidine.

A Schlenk tube equipped with a reflux condenser was rapidly charged with (2S,4S,5R)-2-aminomethyl-5-ethenyl-quinuclidine\(^2\) (4) (1.41 g, 8.51 mmol), evacuated for 30 seconds, filled with N\(_2\), and cooled to 0 °C. Then 98 % formic acid (2.04 mL, 54.1 mmol) and 36.5 % aq. formaldehyde (1.74 mL, 24.5 mmol) were added sequentially and the mixture was refluxed for 3 h. The reaction was cooled to r.t. and dissolved in a solution (1M) of HCl (30 mL) and extracted with Et\(_2\)O (3 x). The aqueous layer was then brought up to pH ≈12 with K\(_2\)CO\(_3\) and extracted with Et\(_2\)O (3 x). The combined organic layers were dried with anh. Na\(_2\)SO\(_4\) and volatiles removed under low pressure to give the title compound (1.56 g, 94 % yield) as a colourless oil.

**MW** = 194.34 g / mol; **R\(_F\)** = 0.58 (CHCl\(_3\) 84%; MeOH 14%; NH\(_3\)(aq) 2%); **[\(\alpha\)]\(_{D}\)^20**: +46 (c = 1.64 CHCl\(_3\)); **IR** (neat, cm\(^{-1}\))): 3340, 3075, 2934, 2860, 2818, 2764, 1636, 1454, 1320, 1263, 1163, 1123, 1027, 990, 908; **\(^1\)H NMR** (400 MHz, CDCl\(_3\)): δ 5.84 (ddd, \(J = 17.2, 10.3\) and 7.6 Hz, 1H), 5.02-4.94 (m, 2H), 3.13 (dd, \(J = 13.8\) and 10.1, 1H), 2.94-2.79 (m, 2H), 2.65-2.57 (m, 2H), 2.42 (dd, \(J = 12.5\) and 8.3, 1H), 2.26-2.20 (m, 1H), 2.19 (s, 6H), 2.07 (dd, \(J = 12.5\) and 6.5, 1H), 1.86-1.79 (m, 1H), 1.70-1.65 (m, 1H), 1.48-1.41 (m, 2H), 0.89 (dddd, \(J = 13.3, 6.7, 2.5\) and 1.7, 1H); **\(^{13}\)C NMR** (125 MHz, CDCl\(_3\)): δ 142.2, 114.1, 64.1, 56.2, 53.6, 45.9, 40.8, 39.9, 28.9, 27.8, 27.4; **HRMS** (ESI) calcd. for C\(_{12}\)H\(_{23}\)N\(_2\) [M+H\(^+\)]: 195.1855, found: 195.1861.

(2S,4S,5R)-N,N-Dimethyl-2-aminomethyl-5-ethylquinuclidine (5).

A two neck round bottom flask equipped charged with (2S,4S,5R)-N,N-dimethyl-2-aminomethyl-5-ethene-quinuclidine (1.12 g, 5.80 mmol) and 10 % Pd/Cl (123 mg, 0.12 mmol). The flask was evacuated and refilled with H\(_2\) from a balloon. Then MeOH (27 mL) was added and the suspension was stirred at r.t. for 16 h. The reaction mixture was filtered
and the solvent evaporated under reduced pressure. The residue was dissolved aq. HCl (1M, 45 mL) and extracted with Et₂O (3 x). The aqueous layer was then brought to pH ≈ 12 with K₂CO₃ and extracted with Et₂O (3 x). The combined organic layers were dried with anh. Na₂SO₄ and volatiles removed under low pressure to give the title compound 5 (1.13 g, 95% yield) as a colourless oil.

**MW** =196.34 g/mol; **Rf** = 0.64 (CHCl₃ 84%; MeOH 14%; NH₃(aq) 2%); [α]D²⁰: +12 (c = 0.70 CHCl₃); **IR** (CHCl₃, cm⁻¹): 3137, 2934, 2864, 2775, 2822, 1457, 1379, 1264, 1093, 1027. **¹H NMR** (400 MHz, CDCl₃): δ 3.17 (dd, J = 13.5 and 9.4, 1H), 2.98-2.81 (m, 2H), 2.71-2.60 (m, 1H), 2.42 (dd, J = 12.3 and 8.0, 1H), 2.46-2.36 (m, 1H), 2.22 (s, 6H), 2.14 (dd, J = 12.3 and 6.8, 1H), 1.85-1.76 (m, 1H), 1.70-1.64 (m, 1H), 1.57-1.30 (m, 5H), 0.87-0.96 (m, 1H), 0.86 (t, J = 7.2, 3H); **¹³C NMR** (100 MHz, CDCl₃): δ 64.2, 57.8, 53.6, 46.1, 41.0, 37.4, 28.6, 27.6, 27.2, 25.6, 12.2; **HRMS** (ESI) calcd. for C₁₂H₂₅N₂ [M+H]+: 197.2012, found: 197.2013.

