Synthesis of Tricyclic Skeletons Mediated by (Diene)Fe(CO)$_3$ Complexes

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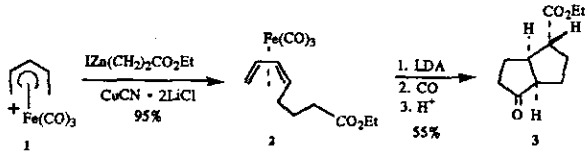
Sequential additions of carbon nucleophiles to the (η^5-pentadienyl)Fe(CO)$_3$ cation afforded tricyclo[6.3.0.0^{2,6}]undecane, tricyclo[6.4.0.0^{2,6}]dodecane, tricyclo[7.3.0.0^{2,7}]dodecane and tricyclo[7.4.0.0^{2,7}]-tridecane derivatives. The same strategy can also be applied to construct heterotricyclic skeletons.

INTRODUCTION

The rapidly growing number of structurally interesting and biologically active polyquinane (polycyclopentanoid) natural products has prompted considerable interest in new methodology for the construction of condensed five-membered ring systems. Functionalized tricyclo[6.3.0.0]undecane compounds are the skeleton of numerous natural compounds. The availability of functionalized tricyclo-[6.3.0.0^{2,6}]undecane building blocks could greatly facilitate the elaboration of more complex target molecules, the design of expedient synthetic routes to such intermediates has been actively pursued.[1] We have recently reported that intramolecular cyclization of acyclic (η^4-diene)Fe(CO)$_3$ complexean bearing functionalized side chain at the terminal position of the diene afforded a fused bicyclo[3.3.0]octane ring skeleton.[2] The starting complex was easily available by addition of the functionalized zinc-copper reagent [IZn(CH$_2$)$_2$CO$_2$Et, CuCN·2LiCl] to (η^5-pentadienyl)Fe-(CO)$_3$ cation salt (**1**) (Scheme I) at 0 °C in high yield. Treatment of the intramolecular cyclization precursor **2** with LDA (lithium diisopropylamide) at -78 °C under CO followed by acid quenching produced fused bicyclo[3.3.0]-ocatanone **3** as the sole diastereomeric isomer in 55% yield.

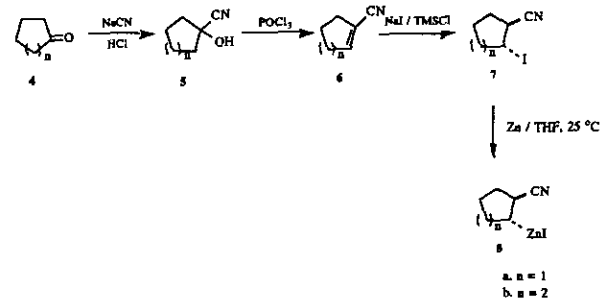
Scheme I



RESULTS AND DISCUSSION

In the effort to construct linear fused tricyclic skeletons, cyclic functionalized zinc-copper reagents are needed for the syntheses of the initial neutral (η^4-diene)Fe(CO)$_3$ precursors. The 5- and 6-membered ring zinc reagents bearing a cyano functionality were prepared according to a procedure described in the literature procedure (Scheme II).[3] Reaction of cyclopentanone **4a** with NaCN in the presence of concentrated HCl gave cyanohydrin **5a** in 55% yield. Dehydration of the cyanohydrin **5a** ($POCl_3$/pyridine) afforded 1-cyanocyclopentene **6a**. Addition of NaI to **6a** in the presence of trimethylsilyl chloride generated 2-iodocyclopentanenitrile **7a** (24% over yield from **4a**).[3] Under the same reaction conditions, cyclohexanone **4b** gave 2-iodocyclohexanenitrile **7b** (20% overall yield from **4b**). Unlike most zinc reagent obtained at 50 °C, zinc reagents **8a** and **8b** can be made by oxidative addition of the corresponding iodides **7a** and **7b** to the zinc metal in THF at 25 °C.[4] It is important to mention that zinc reagents **8a** and **8b** do not undergo β-elimination of the cyano group at 25 °C as is usually observed with most organometallic reagents. Addition of zinc reagent **8a** (Scheme III) with CuCN·2LiCl to cation **1** at 0 °C generated a mixture of diastereomer **9a** and **9b** in 95% yield (Scheme III). Attempts to separate isomers **9a** and **9b** were not successful. The ratio of **9a** and **9b** was determined by the ratio of the intensities of two cyano peaks (122.9 and 122.6 ppm) on ^{13}C NMR spectrum.

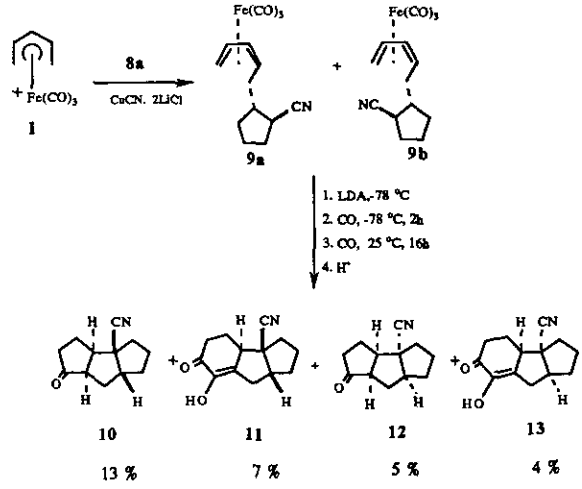
Scheme II



Intramolecular cyclization of the mixture of **9a** and **9b** with lithium diisopropylamide (LDA) in THF/HMPA under CO followed by acid quenching afforded the expected tri-

Dedicated to Professor Yu-Shia Cheng on the occasion of her 65th birthday.

