Supporting Information

Salen-Derived Catalysts Containing Secondary Basic Groups in the Addition of Diethylzinc to Aldehydes

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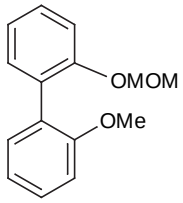
General. Unless otherwise noted, all non-aqueous reactions were carried out under an atmosphere of dry N_2 in dried glassware. All manipulations involving Et_2Zn were carried out using standard Schlenck techniques. When necessary, solvents and reagents were dried prior to use. Toluene and CH_2Cl_2 were de-oxygenated by purging with N_2 and then dried by passing through activated alumina. THF was distilled from Na/benzophenone ketyl. Activated MnO_2, $Ni(OAc)_2{\cdot}4H_2O$ and $Cu(OAc)_2$ were purchased from Strem and used without further purification. 4-*tert*-Butylphenol (**10**) and biphenyl-2,2'-diol were purchased from Acros. (+)-(*R*)-1,1'-Binaphthyl-2,2'-diamine and diphenylethylenediamine were purchased from Aldrich. (-)-(1*R*,2*R*)-1,2-Cyclohexanediamine was prepared as previously described.[1] Benzaldehyde, *p*-anisaldehyde, *o*-tolualdehyde, cyclohexane carboxaldehyde, and 3-ethylbutyraldehyde were distilled *in vacuo* prior to use. $Ti(OiPr)_4$ was distilled and stored as a 1.4M solution in hexanes. Et_2Zn was used as a freshly prepared 1.0M solution in toluene. Bu_2Mg was used as a 1.0M solution in heptane, purchased from Aldrich. All salen ligands and complexes were dried thoroughly with gentle heating on a high vacuum for several hours prior to use.

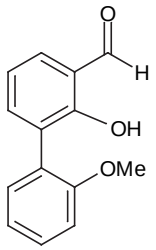
Analytical thin layer chromatography (TLC) was performed on EM Reagents 0.25 mm silica-gel 60-F plates. Preparative thin layer chromatography was performed on EM Reagents 1.00 mm silica-gel plates. Visualization was accomplished with UV light. Chromatography on silica gel was performed using a forced flow of the indicated solvent system on EM Reagents Silica Gel 60 (230-400 mesh).[2] Enantiomeric excesses were determined using GC using a Hewlett-Packard 6890 gas chromatograph with a Supelco β-DEX^{TM} column (30 m x 0.25 mm). ^{1}H NMR spectra were recorded on Bruker AM-500 (500 MHz), AM-250 (250 MHz), or AM-200 (200 MHz) spectrometers. Chemical shifts are reported in ppm from tetramethylsilane (0 ppm) or from the solvent resonance ($CDCl_3$ 7.26 ppm, DMSO-d_6 2.49 ppm, D_2O 4.80 ppm). Data are reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, br = broad, m = multiplet), coupling constants, and number of protons. Mass spectra were obtained on a low resonance Micromass Platform LC in electron spray mode and high resonance VG autospec with an ionization mode of either CI or ES. IR spectra were taken on a Perkin-Elmer FT-IR spectrometer using a thin film on NaCl plates. Melting

points were obtained on Thomas Scientific Unimelt apparatus and are uncorrected. Optical rotations were measured on a Perkin-Elmer Polarimeter 341 with a sodium lamp and are reported as follows $[\alpha]^{T}_{\lambda}$, (c = g / 100 mL, solvent).



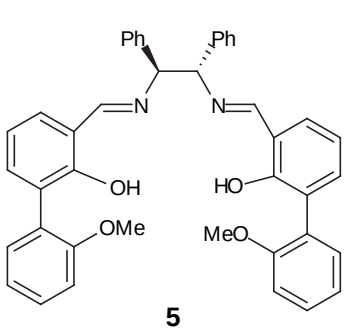
22

2'-Methoxy-2-methoxymethoxy-biphenyl (22). A slurry of NaH (326 mg, 60% dispersion in mineral oil, 7.48 mmol) in THF (25 mL) and DMF (15 mL) was purged with N_2 and cooled to 0 °C. 2'-Methoxy-biphenyl-2-ol[3] (1.0 g, 4.99 mmol) was added as a solution in THF (9 mL). The pale yellow anion was stirred for 1.5 h at 0 °C. MOMCl (570 μL, 7.48 mmol) was added dropwise and the solution was allowed to warm to rt. After stirring for 4 h at rt, the reaction was quenched with water, extracted with EtOAc, dried over $MgSO_4$ and concentrated. Purification by flash chromatography on SiO_2 (5% EtOAc / hexanes) afforded **22** in quantitative yield (1.2 g, 4.99 mmol) as a white solid: ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.32-7.07 (m, 4H), 7.02-6.97 (m, 4H), 5.05 (s, 2H), 3.77 (s, 3H), 3.37 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 157.4, 155.4, 131.9, 131.8, 129.0, 128.4, 122.2, 120.7, 115.9, 111.2, 95.6, 81.2, 56.2, 55.9.



23

2-Hydroxy-2'-methoxy-biphenyl-3-carbaldehyde (23). Aldehyde **23** was prepared from **22** in 90% yield following the procedure for the synthesis of (+/-)-2-hydroxy-2'-methoxy-[1,1']binaphthyl-3-carbaldehyde.[4] Aldehyde **23** has previously been synthesized by similar methods.[5]



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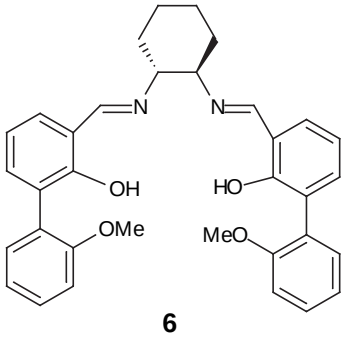


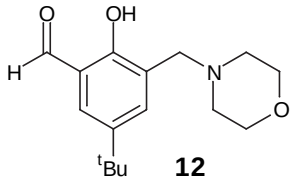
6

General procedure for the synthesis of salens 5 and 6. Salens **5** and **6** were prepared by stirring **23** (2.0 equiv.) with the appropriate diamine (1.0 equiv.) in absolute EtOH at rt for 24 h. The precipitate was collected by gravity filtration, washed with cold EtOH, and dried *in vacuo* for several hours with gentle heat.

