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Synthesis and X-Ray Crystal Structures of Tricyclic Ketone Containing *trans*-Fused Bicyclo[3.3.0]octane Unit

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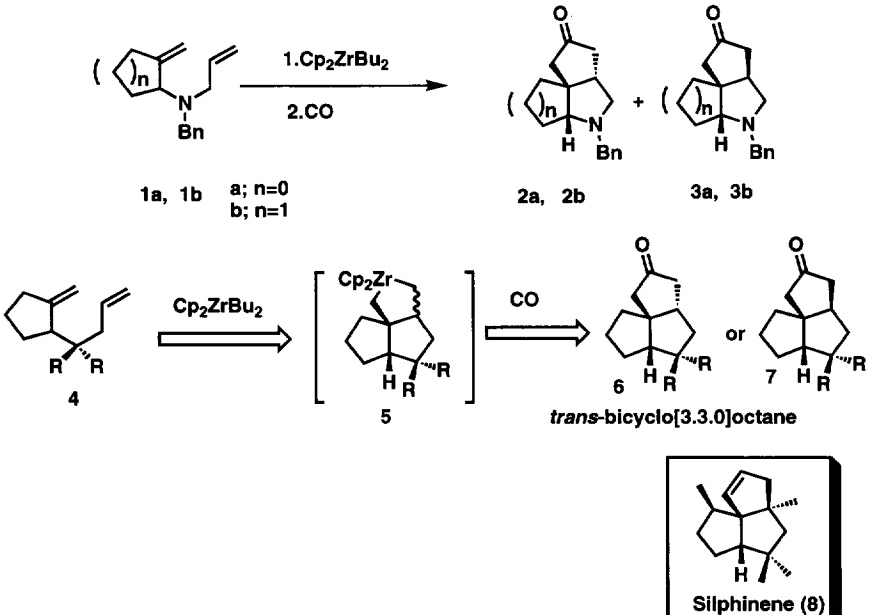
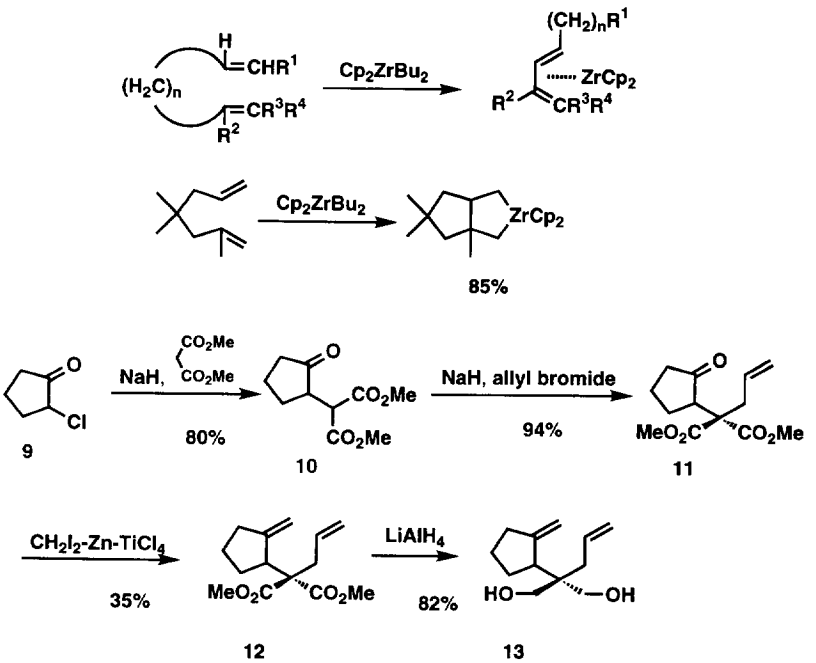
Abstract: Zirconium promoted diene cyclization of **13** and **17** followed by carbonylation and treatment with iodine and then 10% HCl gave two tricyclic ketones, **16a** and **16b**, by one pot. One of them posseces a *trans*-fused bicyclo[3.3.0]octane unit and the other has an angular triquinane, silphinene skeleton.

Zirconium promoted diyne, enyne or diene cyclization is useful for synthetic organic chemistry because a new carbon-carbon bond is formed from multiple bonds. Recently, we reported the synthesis of heterocycles using zirconium promoted cyclization and the total synthesis of (-)-dendrobine.[1] During the course of this study we obtained tricyclic compounds containing *trans*-fused azabicyclo[3.3.0]octane unit.[2] The reaction of **1a** with Cp_2ZrBu_2[3] followed by treatment with carbon monoxide and then iodine provided tricyclic compounds, **2a** and **3a**, in 36% and 18% yields, respectively. The structure of the major product **2a** was confirmed by X-ray diffraction method and its ring junction of 5,5 ring system is *trans*.



