Expanding the Scope of Strained-Alkyne Chemistry:

a Protection-Deprotection Strategy via the Formation of a

Dicobalt-Hexacarbonyl Complex

Pierangelo Gobbo, Tommaso Romagnoli, Stephanie M. Barbon, Jacquelyn T. Price, Jennifer Keir,

Joe B. Gilroy*, Mark S. Workentin*

*Department of Chemistry and the Centre for Materials and Biomaterials Research (CAMBR), The University of Western Ontario, 1151 Richmond Street N., London, Ontario, Canada, N6A 5B7.
Materials and Methods

All reagents were used as received. Cyclooctadiene, rhodium tetracetate dimer \([\text{Rh}_2(\text{OAc})_4]\), ethyl diazoacetate, lithium aluminum hydride (LiAlH\(_4\)), bromine (Br\(_2\)), potassium tertbutoxide (KtBuO) 1M solution in THF, dicobalt-octacarbonyl \([\text{Co}_2(\text{CO})_8]\), \(p\)-nitrophenyl chloroformate \([p\text{-NO}_2\text{PhOC(O)Cl}]\), pyridine, sodium azide (NaN\(_3\)), 2-bromoethylamine hydrobromide, phenylacetylene, triethylamine (NEt\(_3\)), and trimethylamine N-oxide (Me\(_3\)NO) were purchased from Sigma-Aldrich. All common solvents, anhydrous sodium sulfate (Na\(_2\)SO\(_4\)), sodium hydroxide (NaOH), anhydrous magnesium sulfate (MgSO\(_4\)), sodium thiosulfate (Na\(_2\)S\(_2\)O\(_3\)), ammonium chloride (NH\(_4\)Cl), and all common solvents were purchased from Caledon. Solvents were dried using an Innovative Technologies Inc. solvent purification system, collected under vacuum, and stored under a nitrogen atmosphere over 4 Å molecular sieves.

\(^1\)H and \(^{13}\)C NMR spectra were recorded on an Inova 400 MHz spectrometer. \(^1\)H NMR spectra are reported as \(\delta\) in units of parts per million (ppm) relative to chloroform (\(\delta 7.26\), s). Multiplicities are reported as follows: s (singlet), d (doublet), t (triplet), q (quartet), quin (quintuplet), dd (doublet of doublets), m (multiplet), and bs (broad signal). Coupling constants are reported as \(J\) values in Hertz (Hz). The number of protons (n) for a given resonance is indicated as nH, and is based on spectral integration values. \(^{13}\)C NMR spectra are reported as \(\delta\) in units of parts per million (ppm) relative to CDCl\(_3\) (\(\delta 77.23\), t).

Infrared spectra were recorded using a Bruker Vector33 spectrometer by making a thin film of each sample onto a KBr disk. The background was subtracted from each spectrum.

UV-Vis spectra were collected employing a Varian UV-Vis spectrophotometer model Cary 300 Bio, and dissolving the sample in spectroscopic grade CH\(_2\)Cl\(_2\) to obtain a 1\(\cdot10^{-5}\)M solution. The background was subtracted from each spectrum.
Synthesis of BCN-OH endo/exo-1\textsuperscript{[1]}

### Synthesis of bicycle[6.1.0]-nonyne-methanol (BCN-OH) endo-1 and exo-1

In a typical synthesis, Rh\(_2\)(OAc)\(_4\) (0.776 g, 1.76 mmol) was dissolved in dry CH\(_2\)Cl\(_2\) (20 mL) under argon atmosphere. Cyclooctadiene (40 mL, 0.33 mol) was then added to the solution. In a separate flask, ethyl diazoacetate (4.3 mL, 41 mmol) was also dissolved in dry CH\(_2\)Cl\(_2\) (20 mL) and then slowly added to the cyclooctadiene solution. Evolution of nitrogen gas was observed right away. The dark green solution was stirred at room temperature for two days. CH\(_2\)Cl\(_2\) was evaporated, then excess cyclooctadiene was recovered by column chromatography on silica gel using hexanes as the eluent. After elution of cyclooctadiene, the endo/exo-a isomers were separated using hexanes/Et\(_2\)O 9:0.5 as the eluent. The two isomers were obtained as a colorless oil (6.979 g, 88% overall yield, 36% endo and 64% exo). \(R_f \text{ exo} = 0.6, \ R_f \text{ endo} = 0.4\) in hexanes/Et\(_2\)O 9:0.5.

