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Noncovalent Secondary Interactions in Co(II)Salen Complexes: O_2 Binding and Catalytic Activity in Cyclohexene Oxygenation

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The O_2 affinity of Co(II)Salen complexes **1**−**4** and their reactivity in cyclohexene oxygenation reactions of Co(II)Salen complexes **1**−**4** are modulated by noncovalent interactions such as hydrogen bonding and steric hindrance using a functionalized diamino bridge. Higher O_2 affinity is observed in the case of efficient hydrogen-bonding interactions (complex **1**), while increased steric hindrance (cis vs trans diamino bridge) around the Co-coordinated O_2 is influencing the reactivity of the complexes.

Introduction

The oxygen binding abilities of Co(II)Salen (Salen = bis(salicylidene)ethylenediamine) complexes have long been established and have stimulated the research toward reversible O_2 carriers[1,2] and their use as catalysts in oxidation of organic substrates with O_2.[3−7] Variations on the two aromatic rings of the Salen ligand have been introduced to investigate the electronic and the steric factors affecting O_2 binding and the reactivity of the metal−O_2 complex. However, modification of the Salen structure via introduction of *functionalized* diamino bridges has been rarely attempted.[8−10] This is probably as a consequence of the already excellent results obtained by Jacobsen and co-workers in the enantioselective epoxidation of unfunctionalized alkenes using the easily obtainable (*R*,*R*)-[*N*,*N*′-bis(3,5-di-*tert*-butylsalicylidene)-1,2-cyclohexanediamine]Mn(III).[11] Nevertheless, more research in ligand design is of fundamental importance in the field of Salen complexes as a valuable alternative to metal porphyrins for the development of biomimetic heme−protein models.[12,13] Moreover, only recently it has been shown that noncovalent secondary interactions such as metal coordination are very important to obtain highly efficient and selective catalysts based on Salen complexes.[14]

Here, we report the preparation of three novel Co(II)-Salen complexes **1**−**3** bearing (for **1** and **2**) an OH-functionalized diamino bridge. The presence of the hydroxyl groups in **1** increases the affinity for oxygen due to hydrogen bonding with the Co-coordinated O_2 (Figure 1). To the best of our knowledge, this is the first time that hydrogen bonding as a noncovalent secondary

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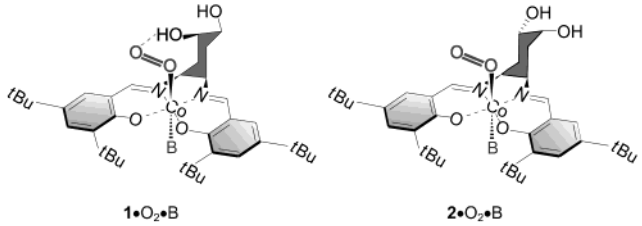
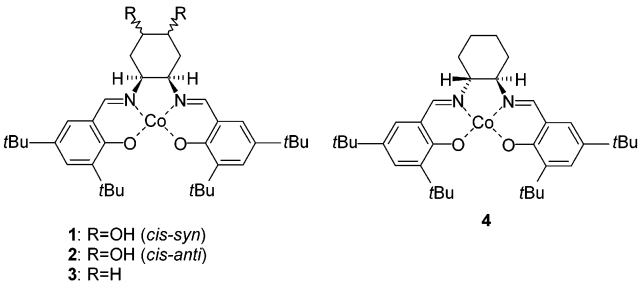


FIGURE 1. Schematic representation of ternary complexes **1**·O_2·B and **2**·O_2·B showing hydrogen-bonding stabilization of Co-coordinated O_2 (left). B = base (1-MeIm or propionaldehyde in the text).

interaction in Salen complexes has been considered.[15] This design mimics the hydrogen-bonding interaction operated by the distal His residue in hemoglobin and myoglobin or by Tyr in O_2 avid *Ascaris* hemoglobin.[16,17] Moreover, Co(II)Salen **1**−**3** and the commercially available **4** have been tested in the aerobic oxidation of cyclohexene (Scheme 3). Reduced catalytic activity is observed as a consequence of the Co−O_2 complex stabilization.