(5): 97% yield; pale yellow solid; mp 128-132 °C; $[\alpha]_D^{20}$ +69 (*c* 0.34, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 13.50 (br s, 2H), 8.40 (s, 2H, HC=N), 7.36-7.00 (m, 22H), 6.86 (t, *J* = 7.5 Hz, 2H), 4.67 (s, 2H), 3.73 (s, 6H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.7 (C=N), 158.9, 157.5, 139.8, 134.9, 131.9, 131.6, 129.3,

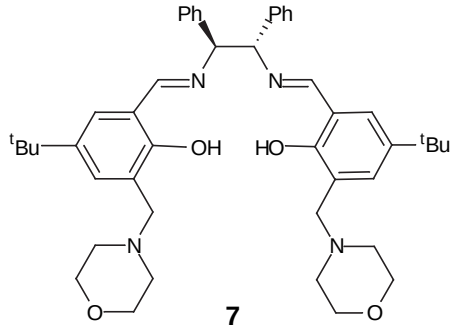
128.7, 128.3, 127.9, 127.1, 120.8, 119.0, 118.5, 111.8, 80.9 (C-N), 56.1; IR (film) 3100-2600 (br), 3059 , 3028, 2891, 2832, 1622 (C=N), 1441, 1239 cm^{-1}; MS (ES) *m/z* 1265 ($M \cdot MH^+$); HRMS (ES) calcd *m/z* 655.2573 ($C_{42}H_{36}N_2O_4Na$, MNa^+), found *m/z* 655.2573.

(6): 87% yield; yellow solid; mp 112-116 °C; $[\alpha]_D^{20}$ -539 (*c* 0.38, $CHCl_3$); ^1H NMR (500 MHz, $CDCl_3$) δ 13.71 (br s, 2H), 8.29 (s, 2H, HC=N), 7.35-6.99 (m, 12H), 6.85 (t, *J* = 7.6 Hz, 2H), 3.75 (s, 6H), 3.27 (m, 2H), 1.91-1.39 (m, 8H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.3 (C=N), 159.0, 157.4, 134.6, 131.9, 131.3, 129.2, 127.2, 127.1, 120.8, 119.0, 118.3, 111.7, 73.0 (C-N), 56.1, 33.6, 24.5; IR (film) 3100-2600 (br), 2931, 2858, 1625 (C=N), 1442, 1240 cm^{-1}; MS (ES) *m/z* 1069 ($M \cdot MH^+$); HRMS (ES) calcd *m/z* 557.2416 ($C_{34}H_{34}N_2O_4Na$, MNa^+), found *m/z* 557.2402.



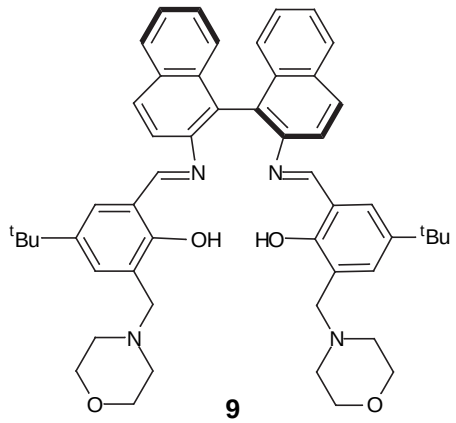
12

5-*tert*-Butyl-2-hydroxy-3-morpholin-4-ylmethyl-benzaldehyde (12). Morpholine (1.16 mL, 13.3 mmol) was added to a suspension of paraformaldehyde (440 mg, 14.7 mmol) in glacial HOAc (5.4 mL). The suspension was stirred at rt for 3 h. 5-*tert*-Butyl-2-hydroxy-benzaldehyde **11**[6] (2.37 g, 13.3 mmol) was then added as a solution in absolute EtOH (21.6 mL) and the mixture was heated at reflux for 4 d. After cooling to rt, the mixture was brought to pH~8 with saturated Na_2CO_3, extracted with $CHCl_3$, dried over Na_2SO_4, and concentrated. Flash chromatography on SiO_2 (30% EtOAc/hexanes) afforded **12** in 58% yield (2.14 g, 7.73 mmol). Phenol **12** has previously been synthesized by an alternative method (see reference 11 in the main text).



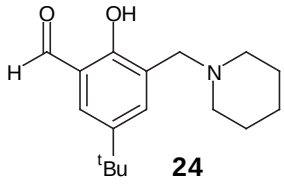
7

Bis[5'-*tert*-butyl-3'-(2"-morpholin-4"'-ylmethyl)salicylidene]-(*S,S*)-1,2-diphenylethylenediamine (7). (*S,S*)-(-)-1,2-Diphenylethylenediamine (115 mg, 0.54 mmol) was added dry to a solution of **12** (300 mg, 1.08 mmol) in absolute EtOH (3.5 mL). The solution was stirred at rt for 24 h, then concentrated. Salen **7** was crystallized from hexanes in 94% yield (371 mg, 0.51 mmol) as a yellow solid: mp 184-188 °C; $[\alpha]_D^{20}$ +25 (*c* 0.35, $CHCl_3$); ^1H NMR (500 MHz, $CDCl_3$) δ 13.25 (br s, 2H), 8.39 (s, 2H), 7.39 (s, 2H), 7.20-7.13 (m, 10H), 7.08 (s, 2H), 4.72 (s, 2H), 3.73 (br s, 8H), 3.62 (m, 4H), 2.51 (br s, 8H), 1.23 (s, 18H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.9 (C=N), 157.5, 140.0, 131.5, 128.7, 128.3, 127.9, 118.3, 80.7, 67.4, 57.0, 54.0, 34.3, 31.8; IR (film) 3030, 2959, 2865, 2808, 1627(C=N), 1469, 1362 cm^{-1}; MS (ES) *m/z* 753 (MNa^+); HRMS (ES) calcd *m/z* 753.4356 ($C_{46}H_{58}N_4O_4Na$, MNa^+), found *m/z* 753.4379.