(2R,4S,5R)-N,N-Dimethyl-2-aminomethyl-5-ethenyl-quinuclididine

A Schlenk tube equipped with a reflux condenser was rapidly charged with (2R,4S,5R)-2-aminomethyl-5-ethenyl-quinuclidine² (1.00 g, 6.03 mmol), evacuated for 30 seconds, filled with N₂, and cooled at 0 °C. Then 98 % formic acid (1.39 mL, 36.0 mmol) and 36.5 % formaldehyde (1.22 mL, 16.4 mmol) were added and the mixture was refluxed for 3 h. Then cooled at r.t., dissolved in a solution (1M) of HCl (30 mL) and extracted with Et₂O (3 x). The aqueous layer was brought to pH ≈12 with K₂CO₃ and extracted with Et₂O (3 x). The combined organic layers were dried with anh. Na₂SO₄ and volatiles removed under low pressure to give the title compound (1.10 g, 94% yield) as colourless oil.

**MW** =194.34 g/mol; **Rf** = 0.58 (CHCl₃ 84%; MeOH 14%; NH₃(aq) 2%); [α]D²⁰: +181 (c = 1.64 CHCl₃); **IR** (neat, cm⁻¹): 3076, 2934, 2862, 2818, 2763, 1682, 1636, 1455, 1321, 1263, 1202, 1029; **¹H NMR** (400 MHz, CDCl₃): δ 5.86 (ddd, J = 17.4, 9.9 and 7.3, 1H), 5.02-4.99 (m, 1H), 4.98-4.96 (m, 1H), 2.96-2.78 (m, 4H), 2.67-2.61 (m, 1H), 2.42 (dd, J = 12.5 and 8.2, 1H), 2.23-2.16 (m, 1H), 2.21 (s, 6H), 2.11 (dd, J = 12.5 and 6.4, 1H), 1.70-1.66 (m, 1H), 1.61-1.46 (m, 3H), 1.26 (dddd, J = 21.6, 8.2, 2.0 and 1.8, 1H); **¹³C NMR** (125 MHz, CDCl₃): δ 141.7, 114.5, 63.1, 53.7, 49.6, 47.7, 46.2, 40.6, 28.0,
27.2, 27.1; HRMS (ESI) calcd. for C_{12}H_{23}N_{2} [M+H]^+ : 195.1855, found: 195.1848.

(2R,4S,5R)-N,N-Dimethyl-2-aminomethyl-5-ethylquinuclidine (7).

A two neck round bottom flask was charged with (2R,4S,5R)-N,N-dimethyl-2-aminomethyl-5-ethenyl-quinuclidine (1.11 g, 5.66 mmol) and 10 % palladium on charcoal (120 mg, 0.11 mmol). The flask was evacuated and refilled with H_2 from a balloon. Then MeOH (26 mL) was added and the suspension was stirred at r.t. for 18 h. The reaction mixture was then filtered and the solvent evaporated under reduced pressure. The residue was dissolved in aq. HCl (1 M, 45 mL) and extracted with Et_2O (3 x). The aqueous layer was brought to pH ≈ 12 with K_2CO_3 and extracted with Et_2O (3 x). The combined organic layers were dried with anh. Na_2SO_4 and volatiles removed under low pressure to give the title compound 7 (933 mg, 84 %) as colourless oil.

MW = 196.34 g / mol; R_F = 0.46 (CHCl_3 84%; MeOH 14%; NH_3(aq) 2%); [α]_D^{20} : +128 (c = 0.93 CHCl_3); IR (neat, cm^{-1}): 2933, 2860, 2817, 2764, 1683, 1456, 1378, 1325, 1263, 1202, 1147, 1034; ^1_H NMR (400 MHz, CDCl_3): δ 2.90-2.73 (m, 4H), 2.39 (dd, J = 12.4 and 7.9, 1H), 2.35 (ddd, J = 14.0, 7.3 and 2.3, 1H), 2.20 (s, 6H), 2.11 (dd, J 12.4 and 6.8, 1H), 1.62-1.51 (m, 2H), 1.49-1.40 (m, 2H), 1.39-1.25 (m, 3H), 1.24-1.15 (m, 1H), 0.82 (t, J 7.3, 3H); ^13_C NMR (100 MHz, CDCl_3): δ 63.2, 53.7, 49.5, 49.2, 46.1, 37.9, 27.8, 26.7, 26.1, 25.8, 12.1; HRMS (ESI) calcd. for C_{12}H_{25}N_{2} [M+H]^+ : 197.2017, found: 197.2005.