In a similar procedure, treatment of **1b** with Cp_2ZrBu_2 afforded **2b** and **3b**, in 31% and 15% yields, respectively. In this case, it was found that the major product also has a *trans*-azabicyclo[3.3.0]octane unit. If cyclopentane derivative **4** reacts with Cp_2ZrBu_2 followed by treatment with carbon monoxide, tricyclic compound, **6** or **7** , would be formed *via* zirconacycle **5**. In general, the ring junction of 5,5 ring system is known to be *cis* and the synthesis of *trans*-fused bicyclo[3.3.0]octane skeleton is quite difficult.[4] If *cis*-fused product **7** is obtained from **4**, it possesses an angular triquinane skeletone, which can be converted into silphinene (**8**).

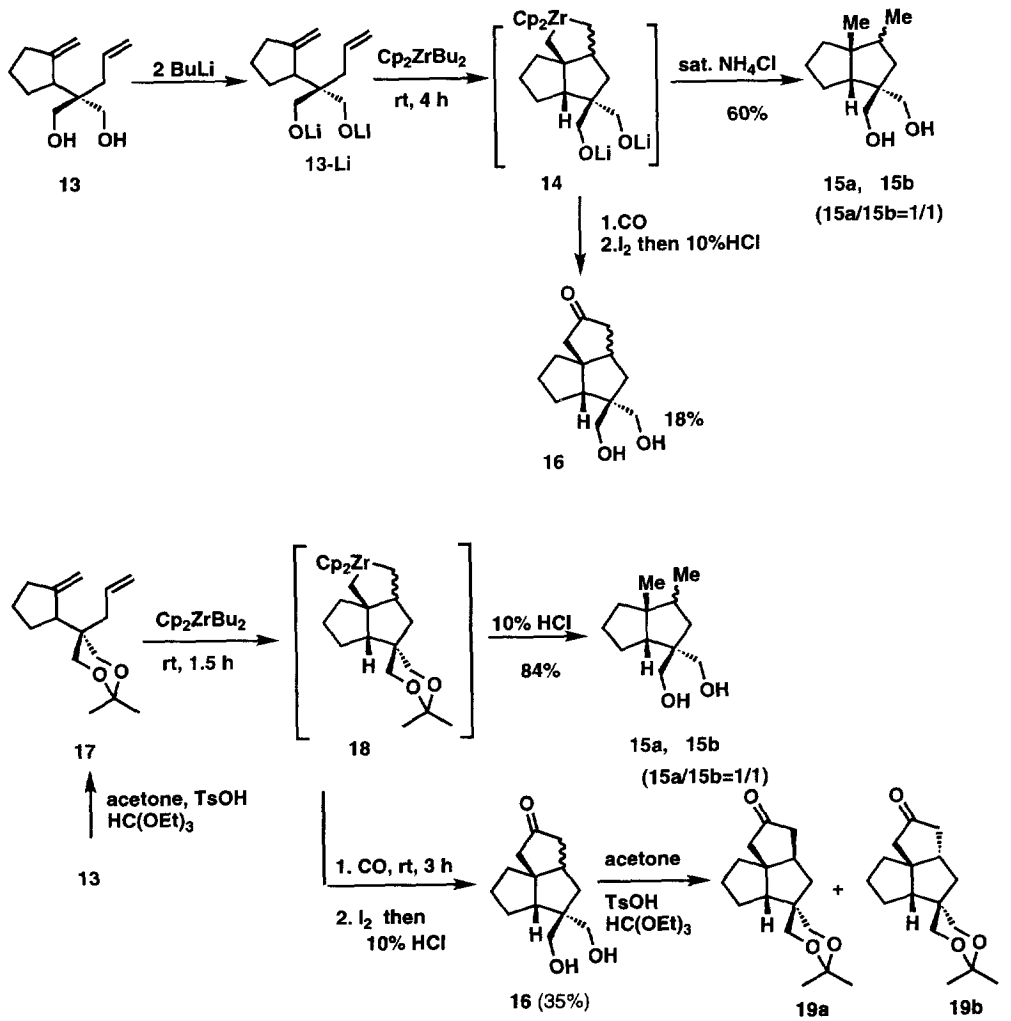
It was known that the reaction of Cp_2ZrCl_2 with non-conjugated dienes containing a mono- or 1,2-disubstituted alkene at one end and a 1,1-di- or trisubstituted alkene at the other gives conjugated diene-zirconocene *via* multipositional regioisomerization, and a cyclization product could not be obtained from these dienes.[5] However, it was also known that the presence of quaternary carbon in the tether part of dienes not only blocks alkene isomerization but also promotes bicyclization.[5] The starting material was prepared from 2-chlorocyclopentanone **9**. Alkylation of dimethylmalonate with **9** afforded **10**, which was further alkylated with allylbromide to give **11** in good yield. Methylenation of keto-carbonyl group of **11** by the Nozaki-Lombardo method[6] afforded **12**, which was followed by $LiAlH_4$ reduction to give diol **13**.