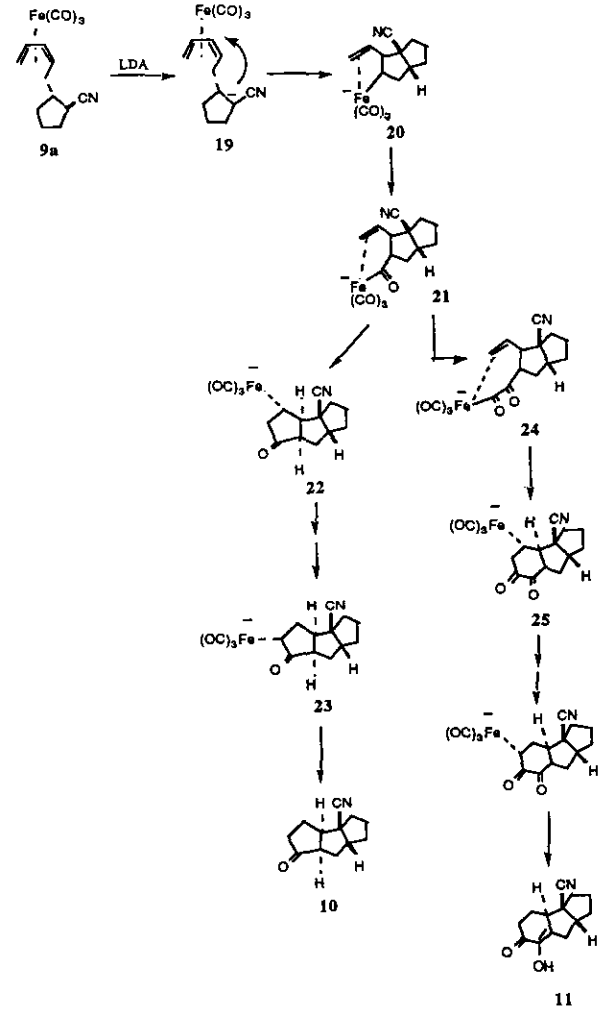
Scheme III



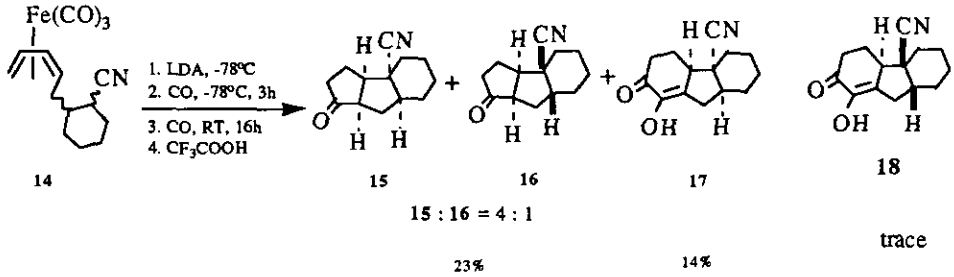
quinanes **10** (13%) and **12** (5%) together with the tricyclo[7.3.0.0^{2,7}]dodecane derivatives **11** (7%) and **13** (4%) (Scheme III). The formation of the tricyclo[7.3.0.0^{2,7}]dodecane ring skeletons may have derived from double CO insertion as shown in Scheme V. Attempts to separate isomers **10** and **12** were unsuccessful. The ratio of 13:5 for compounds **10** and **12** was determined by the intensities of two cyano peaks (125.9, 123.7 ppm) on the ^{13}C NMR spectrum. Nevertheless, the more polar tricyclic compounds **11** and **13** were isolated as pure compounds. Under the same reaction conditions, intramolecular cyclization of the complex bearing a six-membered ring tether, for example, **14** gave tricyclo[7.3.0.0^{2,7}]dodecane derivatives **15** (19%) and **16** (4%), together with the double carbonyl insertion products tricyclo[7.4.0.0^{2,7}]tridecane derivatives **17** (14%) and **18** (trace) (Scheme IV). The ratio of 19:4 for compounds **15** and **16** was determined by the intensities of two keto peaks (221.5, 219.8 ppm) on the ^{13}C NMR spectrum. Only tricyclo-[7.4.0.0^{2,7}]tridecane derivative **17** was isolated as a pure compound. Rigorous proof of the structure of **17** was accomplished by X-ray fraction analysis.