General procedure for the asymmetric acylation of meso-1,2-diols.

A solution of chiral diamine 5 (3.4 mg, 0.017 mmol, 2 mol %) in dry AcOEt (2 ml) was added under N_2 to a mixture of meso-1,2-diol (0.86 mmol) and activated molecular sieves (4Å, 113 mg) in dry AcOEt (6 ml). To the stirred, cold (-60 °C) solution, benzoyl chloride (150 µL, 1.29 mmol) followed by Et_3N (121 µL, 0.86 mmol) were added drop-wise. The resulting mixture was stirred at -60 °C for 22 hours, then quenched with a solution (10 mL) of phosphate buffer (pH = 7) and extracted with Et_2O (3 x). The organic layers were dried with MgSO_4 and all volatiles were removed under reduced pressure. The residue was purified by flash chromatography (Et_2O / pentane) to the monobenzoate.
(+)-(1S,2R)-2-Hydroxy-1-cyclohexyl benzoate (+)-9

Colourless oil; MW = 220.26 g / mol; RF = 0.16 (Et2O / pentane, 1 : 3); [α]D20: +16 (c = 0.68 CHCl3); IR (neat, cm−1): 3441, 2937, 2862, 1715, 1602, 1450, 1272; 1H NMR (300 MHz, CDCl3): δ 8.03-7.99 (m, 2H), 7.60-7.53 (m, 1H), 7.48-7.40 (m, 2H), 5.24-5.20 (m, 1H), 3.99-3.92 (m, 1H), 2.09-1.92 (m, 1H), 1.95 (broad s, 1H), 1.90-1.80 (m, 1H), 1.78-1.62 (m, 4H), 1.51-1.37 (m, 2H); 13C NMR (100 MHz, CDCl3): δ 166.2, 133.1, 130.4, 129.6, 128.4, 74.6, 70.0, 30.4, 27.4, 21.8, 21.6; MS m/z (EI): 202 (2 [M-H2O]+), 174 (2), 149 (4), 115 (14), 105 (100), 98 (95 [M-BzOH]+), 77 (79), 51 (36); HPLC Chiralcel OJ-H, eluent: 95:5 hexane / iPrOH, flow rate: 1 mL / min: retention times 11.3 min ((1S,2R)-enantiomer) and 13.5 min ((1R,2S)-enantiomer).

cis-1,2-Dibenzoyloxycyclohexane (10)

White solid; MW = 324.37 g / mol; RF = 0.48 (Et2O / pentane, 1: 3); MP = 63-64 °C (Ethanol); IR (neat, cm−1): 2942, 1786, 1720, 1600, 1450, 1265, 1210; 1H NMR (400 MHz, CDCl3): δ 8.01 (d, J 7.1, 4H), 7.54 (t, J 8.8, 2H), 7.41 (t, J 8.8, 4H), 5.40-5.38 (m, 2H), 2.14-2.06 (m, 2H), 1.90-1.75 (m, 4H), 1.62-1.53 (m, 2H); 13C NMR (100 MHz, CDCl3): δ 165.8, 132.9, 130.5, 129.6, 128.3, 71.9, 28.0, 21.9; MS m/z (EI): 202 (12 [M-BzOH]+), 198 (15), 182 (5), 122 (3), 105 (100), 77 (81), 51 (62).

(+)-(2S,3R)-3-Hydroxyl-2-butyl benzoate (19):

The starting material was dried over MS 4Å in CH2Cl2 solution.

(+)-19: colourless oil; MW = 194.23 g / mol; RF = 0.26 (Et2O / pentane, 1: 3); [α]D20: +17 (c = 0.70 CH2Cl2); IR (neat, cm−1): 3441, 2981, 1714, 1451, 1315, 1275, 1119, 1091, 1071, 1026, 1008; 1H NMR (400 MHz, CDCl3): δ 8.03 (d, J 7.8, 2H), 7.54 (t, J 7.2, 1H), 7.42 (t, J 7.8, 2H), 5.15-5.07 (m, 1H), 3.99 (cd, J 6.4 and 3.5, 1H), 2.35 (broad s, 1H), 1.33 (d, J 6.4, 3H), 1.23 (d, J 6.4, 3H); 13C NMR (100 MHz, CDCl3): δ 166.2, 133.1,
cis-1,2-Bisbenzoyloxybutane

