New Ring-Expansion Reactions of Hydroxy Propenoyl Cyclic Compounds Under the Palladium(0)/Phosphine-Catalyzed Conditions

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Supporting Information Available:
Typical experimental procedure for the synthesis of compounds 1b, c, 2a-d, 3a-d, 4a, 5a, 6a-c, 7a, 9, 10, 14, and 15 and their physical and spectroscopic data.
(4 pages)

Experimental

All melting points were determined on a Yanaco micro melting point apparatus and are uncorrected. IR spectra were obtained using a Perkin-Elmer 1720 or JASCO FT/IR-420 IR Fourier transform spectrophotometer. ^1H NMR (300 or 400 MHz) and ^{13}C NMR (100 MHz) spectra were recorded on a JEOL JNM-AL300 or JEOL JNM-AL400 spectrometer. Chemical shifts are given in δ values (ppm) using tetramethylsilane (TMS) as an internal standard. HREI-MS were recorded on a JEOL JMS SX-102A spectrometer. Elementary combustion analyses were performed using a Yanaco CHN CORDER MT-5. All reactions were monitored by TLC employing 0.25 mm silica gel plates (Merck 5715; 60 F₂₅₄). Column chromatography was carried out on silica gel (Kanto Chemical N60 (spherical, neutral); 63-210 μm). Anhydrous THF was used as purchased from Kanto Chemical. All other reagents were used as purchased.

General Procedure for Preparation of Indanones 1b and 1c. To a stirred solution of indanone (1.32 g, 10.0 mmol) in dry THF (50 mL) was added NaH (1.20 g, 60% in a mineral oil, 30.0 mmol) at 0 °C under argon. After being stirred for 10 min, ethyl iodide (2.40 mL, 30.0 mmol) was added and then the mixture was stirred at ambient temperature for 6 h. The reaction mixture was cooled to 0 °C, quenched with 1 N HCl, and extracted with ether. The ether extract was washed with an aqueous solution saturated with Na₂S₂O₃, water, brine, dried over MgSO₄, and filtered. The filtrate was evaporated *in vacuo* to afford a crude product, which was purified by column chromatography on silica gel with *n*-hexane-AcOEt (20 : 1) to give 2,2-diethylindan-1-one (**1b**) (1.63 g, 86%) as a pale yellow oil.

2,2-Diethylindan-1-one (1b). pale yellow oil; IR (neat) 1710 cm^{-1} ; ^1H NMR (400 MHz, CDCl₃) δ 0.77 (t, J = 7.6 Hz, 6H), 1.57-1.74 (m, 4H), 2.99 (s, 2H), 7.35 (t, J = 7.6 Hz, 1H), 7.45 (d, J = 7.6 Hz, 1H), 7.58 (t, J = 7.6 Hz, 1H), 7.73 (d, J = 7.6 Hz, 1H); HREI-MS calcd for C₁₃H₁₆O MW 188.1201, found m/z 188.1210 (M^+); Anal. Calcd for C₁₃H₁₆O: C, 82.94; H, 8.57. Found: C, 82.70; H, 8.62.

2,2-Dibuthylindan-1-one (1c). yellowish oil; IR (neat) 1707 cm^{-1} ; ^1H NMR (400 MHz, CDCl₃) δ 0.83 (t, J = 7.2 Hz, 6H), 0.98-1.31 (m, 8H), 1.53-1.67 (m, 4H), 3.00 (s, 2H), 7.35 (t, J = 7.6 Hz, 1H), 7.44 (d, J = 7.6 Hz, 1H), 7.58 (t, J = 7.6 Hz, 1H), 7.73 (d, J = 7.6 Hz, 1H); HREI-MS calcd for C₁₇H₂₄O MW 244.1827, found m/z 244.1809 (M^+); Anal. Calcd for C₁₇H₂₄O: C, 83.55; H, 9.90. Found: C, 83.38; H, 9.93.