The syntheses of endo-1 and exo-1 isomers were carried out separately by reacting the two separate isomers according to the following procedures. A suspension of LiAlH\(_4\) (1.371 g, 36.11 mmol) in dry Et\(_2\)O (80 mL) was cooled to 0 °C. Compound endo/exo-a from the previous step (7.85 g, 40.4 mmol) was also dissolved in dry Et\(_2\)O (90 mL) and cooled to 0 °C before dropwise addition to the reaction flask. The gray solution was stirred for 15 min at room temperature, then it was cooled again to 0 °C and distilled water was added dropwise under normal atmosphere until formation of a white precipitate was observed. The mixture was dried over Na\(_2\)SO\(_4\), and the solids were filtered off and washed with Et\(_2\)O. The solvent was evaporated to obtain intermediate endo/exo alcohol. No further purification was performed.
Compound \textit{endo/exo-b} from the previous step was dissolved in CH$_2$Cl$_2$ (250 mL) and cooled to 0 ºC. A solution of Br$_2$ (2.6 mL, 51 mmol) in CH$_2$Cl$_2$ was added dropwise at 0 ºC to the alkene solution until a light yellow color persisted. The reaction mixture was quenched with a 10% Na$_2$S$_2$O$_3$ solution (70 mL). After vigorous stirring for a few minutes the solution turned colorless and was then extracted with CH$_2$Cl$_2$ (4 x 15 mL). The organic layer was dried with Na$_2$SO$_4$, filtered and concentrated \textit{in vacuo} to give \textit{endo/exo} as a thick yellow oil in 90% yield over the two last steps. No further purification was performed.

The \textit{endo/exo-c} from the previous step was dissolved in dry THF (80 mL) and cooled to 0 ºC. A 1 M solution of KOtBu in THF (120 mL) was added dropwise into the reaction flask. After addition the solution turned orange. At this point the ice-bath was removed, the temperature was raised to 70 ºC, and the reaction mixture was refluxed for 2 h. After cooling to room temperature the reaction mixture was quenched with saturated NH$_4$Cl (200 mL) and the product was extracted with CH$_2$Cl$_2$. The collected organic fractions were dried with MgSO$_4$, filtered and concentrated \textit{in vacuo}. The crude product was purified by column chromatography (3:1 Et$_2$O/hexanes) to give \textit{endo/exo-1} as a white solid (2.579 g, 62% yield).

**BCN-OH exo-1**: $^1$H NMR (CDCl$_3$, 400 MHz): $\delta$ 3.57 (d, $J = 4.0$ Hz, 2H), 2.45-2.41 (m, 2H), 2.34-2.27 (m, 2H), 2.20-2.15 (m, 2H), 1.45-1.36 (m, 3H), 0.73-0.67 (m, 3H). $^{13}$C NMR (CDCl$_3$, 75 MHz): $\delta$ 98.8, 67.2, 33.4, 27.3, 22.6, 21.5. IR (KBr, cm$^{-1}$): 3349, 2980, 2922, 2844, 2723, 2621, 2263, 2187, 2021, 1700, 1441, 1311, 1292, 1238, 1199, 1167, 1128, 1088, 1023, 995, 942, 922, 896, 843, 803, 757, 716. CI-HRMS: calculated for C$_{10}$H$_{15}$O$^+$ [M+1] 151.1123, found 151.1118.