Results and Discussion

Synthesis. Co(II)Salenes **1** and **2** were prepared starting from the two diastereomeric *cis*-1,2-diamino-*cis*-4,5-dihydroxycyclohexanes (**5** and **6**). The corresponding dihydrochloride salts (**5**−Cl and **6**−Cl) were synthesized from *cis*-1,2,3,6-tetraphthalic anhydride **12** following a slightly modified literature procedure (Scheme 1).[18] Catalytic osmylation of Cbz-protected 1,2-diaminocyclohex-4-ene **15** using NMO (4-methylmorpholine *N*-oxide) as primary oxidant and DABCO as ligand afforded a mixture of diastereomeric *cis*-diols **16** and **17** in a 36:64 ratio (80% yield) at room temperature.[19] Deprotection via catalytic hydrogenation and precipitation with HCl in EtOH afforded the desired salts.

Salen ligands **9**, **10**, and **11** were prepared by condensation of 3,5-di-*tert*-butyl-2-hydroxybenzaldehyde **8** with diamine **5** or **6** or with *cis*-1,2-diaminocyclohexane **7**, respectively, in refluxing ethanol in moderate to good yields.[20] Subsequent metalation with $CoAc_2$ afforded Co(II)Salen **1**−**3** in 93−95% yield (Scheme 2).

Structural diversity is introduced in Co(II)Salen complexes **1**−**4** via the 1,2-diaminocyclohexane bridge. The stereochemistry of the two amino groups is (meso)-cis in **1**-**3** and (*R*,*R*)-trans in **4**. As a result, **1**−**3** have nonplanar structures, with the cyclohexyl ring being roughly at 90° to the Co(II)−N_2O_2 plane.[21] Therefore, this spatial arrangement should shield the Co-coordinated O_2. In contrast, as evident from an earlier X-ray crystal structure,[22] the commercially available Co(II)Salen **4** is roughly planar. Additionally, two *cis*-hydroxyl groups have been introduced on the cyclohexane ring of **1** and **2** in position 4 and 5. The orientation of these two OH groups is either syn or anti to the two amino groups (see Scheme 1). A CPK model of Co(II)Salen **1** shows that the syn arrangement of the *cis*-4,5-hydroxyl groups is necessary for one OH to point directly toward the Co−O_2 moiety, thus having the required orientation to form a hydrogen bond with O_2. No hydrogen bond is possible when the hydroxyl groups are arranged anti as in Co(II)Salen **2** and **3** (Figure 1).

Oxygen-Binding Studies. The reversible binding of O_2 to Co(II)Salen complexes **1**−**4** in CH_3CN or 1:1 toluene/CH_3CN in the presence of 1-methylimidazole [1-MeIm, (6−7) × 10^{-3} M] was studied by following the UV−vis spectral changes (Figures 2 and 3) occurring upon equilibration of the solution with O_2/N_2 gas mixtures of varying composition (expressed as O_2 partial pressure p_{O_2}). The experimental data were treated in terms of a 1:1:1 equilibrium[23] between CoL (**2**-**4**), 1-MeIm, and O_2 (eq 1) to evaluate the binding constants,[24] K_{O_2} (eq 2).

$$\text{CoL} + \text{1-MeIm} + O_2 \rightleftarrows \text{CoL·1-MeIm·}O_2 \qquad (1)$$

$$K_{O_2} = [\text{CoL·1-MeIm·}O_2]/([\text{CoL}][\text{1-MeIm}]p_{O_2}) \qquad (2)$$

For complexes **2**−**4**, K_{O_2} values close to 10 M^{-1} $Torr^{-1}$ have been determined at 10 °C (Table 1), while **1**, under identical conditions, showed much higher O_2 affinity. The complexation is so strong that saturation was obtained already at p_{O_2} < 12 Torr, which precluded the measurement of the binding constant with our experimental setup. Nevertheless, considering **1**·1-MeIm·O_2 > 90% at 12 Torr, a lower limit of 100 M^{-1} $Torr^{-1}$ can be estimated

(15) Hydrogen-bond stabilization of the Co-coordinated O_2 has been considered for a Co(II)−Schiff base complex obtained from salicyl aldehyde and L-serine. However, no binding studies have been performed to quantify the interaction; see: Punniyamurthy, T.; Bhatia, B.; Reddy, M. M.; Maikap, G. C.; Iqbal, J. *Tetrahedron* **1997**, *53*, 7649−7670.