Colourless oil; \( MW = 298.34 \text{ g / mol} \); \( R_F = 0.65 \) (Et\(_2\)O / pentane, 1 : 3); \( MP = 73-75 \degree \text{C (CH}_2\text{Cl}_2 / \text{cyclohexane)} \); \( IR \) (neat, cm\(^{-1}\)): 2988, 1787, 1717, 1692, 1601, 1584, 1451, 1316, 1266, 1212, 1113, 1096, 1070, 1038, 1016, 996; \(^1\text{H NMR} \) (400 MHz, CDCl\(_3\)): \( \delta \) 8.04 (d, \( J = 8.3 \), 4H), 7.55 (t, \( J = 7.5 \), 2H), 7.43 (t, \( J = 7.7 \), 4H), 5.42-5.36 (m, 2H), 1.45 (d, \( J = 6.4 \), 6H); \(^{13}\text{C NMR} \) (100 MHz, CDCl\(_3\)): \( \delta \) 166.0, 133.2, 130.5, 129.8, 128.6, 72.5, 15.7; \( MS \) \( m/z \) (EI): 254 (6), 226 (6), 210 (27), 198 (12), 176 (14 [M-PhCOOH]\(^+\)), 149 (13), 132 (12), 105 (100), 77 (70), 51 (47).

\((+)-(1S,2R)-2\text{-Hydroxy-1-cyclopentyl benzoate (20)}\)\(^{3,8,9}\)

The starting material was dried over MS 4Å in CH\(_2\text{Cl}_2\) solution.\(^{[3,12,13]}\) Colourless oil; \( MW = 206.24 \text{ g / mol} \); \( R_F = 0.22 \) (Et\(_2\)O / pentane, 1 : 3); \([\alpha]^{20}_D \): +13 (c = 0.45 CH\(_2\text{Cl}_2\) ); \( IR \) (neat, cm\(^{-1}\)): 3596, 3064, 2974, 2879, 1717, 1602, 1584, 1451, 1272, 1117; \(^1\text{H NMR} \) (300 MHz, CDCl\(_3\)): \( \delta \) 8.03 (dd, \( J = 8.3 \), and 1.1, 2H), 7.36 (dt, \( J = 7.5 \) and 1.5, 1H), 7.41 (dt, \( J = 7.5 \) and 1.5, 2H), 5.24-5.16 (m, 1H), 4.32-4.25 (m, 1H), 2.64 (broad s, 1H), 2.19-1.99 (m, 1H), 1.98-1.87 (m, 3H), 1.82-1.75 (m, 1H), 1.64-1.57 (m, 1H); \(^{13}\text{C NMR} \) (75 MHz, CDCl\(_3\)): \( \delta \) 166.4, 133.1, 130.1, 129.6, 128.4, 77.4, 73.4, 30.9, 28.2, 19.5; \( MS \) \( m/z \) (EI): 206 (1 [M]\(^+\)), 198 (14), 188 (34 [M-H\(_2\text{O}\)]\(^+\)), 106 (50), 105 (100), 77 (73), 51 (50); \( HRMS \) (ESI) calcd. for C\(_{12}\)H\(_{14}\)O\(_3\)Na [M+Na]\(^+\): 229.0835, found: 229.0829; \( HPLC \) Chiralcel OJ-H, eluent: 95:5 hexane / \(^1\text{PrOH}, flow rate: 0.5 \text{ mL / min: retention times 22.3 min ((1S,2R)-enantiomer) and 26.7 min ((1R,2S)-enantiomer).} \)
cis-1,2-Bisbenzoyloxyxyclopentane\textsuperscript{11}

White solid; MW = 310.35 g / mol; \( R_F = 0.59 \) (Et\(_2\)O / pentane, 1 : 3); MP = 45-47 °C (ethanol); \( \text{IR} \) (neat, cm\(^{-1}\)): 3065, 2962, 1720, 1602, 1584, 1451, 1315, 1283, 1272, 1258, 1177, 1122; \( ^1\text{H NMR} \) (300 MHz, CDCl\(_3\)): \( \delta \) 7.97 (dd, \( J \) 8.5, and 1.3, 4H), 7.52 (tt, \( J \) 7.5, and 1.5, 2H), 7.40-7.33 (m, 4H), 5.54-5.48 (m, 2H), 2.27-2.13 (m, 2H), 2.10-1.97 (m, 3H), 1.84-1.72 (m, 1H); \( ^{13}\text{C NMR} \) (125 MHz, CDCl\(_3\)): \( \delta \) 165.9, 132.8, 130.5, 129.6, 128.2, 75.1, 28.6, 19.7; MS \( m/z \) (ESI): 311 (100 [M]+), 205 (24), 189 (99), 106 (8); HRMS (ESI) calcd. for C\(_{19}\)H\(_{19}\)O\(_4\) [M+H]+: 311.1277, found: 311.1277.