Diene **13** was treated with 2 equivalents of BuLi in THF. To the lithium salt **13-Li** in THF was added Cp_2ZrBu_2 at -78 °C[7] and the solution was stirred at room temperature for 4 h. Hydrolysis of the reaction mixture with aqueous NH_4Cl solution gave inseparable mixture of two isomers, **15a** and **15b**, in 60% yield (ratio of **15a** to **15b** is 1 to 1). This means that the presence of quaternary carbon in the tether part of dienes promoted the cyclization and two zirconacycles were formed from this reaction. Though the stereochemistry of **15a** and **15b** could not be determined at this stage, it is estimated that the ring junctions of 5,5 ring

systems of two isomers are *cis*. The ring junction methyl group of **15a** is *cis* to the methyl group on the five membered ring and that of **15b** is *trans* to the methyl group on the five membered ring. An argon atmosphere of a reaction vessel of zirconacycle **14** was changed into carbon monoxide and the solution was stirred for 3 h. A THF solution of iodine was added to the reaction mixture at -78 °C and the solution was stirred at room temperature for 30 min. After the usual workup, the desired carbonylation product **16** was obtained in 18% yield. Though the spectral data of **16** indicated that the product was tricyclic ketone, the two isomers were not able to be separated by column chromatography.[8] Various attempts for the separation of two isomers were unsuccessful. After the diols of **16** were protected with various reagents, the separation of two isomers was carried out, but the two isomers could not be separated.

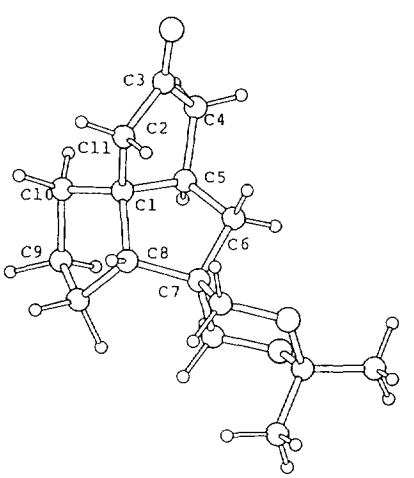
Subsequently, diol **13** was converted into acetonide **17**, which was treated with Cp_2ZrBu_2 in a similar manner. Hydrolysis of zirconacycle **18** with 10% HCl afforded **15** in 84 % yield. From the NMR spectrum, the ratio of **15a** to **15b** was 1 to 1. The insertion of carbon monoxide into zirconacycle **18** followed by

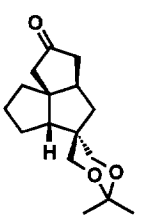


treatment with iodine and then 10% HCl gave tricyclic ketone **16** in 35% yield (**16a/16b**=1/1). The fact that the hydrolysis products, **15a** and **15b**, were obtained in good yields, means that two zirconacycles were formed in good yields. However, the yields of the carbonylation products **16a** and **16b** were modest. Since the hydrolysis products, **15a** and **15b**, were not obtained in this reaction and the ratio of **15a** to **15b** is same as that of **16a** to**16b**, the insertion of carbon monoxide into carbon-zirconium bond of zirconacycle **18** would occur and then partial decomposition of the intermediary zirconacycle containing carbon monoxide would occur.

In order to confirm the stereochemistry of the tricyclic ketones, compound **16** was reconverted into acetonide **19** in 82% yield. Compounds, **19a** and **19b**, could be separated as crystalline products by repeated preparative thin layer chromatography on silica gel and the stereochemistry of each isomer was determined by X-ray diffraction method. The results are shown in Figures 1 and 2. Evidently, all the ring junctions of the 5,5 ring system of **19a** are *cis*[10] and compound **19a** possesses angular triquinane skeleton, silphinene **8**, which would be prepared using this procedure. Compound **19b** has a *trans*-fused bicyclo[3.3.0]octane unit. The bond angle of C(2)-C(1)-C(8), C(4)-C(5)-C(6), C(1)-C(5)-C(4), and C(2)-C(1)-C(5) are 124.3°, 129.2°, 103.5°, and 101.0°, respectively. The bond distances of C(1)-C(5), C(4)-C(5), and C(5)-C(6) are 1.528Å, 1.524Å, and 1.518Å, respectively.