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(19) No further attempt to increase the diastereoselectivity of the osmylation reaction was made.

(20) Judged from NMR spectra, condensation of diamino diols **5** and **6** with aldehyde **8** was quantitative. Poor crystallization from methanol lowered the yield in isolated products **9** and **10** in comparison to **11**.

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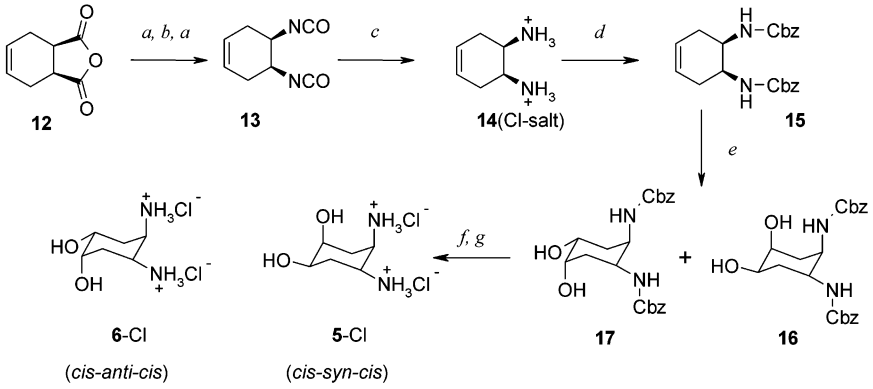
(23) Binding of O_2 has often been considered as a 1:1 equilibrium between O_2 and CoL·B. Experimentally, [B] is required to be high enough to have CoL·B as the predominant species in solution before O_2 addition. This condition is difficult to achieve with complexes **1**−**4** in CH_3CN solution. For instance, binding constants <10 M^{-1} for pyridine to CoL complexes similar to **3** and **4** in $CHCl_3$ are reported; see ref 24.

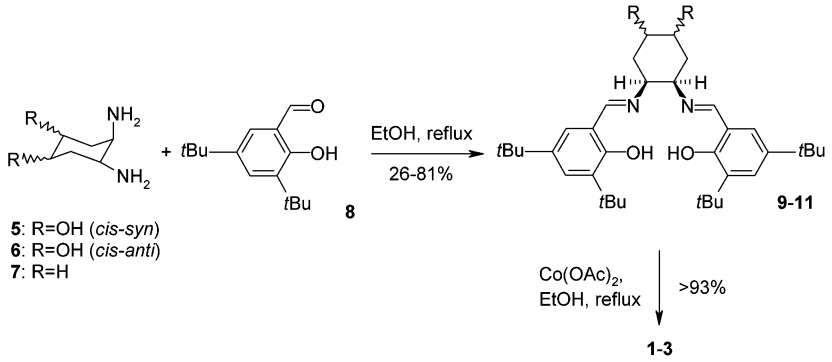
(24) O_2 binding constants for Co(II)Salen complexes similar to **3** and **4** have been reported for pyridine and DMF solutions at 20 °C. However, [O_2] = 1 M was assumed as standard state, and therefore the values are not directly comparable with our results; see: Cesarotti, E.; Gullotti, M.; Pasini, A.; Ugo, R. *J. Chem. Soc., Dalton Trans.* **1977**, 757−763.

SCHEME 1[a]



[a] TMS−N_3, THF, reflux, 3 h. [b] $SOCl_2$, CCl_4, cat. DMF, 50 °C, 2.5 h. [c] Concentrated HCl, THF/acetone, rt, 14 h. [d] Cbz-Cl, *N*,*N*-diisopropyl-*N*-ethylamine, THF/H_2O, 0 °C, 3 h. [e] NMO, OsO_4 (0.02 equiv), DABCO (0.2 equiv) acetone/H_2O, rt, 72 h. Separation of **16** and **17** by column chromatography. [f] 10% Pd/C, H_2, EtOH, rt, 5 h. [g] HCl/EtOH, rt.

SCHEME 2



for K_{O_2}, 1 order of magnitude higher than for the diastereomeric complex **2**.