A reaction pathway for the formation of tricyclic compounds **10** and **11** was proposed in Scheme V. Deprotonation of complex **9a** with LDA produced α-cyano stabilized anion **19**. Anti addition of the anion from the β-face (the bottom face) at the internal C-3 position of the diene ligand would give the homoally anion species **20**. Carbonyl insertion (external 1.0 atm of CO) would generate acyl anion **21**. Double bond insertion into the iron-acyl bond gave **22**. Rearrangement of anion **22** via β-hydride elimination and read-

Scheme V



Scheme IV

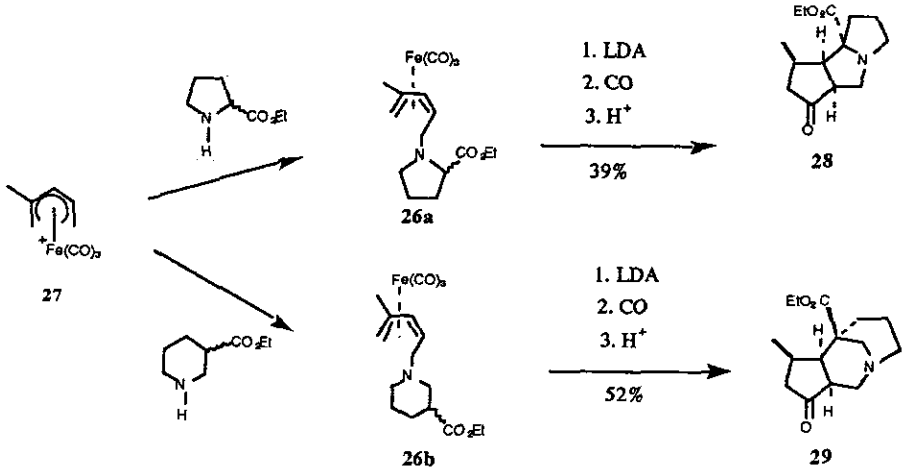


dition produced the more stable α-iron enolate **23**, which after acid quenching afforded triquinane **10**. The second CO insertion into the iron-acyl bond of **21** would generate the dicarbonyl intermediate **24**. Double bond insertion followed by rearrangement as described for the anion intermediate **22** would give **11** as its enol form. It is important to mention that double CO insertion products are not found in the bicyclic system. However, anti addition of the anion from the α-face (the top face) at the internal position of the diene ligand would lead to triquinane **12** and the double CO insertion product **13**.

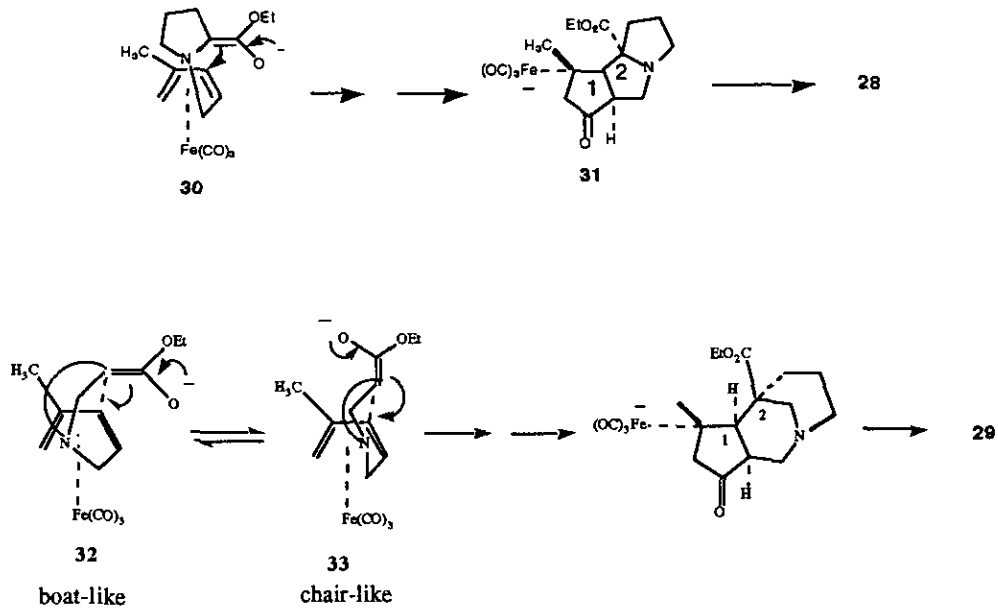
The same strategy can also be applied to the synthesis of tricyclic compounds containing an heteroatom.[5] The results are shown in Scheme VI. The neutral iron-diene complexes **26a** and **26b** were obtained by addition of ethyl prolinate or ethyl nipecotate to cation **27**, respectively. Intramolecular cyclization of **26a** and **26b** under the same reaction conditions (LDA-CO-acid) as described for complexes **9a** and **9b** afforded 6-azatricyclo[6.3.0.0^{2,6}]undecanecarboxylic acid derivative **28** and the bridged 8-azatricyclo[6.3.1.0^{2,6}]dodecanecarboxylic acid derivative **29**, respectively, in moderate yields. It is important to note that four new stereogenic centers of **28** and **29** are created with extreme diastereoselectivity. The product of the relative stereochemistry as shown was based upon comparison of their C-1 proton patterns with those of fused bicyclo[3.3.0]octanone and bicyclo[4.3.0]nonanone derivatives obtained by intramolecular cyclization of (η^4-diene)Fe(CO)$_3$ bearing a carbocster functional group.[2] The intramolecular cyclization of both diasteromers of **26a** and **26b** produced only one diastereomeric isomer of heterotricyclic compounds **28** and **29**. Unlike the α-cyano stabilized anion, the ester enolate **30** was obtained under kinetically controlled reaction conditions (LDA/THF-HMPA/-78 °C). The relative stereochemistry of **28** was assigned as 1,2-*cis*. The stereochemical course is consistent an anti, *si*-face addition of enolate **30** at the internal C-3 position of the diene ligand to give the tricyclic skeleton **31** after CO insertion and double bond insertion. None of the product arising from *re*-face approach of enolate **30** was found. However, the relative stereochemistry of **29** was assigned as 1,2-*trans*. The origin of different stereocontrols for the formation of five- and six-membered ring carboxylic acid is suggested as follows.[6] As stated previously, compound **29** presumably resulted from the anti, *si*-face of enolate **30** at the internal position (C-3) of the diene ligand. However, anti addition of the *si*-face of the enolate **32** with a longer carbon side chain would result in the boat-like transition state **32** (Scheme VII). Under such circumstances, the alternative chair-like transition state derived from the anti addition of the *re*-face of enolate **33** may be favorable and would lead to the 1,2-*trans* stereochemistry of **29** after carbonyl insertion followed by double insertion and protonation.