General Procedure for Preparation of 1-Hydroxy-2,2-dialkyl-1-propenoylindan Derivatives 2a-d and 9. To a solution of methoxyallene (1.05 g, 15.0 mmol) in dry THF (15.0 mL) was added 1.57 M *n*-butyllithium in *n*-hexane (7.64 mL, 12.0 mmol) at -78 °C under argon atmosphere, and the mixture was stirred at -78 °C for 30 min. Then the mixture was added dropwise to a THF (10.0 mL) solution of 2,2-dimethylindan-1-one (**1a**) (1.60 g, 10.0 mmol) at -78 °C in a cannula manner. After being stirred at -78 °C for 30 min, the reaction mixture was acidified by 1 N HCl, homogenized with MeOH and then the reaction temperature was raised to room temperature. After being stirred at room temperature for 1 h, the reaction mixture was extracted with ether. The ether extract was washed with brine, dried over MgSO₄, and filtered. The filtrate was evaporated *in vacuo* to afford a crude product, which was purified by column chromatography on silica gel with *n*-hexane-AcOEt (20 : 1) to give 1-hydroxy-2,2-dimethyl-1-propenoylindan (**2a**) (1.9 g, 88 %) as a pale yellow oil.

1-Hydroxy-2,2-dimethyl-1-propenoylindan (2a). pale yellow oil; IR (neat) 3453, 1683 cm^{-1} ; ^1H NMR (400 MHz, CDCl₃) δ 1.05 (s, 3H), 1.10 (s, 3H), 2.92 (d, J = 16.1 Hz, 1H), 3.01 (d, J = 16.1 Hz, 1H), 4.64 (s, 1H), 5.62 (dd, J = 10.4, 1.6 Hz, 1H), 6.13 (dd, J = 17.0, 10.4 Hz, 1H), 6.43 (dd, J = 17.0, 1.6 Hz, 1H), 7.16 (d, J = 7.6 Hz, 1H), 7.21-7.33 (m, 3H); HREI-MS calcd for C₁₄H₁₆O₂ MW 216.1150, found m/z 216.1162 (M^+); Anal. Calcd for C₁₄H₁₆O₂: C, 77.75; H, 7.46. Found: C, 77.48; H, 7.39.

2,2-Diethyl-1-hydroxy-1-propenoylindan (2b). pale yellow oil; IR (neat) 3451, 1681 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 0.75 (t, $J = 7.5$ Hz, 3H), 0.84 (t, $J = 7.5$ Hz, 3H), 1.40-1.59 (m, 3H), 1.78-1.87 (m, 1H), 2.84 (d, $J = 16.4$ Hz, 1H), 3.06 (d, $J = 16.4$ Hz, 1H), 4.67 (s, 1H), 5.60 (dd, $J = 10.3, 1.7$ Hz, 1H), 6.13 (dd, $J = 17.1, 10.3$ Hz, 1H), 6.43 (dd, $J = 17.1, 1.7$ Hz, 1H), 7.09 (d, $J = 7.6$ Hz, 1H), 7.19-7.30 (m, 3H); HREI-MS calcd for $\text{C}_{16}\text{H}_{20}\text{O}_2$ MW 244.1463, found m/z 244.1478 (M^+); Anal. Calcd for $\text{C}_{16}\text{H}_{20}\text{O}_2$: C, 78.65; H, 8.25. Found: C, 78.42; H, 8.24.

2,2-Dibutyl-1-hydroxy-1-propenoylindan (2c). yellowish oil; IR (neat) 3451, 1683 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 0.84 (q, $J = 7.3$ Hz, 6H), 1.07-1.48 (m, 11H), 1.72-1.80 (m, 1H), 2.84 (d, $J = 16.4$ Hz, 1H), 3.07 (d, $J = 16.4$ Hz, 1H), 4.67 (s, 1H), 5.59 (dd, $J = 10.3, 1.7$ Hz, 1H), 6.13 (dd, $J = 16.9, 10.3$ Hz, 1H), 6.42 (dd, $J = 16.9, 1.7$ Hz, 1H), 7.09 (d, $J = 7.3$ Hz, 1H), 7.19-7.30 (m, 3H); HREI-MS calcd for $\text{C}_{20}\text{H}_{28}\text{O}_2$ MW 300.2089, found m/z 300.2118 (M^+); Anal. Calcd for $\text{C}_{20}\text{H}_{28}\text{O}_2$: C, 79.96; H, 9.39. Found: C, 79.72; H, 9.43.