(+)- 4-Anhydro-2-acyloxyerytritol (21):

White solid, MW = 208.22 g / mol; \( R_F = 0.07 \) (Et\(_2\)O / pentane, 1 : 2); \([\alpha]_D^{20}\): +4 (c = 0.86 CH\(_2\)Cl\(_2\)); MP = 80-81 °C (CH\(_2\)Cl\(_2\), cyclohexane); \( \text{IR} \) (neat, cm\(^{-1}\)): 3417, 2926, 2874, 1715, 1601, 1584, 1451, 1269, 1177, 1118, 1068; \( ^1\text{H NMR} \) (400 MHz, CDCl\(_3\)): \( \delta \) 8.05-8.00 (m, 2H), 7.58-7.52 (m, 1H), 7.37-7.34 (m, 2H), 5.34-5.30 (m, 1H), 4.51 (ddd, \( J \) 11.1, 5.5 and 1.6, 1H), 4.11 (ddd, \( J \) 10.2, 5.8 and 1.7, 1H), 3.98 (ddd, \( J \) 9.3, 5.8 and 9.3, 1H), 3.96 (ddd, \( J \) 12.1, 5.8 and 1.7, 1H), 3.74 (ddd, \( J \) 9.3, 5.5 and 1.8, 1H), 2.83 (broad s, 1H); \( ^{13}\text{C NMR} \) (125 MHz, CDCl\(_3\)): \( \delta \) 166.6, 133.7, 130.0, 129.6, 128.7, 74.5, 72.6, 71.2, 70.7; HRMS (ESI) calcd. for C\(_{11}\)H\(_{13}\)O\(_4\) [M+H]+: 209.0808, found: 209.0817; HPLC Chiralcel AS-H, eluent: 95:5 hexane / \( ^1\text{PrOH} \), flow rate: 1 mL / min: retention times 38.1 min ((-)enantiomer) and 45.6 min ((+)enantiomer).

cis-1,2-Bisbenzoyloxy-4-anhydroerytritol\textsuperscript{13}

Colourless oil; MW = 312.33 g / mol; \( R_F = 0.40 \) (Et\(_2\)O / pentane, 1 : 2); \( \text{IR} \) (neat, cm\(^{-1}\)): 2925, 2872, 1721, 1602, 1584, 1491, 1451, 1345, 1315, 1277, 1177, 1126; \( ^1\text{H NMR} \) (400 MHz, CDCl\(_3\)): \( \delta \) 7.98-7.93 (m, 4H), 7.56-7.50 (m, 2H), 7.39-7.32 (m, 4H), 5.70-5.66 (m, 2H), 5.32-5.26 (m, 2H), 4.08-4.03 (m, 2H); \( ^{13}\text{C NMR} \) (100 MHz, CDCl\(_3\)):...
δ 166.1, 133.6, 130.1, 129.7, 128.7, 72.6, 70.9; HRMS (ESI) calcd. for C_{18}H_{17}O_{5} [M^{+}+H]: 313.1070, found: 313.1066.

\((+)-(1S,2R)-2\text{-Hydroxy-1-cyclohex-4-enyl benzoate (22)}^{10}\)

\begin{center}
\includegraphics[width=0.3\textwidth]{22.png}
\end{center}

Colourless oil; MW = 218.25 g / mol; \(R_F = 0.08\) (Et₂O / pentane, 1 : 3); [\(\alpha\)]\(D^{20}\): + 44 (c = 0.92 CH₂Cl₂); IR (neat, cm\(^{-1}\)): 3597, 3064, 3036, 2929, 2853, 1716, 1602, 1584, 1451, 1315, 1275, 1116; \(^1\)H NMR (500 MHz, CDCl₃): δ 8.04 (d, \(J = 7.9\), 2H), 7.58-7.52 (m, 1H), 7.46-7.40 (m, 2H), 5.70-5.58 (m, 2H), 5.35-5.30 (m, 1H), 4.18-4.14 (m, 1H), 2.64 (broad s, 1H), 2.52-2.43 (m, 3H), 2.39-2.32 (m, 1H); \(^{13}\)C NMR (125 MHz, CDCl₃): δ 166.6, 133.2, 130.3, 129.7, 128.4, 123.9, 123.4, 72.8, 67.6, 31.5, 28.4; MS \(m/z\) (EI): 218 (2 [M]⁺), 164 (2), 123 (18), 105 (100), 96 (84), 77 (19), 67 (17), 51 (11); HRMS (ESI) calcd. for C₁₃H₁₅O₃ [M+H]⁺: 219.1015, found: 219.1009; HPLC Chiralcel OJ-H, eluent: 95:5 hexane / iPrOH, flow rate: 0.5 mL / min: retention times 25.3 min ((1S,2R)-enantiomer) and 31.4 min ((1R,2S)-enantiomer).