**BCN-OH endo-1**: $^1$H NMR (CDCl$_3$, 400 MHz): $\delta$ 3.74 (d, $J = 8.0$ Hz, 2H), 2.35-2.20 (m, 6H), 1.66-1.56 (m, 2H), 1.39- 1.30 (m, 2H), 0.99-0.90 (m, 2H). $^{13}$C NMR (CDCl$_3$, 75 MHz): $\delta$ 98.9, 60.0, 29.0,
21.47, 21.38, 20.0 IR (KBr, cm$^{-1}$): 3350, 2987, 2924, 2845, 2726, 2621, 2177, 2005, 1699, 1479, 1439, 1366, 1336, 1303, 1212, 1197, 1176, 1125, 1089, 1048, 1017, 990, 934, 955, 907, 894, 875, 820, 767, 735. CI-HRMS: calculated for $\text{C}_{10}\text{H}_{15}\text{O}^+ [M+1]$ 151.1123, found 151.1118.
Figure SI1: $^1$H (top) and $^{13}$C NMR (bottom) spectra of exo-1 isomer. * denotes residual solvent signals.
Figure SI2: IR absorption spectrum of exo-1 isomer.
Figure S13: $^1$H (top) and $^{13}$C NMR (bottom) spectra of endo-1 isomer. * denotes residual solvent signals.
Figure S14: IR absorption spectrum of endo-1 isomer.
Representative protection of BCN-OH endo/exo-1 with dicobalt-octacarbonyl

In a glove box BCN-OH endo/exo-1 (0.481 g, 3.20 mmol) was dissolved in 10 ml of dry CH₂Cl₂. To this solution, Co₂(CO)₈ (1.163 g, 3.40 mmol) was quickly added and right away CO(g) evolution was observed. The reaction was monitored by TLC (EtOAc/hexanes 1:1), which indicated the reaction had gone to completion after 1 h. The solvent was evaporated and product endo/exo-2 was purified by column chromatography on silica gel in air using EtOAc/hexanes 1:1 as the eluent. Compound endo/exo-2 was obtained as a red solid in quantitative yield, and could be stored in the freezer at normal atmosphere for months with negligible decomposition. The reaction can be safely performed without the use of a glove box, but extra care needs to be taken in handling Co₂(CO)₈ because it is pyrophoric.

Protected BCN-OH exo-2: ¹H NMR (CDCl₃, 400 MHz): δ 3.57 (2H), 3.25-3.18 (2H), 3.05-2.98 (2H), 2.39-2.36 (2H), 1.29-1.26 (3H), 0.86-0.73 (3H). ¹³C NMR (CDCl₃, 75 MHz): δ 200.5, 98.2, 66.6, 36.7, 29.6, 26.4, 22.9. IR (KBr, cm⁻¹): 3277, 2964, 2963, 2915, 2884, 2845, 2467, 2085, 2039, 1993, 1963, 1627, 1446, 1430, 1361, 1320, 1297, 1234,1206, 1169, 1123, 1091, 1028, 999, 939, 961, 939, 909, 891,851, 795, 747, 717. UV-Vis (CH₂Cl₂): λmax, nm (ε, M⁻¹ cm⁻¹) 263 (19,671), 360 (5,262), 430 (1,228). ESI-HRMS: calculated for C₁₆H₁₄Co₂O₇ [M] 435.9404, found 435.9403.
**Protected BCN-OH endo-2:** $^1$H NMR (CDCl$_3$, 400 MHz): $\delta$ 3.76 (2H), 3.31-3.27 (2H), 3.07-3.00 (2H), 2.24-2.21 (2H), 1.49-1.46 (2H), 1.28-1.10 (4H). $^{13}$C NMR (CDCl$_3$, 75 MHz): $\delta$ 200.5, 98.2, 60.0, 36.8, 30.9, 25.1, 20.5. IR (KBr, cm$^{-1}$): 3289, 3297, 2981, 2917, 2890, 2851, 2082, 2035, 1982, 1624, 1431, 1448, 1364, 1321, 1250, 1234, 1204, 1176, 1121, 1093, 1054, 1019, 972, 943, 907, 873, 824, 757, 724.