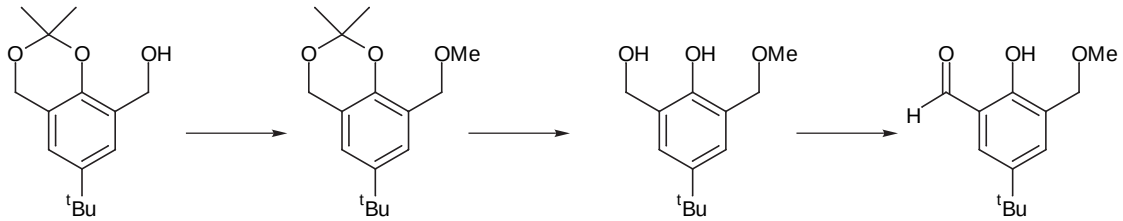
9

Bis[5''-*tert*-butyl-3''-(2'''-morpholin-4'''-ylmethyl)salicylidene]-(*R*)-1,1'-binaphthyl-2,2'-diamine (9). (*R*)-(+)-1,1'-binaphthyl-2,2'-diamine (77 mg, 0.27 mmol) was added dry to a solution of **12** (150 mg, 0.54 mmol) in absolute EtOH (2 mL). The solution was stirred at rt for 24 h, then concentrated. Salen **9** was crystallized from EtOH at -20 °C in 84% yield (182 mg, 0.23 mmol) as a yellow powder: mp 128-134°C; $[\alpha]_D^{20}$ -446 (*c* 0.5, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 12.17 (br s, 2H), 8.66 (s, 2H, C=N), 8.07 (d, *J* = 8.9 Hz, 2H), 7.96 (d, *J* = 8.8 Hz, 2H), 7.59 (d, *J* = 8.2 Hz, 2H), 7.46 (m, 2H), 7.32 (m, 2H), 7.13 (br s, 2H), 3.69 (m, 8H), 3.45 (m, 4H), 2.38 (br s, 8H), 1.24 (s, 18H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 162.6 (C=N), 157.7, 144.6, 141.0, 133.7, 132.9, 131.9, 130.1, 129.5, 128.6, 127.8, 127.3, 126.9, 126.0, 124.5, 118.8, 117.8, 67.5, 56.3, 53.6, 34.2, 31.8; IR (film) 2958, 2860, 1619 (C=N), 1477, 1382, 1364 cm^{-1}; HRMS (ES) calcd *m/z* 803.4536 ($C_{52}H_{59}N_4O_4$, MH^+), found *m/z* 803.4587.



24

5-*tert*-Butyl-2-hydroxy-3-piperidin-1-ylmethyl-benzaldehyde (24). Piperidine (166 μL, 1.68 mmol) was added to a suspension of paraformaldehyde (55.5 mg, 1.85 mmol) in glacial HOAc (1.2 mL). The suspension was stirred at rt for 3 h. 5-*tert*-Butyl-2-hydroxy-benzaldehyde **11** (300 mg, 1.68 mmol) was then added as a solution in absolute EtOH (4.8 mL) and the mixture was heated at reflux for 4 d. After cooling to rt, the mixture was brought to pH~8 with saturated Na_2CO_3, extracted with $CHCl_3$, dried over Na_2SO_4, and concentrated. Preparative TLC on SiO_2 (30% EtOAc/hexanes) afforded **24** in 58% yield (269 mg, 0.98 mmol) as a pale yellow solid: ^{1}H NMR (500 MHz, $CDCl_3$) δ 10.40 (s, 1H), 7.65 (s, 1H), 7.26 (s, 1H), 3.71 (s, 2H), 2.03 (br s, 4H), 1.66 (m, 4H), 1.50 (br s, 2H), 1.28 (s, 9H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 191.1, 159.9, 141.5, 132.3, 123.9, 122.8, 122.4, 61.3, 53.9, 34.1, 31.3, 25.7, 23.8. **24** has previously been synthesized by an alternative method (see reference 11 in the main text)



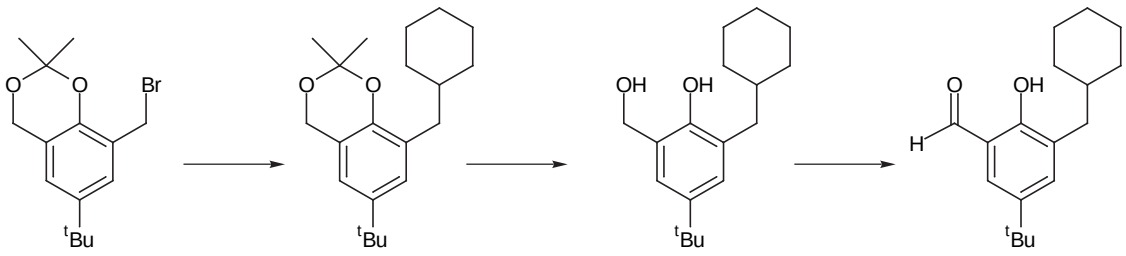
25 **26** **27**

6-*tert*-Butyl-8-methoxymethyl-2,2-dimethyl-4*H*-benzo[1,3]dioxine (25). To a slurry of NaH (71 mg, 60% dispersion in mineral oil, 1.62 mmol) in dry THF (5 mL) was added (6-*tert*-butyl-2,2-dimethyl-4*H*-benzo[1,3]dioxin-8-yl)-methanol[7] (200 mg, 0.81 mmol) as a solution in dry THF (5 mL). After stirring for 1.5 h at rt, MeI (101 μL, 1.62 mmol) was added to the yellow suspension. After

further stirring for 15 h, the reaction was quenched with water, extracted with EtOAc and dried over Na_2SO_4. The crude product was passed through a short plug of SiO_2 to afford **25** in 95% yield (200 mg, 0.77 mmol) as a clear liquid: ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.27 (d, *J* = 2.1 Hz, 1H), 6.89 (d, *J* = 2.1 Hz, 1H), 4.84 (s, 2H), 4.46 (s, 2H), 3.42 (s, 3H), 1.53 (s, 6H), 1.29 (s, 9H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 146.5, 142.7, 125.5, 124.4, 120.4, 118.2, 99.4, 68.8, 61.2, 58.3, 34.1, 31.5, 24.9.