\(cis\)-1,2-Bisbenzoyloxy cyclo-4-hexene

Conversion: 8 % (\(^1\)H-NMR): colourless oil; MW = 322.36 g / mol; \(R_F = 0.47\) (Et₂O / pentane, 1 : 3); IR (neat, cm\(^{-1}\)): 3065, 3038, 2934, 1718, 1584, 1452, 1315, 1303, 1280, 1266, 1253, 1217; \(^1\)H NMR (500 MHz, CDCl₃): δ 8.03-8.01 (m, 4H), 7.57-7.51 (m, 2H), 7.43-7.40 (m, 4H), 5.32-5.27 (m, 1H), 2.39 (broad s, 1H), 2.68-2.56 (m, 4H); \(^{13}\)C NMR (125 MHz, CDCl₃): δ 165.9, 132.9, 130.2, 129.6, 128.3, 123.6, 69.9, 28.8; HRMS (ESI) calcd. for C₂₀H₁₉O₄ [M+H]⁺: 323.1277, found: 323.1279.

\((+)-(1S,2R)-2\text{-Hydroxyl-1-cyclooctanyl benzoate (23)}^{3}\)

Colourless oil; MW = 248.32 g / mol; \(R_F = 0.40\) (Et₂O / pentane, 1: 2). [\(\alpha\)]\(D^{20}\): + 8 (c = 0.90 CH₂Cl₂); IR (neat, cm\(^{-1}\)): 3425, 3036, 2922, 2856, 1710, 1601, 1584, 1450, 1315, 1271, 1176, 1110. \(^1\)H NMR (400 MHz, CDCl₃): δ 8.05-8.01 (m, 2H), 7.56-7.52 (m, 1H), 7.45-7.39 (m, 2H), 5.32-5.27 (m, 1H), 4.07 (ddd, \(J = 6.4, 3.9, 2.4\), 1H) 2.39 (broad s, 1H),
cis-1,2-Bisbenzoyloxycyclooctane:

Colourless oil; MW = 352.43 g / mol; RF = 0.44 (Et₂O / pentane, 1 : 4); IR (neat, cm⁻¹): 3422, 2924, 2853, 1717, 1451, 1378, 1314, 1278, 1176, 1109, 1069, 1026; ¹H NMR (400 MHz, CDCl₃): δ 8.03-7.98 (m, 4H), 7.57-7.51 (m, 2H), 7.43-7.38 (m, 4H), 5.54-5.49 (m, 2H), 2.30-1.19 (m, 2H), 1.96-1.64 (m, 10H); ¹³C NMR (100 MHz, CDCl₃): δ 166.2, 133.2, 130.8, 130.0, 128.7, 128.4, 128.37, 128.33, 127.8, 127.7, 127.6, 127.5, 73.4, 73.3, 73.0, 70.6, 69.8, 68.8; HRMS (ESI) calcd. for C₂₂H₂₅O₅ [M+H]+: 353.1747, found: 353.1745.

(+)-(2S,3R)-1,4-Bisbenzyloxy-3-hydroxyl-2-butyl benzoate (24):

Colourless oil; MW = 406.48 g / mol; RF = 0.16 (Et₂O / pentane, 1 : 2); [α]D²⁰: + 55 (c = 0.23 CH₂Cl₂); IR (neat, cm⁻¹): 3464, 3063, 3031, 2865, 1716, 1452, 1270, 1108, 1070, 1026, 737, 712, 698; ¹H NMR (400 MHz, CDCl₃): δ 8.03 (d, J 8.3, 2H), 7.58 (t, J 7.4, 1H), 7.43-7.41 (m, 2H), 7.31-7.22 (m, 10H), 5.33 (ddd, J 6.7, 4.7, and 3.5, 1H), 4.61-4.49 (m, 4H), 4.27-4.19 (m, 1H), 3.91 (dd, J 10.9 and 4.8, 1H), 3.84 (dd, J 10.9 and 3.5, 1H), 3.65 (dd, J 9.7 and 3.9, 1H), 3.60 (dd, J 9.5 and 5.9, 1H), 2.87 (d, J 5.7, 1H); ¹³C NMR (125 MHz, CDCl₃): δ 165.7, 130.8, 137.7, 133.1, 129.9, 129.7, 128.4, 128.37, 128.33, 127.8, 127.7, 127.6, 127.5, 73.4, 73.3, 73.0, 70.6, 69.8, 68.8; HRMS (ESI) calcd. for C₂₅H₂₇O₅ [M+H]+: 407.1853, found: 407.1862; HPLC Chiralcel AS-H, Gradient 99:1 to 90:10 during 60 min, eluent: hexane / iPrOH, flow rate: 1 mL / min: retention times 35.8 min ((2S,3R)-enantiomer) and 42.6 min ((2R,3S)-enantiomer).