UV-Vis (CH$_2$Cl$_2$): $\lambda_{\text{max}}$, nm ($\epsilon$, M$^{-1}$ cm$^{-1}$) 263 (19,671), 360 (5,262), 430 (1,228). ESI-HRMS: calculated for C$_{16}$H$_{14}$Co$_2$O$_7$ [M] 435.9404, found 435.9416.
**Figure SI5**: $^1$H (top) and $^{13}$C NMR (bottom) spectra of *exo-2* isomer. * denotes residual solvent signals.
**Figure S16:** IR absorption spectrum of complex *exo*-2 isomer.
Figure SI7: $^1$H (top) and $^{13}$C NMR (bottom) spectra of endo-2 isomer. * denotes residual solvent signals.
Figure SI8: IR absorption spectrum of complex endo-2 isomer.
Figure S19: UV-Vis absorption spectrum of complex endo/exo-2 measured in CH$_2$Cl$_2$. 
Representative deprotection of endo/exo-2

To deprotect compound endo/exo-2 and regenerate endo/exo-1, compound endo/exo-2 (0.102 g, 0.230 mmol) was dissolved in dry CH₂Cl₂ in a round bottom flask equipped with a calcium chloride drying tube, and Me₃NO (0.131 g, 1.18 mmol) was added to the solution. During the decomplexation, formation of a gray-green precipitate was observed. The reaction was monitored by TLC (silica gel) using EtOAc/Et₂O 1:6 as the eluent and was completed in 4 h. The solvent was removed in vacuo, and the reaction mixture was purified through column chromatography using EtOAc/Et₂O 1:6 as the eluent and endo/exo-1 was isolated in 85% yield.

Functionalization of exo-2 complex

Synthesis of compound exo-4

Compound exo-2 (0.113 g, 0.260 mmol) was dissolved in 8 mL dry CH₂Cl₂ under argon atmosphere. To this solution pyridine (53 µL, 0.66 mmol) was added at 0°C. Subsequently, p-NO₂PhOC(O)Cl (0.070 g, 0.35 mmol) dissolved in 2 mL dry CH₂Cl₂ was added dropwise to reaction flask at 0°C. The reaction was stirred at room temperature for 75 min. The solvent was evaporated and the product was purified by column chromatography (4:1 hexane/EtOAc) to give a dark brown solid (0.145 g, 93% yield). ¹H NMR (400 MHz, CDCl₃): δ 8.30 (d, J = 8 Hz, 2H), 7.40 (d, J = 8 Hz, 2H), 4.23 (d, J = 8 Hz, 2H), 3.28-3.23 (m,
2H), 3.07-3.00 (m, 2H), 2.43-2.40 (m, 2H); 1.36-1.30 (m, 2H), 1.04-1.01 (m, 2H), 0.91-0.88 (m, 1H).

$^{13}$C NMR (75 MHz, CDCl$_3$):  δ 200.4, 155.6, 152.3, 145.4, 125.3, 121.8, 97.8, 73.4, 36.4, 29.3, 23.6, 22.2. IR (KBr, cm$^{-1}$): 3085, 3031, 2924, 2852, 2084, 2040, 2009, 1765, 1559, 1526, 1455, 1215, 1102, 1042, 1005, 927, 859, 750, 718, 672. UV-Vis (CH$_2$Cl$_2$): $\lambda_{\text{max}}$, nm (ε, M$^{-1}$ cm$^{-1}$) 268 (22,226), 360 (3,643), 430 (693).

**Figure SI10:** Solid-state structure of *exo*-4. Thermal ellipsoids are shown at 50% probability and hydrogen atoms have been removed for clarity.
Figure SI11: $^1$H (top) and $^{13}$C NMR (bottom) spectra of exo-4 isomer. * denotes residual solvent signals.
Figure SI12: IR absorption spectrum of complex exo-4 isomer.
Synthesis of unprotected compound \textit{exo}-3