1-Hydroxy-1-propenoylindan-2-spiro-1'-cyclopentane (2d). colorless oil; IR (neat) 3583, 1684 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 1.34-1.53 (m, 3H), 1.61-1.73 (m, 4H), 2.08-2.15 (m, 1H), 2.93 (d, $J = 16.0$ Hz, 1H), 3.04 (d, $J = 16.0$ Hz, 1H), 4.72 (s, 1H), 5.62 (dd, $J = 10.4, 1.7$ Hz, 1H), 6.16 (dd, $J = 17.1, 10.4$ Hz, 1H), 6.42 (dd, $J = 17.1, 1.7$ Hz, 1H), 7.16 (d, $J = 7.3$ Hz, 1H), 7.21-7.31 (m, 3H); HREI-MS calcd for $\text{C}_{16}\text{H}_{18}\text{O}_2$ MW 242.1307, found m/z 242.1320 (M^+).

17-Hydroxy-3-methoxy-13-methyl-17-propenoyl-7,8,9,11,12,13,14,15,16,17-decahydro-6H-cyclopenta[a]phenanthren (9). pale yellow powder; IR (KBr) 3492, 1726, 1682 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 0.99 (s, 3H), 1.26-1.80 (m, 8H), 1.88-1.95 (m, 2H), 2.07-2.14 (m, 1H), 2.22-2.27 (m, 1H), 2.37-2.45 (m, 1H), 2.84-2.88 (m, 3H), 3.77 (s, 3H), 5.73 (dd, $J = 10.5, 2.0$ Hz, 1H), 6.40 (dd, $J = 17.1, 2.0$ Hz, 1H), 6.62 (d, $J = 2.7$ Hz, 1H), 6.69 (dd, $J = 8.3, 2.7$ Hz, 1H), 6.96 (dd, $J = 17.1, 10.5$ Hz, 1H), 7.14 (d, $J = 8.3$ Hz, 1H); HREI-MS calcd for $\text{C}_{12}\text{H}_{28}\text{O}_3$ MW 340.2038, found m/z 340.2041 (M^+).

Typical Procedure for the Ring Expansion Reaction. A mixture of 1-hydroxy-2,2-dimethyl-1-propenoylindan (**2a**) (31.8 mg, 0.147 mmol), $\text{Pd}(\text{PPh}_3)_4$ (8.5 mg, 0.007 mmol), $\text{P}(o\text{-tolyl})_3$ (3.9 mg, 0.015 mmol) in THF (1.5 mL) was refluxed under argon atmosphere for 7 h. The reaction mixture was evaporated *in vacuo* to afford a crude product, which was purified by column chromatography on silica gel with *n*-hexane-AcOEt (10 : 1) to give 2-hydroxy-3,3-dimethyl-2-vinyl-1-tetralone (**3a**) (29.3 mg, 92%) as white crystals.

2-Hydroxy-3,3-dimethyl-2-vinyl-1-tetralone (3a). white crystals; mp 48.5-49.0 $^\circ\text{C}$ (*n*-hexane); IR (KBr) 3469, 1685 cm^{-1} ; ^1H NMR (300 MHz, CDCl_3) δ 0.97 (s, 3H), 1.14 (s, 3H), 2.74 (d, $J = 17.6$ Hz, 1H), 3.17 (d, $J = 17.6$ Hz, 1H), 3.89 (s, 1H), 5.24 (dd, $J = 10.7, 1.5$ Hz, 1H), 5.54 (dd, $J = 16.9, 1.5$ Hz, 1H), 6.01 (dd, $J = 16.9, 10.7$ Hz, 1H), 7.24 (d, $J = 7.7$ Hz, 1H), 7.33 (t, $J = 7.7$ Hz, 1H), 7.54 (t, $J = 7.7$ Hz, 1H), 7.98 (d, $J = 7.7$ Hz, 1H); HREI-MS calcd for $\text{C}_{14}\text{H}_{16}\text{O}_2$ MW 216.1150, found m/z 216.1166 (M^+); Anal. Calcd for $\text{C}_{14}\text{H}_{16}\text{O}_2$: C, 77.75; H, 7.46. Found: C, 77.55; H, 7.49.