Figure 1 A Perspective view of **19a**

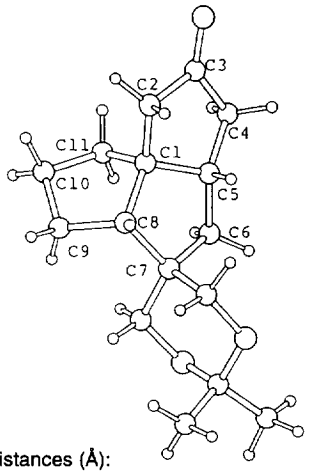


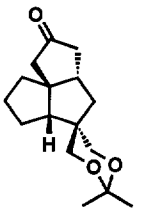


19a

Bond distances (Å):
C(4)-C(5), 1.531(5); C(1)-C(5), 1.548(4); C(1)-C(2), 1.540(3);
C(5)-C(6), 1.522(5); C(1)-C(8), 1.558(4); C(1)-C(12), 1.539(6)
Bond angles (°):
C(2)-C(1)-C(8), 115.2(2); C(4)-C(5)-C(6), 114.3(3);
C(1)-C(5)-C(4), 105.8(2); C(2)-C(1)-C(5), 102.8(2);
C(5)-C(1)-C(8), 105.0(2); C(1)-C(5)-C(6), 103.1(2)

Figure 2 A Perspective view of **19b**





19b

Bond distances (Å):
C(4)-C(5), 1.524(4); C(1)-C(5), 1.528(4); C(1)-C(2), 1.531(3);
C(5)-C(6), 1.518(4); C(1)-C(8), 1.550(3); C(1)-C(12), 1.522(3)
Bond angles (°):
C(2)-C(1)-C(8), 124.3(2); C(4)-C(5)-C(6), 129.2(3);
C(1)-C(5)-C(4), 103.5(2); C(2)-C(1)-C(5), 101.0(2);
C(5)-C(1)-C(8), 104.0(2); C(1)-C(5)-C(6), 104.2(2)

It is obvious that the ring junction of 5,5 ring system (five-membered ring having carbonyl moiety and five-membered ring having acetonide moiety) is *trans*. It was interesting that the *trans*-fused bicyclo[3.3.0]octane unit was synthesized from an easily obtainable starting material by a one pot reaction.

EXPERIMENTAL SECTION

All manipulations were performed under an argon atmosphere. Solvents were distilled under an argon atmosphere from sodium benzophenone (THF) or CaH_2 (CH_2Cl_2). All other reagents and solvents were purified when necessary using standard procedures. Zinc dust was washed several times with 5% HCl, and then water, EtOH, and ether and dried under reduced pressure. Column chromatography was performed on silicagel 60 (70-230 mesh, 60 Å) and flash chromatography was performed on silicagel 60 (230-400 mesh, 60 Å) using the indicated solvent.

Dimethyl 2-(2-oxocyclopentanyl) malonate (10). Dimethyl malonate (0.97 mL, 8.50 mmol) was added a suspension of NaH (60% oil dispersion, 267 mg, 6.70 mmol) in THF-DMF (20 mL, 1:1) at 0 °C and the solution was stirred for 30 min at room temperature. 2-Chlorocyclopentanone (0.5 mL, 5.00 mmol) was added to the solution at 0 °C and the solution was stirred at room temperature for 8 h. Sat. aqueous NH_4Cl solution was added to the mixture and the aqueous layer was extracted with ether. The organic layer was washed with sat. $NaHCO_3$ solution, brine , dried over Na_2SO_4 and concentrated, The residue was purified by column chromatography on silica gel (hexane:ethyl acetate, from 5:1 to 2:1) to give colorless oil of **10** (855 mg, 80%). IR (neat) υ 1738cm^{-1}; ^{1}H-NMR (270 MHz, $CDCl_3$) δ 1.70-2.00 (m, 2 H), 2.00-2.50 (m, 4 H), 2.60-2.80 (m, 1 H), 3.73 (s, 3 H), 3.78 (s, 3 H), 3.84 (d, J = 5.8 Hz, 1 H); MS 214 (M+), 183, 155, 151 (bp), 132, 123, 83, 59, 55; HRMS for $C_{10}H_{14}O_5$, calcd 214.0841, found 214.0870.

Dimethyl 2-allyl-2-(2-oxocyclopentanyl) malonate (11). To the suspension of NaH (60 % oil dispersion, 189 mg, 4.71 mmol) in THF (20 mL) was added a solution of 10 in THF (1 mL) at 0 °C and the solution was stirred at room temperature for 30 min. Allyl bromide (0.48 mL, 5.59 mmol) was added to the solution and the solution was stirred at room temperature for 17 h. Sat. aqueous NH_4Cl solution was added to the mixture and the aqueous layer was extracted with ether. The organic layer was washed with sat, $NaHCO_3$ solution, brine, dried over Na_2SO_4 and concentrated, The residue was purified by column chromatography on silica gel (hexane:ethyl acetate, from 5:1 to 2:1) to give colorless oil of **11** (951 mg, 94%). IR (neat) υ 1738, 1638 cm^{-1}; ^1H-NMR (270 MHz, $CDCl_3$) δ 1.65-1.85 (m, 2 H), 2.00-2.10 (m, 1 H), 2.15-2.30 (m, 3 H), 2.55-2.85 (m, 3 H), 3.74 (s, 3 H), 3.75 (s, 3 H), 5.06-5.17 (m, 2 H), 5.86-6.03 (m, 1 H); MS 254 (M^+), 223, 195, 171, 139 (bp), 59, 55, 41; HRMS for $C_{13}H_{18}O_5$, calcd 254.1154, found 254.1130.