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OH

O

O

(+)23

2.23-2.11 (m, 1H), 1.94-1.47 (m, 11H); ¹³C NMR (100 MHz, CDCl₃): δ 166.1, 132.9, 130.3, 129.5, 128.3, 77.6, 71.7, 30.5, 27.8, 26.8, 25.6, 24.1, 22.0; HRMS (ESI) calcd. for C₁₅H₂₁O₃ [M+H]+: 249.1485, found: 249.1481; HPLC Chiralcel OJ-H, eluent: 95:5 hexane / iPrOH, flow rate: 1 mL / min: retention times 8.9 min ((1S,2R)-enantiomer) and 10.7 min ((1R,2S)-enantiomer).
cis-2,4-Bisbenzoyloxy-1,4-benzyloxybutane

White solid; **MW** = 510.59 g / mol; **R**<sub>F</sub> = 0.51 (Et₂O / pentane, 1 : 2); **MP** = 114-116 °C (CH₂Cl₂ / cyclohexane); **IR** (neat, cm⁻¹): 3064, 3032, 2928, 2856, 1788, 1719, 1601, 1585, 1451, 1258, 1096; **<sup>1</sup>H NMR** (400 MHz, CDCl₃): δ 8.03-7.99 (m, 4H), 7.57 (tt, **J** = 7.5 and 1.3, 2H), 7.44 (t, **J** = 7.8, 4H), 7.27-7.18 (m, 10H), 5.76-7.72 (m, 2H), 4.56 (d, **J** = 12.1, 2H), 4.48 (d, **J** = 12.1, 2H), 3.88 (dd, **J** = 10.8 and 3.8, 2H), 3.82 (dd, **J** = 10.8 and 3.8, 2H); **<sup>13</sup>C NMR** (125 MHz, CDCl₃): δ 165.5, 138.0, 133.4, 130.2, 130.1, 128.7, 128.6, 128.0, 127.9, 77.3, 73.8, 68.4; **MS** m/z (EI): 403 (2 [M-BnO]⁺), 313 (65), 267 (2), 191 (5), 158 (4), 105 (100), 91 (84); **HRMS** (EI) calcd. for C<sub>25</sub>H<sub>23</sub>O<sub>5</sub> [M-BnO]⁺: 403.1545, found: 403.1544.

(+)-(2S,3R)-3-Hydroxyl-2-tetralinyl benzoate (25):

Colourless oil; **MW** = 268.32 g / mol; **R**<sub>F</sub> = 0.20 (Et₂O / pentane, 1 : 2); [α]<sub>D</sub><sup>20</sup>: + 20 (c = 0.69 CH₂Cl₂), 81.7 % ee; **IR** (neat, cm⁻¹): 3423, 3064, 2931, 1712, 1601, 1583, 1495, 1451, 1315, 1270, 1113, 1068; **<sup>1</sup>H NMR** (400 MHz, CDCl₃): δ 8.06-8.01 (m, 2H), 7.58-7.52 (m, 1H), 7.41 (t, **J** = 7.8, 2H), 7.20-7.10 (m, 4H), 5.55-5.50 (m, 1H), 4.37-4.32 (m, 1H), 3.31-3.04 (m, 4H), 2.75 (broad s, 1H); **<sup>13</sup>C NMR** (100 MHz, CDCl₃): δ 166.9, 133.5, 133.2, 132.7, 130.2, 130.0, 129.5, 129.2, 128.6, 126.6, 126.5, 73.3, 68.1, 34.9, 32.1; **MS** m/z (EI): 146 (100 [M-PhCOOH]⁺), 145 (56), 128 (55), 117 (60), 105 (88), 77 (69). **HRMS** (ESI) calcd. for C<sub>17</sub>H<sub>17</sub>O<sub>3</sub> [M+H]⁺: 269.1172, found: 269.1179; **HPLC** Chiralcel AS-H, Gradient 99:1 to 90:10 during 60 min, eluent: hexane / PrOH, flow rate: 1 mL / min: retention times 35.6 ((2S,3R)-enantiomer) min and 47.7 min((2R,3S)-enantiomer).

cis-2,4-Bisbenzoyloxytetralin.