The reactions outlined herein demonstrate that the intramolecular iron-mediated cycloaddition can be an efficient method for the formation of tricyclo[6.3.0.0^{2,6}]undecane and tricyclo[7.3.0.0^{2,7}]dodecane ring skeletons. The ability to achieve the excellent stereocontrol of four stereogenic centers in hetero tricyclic compounds in a simple reaction may have further applications. Specially, the preparation of more highly substituted systems for natural product synthesis would be expected to demonstrate still higher levels of stereocontrol, as is often the case for the intramolecular Diels-Alder reaction.[7]

Scheme VI



Scheme VII



EXPERIMENTAL SECTION

All reactions were run under a nitrogen atmosphere in oven-dried glassware unless otherwise indicated. Anhydrous solvents or reaction mixtures were transferred via an oven-dried syringe or cannula. Diethyl ether (ether) and tetrahydrofuran (THF) were distilled under nitrogen from a deep blue sodium benzophenone ketyl solution. Methylene chloride was distilled from calcium chloride. Copper cyanide (CuCN), ethyl prolinate, ethyl nipecotate, cyclopentanone, and cyclohexanone were purchased from Aldrich Chemical Co. and used as received. Cations **1** and **27** were synthesized according to the procedure in the literature.[8] Flash column chromatography, following the method of Still,[9] was carried out with E. Merck silica gel (Kieselgel 60, 230-400 mesh) using the indicated solvents. Analytical thin-layer chromatography was performed with silica gel 60 F_{254} plastic plates of 0.2-mm thickness from E. Merck. The term "concentration" refers to the removal of solvent with an aspirator pump (Yamato Instrument Company Model WP-15) with a Buchi Rotovapor-R. The term "under nitrogen" implies that the apparatus was evacuated (oil pump) and then filled with nitrogen three times. Melting points were determined in open capillaries with a Thomas-Hoover apparatus and are uncorrected. ^{1}H nuclear magnetic resonance (NMR) spectra were obtained with JEOL-EX 400 (400 MHz). Chemical shifts are reported in parts per million with either tetramethylsilane (0.00 ppm) or $CHCl_3$ (7.26 ppm) as internal standards. ^{13}C NMR spectra were recorded with JEOL-EX 400 (100.4 MHz) spectrometers with $CDCl_3$ (77.0 ppm) as the internal standard. Infrared (IR) spectra were recorded with a JASCO IR-700 spectrometer. Mass spectra were acquired on a JEOL JMS-D 100 spectrometer at an ionization potential of 70 eV and are reported as mass/charge (*m/z*) with percent relative abundance. High-resolution mass spectra were obtained with an AEI MS-9 double-focusing mass spectrometer and a JEOL JMS-HX 110 spectrometer in the Department of Chemistry, Central Instrument Center, Taichung.

General Procedure I. Addition of Cyclic Zinc-Copper Reagents 8a and 8b to (η^5-Pentadienyl)Fe(CO)$_3$ Cation (1)

A solution of zinc-copper reagents **8a** or **8b** (3.0 mol-equiv.) in 5 mL of THF was added to a stirred suspension of cation **1** in 5 mL of THF at 5 °C under nitrogen. A homogeneous solution was obtained after the reaction mixture was stirred at 25 °C for 2 h. The reaction mixture was then quenched with saturated aqueous ammonium chloride solution at 0 °C and was diluted with 100 mL of 50% ethyl acetate/hexanes. The resultant solution was washed with water (100 mL × 3), brine (100 mL × 3), dried over anhydrous magnesium sulfate (10 g), and concentrated to give the crude mixture.

General Procedure II. Addition of Amino Acid Derivatives (ethyl prolinate or ethyl nipecotate to (η^5-2-Methylpentadienyl)Fe(CO)$_3$ Cation (27)

Ethyl prolinate or ethyl nipecotate (1.2 molar equiv) and triethylamine (1.2 molar equiv) in 5.0 mL of THF at -40

°C was added to a stirred suspension of cation **27** in 20 mL of THF under nitrogen. A homogeneous solution was obtained after the reaction mixture was stirred at -40 °C for 20 min. The reaction mixture was further stirred at 25 °C for 30 min and was then diluted with 100 mL of 50% ethyl acetate/hexanes. The resultant solution was washed with water (100 mL × 3) and brine (100 mL × 3), dried over anhydrous magnesium sulfate (10 g), and concentrated to give the crude mixture.