Dimethyl 2-allyl-2-(2-methylenecyclopentyl) malonate (12). To a THF suspension of Zn (800 mg, 12.2 mmol) in THF (14 mL) was added diiodomethane (0.55 mL, 6.80 mmol) at 0 °C for 30 min. To the suspension was added $TiCl_4$ (1.0 M CH_2Cl_2 solution, 1.5 mL, 1.5 mmol) and the suspension was stirred for 16 h. 10% HCl solution was added to the suspension at 0°C and the aqueous layer was extracted with ether. The organic layer was extracted with sat. $NaHCO_3$ solution, and brine, dried over Na_2SO_4 and concentrated. The residue was purified by column chromatography on silica gel (hexane:ethyl acetate, 10:1) to give colorless oil of **12** (121 mg, 35 %). IR (neat) υ 1732, 1649, 1640 cm^{-1}; ^1H-NMR (270 MHz, $CDCl_3$) δ 1.36-1.54 (m, 1 H), 1.63-1.78 (m, 2 H), 1.96-2.10 (m, 1H), 2.10-2.34 (m, 2 H), 2.68 (dddd, J = 1.2, 1.2, 7.2, 14.2 Hz, 1 H), 2.74 (dddd, J = 1.2, 1.2, 7.2, 14.2 Hz, 1 H), 3.14 (dddd, J = 1.9, 2.1, 8.2, 10.3 Hz, 1 H), 3.70 (s, 3 H), 3.71 (s, 3 H), 4.86 (m, 1 H), 4.99 (m, 1 H), 5.06 (dddd, J = 1.2, 1.2, 2.1, 10.2 Hz, 1 H), 5.08 (dddd, J = 1.2, 1.2, 2.1, 17.3 Hz, 1 H), 5.86 (dddd, J = 7.2, 7.2, 10.2, 17.3 Hz, 1 H); MS 251 (M^+-1), 221, 220, 193, 192, 179, 161, 147, 133, 81 (bp), 59; HRMS for $C_{13}H_{17}O_3$ (M^+-OMe), calcd 221.1177, found 221.1154.

2-hydroxymethyl -2-(2-nethylene cyclopentyl)-4-pentene-1-ol. A suspension of $LiAlH_4$ in THF (0.5 mL) was added a solution of **12** (16.9 mg, 0.067 mmol) in THF (1.0 mL) at 0 °C and the suspension was stirred at 0 °C for 1.5 h. Na_2SO_4•$10H_2O$ was added to the reaction mixture and the suspension was stirred till the precipitates was chaged to white solid. Undissolved material was filtered off and the filtrate was concentrated. The residue was purified by column chromatography on silica gel (hexane:ethyl acetate, 5:1 to 2:1) to give colorless oil of **13** (11 mg, 82 %). IR (neat) υ 3358, 1638 cm^{-1}; ^1H-NMR (270 MHz, $CDCl_3$) δ 1.25-1.50 (m, 1 H), 1.56-1.96 (m, 3 H), 2.08-2.36 (m, 6 H), 2.79 (m, 1 H), 3.64-3.86 (m, 4 H), 4.89 (m, 1 H), 5.04-5.15 (m, 3 H), 5.88 (m, 1 H); MS 178 (M^+-H_2O), 165, 147, 81 (bp), 67; HRMS for $C_{12}H_{18}O$ (M^+-H_2O), calcd 178.1358, found 178.1387.