White solid; **MW** = 372.42 g / mol; **R**<sub>F</sub> = 0.69 (Et₂O / pentane, 1 : 2); **MP** = 91 °C (Ethanol); **IR** (neat, cm⁻¹): 3066, 1787, 1720, 1600, 1584, 1451, 1315, 1278, 1212, 1174, 1109, 1040; **<sup>1</sup>H NMR** (400 MHz, CDCl₃): δ 8.02-7.95 (m, 4H), 7.57-7.51 (m, 10H), 7.46-7.36 (m, 5H), 7.28-7.18 (m, 10H), 5.75-7.65 (m, 2H), 4.56-4.47 (d, **J** = 12.1, 2H), 4.48-4.30 (d, **J** = 12.1, 2H), 3.88-3.64 (dd, **J** = 10.8 and 3.8, 2H), 3.82-3.58 (dd, **J** = 10.8 and 3.8, 2H); **<sup>13</sup>C NMR** (125 MHz, CDCl₃): δ 165.5, 138.0, 133.4, 130.2, 130.1, 128.7, 128.6, 128.0, 127.9, 77.3, 73.8, 68.4; **MS** m/z (EI): 403 (2 [M-BnO]⁺), 313 (65), 267 (2), 191 (5), 158 (4), 105 (100), 91 (84); **HRMS** (EI) calcd. for C<sub>25</sub>H<sub>23</sub>O<sub>5</sub> [M-BnO]⁺: 403.1545, found: 403.1544.
(-)-(1S,2R)-1,4-Diphenyl-2-hydroxyl-1-butyl benzoate (26)\(^3\)

White solid; \(MW = 318.38 \text{ g / mol} \); \(R_F = 0.21 \) (Et\(_2\)O / pentane, 1: 3); \([\alpha]\)\(^{20D}\) = -8 (c= 0.22 CH\(_2\)Cl\(_2\)); \(MP = 158-159 \) (CH\(_2\)Cl\(_2\) / cyclohexane); \(IR\) (neat, cm\(^{-1}\)): 3477, 3028, 1720, 1451, 1316, 1272, 1177, 1113, 1027, 701; \(^1\)H NMR (400 MHz, CDCl\(_3\)): \(\delta\) 8.03-7.98 (m, 2H), 7.59-7.53 (m, 1H), 7.46-7.40 (m, 2H), 7.34-7.26 (m, 10H), 6.16 (d, \(J = 5.8, 1\)H), 5.16 (d, \(J = 5.8, 1\)H), 2.26 (broad s, 1H); \(^{13}\)C NMR (125 MHz, CDCl\(_3\)): \(\delta\) 165.7, 139.8, 136.8, 133.5, 130.1, 130.0, 128.8, 128.7, 128.6, 128.5, 128.4, 127.9, 127.3, 79.8, 76.9; \(MS \ m/z\) (EI): 318 (2 \([\text{M}^+\]), 212 (51), 167 (15), 149 (3), 122 (5), 105 (100), 77 (64), 51 (10); HPLC Chiralcel OJ-H, eluent: 95:5 hexane / iPrOH, flow rate: 1 mL / min: retention times 33.8 min ((1R,2S)-enantiomer) and 57.3 min ((1S,2R)-enantiomer).

cis-2,3-Bisbenzoyloxy-1,4-diphenylbutane\(^10\)

White solid; \(MW = 422.49 \text{ g / mol} \); \(R_F = 0.39 \) (Et\(_2\)O / pentane, 1 : 2); \(MP = 241-239 \) \(^\circ\text{C}\) (CH\(_2\)Cl\(_2\) / cyclohexane); \(IR\) (neat, cm\(^{-1}\)): 2924, 2852, 1709, 1451, 1266, 1110, 1069, 710; \(^1\)H NMR (400 MHz, CDCl\(_3\)): \(\delta\) 8.01 (d, \(J = 8.0, 4\)H), 7.56 (t, \(J = 7.6, 2\)H), 7.43 (t, \(J = 7.6, 4\)H), 7.29 (s, 10H), 6.49 (s, 2H); \(^{13}\)C NMR (100 MHz, CDCl\(_3\)): \(\delta\) 165.5, 136.2, 133.4, 130.1, 130.0, 128.78, 128.72, 128.4, 127.8, 77.6; HRMS (ESI) calcd. for C\(_{28}\)H\(_{20}\)O\(_4\) \([\text{M+H}]^+\): 440.1856, found: 440.1851.
References

2. purchased from Buchler-GMBH, Braunschweig, Germany