The synthesis of compound \textit{exo}-3 was carried out under the same reaction conditions as for the synthesis of compound \textit{exo}-4, but in the absence of the dicobalt-hexacarbonyl protecting group. To a solution of \textit{exo}-1 (0.500 g, 3.33 mmol) in 25 mL of dry CH$_2$Cl$_2$ and at 0 °C was added pyridine (229 µL, 8.31 mmol) and subsequently a solution of \textit{p}-NO$_2$PhOC(O)Cl (0.838 g, 4.16 mmol) in 20 mL of CH$_2$Cl$_2$. The ice-bath was removed and the reaction was carried out at room temperature. The reaction was complete after 15 min. Subsequently, the reaction mixture was quenched with saturated NH$_4$Cl-solution (75 mL) and extracted with 3 x 20 mL of CH$_2$Cl$_2$. The organic layer was dried over Na$_2$SO$_4$ and concentrated \textit{in vacuo}. The residue was purified by column chromatography using Et$_2$O/hexanes 1:1 as the eluent to afford product (10) as a white solid in 73% yield. $^1$H NMR (400MHz, CDCl$_3$): $\delta$ 8.29 (d, $J = 12$ Hz, 2H), 7.40 (d, $J = 12$ Hz, 2H), 4.23 (d, $J = 8$ Hz, 2H), 2.48-2.17 (m, 6H), 1.47-1.38 (m, 2H), 0.89-0.83 (m, 3H). $^{13}$C NMR (75 MHz, CDCl$_3$): $\delta$ 155.6, 152.5, 145.3, 125.3, 121.7, 98.7, 68.0, 29.0, 21.3, 20.5, 17.2. ESI-HRMS: Calc. for C$_{11}$H$_{13}$O$_2$ [M] 315.1107, found 315.1223.
Figure SI13: $^1$H (top) and $^{13}$C NMR (bottom) spectra of exo-3 isomer. * denotes residual solvent signals.
Synthesis of 2-azidoethanamine

2-bromoethylamine hydrobromide (2.00 g, 9.76 mmol) was dissolved in 10 mL water, then NaN₃ (1.91 g, 29.3 mmol) was added to reaction flask. The reaction mixture was heated to 80 ºC and stirred overnight. The reaction mixture was let to cool down to room temperature, and it was quenched by the addition of 4 equivalents of NaOH. The crude product was extracted with CH₂Cl₂ (3 x 50 mL) then dried with anhydrous Na₂SO₄. The solvent was evaporated then the final product was concentrated in vacuo to give a light yellow liquid. ¹H NMR (400 MHz, CDCl₃): δ 3.38 (t, J = 8 Hz, 2H), 2.89 (t, J = 8 Hz, 2H), 1.42 (s, 2H). ¹³C NMR (75 MHz, CDCl₃): δ 54.6, 41.3. IR (KBr, cm⁻¹): 3275, 2928, 2098, 2020, 1746, 1663, 1575, 1455, 1347, 1293, 1130, 974, 912, 809.
Figure SI14: $^1$H (top) and $^{13}$C NMR (bottom) spectra of 2-azidoethanamine. * denotes residual solvent signals.
Figure SI15: IR absorption spectrum of complex 2-azidoethanamine.
Synthesis of compound *exo*-5

Compound *exo*-4 (0.0888 g, 0.148 mmol) was dissolved in 1.0 mL of dry DMF under argon atmosphere and at 0 °C. To this solution, a solution of 2-azidoethanamine (0.0272 g, 0.316 mmol) and Et$_3$N (44 µL, 0.315 mmol) in 0.5 mL DMF was added under argon atmosphere and at 0 °C. The reaction was stirred at room temperature for 30 min. The solvent was evaporated and the crude product was purified by column chromatography (4:1 hexane/EtOAc) to give a dark brown oil (0.0639 g, 80% yield). $R_f = 0.31$ in 4:1 hexane/EtOAc. $^1$H NMR (400 MHz, CDCl$_3$): $\delta$ 4.97 (m, 1H), 3.99 (m, 2H), 3.46-3.38 (m, 4H), 3.24-3.20 (m, 2H), 3.04-2.97 (m, 2H), 2.38-2.34 (m, 2H), 1.26 (m, 2H), 0.91 (m, 2H), 0.74 (m, 1H). $^{13}$C NMR (75 MHz, CDCl$_3$): $\delta$ 200.4, 156.6, 98.2, 68.8, 51.2, 40.4, 36.5, 29.5, 23.3, 22.9. IR (KBr, cm$^{-1}$): 3328, 2924, 2852, 2103, 2085, 2040, 2007, 1708, 1517, 1450, 1431, 1249, 1145, 1097, 1015. UV-Vis (CH$_2$Cl$_2$): $\lambda_{\text{max}}$, nm ($\epsilon$, M$^{-1}$ cm$^{-1}$) 263 (13,3166), 360 (3,397), 430 (839).
Figure SI16: $^1$H (top) and $^{13}$C NMR (bottom) spectra of exo-5 isomer. * denotes residual solvent signals.
Figure SI17: IR absorption spectrum of complex exo-5 isomer.
**Synthesis of compound exo-6**