This result agrees with the proposed hydrogen-bonding stabilization of Co-coordinated O_2, which, according to the three-dimensional arrangement of its hydroxyl groups, is specific for **1**. Moreover, the similar and lower K_{O_2} values determined for **2**−**4** show that the spatial arrangement of the diamino bridges of these complexes has no appreciable influence on O_2 binding.

In the absence of 1-methylimidazole, O_2 binding to **1**−**4** was not observed either at 10 or at −10 °C. This result confirms that strong O_2 complexation to **1** is due to secondary interactions (hydrogen bonding) stabilizing the ternary complex **1**·1-MeIm·O_2 and not to alteration of the metal center's electronic properties.

Oxygenation of Cyclohexene. Co(II) Schiff's base complexes[3] as well as Co(II)porphyrins[25] catalyze the

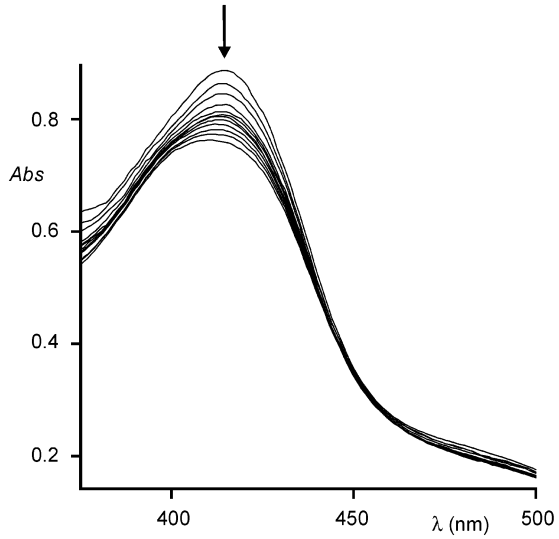


FIGURE 2. Spectral changes as function of increasing p_{O_2} in equilibrium with a solution of **2** at 10 °C. [**2**] = 11 × 10^{-5} M, in CH_3CN; [1-MeIm] = 7 × 10^{-3} M. Maximum p_{O_2} = 152 Torr.

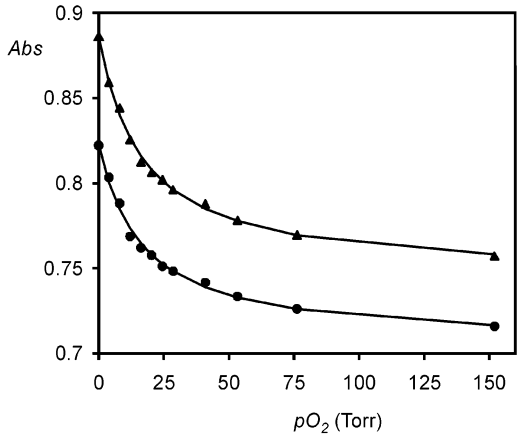


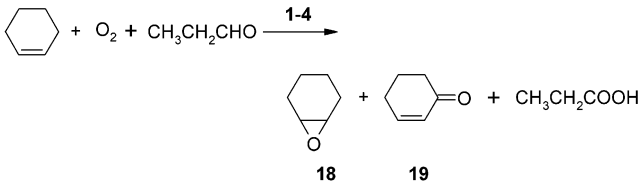
FIGURE 3. Absorbance changes at 416 nm (▲) and at 424 nm (●) as function of the p_{O_2} in equilibrium with an 11 × 10^{-5} M solution of **2** in CH_3CN; [1-MeIm] = 7 × 10^{-3}. Solid lines are the best fitting according to a 1:1:1 model (see the text).

TABLE 1. Formation Constants of Ternary Complexes CoL·1-MeIm·O_2 in CH_3CN Solutions at 10°C[a]

	K_{O_2} (M^{-1} $Torr^{-1}$)		K_{O_2} (M^{-1} $Torr^{-1}$)
1	≥100[b]	**3**	13.6
2	8.4	**4**	9.5[c]

[a] [CoL] = (6−11) × 10^{-5} M, [1-MeIm] = (6−7) × 10^{-3} M. [b] Estimated value (see the text). [c] 1:1 toluene/acetonitrile.