4-*tert*-Butyl-2-hydroxymethyl-6-methoxymethyl-phenol (26). Acetonide **25** (3.17 g, 12.2 mmol) dissolved in THF (30 mL) and 1N HCl (30 mL) was heated to reflux for 3.5 h. The reaction was neutralized with saturated $NaHCO_3$, extracted with EtOAc, washed with saturated $NaHCO_3$ and dried over Na_2SO_4. Flash chromatography on SiO_2 afforded **26** in 73% yield (1.9 g, 8.5 mmol) as a yellow liquid: ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.76 (br s, 1H), 7.16 (d, *J* = 2.4 Hz, 1H), 7.02 (d, *J* = 2.4 Hz, 1H), 4.74 (s, 2H), 4.65 (s, 2H), 3.48 (s, 3H), 2.4 (br s, 1H), 1.28 (s, 9H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 152.1, 142.5, 126.6, 125.4, 124.7, 121.9, 73.7, 63.1, 58.4, 34.0, 31.5.

5-*tert*-Butyl-2-hydroxy-3-methoxymethyl-benzaldehyde (27). Diol **26** (100 mg, 0.45 mmol) was dissolved in dry CH_2Cl_2 (5 mL) and MnO_2 (388 mg, 4.5 mmol) was added. After stirring for 8 h at rt, the reaction was filtered through a pad of celite to remove MnO_2 and concentrated. The crude product was passed through a short SiO_2 plug to afford **27** in 91% yield (90 mg, 0.41 mmol) as a pale yellow solid: mp 23-25 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 11.11 (s, 1H), 9.90 (s, 1H), 7.68 (d, *J* = 2.0 Hz, 1H), 7.46 (d, *J* = 2.4 Hz, 1H), 4.55 (s, 2H), 3.47 (s, 3H), 1.34 (s, 9H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 196.8, 157.2, 142.5, 133.9, 129.1, 126.3, 119.8, 68.6, 58.6, 34.2, 31.3, 29.7; IR (film) 3157 (br), 2961, 2920, 2869, 1655 (C=O), 1462, 1380, 1270, 1216 cm^{-1}; HRMS (ES) calcd *m/z* 245.1154 ($C_{13}H_{18}O_3Na$, MNa^+), found *m/z* 245.1147.



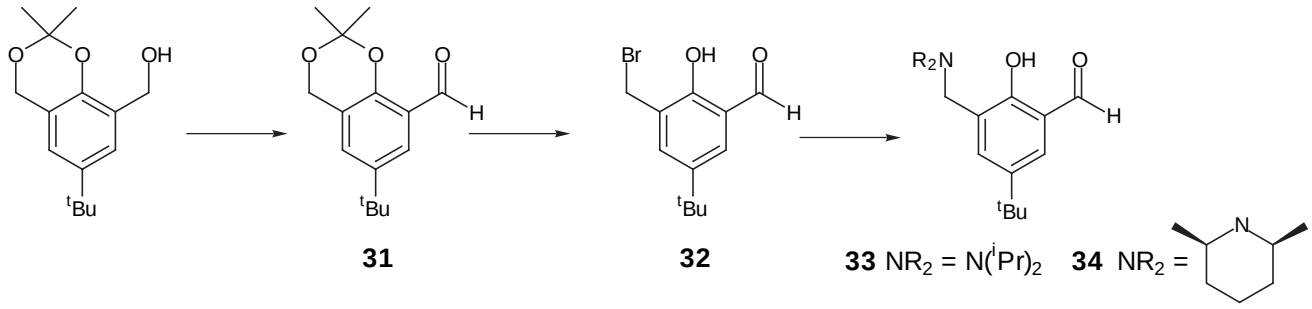
28 **29** **30**

6-*tert*-Butyl-8-cyclohexylmethyl-2,2-dimethyl-4*H*-benzo[1,3]dioxine (28). 8-Bromomethyl-6-*tert*-butyl-2,2-dimethyl-4*H*-benzo[1,3]dioxine[6] (100 mg, 0.32 mmol) was dissolved in dry THF (3 mL) and the solution was cooled to 0 °C. Cyclohexylmagnesium chloride (191 μL, 2.0M in Et_2O, 0.38 mmol) was added, followed by Li_2CuCl_4 (160 μL, freshly prepared 0.1M solution in THF, 0.02 mmol). The yellow solution was stirred for 3 h at 0 °C, eventually becoming brown. The reaction was quenched with saturated NH_4Cl, extracted with Et_2O and dried over Na_2SO_4. Preparative TLC on SiO_2 (30% EtOAc/hexanes) afforded **28** in 63% yield (64 mg, 0.20 mmol) as a pale yellow thick oil: ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.0 (d, *J* = 2.3 Hz, 1H), 6.81 (d, *J* = 2.2 Hz, 1H), 4.86 (s, 2H), 2.48 (d, *J* = 7.0 Hz, 2H),

1.72-1.69 (m, 5H), 1.56 (s, 6H), 1.32 (s, 9H), 1.21 (m, 4H), 1.01 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 146.9, 142.1, 128.7, 126.6, 118.5, 117.9, 99.1, 61.3, 38.6, 37.4, 33.9, 33.3, 31.5, 26.7, 26.4, 24.9.