3,3-Diethyl-2-hydroxy-2-vinyl-1-tetralone (3b). pale yellow oil; IR (neat) 3470, 1685 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 0.76 (t, $J = 7.4$ Hz, 3H), 0.99 (t, $J = 7.4$ Hz, 3H), 1.12 (sext, $J = 7.4$ Hz, 1H), 1.42-1.51 (m, 1H), 1.69-1.87 (m, 2H), 2.88 (d, $J = 18.1$ Hz, 1H), 2.93 (d, $J = 18.1$ Hz, 1H), 3.95 (s, 1H), 5.24 (dd, $J = 10.5, 1.7$ Hz, 1H), 5.59 (dd, $J = 16.6, 1.7$ Hz, 1H), 6.02 (dd, $J = 16.6, 10.5$ Hz, 1H), 7.25 (d, $J = 7.6$ Hz, 1H), 7.33 (t, $J = 7.6$ Hz, 1H), 7.54 (td, $J = 7.6, 1.2$ Hz, 1H), 7.97 (dd, $J = 7.6, 1.2$ Hz, 1H); HREI-MS calcd for $\text{C}_{16}\text{H}_{20}\text{O}_2$ MW 244.1463, found m/z 244.1468 (M^+); Anal. Calcd for $\text{C}_{16}\text{H}_{20}\text{O}_2$: C, 78.65; H, 8.25. Found: C, 78.87; H, 8.32.

3,3-Dibutyl-2-hydroxy-2-vinyl-1-tetralone (3c). colorless oil; IR (neat) 3470, 1685 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 0.76-1.75 (m, 18H), 2.90 (d, $J = 17.8$ Hz, 1H), 2.95 (d, $J = 17.8$ Hz, 1H), 3.96 (s, 1H), 5.23 (d, $J = 10.5$ Hz, 1H), 5.57 (d, $J = 16.8$ Hz, 1H), 6.01 (dd, $J = 10.5, 16.8$ Hz, 1H), 7.23-7.35 (m, 1H), 7.34 (t, $J = 7.6$ Hz, 1H), 7.54 (t, $J = 7.6$ Hz, 1H), 7.97 (d, $J = 7.6$ Hz, 1H); HREI-MS calcd for $\text{C}_{20}\text{H}_{28}\text{O}_2$ MW 300.2089, found m/z 300.2095 (M^+); Anal. Calcd for $\text{C}_{20}\text{H}_{28}\text{O}_2$: C, 79.96; H, 9.39. Found: C, 80.04; H, 9.50.

2-Hydroxy-3-spiro-1'-cyclopentane-2-vinyl-1-tetralone (3d). colorless oil; IR (neat) 3481, 1709 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 1.14-1.18 (m, 1H), 1.35-1.41 (m, 1H), 1.56-1.73 (m, 5H), 2.05-2.12 (m, S-31H), 2.90 (d, $J = 17.6$ Hz, 1H), 3.14 (d, $J = 17.6$ Hz, 1H), 3.93 (s, 1H), 5.19 (dd, $J = 10.7, 1.5$ Hz, 1H), 5.46 (dd, $J = 17.1, 1.5$ Hz, 1H), 6.08 (dd, $J = 17.1, 10.5$ Hz, 1H), 7.24 (d, $J = 7.6$ Hz, 1H), 7.34 (t, $J = 7.6$ Hz, 1H), 7.52 (td, $J = 7.6, 1.2$ Hz, 1H), 7.99 (dd, $J = 7.6, 1.2$ Hz, 1H); HREI-MS calcd for $\text{C}_{16}\text{H}_{18}\text{O}_2$ MW 242.1307, found m/z 242.1324 (M^+); Anal. Calcd for $\text{C}_{16}\text{H}_{18}\text{O}_2$: C, 79.31; H, 7.49. Found: C, 79.27; H, 7.60.