1, 3-dioxa-2,2-dimethyl-5-allyl-5-(2-methylene cyclopentyl)vyvlohexene (17). A solution of **13** (71.2 mg, 0.36 mmol), TsOH•H_2O (6.8 mg, 0.04 mmol) and ethyl orthoformate (0.3 mL, 1.80 mmol) in acetone (3.0 mL) was stirred at room temperature for 1 h. Sat. $NaHCO_3$ solution was added to the reaction mixture at 0 °C and the aqueous layer was extracted with ethyl ether. The organic layer was washed with brine, dried over Na_2SO_4 and concentrated. The residue was purified by column chromatography on silica gel (hexane:ethyl acetate, 10:1) to give colorless oil of 14 (80.2 mg, 94%). IR (neat) υ 1646, 1638 cm^{-1}; ^1H-NMR (270 MHz, $CDCl_3$) δ 1.30-1.48 (m, 1 H), 1.40 (s, 6 H), 1.50-1.93 (m, 3 H), 2.08-2.26 (m, 2 H), 2.29 (dddd, J = 1.4, 2.1, 7.5, 14.3 Hz, 1 H), 2.44 (ddd, J = 1.2, 7.5, 14.3 Hz, 1 H), 2.64 (m, 1 H), 3.59 (dd, J = 1.4, 11.6 Hz, 1 H), 3.66 (dd, J = 1.4, 11.5 Hz, 1 H), 3.83 (d, J = 11.6 Hz, 1 H), 3.84 (d, J = 11.5 Hz, 1 H), 4.82 (m, 1 H), 5.06 (m, 1 H), 5.08 (dddd, J = 1.2, 2.4, 10.3 Hz, 1 H), 5.09 (ddd, J = 1.4, 2.4, 17.8 Hz, 1 H), 5.87 (dddd, J = 7.5, 7.5, 10.3, 17.8 Hz, 1 H); MS 236 (M^+), 221, 161, 148, 133, 119, 105, 87 (bp), 79, 67, 59, 43, 41; HRMS for $C_{14}H_{21}O_2$ (M^+-Me), calcd 221.1542, found 221.1525.

(1S*,2S*,5S*)-4,4-Dihydroxymethyl-1,2-dimethylbicyclo[3.3.0]octane (15a) and (1S*,2R*,5S*)-4,,4-Dihydroxymethyl-1,2-dimethylbicyclo [3.3.0] octane (15b). From 13: To a solution of **13** (29.0 mg, 0.15 mmol) in THF (1.0 mL) was added n-BuLi (1.71 M hexane solution, 0.18 mL, 0.30 mmol) at -78 °C and the solution was stirred at -78 °C for 1 h. The

solution was added to the solution of Cp_2ZrBu_2 prepared from Cp_2ZrCl_2 (58.5 mg, 0.20 mmol) and n-BuLi (1.71 M hexane solution, 0.22 mL, 0.38 mmol) in THF (0.5 mL) at -78°C, and the solution was gradually warmed to room temperature. After the solution was stirred at room temperature for 3 h, aqueous NH_4Cl solution was added . The aqueous layer was extracted with ethyl ether. The organic layer was washed with sat. $NaHCO_3$ solution and brine, dried over Na_2SO_4 and concentrated. The residue was purified by column chromatography on silica gel (hexane:ethyl acetate, 4:1, 3:1, to 3:2) to give colorless oil of a mixture of **15a** and **15b** (17.8 mg, 60%). IR (neat) υ 3330 cm^{-1}; ^{1}H-NMR (270 MHz, $CDCl_3$) δ 0.86 (d, J = 6.5 Hz, 6/30 H), 0.89 (d, J = 6.7 Hz, 5/30 H), 0.92 (s, 6/30 H), 1.03 (s, 5/30 H), 1.07-1.88 (m, 10 H), 2.10-2.80 (m, 2 H), 3.55-3.82 (m, 2 H); MS 180 (M^+-H_2O), 162, 149, 109, 93, 81, 43 (bp); HRMS for $C_{12}H_{20}O$, calcd 180.1515, found 180.1507. **From 17**: To a solution of **17** (20.2 mg, 0.085 mmol) in THF (1.0 mL) was added the solution of Cp_2ZrBu_2 prepared from Cp_2ZrCl_2 (32.2 mg, 0.11 mmol) and n-BuLi (1.71 M hexane solution, 0.18 mL, 0.21 mmol) in THF (0.5 mL) at -78°C, and the solution was gradually warmed to room temperature. After the solution was stirred at room temperature for 3 h, 10% HCl solution was added . The aqueous layer was extracted with ether. The organic layer was washed with sat. $NaHCO_3$ solution and brine, dried over Na_2SO_4 and concentrated. The residue was purified by column chromatography on silica gel (hexane:ethyl acetate, 10:1, to 1:1) to give colorless oil of a mixture of **15a** and **15b** (14.1 mg, 84%).