General Procedure III. Intramolecular Cyclization of (η^4-Diene)Fe(CO)$_3$ Complexes 9a-b, 14, 26a and 26b

In a typical procedure, to a solution of diisopropylamine (0.64 mL, 4.5 mmol) in 4.0 mL of THF under nitrogen at -78 °C was added rapidly, neat, via syringe, a solution of *n*-butyllithium (2.8 mL, 4.5 mmol, 1.6 M) in hexane followed by addition of 0.80 mL of hexamethylphosphoramide. The reaction mixture was stirred at -78 °C for 20 min. With the solution at -78 °C, carbon monoxide was added to the system via a syringe needle and was pressurized to *ca.* 2 psig (always keeping a positive pressure on the system) as measured by a regulator at the CO cylinder. The CO pressure was then released via an additional needle, and the CO was allowed to flow through the system for 20 s. A solution of a diene-iron complex (4.0 mmol) in 3.0 mL of THF was added dropwise via syringe, the gas exit needle was removed, and the closed system was pressurized to *ca.* 14 psig with CO. The mixture was stirred at -78 °C for 2 h and 25 °C for 2 h. After this time, the mixture was again cooled to -78 °C. The CO needle was removed, and the system was depressurized via insertion of a syringe needle into the septum, which was quickly removed when gas flow could no longer be heard. The reaction mixture was quenched with trifluoroacetic acid (5.0 molar equiv) via a syringe needle and was stirred at 25 °C for 2 h. After this time, the reaction mixture was diluted with a mixture of ethyl acetate/hexanes (1/2, 100 mL). The resultant solution was washed with water (100 mL × 3) and brine (100 mL × 3), dried over anhydrous magnesium sulfate (10 g), and concentrated to give the crude mixture.

Formation of Complexes 9a and 9b

The reaction mixture derived from General Procedure I (zinc-copper reagent **8a**, 15.0 mmol, cation **1**, 5.0 mmol) was separated by flash-column chromatography (5% ethyl acetate in hexane) to provide diastereomeric isomers **9a** and **9b** (1.1 g, 3.9 mmol, 79%) in a 1:1 ratio (based on their intensities on ^{13}C NMR). Attempts to separate the mixture were unsuccessful. IR (CH_2Cl_2) 3059, 2971, 2238, 2049, 1981, 1620, 1453, 1381, 1101, 912, 876, 851 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.45 (m, 2 H), 5.34 (m, 2 H), 2.53 (m, 2 H), 2.25 (m, 2 H), 2.08-2.00 (m, 4 H), 1.98-1.71 (m, 12 H), 1.64 (m, 2 H), 1.41 (m, 1 H), 1.22 (m, 1 H), 1.09 (m, 1 H), 0.96 (m, 1 H) ppm; ^{13}C NMR (100.4 MHz, $CDCl_3$) δ 210.8, 122.9, 122.6, 90.9, 90.8, 87.4, 87.1, 56.7, 56.5, 48.5, 48.3, 40.9, 40.8, 34.1, 33.6, 33.5, 31.8, 31.2, 30.8, 30.7, 24.2, 23.8 ppm; MS (EI) *m/z* (rel intensity) 273 (M^+-CO, 6), 245 (98), 217 (100), 214 (48), 189 (5), 163 (6), 161 (10), 148 (11), 134 (12), 92 (7), 67 (14), 54 (17); HRMS (EI) calcd for $C_{13}H_{15}FeNO_2$ (M^+-CO) 273.0448, found 273.0447.

Formation of Complex 14

The reaction mixture derived from General Procedure I (zinc-copper reagent **8b**, 15.0 mmol, cation **1**, 5.0 mmol) was separated on a flash-column chromatography (5% ethyl acetate in hexane) to provide a mixture of diastereomeric isomer **14** (1.2 g, 3.8 mmol, 76%) in a 1:1 ratio (based on their intensities on ^{13}C NMR). Attempts to separate the mixture were unsuccessful. IR (CH_2Cl_2) 3061, 3054, 2988, 2940, 2236, 2049, 1975, 1620, 1449, 1364, 1271, 1223, 1107, 895 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.32 (m, 2 H), 5.24 (m, 2 H), 2.78 (m, 2 H), 2.35 (m, 2 H), 1.88 (m, 2 H), 1.78 (m, 2 H), 1.65 (m, 4 H), 1.57 (m, 4 H), 1.46-1.39 (m, 8 H), 1.36 (m, 2 H), 1.22 (m, 2 H), 0.96 (m, 2 H) ppm; ^{13}C NMR (100.4 MHz, $CDCl_3$) δ 210.9, 121.9, 91.0, 90.8, 87.4, 87.3, 55.7, 55.5, 43.0, 41.6, 41.5, 40.9, 34.2, 34.1, 33.8, 33.5, 30.4, 30.0, 29.7, 29.4, 24.8, 24.7, 24.6, 24.0, 22.6, 22.0, 14.0 ppm; MS (EI) *m/z* (rel intensity) 287 (M^+, 6), 259 (80), 231 (100), 229 (46), 203 (6), 153 (29), 147 (28), 133 (71), 123 (26), 109 (17), 67 (29), 56 (40); HRMS (EI) calcd for $C_{14}H_{17}FeNO_2$ (M^+) 287.0604, found 287.0611.