2-Ethyl-2-hydroxy-3,3-dimethyl-1-tetralone (7a). colorless needles.; mp 70.0-70.5 $^\circ\text{C}$ (CHCl_3 - n -hexane- Et_2O); IR (KBr) 3476, 1678 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 0.70 (t, $J = 7.3$ Hz, 3H), 0.93 (s, 3H), 1.21 (s, 3H), 1.65-1.74 (m, 1H), 1.82-1.91 (m, 1H), 2.74 (d, $J = 17.7$ Hz, 1H), 3.18 (d, $J = 17.7$ Hz, 1H), 3.88 (s, 1H), 7.21 (d, $J = 7.6$ Hz, 1H), 7.33 (t, $J = 7.6$ Hz, 1H), 7.52 (td, $J = 7.6, 1.2$ Hz, 1H), 7.95 (dd, $J = 7.6, 1.2$ Hz, 1H); HREI-MS calcd for $\text{C}_{14}\text{H}_{18}\text{O}_2$ MW 218.1307, found m/z 218.1305 (M^+); Anal. Calcd for $\text{C}_{14}\text{H}_{18}\text{O}_2$: C, 77.03; H, 8.31. Found: C, 76.76; H, 8.28.

17 β -Hydroxy-3-methoxy-17 α -vinyl-*D*-homoestra-1,3,5(10)-trien-17a-one (10). colorless plates; mp 214-215 $^\circ\text{C}$ (CHCl_3 - n -hexane- Et_2O); IR (KBr) 3489, 1712 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 0.82 (s, 3H), 1.34-1.60 (m, 4H), 1.68-1.73 (m, 2H), 1.89-1.95 (m, 1H), 2.08-2.14 (m, 1H), 2.26-2.34 (m, 3H), 2.51-2.67 (m, 2H), 2.83-2.88 (m, 2H), 3.78 (s, 3H), 3.95 (s, 1H), 5.33 (dd, $J = 10.5, 1.8$ Hz, 1H), 5.60 (dd, $J = 16.6, 1.8$ Hz, 1H), 6.38 (dd, $J = 16.6, 10.5$ Hz, 1H), 6.63 (d, $J = 2.8$ Hz, 1H), 6.72 (dd, $J = 8.7, 2.8$ Hz, 1H), 7.21 (d, $J = 8.7$ Hz, 1H); HREI-MS calcd for $\text{C}_{22}\text{H}_{28}\text{O}_3$ MW 340.2039, found m/z 340.2020 (M^+); Anal. Calcd for $\text{C}_{22}\text{H}_{28}\text{O}_3$: C, 77.61; H, 8.29. Found: C, 77.46; H, 8.34.

17 α -Ethyl-17 β -hydroxy-*D*-homoestra-1,3,5(10)-trien-17a-one (15). colorless plates; mp 150-151 $^\circ\text{C}$ (CHCl_3 - n -hexane- Et_2O); IR (KBr) 3488, 1709 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 0.73 (t, $J = 7.3$ Hz, 3H), 0.77 (s, 3H), 1.26-1.52 (m, 4H), 1.74-1.92 (m, 4H), 2.00-2.11 (m, 2H), 2.21-2.53 (m, 5H), 2.85-2.87 (m, 2H), 3.78 (s, 3H), 3.82 (s, 1H), 6.63 (d, $J = 2.4$ Hz, 1H), 6.72 (dd, $J = 8.6, 2.4$ Hz, 1H), 7.22 (d, $J = 8.6$ Hz, 1H); HREI-MS calcd for $\text{C}_{22}\text{H}_{30}\text{O}_3$ MW 342.2195, found m/z 342.2185 (M^+); Anal. Calcd for $\text{C}_{22}\text{H}_{30}\text{O}_3$: C, 77.16; H, 8.83. Found: C, 77.01; H, 8.60.