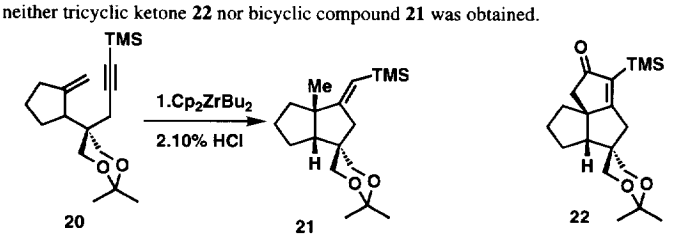
(1R*,5S*,8S*)-7,7-dihydroxymethyltricyclo[6.3.0.0^{1,5}]undecan-3-one (16a) (1R*,5R*,8S*)-7,7-dihydroxymethyltricyclo[6.3.0.0^{1,5}]undecan -3-one (16b). **From 13**: To a solution of **13** (39.5 mg, 0.20 mmol) in THF (1.0 mL) was added n-BuLi (1.71 M hexane solution, 0.12 mL, 0.20 mmol) at -78 °C and the solution was stirred at -78 °C for 1 h. The solution was added to a solution of Cp_2ZrBu_2 prepared from Cp_2ZrCl_2 (76.5 mg, 0.26 mmol) and n-BuLi (1.71 M hexane solution, 0.29 mL, 0.50 mmol) in THF (0.5 mL) at -78°C, and the solution was gradually warmed to room temperature. After the solution was stirred at room temperature for 4 h, an argon atmospher was exchanged to carbon monoxide and the solution was stirred at room temperature for 3 h. To the reaction mixture was added iodine (215 mg, 0.85 mmol) in THF (1.0 mL) at -78 °C and the solution was stirred at room temperature for 30 min. Aqueous 10% $Na_2S_2O_3$ solution was added and the aqueous layer was extracted with ether. The organic layer was washed with $NaHCO_3$ solution and brine, dried over Na_2SO_4 and concentrated. The residue was purified by column chromatography on silica gel (hexane:ethyl acetate, 3:1 to 2:1 then ethyl acetate only) to give a colorless oil of a mixture of **16a** and **16b** (8.1 mg, 18%). IR (neat) υ 3405, 1736 cm^{-1}; ^{1}H-NMR (270 MHz, $CECl_3$) δ 0.70-2.60 (m, 16 H), 3.30-3.90 (m, 4 H); MS 224 (M^+), 207, 206, 193, 176, 133, 119, 105, 79, 55, 41 (bp); HRMS for $C_{13}H_{18}O_2$ (M^+-H_2O), calcd 206.1307, found 206.1283. **From 17**: To a solution of **17** (66.5 mg, 0.28 mmol) in THF (1.0 mL) was added a solution of Cp_2ZrBu_2 prepared from Cp_2ZrCl_2 (105 mg, 0.36 mmol) and n-BuLi (1.71 M hexane solution, 0.41 mL, 0.70 mmol) in THF (1.0 mL) at -78°C, and the solution was gradually warmed to room temperature. After the solution was stirred at room temperature for 3 h, an argon atmospher was exchanged to carbon monoxide and the solution was stirred at room temperature for 3 h. To the reaction mixture was added iodine (274 mg, 1.08 mmol) in THF (2.0 mL) at -78 °C and the solution was stirred at room temperature for 30 min. Aqueous 10% $Na_2S_2O_3$ solution was added and the aqueous layer was extracted with ether. The organic layer was washed with $NaHCO_3$ solution and brine, dried over Na_2SO_4 and concentrated. The residue was purified by column chromatography on silica gel (ethyl acetate) to give a colorless oil of a mixture of **16a** and **16b** (21.8 mg, 35%).

(1R*,5S*,8S)-7,7-(O-isopropylidene)dihydroxymethyl-tricyclo[6.3.0.0^{1,5}]undecan-3-one (19a) (1R*,*5R*,8S*)-7,7-(O-isopropylidene)dihydroxymethyl-tricyclo[6.3.0.0^{1,5}]undecan -3-one (19b). To an acetone (1.0 mL) solution of a mixture of **19a** and **19b**, TsOH•H_2O, and ethyl orthoformate (0.08 mL, 0.49 mmol) was stirred at room temperature for 16 h. Sat. $NaHCO_3$ solution was added and the aqueous layer was extracted with ether. The organic layer was washed with brine dried over Na_2SO_4 and concentrated. The residue was purified by column chromatography on silica gel eluted (hexane-ethyl acetate, 2:1) to give colorless oil of a mixture of **19a** and **19b** (21.0 mg, 82%). A mixture was separated by preparative thin layer chromatography on