In a glove box, phenylacetylene (40 µL, 0.3642 mmol) and CuI (0.075 g, 0.39 mmol) were dissolved in 5 mL of dry MeCN to give a colorless solution with a white precipitate. To this mixture, Et₃N (56 µL, 0.40 mmol) was added to reaction flask and a bright yellow precipitate quickly formed. Finally, azide exo-5 (0.127 g, 0.2318 mmol) was added to the reaction mixture and let stir for 4 h. The crude product was purified by column chromatography (2:1 EtOAc/hexane) to give a dark brown solid (0.105 g, 70% yield). R_f = 0.38 in 2:1 EtOAc/hexane. 

**1H NMR** (400 MHz, CDCl₃): δ 7.85-7.79 (m, 2H), 7.45-7.43 (m, 2H), 7.36 (m, 1H), 5.08 (m, 1H), 4.55 (m, 2H), 3.97 (m, 2H), 3.78 (m, 2H), 3.20-3.15 (m, 2H), 3.00-2.93 (m, 2H), 2.33-2.29 (m, 2H), 1.24 (m, 2H), 0.88 (m, 2H), 0.71 (m, 1H).

**13C NMR** (75 MHz, CDCl₃): δ 200.4, 156.7, 147.9, 130.3, 128.9, 128.3, 125.9, 120.4, 98.1, 69.0, 49.9, 40.8, 36.5, 29.5, 23.3, 22.8. IR (KBr, cm⁻¹): 3335, 3117, 3085, 3031, 2921, 2886, 2848, 2083, 1985, 1690, 1529, 1464, 1448, 1427, 1363, 1331, 1278, 1256, 1228, 1171, 1148, 1080, 1005, 969, 938, 847, 763, 693, 668. UV-Vis (CH₂Cl₂): λ_max, nm (ε, M⁻¹ cm⁻¹) 243 (32,299), 360 (3,659), 430 (880).
Figure SI18: $^1$H (top) and $^{13}$C NMR (bottom) spectra of exo-6 isomer. * denotes residual solvent signals.
Figure SI19: IR absorption spectrum of complex exo-6 isomer.
Synthesis of compound _exo-7_

Compound _exo-6_ (0.0503 g, 0.0773 mmol) was dissolved in 5 mL dry CH₂Cl₂ in a flask equipped with a calcium chloride drying tube. To this solution, Me₃NO (0.0454 g, 0.409 mmol) was added, and the reaction was stirred at room temperature for 4 h. Upon removal of the solvent, the crude product was purified by column chromatography (4:1 EtOAc/hexane) to give the final product as a yellow oil (0.0169 g, 60%).

Rᵣ = 0.37 in 2:1 EtOAc/hexane. ¹H NMR (400 MHz, CDCl₃): δ 7.83-7.79 (m, 3H), 7.46-7.42 (m, 2H), 7.37-7.33 (m, 2H), 5.16 (bs, 1H), 4.56-4.54 (m, 2H), 4.00-3.98 (d, 2H, 8 Hz), 3.79-3.75 (m, 2H), 2.39-2.36 (m, 2H), 2.31-2.24 (m, 2H), 2.16-2.12 (m, 2H), 1.40-1.34 (m, 2H), 0.90-0.84 (bs, 2H), 0.74-0.71 (m, 1H). ¹³C NMR (75 MHz, CDCl₃): δ 156.8, 147.8, 130.3, 128.9, 128.3, 125.7, 120.5, 98.7, 69.5, 49.9, 40.8, 33.2, 23.6, 22.9, 21.3. CI-HRMS: Calculated for C₂₁H₂₅N₄O₂ [M+1]: 365.1972, found 365.1974.
Figure SI20: $^1$H (top) and $^{13}$C NMR (bottom) spectra of *exo*-7 isomer. * denotes residual solvent signals.
Synthesis of compound \( \text{exo-8} \)