Formation of Triquinane Derivatives 10 and 12

The reaction mixture derived from General Procedure III (complexes **9a** and **9b**, 1.35 g, 4.5 mmol) was separated by flash-column chromatography (5% ethyl acetate in hexane) to provide a mixture of diastereomeric isomers **10** and **12** (0.40 g, 1.73 mmol, 20% and in a 3:1 ratio (based on their intensities on ^{13}C NMR), tricyclic compound **11** (0.16 g, 0.75 mmol, 8%) and **13** (0.80 g, 0.37 mmol, 4%). Attempts to separate the mixture of **10** and **12** were unsuccessful. Triquinanes **10** and **12**: IR (CH_2Cl_2) 3052, 2967, 2232, 1740, 1661, 1451, 1410, 1148, 812 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.15 (m), 2.97-2.70 (m), 2.36-1.65 (m), 1.47-1.38 (m), 1.21 (m) ppm; ^{13}C NMR (100.4 MHz, $CDCl_3$) δ 218.3, 125.9, 123.7, 54.5, 53.9, 52.4, 51.7, 50.7, 49.9, 40.0, 38.1, 34.4, 33.1, 33.0, 32.9, 31.4, 26.5, 25.7, 25.4, 21.9 ppm; MS (70 eV) *m/z* (rel intensity) 189 (M^+, 10), 188 (73), 161 (33), 160 (67), 159 (33), 134 (73), 133 (87), 132 (27), 121 (20),

120 (67), 105 (67), 96 (47), 91 (53), 79 (27), 68 (52), 55 (100), 54 (47); HRMS (EI) m/e calcd. for $C_{12}H_{15}NO$ (M^+) 189.1154, found 189.1153.

(1*S,2*S**,6*R**)-2-Cyano-9-hydroxy-10-oxotricyclo[6.4.0.0^{2,6}]dodec-8-ene (11)**

mp: 172-173 °C; IR (CH_2Cl_2) 3453, 3052, 2963, 2234, 1734, 1698, 1659, 1453, 1381, 1356, 1292, 1242, 1154, 1046 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.04 (s, OH), 3.39 (dd, *J* = 9.7, 4.3 Hz, 1 H), 3.05 (m, 1 H), 2.92 (dd, *J* = 22.0, 12.7 Hz, 1 H), 2.68 (ddd, *J* = 17.1, 4.9, 2.5 Hz, 1 H), 2.47 (ddd, *J* = 17.1, 15.6, 5.8 Hz, 1 H), 2.33 (m, 1 H), 2.29 (m, 1 H), 2.22 (m, 1 H), 1.96-1.91 (m, 3 H), 1.81 (m, 1 H), 1.73-1.56 (m, 2 H) ppm; ^{13}C NMR (100.4 MHz, $CDCl_3$) δ 193.6, 142.6, 135.3, 123.9, 51.3, 49.8, 48.7, 35.0, 34.1, 31.6, 31.4, 25.0, 24.6 ppm; MS (70 eV) *m/z* (rel intensity) 217 (M^+, 38), 190 (8), 171 (14), 124 (100), 119 (11), 105 (16), 96 (27), 94 (49), 67 (24); HRMS (EI) m/e calcd. for $C_{13}H_{15}NO_2$ (M^+) 217.1103, found 217.1100.

(1*S,2*R**,6*S**)-2-Cyano-9-hydroxy-10-oxotricyclo[6.4.0.0^{2,6}]dodec-8-ene (13)**

mp: 139-140 °C; IR (CH_2Cl_2) 3457, 3065, 3046, 2965, 2232, 1748, 1698, 1659, 1422, 1383, 1263, 1181, 1142, 912 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.06 (s), 3.12 (m, 1 H), 3.03 (m, 1H), 2.78-2.69 (m, 2 H), 2.45 (m, 1 H), 2.39 (d, *J* = 19.0 Hz, 1 H), 2.24-2.03 (m, 5 H), 1.94 (m, 2 H), 1.52 (m, 1 H) ppm; ^{13}C NMR (100.4 MHz, $CDCl_3$) δ 193.5, 141.6, 137.0, 122.6, 52.5, 51.3, 48.3, 36.3, 35.3, 33.1, 32.4, 26.1, 25.6 ppm; MS (70 eV) *m/z* (rel intensity) 217 (M^+, 71), 203 (11), 200 (8), 172 (22), 161 (9), 124 (100), 120 (12), 106 (16), 94 (38), 91 (10); HRMS (EI) *m/z* calcd. for $C_{13}H_{15}NO_2$ (M^+) 217.1103, found 217.1101.

Formation of Tricyclic Compounds 15 and 16

The reaction mixture derived from General Procedure III (complex **14**, 0.7 g, 2.2 mmol) was separated by flash-column chromatography (5% ethyl acetate in hexane) to provide a mixture of diastereomeric isomers **15** and **16** (0.10 g, 0.5 mmol, 23% and in a 7:2 ratio (based on their intensities on ^{13}C NMR), tricyclic compound **17** (0.07 g, 0.3 mmol, 14%) and **18** (trace). Attempts to separate the mixture of **15** and **16** were unsuccessful. Tricyclic compounds **15** and **16**: IR (CH_2Cl_2) 3179, 2895, 2731, 2259, 1738, 1219, 934, 922 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.19 (m), 2.82-2.74 (m), 2.49-2.00 (m), 1.89-1.33 (m), 0.87 (m) ppm; ^{13}C NMR (100.4 MHz, $CDCl_3$) δ 193.4, 143.0, 134.7, 122.9, 51.4, 42.9, 42.3, 35.2, 31.5, 28.3, 25.8, 23.9, 22.9, 22.6, 22.1, 19.2 ppm; MS (30 eV) *m/z* (rel intensity) 203 (M^+, 50), 176 (35), 175 (25), 158 (98), 148 (45), 147 (30), 141 (25), 134 (25), 128 (55), 116 (33), 100 (25), 96 (30), 86 (100), 83 (65); HRMS (EI) *m/z* calcd. for $C_{13}H_{17}NO$ (M^+) 203.1310, found 203.1314.