silica gel (CH_2Cl_2) to give **19a** and **19b** (1:1). **19a** (high er Rf value): colorless crystals, mp 92-93 °C (from petroleum ether); IR (neat) υ 1744 cm^{-1}; ^{1}H-NMR (270 MHz, $CDCl_3$) δ 1.04-2.34(m, 14 H), 1.39 (s, 3 H), 1.40 (s, 3 H), 3.50-3.68 (m, 3 H), 3.86 (d, J=11.4 Hz, 1 H); ^{13}H-NMR (400 MHz, $CDCl_3$) 22.2, 25.5, 27.9, 28.4, 40.7, 42.6, 43.3, 44.4, 45.2, 52.5, 57.7, 58.8, 65.6, 71.1, 97.8, 219.6; MS 264 (M^+), 263 (M^+-1), 249, 189, 176, 161, 147, 131, 119, 43; HRMS for $C_{16}H_{24}O_3$, calcd 264.1726, found 264.1744. Anal Calcd. for $C_{16}H_{24}O_3$: C, 72.69, H: 9.15. Found: C, 72.57; H, 9.18. **19b** (lower Rf value): colorless crystals, mp 88-89 °C (from petroleum ether); IR (neat) υ 1738 cm^{-1}; ^{1}H-NMR (270 MHz, $CDCl_3$) δ 1.30-2.55 (m, 14 H), 1.39 (s, 3 H), 1.41 (s, 3 H), 3.51 (dd, J=1.7, 11.4 Hz, 1 H), 3.60 (dd, J=1.7, 11.4 Hz, 1 H), 3.73 (d, J=11.4 Hz, 1 H), 3.86 (d, J=11.6 Hz, 1 H); ^{13}H-NMR (400 MHz, $CDCl_3$) 22.0, 24.9, 25.8, 25.9, 31.1, 32.7, 40.7, 45.8, 45.9, 51.3, 52.0, 61.4, 68.1, 69.8, 97.8, 219.6; MS 264 (M^+), 263 (M^+-1), 249, 207, 189, 176, 161, 147, 133, 119, 43; HRMS for $C_{16}H_{24}O_3$, calcd 264.1726, found 264.1717. Anal Calcd. for $C_{16}H_{24}O_3$: C, 72.69, H: 9.15. Found: C, 72.69; H, 9.15.

REFERENCES AND NOTES

1. Mori, M.; Uesaka, N.; Shibasaki, M. *J. Chem. Soc., Chem. Commun.*, **1990**, 222. Mori, M.; Uesaka, N.; Shibasaki, M. *J. Org. Chem.*, **1992**, *57*, 3519. Mori, M.; Saitoh, F.; Uesaka, N.; Shibasaki, M. *Chem. Lett.*, **1993**, 213.
2. Mori. M.; Saitoh, F.; Uesaka, N.; Okamura, K.; Date, T. *J. Org. Chem.*, **1994**, *58*, in press.
3. Negishi, E.; Cederbaum, F. E.; Takahashi, T. *Tetrahedron Lett.*, **1986**, *27*, 2829. Negishi, E.-i.; Holmes, S. J.; Tour, J. M.; Miller, J. A.; Cederbaum, F. E.; Swanson, D. R.; Takahashi, T. *J. Am. Chem. Soc.*, **1989**, *111*, 3336.
4. Grieco, P. A.; Brandes, E. B.; McCann, S.; Clark, J. D. *J. Org. Chem.*, **1989**, *54*, 5849. Grieco, P. A.; Clark, J. D.; Jagoe, C. T. *J. Am. Chem. Soc.*, **1991**, *113*, 5488. Smith, W. A.; Buhanjuk, S. M.; Simonyan, S. O.; Shashkov, A. S.; Struchkov, V. T.; Yanovsky, A. I.; Caple, R.; Gybin, A. S.; Anderson, L. G.; Whiteford, J. A. *Tetrahedron Lett.*, **1991**, *32*, 2105. Keese, R., *Angew. Chem. Int. Ed. Ing.*, **1992**, *31*, 344. References cited therein. J-Gregoire, B.; Brosse, N,; Ianelli, S.; Nardelli, M.; Caubere, P. *J. Org. Chem.*, **1993**, *58*, 4572. Clive, D. L. J.; Cole, D. C.; Tao, Y. J. Org. Chem., 1994, 59, 1396.
5. Maye, J. P.; Negishi, E. *Tetrahedron Lett.*, **1993**, *34*, 3359.
6. Takai, K.; Hotta, Y.; Oshima, K.; Nozaki, H. *Bull. Chem. Soc. Jpn.*, **1980**, *53*, 1698. Lomardo, L. *Tetrahedron Lett.*, **1982**, *23*, 4293.
7. Nugent, W. A.; Thaber, D. F. *J. Am. Chem. Soc.*, **1989**, *111*, 6435.
8. We could not determined whether or not the product is single isomer from the NMR spectrum. Since hydrolysis products of zirconacycle constitutes of two isomers, tricyclic ketone we considered to be contain two isomers.
9. Reaction of enyne **20** with Cp_2ZrBu_2 followed by treatment with 10% HCl provided bicyclic compound **21** in 72% yield. However, the similar treatment of **20** with Cp_2ZrBu_2 followed by tretment with carbon monoxidegave the complex mixture and neither tricyclic ketone **22** nor bicyclic compound **21** was obtained.



10. The X-ray crystarography of **19a** indicates that **19a** is a disordered structure.

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