Compound \( \text{exo-7} \) (0.0150 g, 0.0412 mmol) was dissolved in 2 mL of \( \text{CH}_2\text{Cl}_2 \). To this solution was added benzyl azide (5.1 \( \mu \)L, 0.041 mmol) and the reaction was stirred for 10 min. Solvent and any residual benzyl azide were removed \textit{in vacuo}, and compound \( \text{exo-8} \) could be obtained pure in a mixture of 1,4- and 1,5-substituted regioisomers in essentially quantitative yield by NMR (0.020 g). \( R_f = 0.33 \) in EtOAc. \( ^1\text{H} \) NMR (400 MHz, CDCl\(_3\)): \( \delta \) 7.83-7.79 (m, 3H), 7.45-7.42 (m, 2H), 7.37-7.31 (m, 4H), 7.13-7.11 (m, 2H), 5.49 (s, 2H), 5.14 (bs, 1H), 4.55-4.53 (m, 2H), 3.94-3.82 (m, 2H), 3.78-3.74 (m, 2H), 3.16-3.12 (bs, 1H), 2.92-2.86 (bs, 1H), 2.75-2.72 (bs, 1H), 2.54-2.48 (bs, 1H), 2.40-2.35 (bs, 1H), 2.20-2.15 (bs, 1H), 1.36-1.30 (bs, 2H), 0.89-0.85 (bs, 2H), 0.69-0.68 (bs, 1H). \( ^{13}\text{C} \) NMR (75 MHz, CDCl\(_3\)): \( \delta \) 157.2, 148.0, 145.4, 135.9, 134.4, 131.3, 129.44, 129.38, 129.30, 128.77,128.67, 128.63, 127.5, 126.1, 121.1, 69.1, 55.3, 52.6, 50.5, 41.4, 32.48, 32.42, 32.25, 30.2, 30.08, 30.02, 29.99, 29.91, 29.83, 29.79, 29.76, 29.64, 27.50, 27.14, 26.64, 26.02, 24.56, 23.46, 23.24, 23.22, 23.17, 23.10, 23.03, 22.9, 14.43, 14.41. 

CI-HRMS: Calculated for \( \text{C}_{28}\text{H}_{32}\text{N}_7\text{O}_2 \) \([\text{M+1}]\): 498.2617, found 498.2638.
Figure SI21: $^1$H (top) and $^{13}$C NMR (bottom) spectra of exo-8 isomer. * denotes residual solvent signals.
**X-ray Crystallography**

Single crystals of complexes *exo-2*, *endo-2*, and *exo-4* suitable for X-ray diffraction studies were grown by slow evaporation of a concentrated solution of each compound in dichloromethane. The samples were mounted on a Mitegen polyimide micromount with a small amount of Paratone N oil. All X-ray measurements were made on a Bruker Kappa Axis Apex2 diffractometer at a temperature of 110 K. The data collection strategy included a number of $\omega$ and $\phi$ scans which collected data over a range of angles, 20. The frame integration was performed using SAINT. The resulting raw data was scaled and absorption corrected using a multi-scan averaging of symmetry equivalent data using SADABS. The structures were solved by direct methods using the SIR92 program (*exo-2*)\(^4\) or XS program (*endo-2*),\(^5\) and by a dual space methodology using the SHELXT program (*exo-4*).\(^6\) All non-hydrogen atoms were obtained from the initial solution. Atoms H7 and H7A (*exo-2*) and atoms H7A, H7B, H7C (*endo-2*) were disordered over two positions. The disorder arises because of close H···H contacts across a crystallographic inversion centre. The O—H bond lengths for the disordered hydrogen atoms were fixed to 0.84 Å and the isotropic displacement parameter was set to 1.5 times the value of $U_{\text{equiv}}$ for the parent oxygen atom. Each of the disordered hydrogen atoms forms O—H···O hydrogen bonds with neighbouring oxygen atoms. The hydrogen atoms were introduced at idealized positions and were allowed to ride on the parent atom. The structural model was fit to the data using full matrix least-squares based on $F^2$. The calculated structure factors included corrections for anomalous dispersion from the usual tabulation. The structure was refined using the SHELXL-2014 program from SHELXTL. See Table SI1 for additional crystallographic data.
Table SII. X-ray diffraction data collection and refinement details for complexes *exo*-2, *endo*-2, and *exo*-4.