(1*S,2*R**,7*S**)-2-Cyano-10-hydroxy-11-oxotricyclo[7.4.0.0^{2,7}]tridec-9-ene (17)**

mp: 200-201 °C; IR (CH_2Cl_2) 3451, 3057, 2900, 1659, 1385, 1260, 1140, 907, 891 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.03 (s, OH), 3.22 (d, *J* = 11.7 Hz, 1 H), 2.68-2.54 (m, 4 H), 2.43 (m, 1 H), 2.12 (m, 1 H), 1.89-1.46 (m, 7 H), 1.35 (m, 1 H), 1.16 (m, 1 H); ^{13}C NMR (100.4 MHz, $CDCl_3$) δ 193.5, 143.0, 134.8, 122.9, 51.4, 43.0, 42.3, 35.2, 28.4, 25.8, 23.9, 22.9, 22.1, 19.2; MS (70 eV) *m/z* (rel intensity) 231 (M^+, 100), 230 (15), 213 (13), 184 (18), 147 (10), 125 (15), 107 (69), 96 (45), 91 (15), 67 (20); HRMS (EI) *m/z* calcd. for $C_{14}H_{17}NO_2$ (M^+) 231.1259, found 231.1262.

Formation of [Ethyl 4-Methyl N-[(2-5-η)-2,4-pentadienyl]*prolinate*]tricarbonyliron Complex (26a)

The reaction mixture derived from General Procedure II (ethyl propionate 1.3 g, 9.2 mmol, cation **27**, 2.4 g, 7.7 mmol) was separated by flash-column chromatography (5% ethyl; acetate in hexane) to provide two diastereomeric isomers of ***26a*** (2.1 g, 5.8 mmol, 75%) in a 1:1 ratio (based on their intensities on ^{13}C NMR). Isomer (a) IR (CH_2Cl_2) 3050, 2990, 2048, 1976, 1734, 1260, 1252, 1190, 1090, 900 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.32 (d, *J* = 7.3 Hz, 1 H),4.17 (q, *J* = 7.3 Hz, 2 H), 3.18 (m, 1 H), 3.10 (m, 1 H), 2.93 (dd, *J* = 12.7, 4.4 Hz, 1 H), 2.48 (m, 1 H), 2.24 (m, 1 H,), 2.18 (s, 3 H), 2.04-1.98 (m, 2 H), 1.90-1.77 (m, 4 H), 1.59 (s, 1 H), 1.27 (t, *J* = 7.3 Hz, 3 H) ppm; ^{13}C NMR (100.4 MHz, $CDCl_3$) δ 210.7, 173.7, 108.4, 87.0, 64.5, 60.5, 52.5, 52.1, 51.9, 42.7, 29.2, 24.2, 22.8, 14.2 ppm. Isomer (b) IR (CH_2Cl_2) 3042, 2991, 2048, 1975, 1732, 1290, 1260, 1245, 1097, 910 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.28 (d, *J* = 7.3 Hz, 1 H), 4.18 (m, 2 H), 3.10 (m, 2 H), 2.81 (dd, *J* = 8.4, 4.0 Hz, 1 H), 2.48 (m, 1 H), 2.39 (m, 1 H), 2.24 (m, 1 H), 2.19 (s, 3 H), 2.07 (m, 1 H), 1.89-1.78 (m, 4 H), 1.51 (s, 1 H), 1.28 (t, *J* = 7.3 Hz, 3 H) ppm; ^{13}C NMR (100.4 MHz, $CDCl_3$) δ 210.7, 173.7, 108.4, 87.0, 64.5, 60.5, 52.5, 52.1, 51.9, 42.7, 29.2, 24.2, 22.8, 14.2 ppm; MS (70 eV) *m/z* (rel intensity) 307 (M^+ - 2CO, 50), 280 (58), 279 (36), 278 (22), 277 (21), 221 (22), 208 (14), 198 (100), 170 (53), 169 (44), 150 (28), 126 (44); HRMS (EI) *m/z* calcd. for $C_{14}H_{21}FeNO_3$ (M^+ - 2CO) 307.0870, found 307.0862.