General Procedure for Preparation of Cyclic Hydroxy Conjugated Enones 4a and 5a. To a solution of methoxyallene (105.1 mg, 1.5 mmol) in dry THF (1.5 mL) was added 1.58 M n -butyllithium in n -hexane (0.76 mL, 1.2 mmol) at -78°C under argon atmosphere, and the mixture was stirred at -78°C for 30 min. Then the mixture was added dropwise to a THF (1.0 mL) solution of 2,2-dimethyl-1-tetralone (174.2 mg, 1.0 mmol) at -78°C in a cannula manner. After being stirred at -78°C for 1 h, the reaction mixture was acidified by 1 N HCl, and then the reaction temperature was raised to room temperature. After being stirred for 16 h, the reaction mixture was extracted with ether, and the ether extract was washed with brine, dried over MgSO_4 , and filtered. The filtrate was evaporated *in vacuo* to afford a crude product, which was purified by column chromatography on silica gel with n -hexane-AcOEt (20 : 1) to give 1-hydroxy-2,2-dimethyl-1-propenoyltetralin (**4a**) (136.5 mg, 59 %) as a colorless oil.

1-Hydroxy-2,2-dimethyl-1-propenoyltetralin (4a). colorless oil; IR (neat) 3454, 1681 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 0.90 (s, 3H), 1.05 (s, 3H), 1.75-1.81 (m, 1H), 1.95-2.03 (m, 1H), 2.88-2.95 (m, 1H), 3.02-3.10 (m, 1H), 4.73 (s, 1H), 5.59 (t, $J = 6.1$ Hz, 1H), 6.34 (d, $J = 6.1$ Hz, 2H), 7.14-7.24 (m, 4H); ^{13}C -NMR (75 MHz, CDCl_3) δ 23.5, 24.6, 25.5, 33.8, 36.9, 83.1, 126.6, 127.9, 128.1, 129.1, 129.2, 132.0, 136.3, 136.6, 201.4; HREI-MS calcd for $\text{C}_{15}\text{H}_{18}\text{O}_2$ MW 230.1307, found m/z 230.1319 (M^+).

1-Hydroxy-2,2-5-dimethyl-1-propenoylbenzosuberan (5a). colorless powder; mp 46.5-47.5 $^\circ\text{C}$ (CHCl_3 - n -hexane- Et_2O); IR (KBr) 3477, 1698 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 0.72 (s, 3H), 1.23 (s, 3H), 1.55-1.63 (m, 1H), 1.73-1.82 (m, 2H), 2.44-2.50 (m, 1H), 2.59-2.65 (m, 1H), 2.76-2.81 (m, 1H), 4.77 (brs, 1H), 5.54 (dd, $J = 10.3, 2.0$ Hz, 1H), 6.33 (dd, $J = 17.1, 2.0$ Hz, 1H), 6.54 (dd, $J = 17.1, 10.3$ Hz, 1H), 7.06 (d, $J = 7.3$ Hz, 1H), 7.16-7.23 (m, 2H), 7.61 (d, $J = 7.3$ Hz, 1H); HREI-MS calcd for $\text{C}_{16}\text{H}_{20}\text{O}_2$ MW 244.1463, found m/z 244.1473 (M^+); Anal. Calcd for $\text{C}_{16}\text{H}_{20}\text{O}_2$: C, 78.65; H, 8.25. Found: C, 78.60; H, 7.95.

General Procedure for Preparation of 1-Hydroxy-2,2-dialkyl-1-propanoylindan Derivatives 6a-c. A mixture of 1-hydroxy-2,2-dimethyl-1-propenoylindan (**2a**) (74.6 mg, 0.344 mmol) and 10% Pd/C (25

mg) in AcOEt (10 mL) was stirred under hydrogen atmosphere at 1 atm for 18.5 h. The solution was filtered and the filtrate was evaporated *in vacuo*. The residue was purified by column chromatography on silica gel with *n*-hexane-AcOEt (20 : 1) to give 1-hydroxy-2,2-dimethyl-1-propanoylindan (**6a**) (58.7 mg, 79 %) as a colorless oil.

1-Hydroxy-2,2-dimethyl-1-propanoylindan (6a). colorless oil; IR (neat) 3454, 1697 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 0.94 (t, $J = 7.3$ Hz, 3H), 1.03 (s, 3H), 1.08 (s, 3H), 2.04 (dq, $J = 18.1, 7.3$ Hz, 1H), 2.31 (dq, $J = 18.1, 7.3$ Hz, 1H), 2.89 (d, $J = 16.0$ Hz, 1H), 3.07 (d, $J = 16.0$ Hz, 1H), 4.54 (s, 1H), 7.14 (d, $J = 7.3$ Hz, 1H), 7.20-7.31 (m, 3H); HREI-MS calcd for $\text{C}_{14}\text{H}_{18}\text{O}_2$ MW 218.1307, found m/z 218.1314 (M^+); Anal. Calcd for $\text{C}_{14}\text{H}_{18}\text{O}_2$: C, 77.03; H, 8.31. Found: C, 76.93; H, 8.21.