<table>
<thead>
<tr>
<th></th>
<th><em>exo</em>-2</th>
<th><em>endo</em>-2</th>
<th><em>exo</em>-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Formula</td>
<td>C₁₆H₁₄Co₂O₇</td>
<td>C₁₆H₁₄Co₂O₇</td>
<td>C₂₃H₁₇Co₂NO₁₁</td>
</tr>
<tr>
<td>Formula Weight (g/mol)</td>
<td>436.13</td>
<td>436.13</td>
<td>601.23</td>
</tr>
<tr>
<td>Crystal Habit</td>
<td>red block</td>
<td>red block</td>
<td>orange needle</td>
</tr>
<tr>
<td>Crystal System</td>
<td>triclinic</td>
<td>triclinic</td>
<td>monoclinic</td>
</tr>
<tr>
<td>Space Group</td>
<td>P -1</td>
<td>P -1</td>
<td>C 2/c</td>
</tr>
<tr>
<td>λ (Å)</td>
<td>0.71073</td>
<td>0.71073</td>
<td>0.71073</td>
</tr>
<tr>
<td>T (K)</td>
<td>110</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>a (Å)</td>
<td>9.074(3)</td>
<td>8.893(3)</td>
<td>39.343(20)</td>
</tr>
<tr>
<td>b (Å)</td>
<td>12.983(6)</td>
<td>16.495(6)</td>
<td>8.101(4)</td>
</tr>
<tr>
<td>c (Å)</td>
<td>16.699(5)</td>
<td>19.797(9)</td>
<td>16.720(6)</td>
</tr>
<tr>
<td>α (deg)</td>
<td>110.879(17)</td>
<td>101.280(16)</td>
<td>90</td>
</tr>
<tr>
<td>β (deg)</td>
<td>96.205(8)</td>
<td>102.130(12)</td>
<td>110.966(13)</td>
</tr>
<tr>
<td>γ (deg)</td>
<td>98.023(9)</td>
<td>103.697(12)</td>
<td>90</td>
</tr>
<tr>
<td>V (Å³)</td>
<td>1793.4(11)</td>
<td>2664.9(18)</td>
<td>4976(4)</td>
</tr>
<tr>
<td>Z</td>
<td>4</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>ρ (g/cm)</td>
<td>1.615</td>
<td>1.631</td>
<td>1.605</td>
</tr>
<tr>
<td>μ, (cm⁻¹)</td>
<td>1.883</td>
<td>1.900</td>
<td>1.394</td>
</tr>
<tr>
<td>R&lt;sub&gt;1&lt;/sub&gt;, wR&lt;sub&gt;2&lt;/sub&gt; [I &gt; 2σ]</td>
<td>0.0285, 0.0668, 0.0231, 0.0571, 0.0360, 0.0636</td>
<td>0.0360, 0.0600, 0.0672, 0.0724</td>
<td></td>
</tr>
<tr>
<td>R&lt;sub&gt;1&lt;/sub&gt;, wR&lt;sub&gt;2&lt;/sub&gt; (all data)</td>
<td>0.0360, 0.0701, 0.0296, 0.0600</td>
<td>0.0672, 0.0724</td>
<td></td>
</tr>
<tr>
<td>GOF&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.029</td>
<td>1.046</td>
<td>1.011</td>
</tr>
</tbody>
</table>

<sup>a</sup>R₁ = Σ( |F<sub>o</sub>| - |F<sub>c</sub>| ) / Σ |F<sub>o</sub>|, <sup>b</sup>wR<sub>2</sub> = [ Σ(w( F<sub>o</sub>² - F<sub>c</sub>²)²) / Σ(w F<sub>o</sub>⁴) ]<sup>½</sup>, <sup>c</sup>GOF = [ Σ( w( F<sub>o</sub>² - F<sub>c</sub>²)² ) / (No. of reflns. - No. of params. ) ]<sup>½</sup>

References