SCHEME 3



oxidation of organic substrates (e.g. alkenes and alkanes) with O_2 as the bulk oxidant in the presence of reducing agents such as aldehydes. Therefore, oxidation of cyclohexene with O_2 in the presence of propanal (Scheme 3) was chosen as a model reaction to study the relationship between noncovalent secondary interactions stabilizing O_2 binding and the catalytic activity of complexes **1**−**4**. A mechanistic study of the oxygenation of cyclohexene with Co(II)Salens **1**−**4** is beyond the scope of this work. However, it has been reported for similar systems that the reaction probably starts with the formation of a CoL·B·O_2 complex (where B = aldehyde)[26] in close analogy with the formation of CoL·1-MeIm·O_2 under the equilibrium conditions reported here.

Complexes **1**−**4** efficiently catalyze cyclohexene oxidation under mild conditions (20 °C, 1 atm of O_2, 0.5 mol % of catalyst, propionaldehyde as coreductant), affording, independently from the catalyst used, two oxygenation products,[27] viz. cyclohexene oxide **18** and 2-cyclohexene-1-one **19** in 4.7 ± 0.5 ratio (**18**/**19**) at 70% conversion.[28] The constant product selectivity observed for different metal catalyst shows a common catalytic pathway for all the reactions, which probably involves radical chain reactivity, a well-documented pathway for Co complex-catalyzed oxidations.[5,7,29] Nevertheless, different catalysts exhibit distinct reactivities, as evident from the measured induction times (t_{ind}), initial reaction rate (r_i), and half-life times for cyclohexene conversion ($t_{1/2}$) (Table 2). These differences can be related to the catalyst structure and, in particular, to the hydrogen-bonding ability of **1** vs **2**−**4** and possibly to the sterical hindrance around the metal center caused by the orientation of the cyclohexyl ring with respect to the Co(II)−N_2O_2 plane (coplanar as in **4** vs bent as in **1**−**3**).

During t_{ind} no oxygenation products were detected in the reaction mixture via gas chromatographic analysis (GC). However, the reaction mixture underwent a series of color changes from brick red to brown and finally green, which is similar to previous observations for analogous reactions.[30] The color change to green has been attributed to the formation of Co(III)−hydroperoxide complexes in solution from the starting CoL·B·O_2 complexes via radical reaction with the aldehyde (H-abstraction) during the initiation step. The longest t_{ind} (8800 s) is observed for Co(II)Salen **1** and indicates a retarded formation of the Co(III)−hydroperoxide intermediate. Thus, the hydrogen bond reduces the radical reactivity of **1**·B·O_2 in comparison to complexes (**2**−**4**)·B·O_2. The shortest t_{ind} (400 s) is observed for **4**, which is consistent with the absence of hydrogen bond and of steric hindrance that protects the Co−O_2 moiety due to its planar structure. The t_{ind} for **2** and **3** are somewhere between, as expected for complexes without hydrogen bond possibilities but with a nonplanar structure. The relative order of these values remains still unclear. Furthermore, the initial reaction rate (r_i) and the half-life time for cyclohexene conversion ($t_{1/2}$, time at which 50% of the cyclohexene is converted minus t_{ind}) are different within the series of catalyst **1**−**4** (Table 2). It is generally accepted that acylperoxy radicals and Co-coordinated acylperoxy complexes are the active oxygen transfer species formed during propagation of the oxidation reaction catalyzed by Co(II) complexes.[7,31,32] Thus, the results reported in Table 2 suggest that Co(II)Salens **1**−**4** participate to some extent in the oxygen transfer to the substrate, possibly as Co-coordinated acylperoxy species, and not only in the initiation step. Consequently, hydrogen bonding and steric hindrance also play an important role in stabilizing these intermediate species during the propagation step of the reaction. In fact **1** is the least reactive catalyst presenting the smallest r_i and the longest $t_{1/2}$, while **4** is the most reactive one having the shortest $t_{1/2}$. The r_i values for **4** are somehow smaller than expected. However, this catalyst also exhibits a slightly different concentration vs time profile when compared to catalysts **1**−**3**.[33]

TABLE 2. Catalytic Oxidation of Cyclohexene with Co(II)Salen 1−4: Induction Times (t_{ind}), Initial Rates for Cyclohexene Consumption and Product Formation (r_i), and Cyclohexene Half-life Times ($t_{1/2}$)[a]

	t_{ind} ($\times 10^3$ s)	r_i ($\times 10^5$ mol l^{-1} s^{-1})			$t_{1/2}$ ($\times 10^3$ s)
1	8.82	2.33	2.13	0.48	4.79
2	2.73	2.48	2.18	0.65	4.23
3	4.62	2.87	3.15	0.77	3.77
4	0.40	1.07	2.56	0.35	2.58

[a] Typical reaction conditions are as in Figure 4.