Formation of [Ethyl 4-Methyl N-[(2-5-η)-2,4-pentadienyl]nipecotate]tricarbonyliron Complex (26b)

The reaction mixture derived from General Procedure II (ethyl nipecotate 0.79 g, 5.0 mmol, cation **27**, 1.5 g, 5.0

mmol) was separated on a flash-column chromatography (5% ethyl; acetate in hexane) to provide two diastereomeric isomers of **26b** as a yellow oil (1.6 g, 4.2 mmol, 85%) in a 1:1 ratio (based on their intensities on ^{13}C NMR). IR (CH_2Cl_2) 3065, 2984, 2046, 1975, 1713, 1262, 901, 874, 822, 785 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.29 (d, J = 7.3 Hz, 2 H), 4.06 (m, 4 H), 2.94 (m, 1 H), 2.73 (m, 2 H), 2.65-2.59 (m, 2 H), 2.49-2.42 (m, 3 H), 2.34 (m, 2 H) ppm; ^{13}C NMR (100.4 MHz, $CDCl_3$) δ 210.9, 174.2, 174.1, 125.5, 108.1, 87.5, 64.9, 60.3, 57.6, 55.4, 54.2, 53.6, 52.4, 51.5, 51.4, 42.8, 42.7, 41.9, 41.8, 26.9, 26.8, 24.6, 24.4, 24.2, 14.2, 14.1 ppm; MS (20 eV) *m/z* (rel intensity) 321 (M^+ - 2CO, 100), 294 (91), 291 (74), 238 (35), 222 (35), 220 (26), 212 (78), 183 (26), 171 (35), 139 (7); HRMS (EI) *m/z* calcd. for $C_{15}H_{23}FeNO_3$ (M^+ - 2CO) 321.1027, found 321.1020.

Formation of (1*R,2*R**,8*S**,11*S**)-2-Carbethoxy-11-methyl-9-oxo-6-azatricyclo[6.3.0.0^{2,6}]undecane (28)**

The reaction mixture derived from General Procedure III (complexes **26a**, 1.8 g, 4.8 mmol) was separated by flash-column chromatography (30% ethyl; acetate in hexane) to provide **28** as a colorless oil (0.48 g, 1.9 mmol, 39%). IR (CH_2Cl_2) 2997, 2968, 1734, 1460, 1304, 1188, 1113 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.23 (m, 1 H), 4.12 (m, 1 H), 3.46 (dd, J = 10.7, 3.9 Hz, 1 H), 3.21 (m, 1 H), 3.08 (m, 1 H), 3.03 (m, 1 H), 2.97 (dd, J = 17.6, 10.7 Hz, 1 H), 2.77 (m, 1 H), 2.69 (m, 1 H), 2.50 (m, 1 H), 2.43 (dd, J = 18.1, 9.8 Hz, 1 H), 2.09 (dd, J = 18.1, 7.3 Hz, 1 H), 1.88 (m, 1 H), 1.85-1.77 (m, 2 H), 1.29 (t, J = 7.3 Hz, 3 H), 1.06 (d, J = 7.3 Hz, 3 H); ^{13}C NMR (100.4 MHz, $CDCl_3$) δ 219.1, 174.5, 78.6, 61.0, 56.3, 56.1, 54.8, 53.4, 46.4, 36.6, 30.5, 24.3, 15.9, 13.7 ppm; MS (70 eV) *m/z* (rel intensity) 252 (M^++1, 99), 180 (17), 178 (100), 134 (18), 126 (25), 108 (99), 106 (50), 80 (78); HRMS (EI) *m/z* calcd. for $C_{14}H_{21}NO_3$ (M^+) 251.1521, found 251.1516.

Formation of (1*R,2*R**,3*R**,6*S**)-1-Carbethoxy-3-methyl-5-oxo-8-azatricyclo[6.3.1.0^{2,6}]dodecane (29)**

The reaction mixture derived from General Procedure III (complexes **26b**, 1.1 g, 2.9 mmol) was separated by flash-column chromatography (30% ethyl; acetate in hexane) to provide **29** as a colorless oil (0.36 g, 1.4 mmol, 50%). IR (CH_2Cl_2) 3067, 2980, 1726, 1450, 1371, 1300, 1244, 1074, 880 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.23 (q, J = 6.8 Hz, 2 H), 3.30 (m, 1 H), 3.23 (dd, J = 14.2, 2.3 Hz, 1 H), 3.07 (d, J = 14.2 Hz, 1 H), 3.01 (m, 2 H), 2.92-2.83 (m, 3 H), 2.75 (m, 1 H), 2.52 (dd, J = 17.1, 7.8 Hz, 1 H), 2.11 (m, 1 H), 2.06 (d, J = 17.1 Hz, 1 H), 1.95 (m, 1 H), 1.81 (td, J = 18.6, 5.4 Hz, 1 H), 1.55 (m, 1 H), 1.30 (t, J = 6.8 Hz, 3 H), 0.99 (d, J = 7.3 Hz, 3 H) ppm; ^{13}C NMR (100.4 MHz, $CDCl_3$) δ 219.2, 176.0, 61.7, 51.9, 51.5, 51.4, 48.4, 44.4, 43.7, 38.8, 37.9, 33.4, 21.6, 18.9, 14.0; MS (70 eV) *m/z* (rel intensity) 265 (M^+, 60), 192 (40), 169 (43), 169 (100), 140 (42), 96 (90); HRMS (EI) *m/z* calcd. for $C_{14}H_{21}NO_3$ (M^+) 251.1678, found 265.1685.

SUPPLEMENTARY MATERIALS

ORTEP diagram showing the atom numbering scheme and tables of crystallographic data, and bond lengths and angles for **17** (4 pages).

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Diene iron complex; Triquinane; Tricyclic compound; Heterotricycles.

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