4-*tert*-Butyl-2-cyclohexymethyl-6-hydroxymethyl-phenol (29). Acetonide **28** (50 mg, 0.140 mmol) dissolved in THF (1 mL) and 1N HCl (1 mL) was heated to reflux for 10 h, then cooled to rt, and allowed to stir over night. The solution was extracted with EtOAc, washed with saturated $NaHCO_3$, and dried over Na_2SO_4. Chromatography on SiO_2 (10% EtOAc / hexanes) afforded **29** in 95% yield (38 mg, 0.137 mmol) as a clear oil: ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.07 (br s, 1H), 7.04 (d, *J* = 2.5 Hz, 1H), 6.89 (d, *J* = 2.5 Hz, 1H), 4.84 (s, 2H), 2.51 (d, *J* = 7.0 Hz, 2H), 2.11 (br s, 1H), 1.73-1.65 (m, 6H), 1.28 (s, 9H), 1.27-1.18 (m, 3H), 1.0-0.98 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 151.9, 141.9, 128.3, 128.0, 123.5, 122.3, 65.4, 38.3, 38.1, 33.9, 33.4, 31.5, 26.6, 26.4.

5-*tert*-Butyl-3-cyclohexylmethyl-2-hydroxy-benzaldehyde (30). Diol **29** (550 mg, 1.99 mmol) was dissolved in dry CH_2Cl_2 (25 mL) and MnO_2 (1.21g, 13.9 mmol) was added. After stirring at rt for 5.5 h, the mixture was filtered through a pad of celite to remove MnO_2. Chromatography on SiO_2 (2% EtOAc / hexanes) afforded **30** in 20% yield (109 mg, 0.40 mmol) as a yellow oil: ^{1}H NMR (500 MHz, $CDCl_3$) δ 11.09 (s, 1H), 9.86 (s, 1H), 7.37 (d, *J* = 2.4 Hz, 1H), 7.34 (d, *J* = 2.4 Hz, 1H), 2.54 (d, *J* = 7.0 Hz, 2H), 1.64 (m, 5H), 1.32 (s, 9H), 1.19 (m, 4H), 0.98 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 197.0, 157.9, 141.9, 136.1, 129.4, 127.5, 119.6, 37.9, 37.3, 33.9, 33.2, 31.3, 26.6, 26.3.



6-*tert*-Butyl-2,2-dimethyl-4*H*-benzo[1,3]dioxine-8-carbaldehyde (31). (6-*tert*-butyl-2,2-Dimethyl-4*H*-benzo[1,3]dioxin-8-yl)-methanol[7] (1.16 g, 4.73 mmol) was dissolved in dry CH_2Cl_2 (60 mL) and PCC (1.53 g, 7.09 mmol) was added at once. After stirring for 2 h at rt, the slurry was filtered through celite and then through a pad of SiO_2 to remove the PCC byproducts. After concentration, **31** was obtained in quantitative yield (1.15 g, 4.73 mmol) as a pale yellow solid: ^{1}H NMR (500 MHz, $CDCl_3$) δ 10.40 (s, 1H), 7.74 (d, *J* = 2.4 Hz, 1H), 7.21 (d, *J* = 2.2 Hz, 1H), 4.89 (s, 2H), 1.60 (s, 6H), 1.29 (s, 9H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 189.4, 152.1, 143.0, 128.0, 123.7, 123.4, 119.8, 100.5, 60.9, 34.3, 31.3, 24.9. IR (film) 2961, 2904, 2864, 1684 (C=O), 1482, 1363 cm^{-1}; MS (ES) *m/z* 249 (MH^+); HRMS (ES) calcd *m/z* 271.1310 ($C_{15}H_{20}O_3Na$, MNa^+), found *m/z* 271.1300.

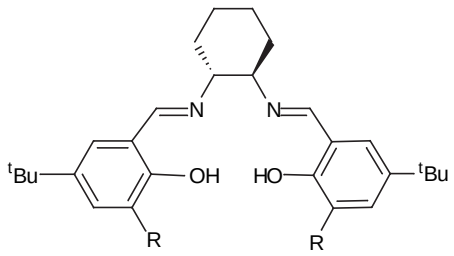
3-Bromomethyl-5-*tert*-butyl-2-hydroxy-benzaldehyde (32). In a two-neck round bottom flask fitted with a gas inlet and outlet, **31** (662 mg, 2.71 mmol) was dissolved in dry hexanes (20 mL). HBr(g) was generated *in situ* by dripping H_2SO_4 (7 mL, 131 mmol) into NaBr (14 g, 136 mmol) in a second two-neck round bottom flask equipped with an addition funnel and a gas outlet to the

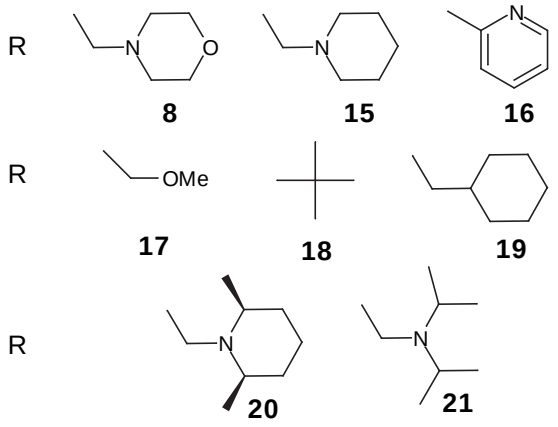
reaction flask. After bubbling the HBr(g) into the reaction solution for approximately 10 min, the pink solution was allowed to stir at rt for 30 min. The solution was then passed through a plug of Na_2SO_4 and concentrated to afford **32** in quantitative yield (735 mg, 2.77 mmol) as a pink-red oil: ^{1}H NMR (500 MHz, $CDCl_3$) δ 11.31 (s, 1H), 9.89 (s, 1H), 7.64 (d, *J* = 2.5 Hz, 1H), 7.51 (d, *J* = 2.5 Hz, 1H), 4.59 (s, 2H), 1.34 (s, 9H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 196.6, 157.4, 142.9, 135.5, 130.6, 125.7, 120.2, 34.1, 31.2, 27.0; MS (ES) *m/*z 271 (MH^+); HRMS (ES) calcd *m/z* 271.0334 ($C_{12}H_{16}O_2Br$, MH^+), found *m/z* 271.0292.