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(26) Kalra, S. J. S.; Punniyamurthy, T.; Iqbal, J. *Tetrahedron Lett.* **1994**, *35*, 4847−4850.
(27) 2-Cyclohexen-1-ol (product of allylic oxidation) was not detected by GC in all the cases reported here.
(28) GC analysis showed that conversion up to 98% could be reached by extension of the reaction time (overnight). A control experiment was carried out using the same reaction conditions in the absence of catalyst. No oxidation of the cyclohexene or aldehyde was observed.
(29) Sheldon, R. A.; Kochi, J. K. *Metal-Catalyzed Oxidations of Organic Compounds*; Academic Press: New York, 1981.
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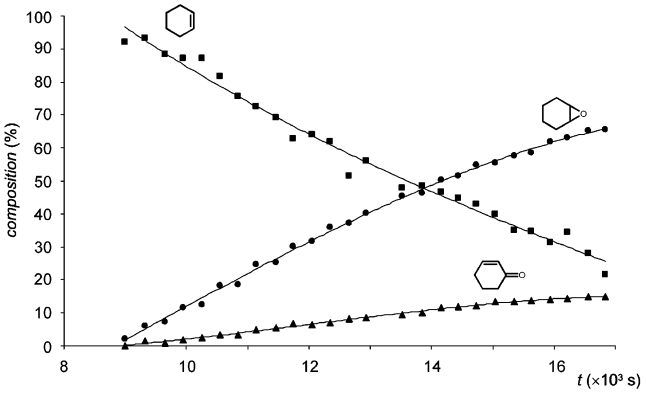

FIGURE 4. Concentration vs time profile for cyclohexene (0.18 M in CH_3CN) oxidation catalyzed by Co(II)Salen **1** (0.005 equiv). Conditions: 20 °C, O_2 1 atm, propanal (4 equiv).

Conclusions

We have demonstrated via O_2 affinity studies on novel Co(II)Salen complexes **1**−**3** (and on commercially available **4**) that noncovalent secondary interactions and especially hydrogen bonding largely increase O_2 binding (**1** vs **2**−**4**). The observed enhanced O_2 binding for **1** is also reflected in the lower catalytic reactivity in the cyclohexene oxidation. The simple variations introduced on the Salen ligand skeleton, and in particular on the diamino bridge, show substantial control on the binding properties of Co(II)Salen complexes by secondary interactions. These results might allow introduction of an alternative model to the heavily exploited field of biomimetic superstructured porphyrins.

Experimental Section

^{1}H NMR chemical shift values (300 MHz) are expressed in ppm relative to residual CHD_2OD (δ 3.30) or $CHCl_3$ (δ 7.26). ^{13}C NMR chemical shift values (100 MHz) are expressed in ppm relative to residual CD_3OD (δ 49.0) or $CDCl_3$ (δ 76.9). Infrared spectra were recorded on KBr pellets. MS FAB spectra were measured with *m*-nitrobenzyl alcohol (NBA) as the matrix. GC analysis was performed on a gas chromatograph equipped with a flame ionization detector (FID), using a capillary column (30 m, 0.25 μm film thickness) with DB-5MS stationary phase (for temperature program and response factor determination, see Supporting Information).

General Procedure for the Synthesis of Salenes 9 and 10. 3,5-Di-*tert*-butyl-2-hydroxybenzaldehyde **8** (280 mg, 1.2 mmol) was added to a solution of *cis*-1,2-diamino-*cis*-4,5-dihydroxycyclohexane dihydrochloride salt **5**−Cl[18] (or **6**−Cl)[18] (120 mg, 0.55 mmol) and $NaHCO_3$ (100 mg, 1.2 mmol) in 10 mL of EtOH at room temperature. The reaction mixture was stirred for 1 h at 75 °C, and the solvent was removed under vacuum. The product was extracted from the solid residue with $CHCl_3$ and recrystallized from CH_3OH.

(1*R*,2*S*,3*R*,4*S*)-[*N*,*N*′-Bis(3,5-di-*tert*-butylsalicylidene)-4,5-dihydroxy-1,2-cyclohexanediamine 10. Yield: 26%. ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 12.88 (bs, 2H), 8.26 (s, 2H), 7.27 (d, 2H, J = 2.2 Hz), 6.96 (d, 2H, J = 2.2 Hz), 3.95−3.86 (m, 2H), 3.59−3.52 (m, 2H), 2.56 (bs, 2H), 2.35−2.25 (m, 2H), 1.98−1.90 (m, 2H), 1.28 (s, 18H), 1.18 (s, 18H). ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 166.59, 158.08, 140.38, 137.01, 127.62, 126.40, 117.86, 69.96, 67.90, 35.23, 34.30, 31.64, 29.59. IR: (cm^{-1}) 3369, 2958, 2910, 2870, 1629, 1467, 1439, 1391, 1362, 1274, 1251, 1203, 1173, 1100, 1039, 968, 773. FAB-MS: *m*/*z* 578.3 ($[M]^+$, calcd 578.4). Anal. Calcd for $C_{36}H_{54}N_2O_4$: C 74.70, H 9.40, N 4.84. Found: C 74.25, H 9.50, N 4.75.

(1*R*,2*S*,3*S*,4*R*)-[*N*,*N*′-Bis(3,5-di-*tert*-butylsalicylidene)-4,5-dihydroxy-1,2-cyclohexanediamine 9. Yield: 65% yield. ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 13.46 (bs, 2H), 8.40 (s, 2H), 7.37 (d, 2H, J = 2.3 Hz), 7.07 (d, 2H, J = 2.3 Hz), 4.38−4.31 (m, 2H), 3.90−3.80 (m, 2H), 2.25 (bs, 2H), 2.21−2.10 (m, 4H), 1.40 (s, 18H), 1.29 (s, 18H). ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 166.64, 158.22, 140.28, 136.82, 127.34, 126.31, 118.01, 68.71, 35.22, 34.31, 34.01, 31.67, 29.64. IR: (cm^{-1}) 3422, 2957, 2909, 2871, 1628, 1459, 1439, 1390, 1362, 1274, 1250, 1202, 1174, 1088, 1027. FAB-MS: *m*/*z* 578.3 ($[M]^+$, calcd 578.4). Anal. Calcd for $C_{36}H_{54}N_2O_4$: C 74.70, H 9.40, N 4.84. Found: C 73.99, H 9.52, N 4.76.

Preparation of (1*R*,2*S*)-[*N*,*N*′-Bis(3,5-di-*tert*-butylsalicylidene)-1,2-cyclohexanediamine 11. 3,5-Di-*tert*-butyl-2-hydroxybenzaldehyde **8** (490 mg, 2.1 mmol) was added to a solution of *cis*-1,2-diaminocyclohexane **7** (120 μL, 1.0 mmol) in 20 mL of EtOH at room temperature. The reaction mixture was stirred for 1 h at 75 °C and gradually cooled to room temperature to allow precipitation of the product. The bright yellow solid was then filtrated and washed several times with cold CH_3OH. Yield: 81% (445 mg, 0.81 mmol).

^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 13.77 (bs, 2H), 8.37 (s, 2H), 7.36 (d, 2H, J = 2.3 Hz), 7.07 (d, 2H, J = 2.3 Hz), 3.63−3.57 (m, 2H), 2.09−1.92 (m, 2H), 1.82−1.73 (m, 2H), 1.67−1.55 (m, 2H), 1.42 (s, 18H), 1.29 (s, 18H). ^{13}C NMR (100 MHz, $CDCl_3$): δ (ppm) 165.41, 158.40, 140.00, 136.80, 127.03, 126.17, 118.15, 69.53, 35.24, 34.30, 31.70, 30.65, 29.67, 22.94. IR: (cm^{-1}) 2997, 2955, 2864, 1630, 1598, 1459, 1441, 1390, 1362, 1273, 1251, 1204, 1174, 1134, 1083, 989, 879, 853, 827, 773. FAB-MS: *m*/*z* 546.3 ($[M]^+$, calcd 546.4), 547.3. Anal. Calcd for $C_{36}H_{54}N_2O_2$: C 79.07, H 9.95, N 5.12. Found: C 78.99, H 10.13, N 5.25.