General procedure for the synthesis of 33 and 34. Bromide **32** (2.71 mmol) was dissolved in dry THF (20 mL) and the amine (8.13 mmol) was added dropwise with the immediate formation of a precipitate. After stirring for 2-12 h at rt, the slurry was filtered to remove the salt and the filtrate was concentrated.

5-*tert*-Butyl-3-[(diisopropylamino)-methyl]-2-hydroxy-benzaldehyde (33): 100% yield; yellow-orange solid; ^{1}H NMR (500 MHz, $CDCl_3$) δ 10.41 (s, 1H), 7.63 (d, *J* = 2.4 Hz, 1H), 7.28 (bs, 1H), 3.87 (s, 2H), 3.18 (sept, *J* = 6.6 Hz, 2H), 1.28 (s, 9H), 1.13 (d, *J* = 6.6 Hz, 12H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 191.1, 160.7, 141.2, 131.8, 124.0, 123.3, 122.4, 48.3, 34.1, 31.6, 31.3, 19.7.

5-*tert*-Butyl-3-(2,6-*cis*-dimethyl-piperidin-1-ylmethyl)-2-hydroxy-benzaldehyde (34): 100% yield; pale yellow solid; mp 72-74 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 14.0 (br s, 1H) 10.37 (s, 1H), 7.57 (br s, 1H), 7.24 (br s, 1H), 3.99 (s, 2H), 2.58 (br s, 2H), 1.74 (m, 2H), 1.49-1.41 (m, 4H), 1.28 (s, 9H), 1.15 (d, *J* = 6.3 Hz, 6H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 191.5, 160.5, 141.0, 130.3, 124.5, 123.3, 122.8, 59.5, 54.3, 34.1, 31.3, 30.5, 23.6, 23.1, 20.9, 19.5; IR (film) 3448, 2963, 2860, 1677, 1605, 1480, 1384, 1216; MS (ES) *m/*z 304 (MH^+); HRMS (ES) calcd *m/z* 304.2276 ($C_{19}H_{30}O_2N$, MH^+), found *m/z* 304.2276.





General procedure for the synthesis of salens 8 and 15 - 21. The aldehyde (2.0 eq.) was dissolved in EtOH and (-)-(1*R*,2*R*)-1,2-cyclohexanediamine (1.0 equiv.) was added. The mixture was stirred for 1 d at rt, then concentrated. The salen was crystallized from the indicated solvent, isolated and dried *in vacuo* for several hours with gentle heating.

Bis[5'-*tert*-butyl-3'-(2"-*tert*-butyl)salicylidene]-(*R*,*R*)-1,2-cyclohexanediamine (18)[8] and **bis[5'-*tert*-butyl-3'-(2"-pyridyl)salicylidene]-(*R*,*R*)-1,2-cyclohexanediamine (16)**[9] were prepared according to literature procedures.

Bis[5'-*tert*-butyl-3'-(2"-morpholin-4"'-ylmethyl)salicylidene]-(*R*,*R*)-1,2-cyclohexanediamine (8). Crystallized from hexanes at -20 °C as pale yellow clusters in 99% yield: mp 96-98 °C; $[\alpha]_D^{20}$ -220 (*c* 0.38, $CHCl_3$); ^1H NMR (500 MHz, $CDCl_3$) δ 13.46 (br s, 2H), 8.32 (s, 2H, HC=N), 7.39 (s, 2H), 7.10 (s, 2H), 3.74 (m, 8H), 3.63 (d, *J* = 13.3 Hz, 2H), 3.54 (d, *J* = 13.3 Hz, 2H), 3.33 (m, 2H), 2.52 (br s, 8H), 1.95-1.49 (m, 8H), 1.28 (s, 18H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.4 (C=N), 157.7, 141.0, 131.2, 127.3, 124.5, 118.2, 73.1, 67.4, 57.1, 54.1, 33.7, 31.8, 25.7, 24.6; IR (film) 2953, 2856, 2806, 1629 (C=N), 1470, 1454, 1271 cm^{-1}; MS (ES) *m/z* 633 (MH^+); HRMS (ES) calcd *m/z* 633.4380 ($C_{38}H_{57}N_4O_4$, MH^+), found *m/z* 633.4375. Racemic **8** has previously been synthesized (see reference 11 in the main text).

Bis[5'-*tert*-butyl-3'-(2"-piperidin-1"'-ylmethyl)salicylidene]-(*R*,*R*)-1,2-cyclohexanediamine (15). Crystallized from EtOH as yellow clusters in 90% yield: mp 88-94 °C; $[\alpha]_D^{20}$ -315 (*c* 0.5, $CHCl_3$); ^1H NMR (500 MHz, $CDCl_3$) δ 13.35 (br s, 2H), 8.29 (s, 2H) (HC=N), 7.36 (s, 2H), 7.06 (s, 2H), 3.54 (dd, *J* = 13.5, 27.3 Hz, 4H), 3.29 (m, 2H), 2.43 (br s, 8H), 1.87 (m, 4H), 1.70-1.36 (m, 16H),1.24 (s, 18H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 164.8 (C=N), 157.2, 140.4, 130.5, 126.4, 125.0, 117.9, 72.7, 57.0, 54.5, 33.8, 32.3, 31.4, 26.0, 24.4, 24.3; IR (film) 2933, 2857, 2791, 2756, 1629 (C=N), 1467, 1271 cm^{-1}; MS (ES) *m/z* 629 (MH^+); HRMS (ES) calcd *m/z* 629.4794 ($C_{40}H_{61}N_4O_2$, MH^+), found *m/z* 629.4786. Racemic **15** has previously been synthesized (see reference 11 in the main text).

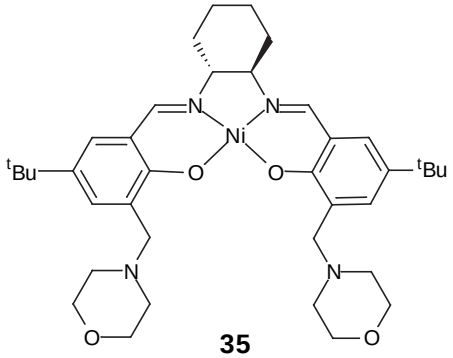
Bis[5'-*tert*-butyl-3'-(2"-methoxymethyl)salicylidene]-(*R*,*R*)-1,2-cyclohexanediamine (17). Crystallized from hexanes at -20 °C as yellow clusters in 99% yield: mp 84-88 °C; $[\alpha]_D^{20}$ -268 (*c* 0.5, $CHCl_3$); ^1H NMR (500 MHz, $CDCl_3$) δ 13.54 (br s, 2H), 8.29 (s, 2H) (HC=N), 7.36 (d, *J* = 2.4 Hz, 2H), 7.13 (br s, 2H), 4.51 (dd, *J* = 9.0, 11.8 Hz, 4H), 3.42 (s, 6H), 3.32 (m, 2H), 1.93-1.86 (m, 4H), 1.71 (m, 2H), 1.46 (m, 2H), 1.25 (s, 18H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.1 (C=N), 156.9, 140.9, 129.6, 127.6, 124.9, 117.6, 72.5, 69.7, 58.4, 33.9, 33.2, 31.4, 24.2; IR (film) 2953, 2931, 1630 (C=N), 1469, 1272 cm^{-1}; MS (ES) *m/z* 545 (MNa^+); HRMS (ES) calcd *m/z* 545.3355 ($C_{32}H_{46}N_2O_4Na$, MNa^+), found *m/z* 545.3367, calcd *m/z* 523.3536 ($C_{32}H_{47}N_2O_4$, MH^+), found *m/z* 523.3547.

Bis[5'-*tert*-butyl-3'-(2"-cyclohexylmethyl)salicylidene]-(*R*,*R*)-1,2-cyclohexanediamine (19). Crystallized from EtOH as a yellow powder in 65% yield: $[\alpha]_D^{20}$ -189 (*c* 0.5, $CHCl_3$); ^1H NMR (500 MHz, $CDCl_3$) δ 13.33 (br s, 2H), 8.27 (s, 2H, C=N), 7.09 (d, *J* = 2.4 Hz, 2H), 6.98 (D, *J* = 2.4 Hz, 2H), 3.30 (m, 2H), 2.54-2.47 (m, 4H), 1.71-1.66 (m, 4H), 1.63-1.55 (br m, 17 H), 1.24 (s, 18H), 1.20 (m, 6H), 0.95 (m, 5H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.4 (C=N), 156.9, 140.3, 131.2, 128.1, 125.6, 117.5, 72.6, 38.0, 37.7, 34.0, 33.7, 33.5, 33.4, 33.3, 31.4, 26.7, 26.3, 24.3; IR (film) 2922, 2950, 1628 (C=N), 1470, 1263 cm^{-1}; MS (ES) *m/z* 627 (MH^+); HRMS (ES) calcd *m/z* 627.4889 ($C_{42}H_{63}N_2O_2$, MH^+), found *m/z* 627.4892.

Bis[5'-*tert*-butyl-3'-(2"-2"',6"'-*cis*-dimethyl-piperidin-1"'-ylmethyl)salicylidene]-(*R*, *R*)-1,2-cyclohexanediamine (20). Crystallized from EtOH as pale yellow clusters in 65% yield: mp 112-116 °C; $[\alpha]_D^{20}$ -245 (*c* 1.0, $CHCl_3$); ^1H NMR (500 MHz, $CDCl_3$) δ 13.56 (brs, 2H), 8.30 (s, 2H, C=N), 7.82 (br s, 2H), 7.01 (br s, 2H), 3.78 (br s, 4H), 3.30 (m, 2H), 2.83 (m, 2H), 2.56 (br s, 4H), 1.9-1.28 (m, 18 H), 1.25 (s,

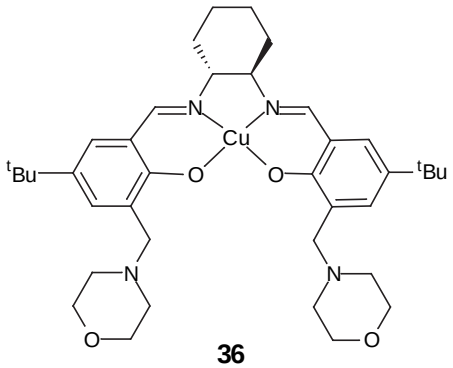
18H), 0.98 (br s, 12H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 165.0 (C=N), 140.9, 140.3, 130.1, 130.0, 125.1, 124.8, 72.5, 58.9, 58.7, 54.8, 53.4, 34.5, 34.3, 34.0, 33.6, 33.4, 33.3, 32.4, 31.44, 31.39, 31.34, 24.9, 24.7, 24.2, 24.1, 24.0, 21.8, 21.4; IR (film) 2930, 2859, 1628 (C=N), 1460, 1268 cm^{-1}; MS (ES) *m/z* 685 (MH^+), HRMS (ES) calcd *m/z* 685.5420 ($C_{44}H_{69}N_4O_2$, MH^+), found *m/z* 685.5428.