General Procedure for the Synthesis of Co(II)Salens 1−3. Salens **9**−**11** (1 equiv) were dissolved under nitrogen in degassed EtOH (typically 0.7 mmol in 10 mL). A $Co(Ac)_2{\cdot}4H_2O$ solution in degassed EtOH (1.5 equiv in 5 mL) was then added, causing an immediate turning of the solution from bright yellow to deep red. The reaction mixture was refluxed for 1 h under nitrogen and dried in vacuo. The product was extracted from the solid residue with $CHCl_3$, dried under vacuum, and washed with CH_3OH, affording **1**−**3** as brick red/dark red solids which were always stored under nitrogen at −30 °C.

Co(II)Salen 1. Yield: 97%. FAB-MS: *m*/*z* 635.3 ($[M]^+$, calcd. 635.3). Anal. Calcd for $C_{36}H_{52}N_2O_4Co$: C 68.01, H 8.24, N 4.41. Found: C 67.74, H 8.36, N 4.35.

Co(II)Salen 2. Yield: 100%. FAB-MS: *m*/*z* 635.3 ($[M]^+$, calcd. 635.3). Anal. Calcd for $C_{36}H_{52}N_2O_4Co$: C 68.01, H 8.24, N 4.41. Found: C 67.60, H 8.51, N 4.26.

Co(II)Salen 3. Yield: 93%. FAB-MS: *m*/*z* 603.3 ($[M]^+$, calcd. 603.3). Anal. Calcd for $C_{36}H_{52}N_2O_2Co$: C 71.62, H 8.68, N 4.64. Found: C 72.03, H 8.45, N 4.80.

Oxygen-Binding Measurements. . O_2 affinities were measured spectrophotometrically under equilibrium conditions with a UV−vis spectrophotometer equipped with a optical fiber probe (path length = 1.000 cm), using solvents of spectroscopic grade. Solutions of Co(II)Salenes **1**−**4** [(6−10) × 10^{-5} M] in CH_3CN containing 1-MeIm [(6−7) × 10^{-3} M] were prepared under nitrogen using degassed solvent. The solutions were transferred to a measuring chamber thermostated at 10 °C and equipped with the UV−vis optical probe. O_2 content in the gas layer in equilibrium with the solution in the chamber was varied using the flow method.[34] p_{O_2} was varied between 3.9 and 152 Torr.

(33) The oxidation time course obtained for catalyst **4** resembles that of an autocatalytic reaction (Supporting Information, Figure S2). Probably for this reason the initial rates (r_i) for **4** (Table 2) are the smallest in the series, while $t_{1/2}$ is the shortest, indicating higher reactivity.

(34) Collman, J. P.; Brauman, J. I.; Doxsee, K. M.; Halbert, T. R.; Hayes, S. E.; Suslick, K. S. *J. Am. Chem. Soc.* **1978**, *100*, 2761−2766.

General Procedure for the Catalytic Oxidation of Cyclohexene. In an external-cooling-jacketed reactor at 20 °C with vigorous stirring, a freshly prepared solution of Co(II)Salen (**1**−**4**, 0.005 equiv respect to cyclohexene) and 1,2-dichlorobenzene as internal standard (200 μL) in CH_3CN (25 mL) was equilibrated (2−5 min) with O_2 (1 atm). Propanal (1.4 mL, 20 mmol) and cyclohexene (500 μL, 5.0 mmol) were then added simultaneously to start the reaction. The reaction course was monitored via GC analysis: 50 μL samples were withdrawn from the reaction mixture and diluted with 250 μL of CH_2Cl_2 before injection. The detected products were epoxide **18**, unsaturated ketone **19**, propionic acid, and traces of propionaldehyde.

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Supporting Information Available: GC analysis of the catalytic oxidation of cyclohexene. This material is available free of charge via the Internet at http://pubs.acs.org.

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