Bis[5'-*tert*-butyl-3'-(2"-diisopropylaminomethyl)salicylidene]-(*R, R*)-1,2-cyclohexanediamine (21). Crystalized from EtOH at -20 °C as yellow clusters in 97% yield: mp 94-98 °C; $[\alpha]_D^{20}$ -200 (*c* 1.0, $CHCl_3$); ^{1}H NMR (500 MHz, $CDCl_3$) δ 13.46 (br s, 2H), 8.32 (s, 2H, C=N), 7.72 (br s, 2H), 7.02 (br s, 2H), 3.74-3.65 (dd, *J* = 9.6, 17.0 Hz, 4H), 3.29 (m, 2H), 3.07-3.02 (m, 4H), 1.92-1.85 (m, 4H), 1.47 (m, 2H), 1.29 (m, 2H), 1.25 (s, 18H), 1.02 (d, *J* = 6.3 Hz, 24H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 164.7 (C=N), 156.5, 140.5, 131.8, 129.1, 124.9, 117.3, 72.7, 54.8, 48.6, 42.8, 33.3, 31.4, 24.3, 20.7; IR (film) 2963, 2866, 1630 (C=N), 1466, 1363, 1269 cm^{-1}; MS (ES) *m/z* 661 (MH^+), HRMS (ES) calcd *m/z* 661.5420 ($C_{42}H_{69}N_4O_2$, MH^+), found *m/z* 661.5449.



35

Nickel(II)-bis[5'-*tert*-butyl-3'-(2"-morpholin-4"'-ylmethyl)salicylidene]-(*R,R*)-1,2-cyclohexanediamine (35). Salen **8** (100 mg, 0.16 mmol) and $Ni(OAc)_2{\cdot}4H_2O$ (27.9 mg, 0.16 mmol) were combined in a flask. The addition of absolute EtOH (3.3 mL) resulted in the immediate formation of a cloudy orange suspension. The mixture was allowed to stir at rt for 4.5 h and NaOH (330 μL, 1.0M in H_2O, 0.33 mmol) was added. The mixture was stirred for 1 h then cooled to 0 °C for 0.5 h. The orange precipitate was isolated by vacuum filtration and washed with cold EtOH. Drying *in vacuo* for several hours with gentle heat afforded **35** in 59% yield (54 mg, mmol) as a yellow orange solid: mp > 300 °C (dec.); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.43 (s, 2H), 7.39 (s, 2H), 6.95 (s, 2H), 3.75 (br s, 8H), 3.63 (br s, 4H), 3.00 (br s, 2H), 2.55 (br s, 8H), 2.46 (br s, 2H), 1.94 (br s, 2H), 1.34 (br s, 4H), 1.27 (s, 18H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 162.3 (C=N), 157.8, 136.9, 133.0, 127.9, 127.0, 119.2, 70.4 , 67.6, 57.5, 54.1, 34.0, 31.7, 29.1, 24.8; IR (film) 2955, 2860, 2805, 1618 (C=N), 1544, 1449 cm^{-1}; MS (ES) *m/*z 689 (M^+); HRMS (ES) calcd *m/z* 689.3577 ($C_{38}H_{54}N_4O_4Ni$, M^+), found *m/z* 389.3561.



36

Copper(II)-bis[5'-*tert*-butyl-3'-(2"-morpholin-4"'-ylmethyl)salicylidene]-(*R,R*)-1,2-cyclohexanediamine (36). Salen **8** (100 mg, 0.16 mmol) and $Cu(OAc)_2$ (28.7 mg, 0.16 mmol) were combined in a flask. The addition of absolute EtOH (5 mL) and NaOH (330 μL, 1.0M in H_2O, 0.33 mmol) resulted in the immediate formation of a cloudy orange suspension. The mixture was heated at reflux for 5 h then stored at 0 °C overnight. The brown precipitate was isolated by vacuum filtration and washed with cold EtOH. Drying *in vacuo* for

several hours with gentle heat afforded **36** in 67% yield (73 mg, 0.11 mmol) as a purple-brown solid: mp >300 °C (dec.); IR (film) 2952, 2855, 2800, 1620 (C=N), 1538, 1436, 1267 cm^{-1}; MS (ES) *m/z* 716 (MNa^+); HRMS (ES) calcd *m/z* 694.3519 ($C_{38}H_{55}N_4O_4Cu$, MH^+), found *m/z* 694.3534, calcd *m/z* 716.3339 ($C_{38}H_{54}N_4O_4CuNa$, MNa^+), found *m/z* 716.3353.

General procedure for the diethylzinc addition to aldehydes. The salen (0.025 mmol) was introduced into a dry Schlenk flask, and the system purged with N_2. The salen was dissolved in dry toluene (1 mL) and Et_2Zn (25 μL, 1.0 M in toluene, 0.025 mmol) was added. The mixture was allowed to stir at rt for 1 h then cooled to the indicated reaction temperature. For the Ni, Cu, Mg, and Ti catalysts the salen metal complexes were dissolved in toluene (1 mL) at the indicated reaction temperature and then treated with the same protocol as the *in situ* generated zinc complexes. Et_2Zn (500 μL, 1.0M in toluene, 0.500 mmol) was added slowly. After 5 minutes, the aldehyde was added dropwise. At various intervals, 100 μL aliquots were removed from the reaction, quenched with 1N HCl (aromatic aldehydes) or Ac_2O for 0.5 h followed by saturated NH_4Cl (aliphatic aldehydes), and then extracted with pentane. The reaction progress was monitored by GC (Carrier gas: N_2. Detector: FID, 270 °C. Injector: 250 °C). GC oven temperatures and retention times for the alcohol products are listed below:

1-Phenyl-1-propanol. t_R = 16.0 min, t_S = 16.7 min (115 °C).

1-(4-Methoxyphenyl)-1-propanol. t_R = 19.4 min, t_S = 20.1 min (140 °C).

1-(2-Methylphenyl)-1-propanol. t_1= 26.6 min, t_2= 30.1 min (115 °C).

1-Cyclohexyl-1-propanol. The enantiomeric excess was measured by analyzing the acetate esters: t_S = 25.8 min, t_R= 26.9 min (100 °C for 3 min, then 100 °C to 130 °C at 1 C° / min).

1-(4-Chlorophenyl)-1-propanol. t_1= 20.9 min, t_2= 22.3 min (136 °C).

3-Ethylhexan-3-ol. t_1= 10.5 min, t_2= 11.0 min (75 °C).

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