2,2-Diethyl-1-hydroxy-1-propanoylindan (6b). colorless oil; IR (neat) 3450, 1698 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 0.73 (t, $J = 7.4$ Hz, 3H), 0.86 (t, $J = 7.4$ Hz, 3H), 0.93 (t, $J = 7.2$ Hz, 3H), 1.36-1.56 (m, 3H), 1.80 (sext, $J = 7.3$ Hz, 1H), 1.94-2.04 (m, 1H), 2.29-2.39 (m, 1H), 2.88 (d, $J = 16.4$ Hz, 1H), 3.03 (d, $J = 16.4$ Hz, 1H), 4.57 (s, 1H), 7.08 (d, $J = 7.3$ Hz, 1H), 7.18-7.28 (m, 3H); HREI-MS calcd for $\text{C}_{16}\text{H}_{22}\text{O}_2$ MW 246.1620, found m/z 246.1620 (M^+); Anal. Calcd for $\text{C}_{16}\text{H}_{22}\text{O}_2$: C, 78.01; H, 9.00. Found: C, 77.80; H, 9.02.

2,2-Dibutyl-1-hydroxy-1-propanoylindan (6c). colorless oil; IR (neat) 3451, 1698 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 0.80-1.80 (m, 21H), 1.90-2.05 (m, 1H), 2.28-2.41 (m, 1H), 2.88 (d, $J = 16.3$ Hz, 1H), 3.05 (d, $J = 16.3$ Hz, 1H), 4.57 (s, 1H), 7.07 (d, $J = 7.3$ Hz, 1H), 7.20-7.26 (m, 3H); HREI-MS calcd for $\text{C}_{20}\text{H}_{30}\text{O}_2$ MW 302.2246, found m/z 302.2232 (M^+); Anal. Calcd for $\text{C}_{20}\text{H}_{30}\text{O}_2$: C, 79.42; H, 10.00. Found: C, 79.56; H, 10.02.

17 β -Hydroxy-3-methoxy-17 α -propanoylestra-1,3,5(10)-trien (14). To a solution of methoxyallene (421.9 mg, 6.02 mmol) in dry THF (6.0 mL) was added 1.56 M *n*-butyllithium in *n*-hexane (3.85 mL, 6.0 mmol) at -78°C under argon atmosphere, and the mixture was stirred at -78°C for 30 min. Then the mixture was added dropwise to a dry THF (40.0 mL) solution of 3-methoxy-estra-1,3,5(10)-trien-17-one (**8**) (568.8 mg, 2.0 mmol) at -78°C in a cannula manner. After being stirred at -78°C for 2 h, the reaction mixture was acidified by 1 N HCl, homogenized with MeOH, and then the temperature was raised to room temperature. After being stirred for 1.5 h, the reaction mixture was extracted with ether, and the ether extract was washed with brine, dried over MgSO_4 , and filtered. The filtrate was evaporated *in vacuo* to afford a crude product **9**. A mixture of crude compound **9** and 10% Pd/C (228.0 mg) in THF (20 mL) was subjected to hydrogenation under H_2 at 1 atm for 18 h. The solution was filtered and the filtrate was evaporated *in vacuo*. The residue was purified by column chromatography on silica gel with *n*-hexane-AcOEt (5 : 1) to give 17 β -hydroxy-3-methoxy-17 α -propanoylestra-1,3,5(10)-trien (**14**) (549.9 mg, 80 %) as colorless prisms.; mp 117-118 $^\circ\text{C}$ (CHCl_3 -*n*-hexane- Et_2O); IR (KBr) 3536, 1697 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 0.96 (s, 3H), 1.02-1.10 (m, 4H), 1.35-1.55 (m, 4H), 1.61-1.68 (m, 1H), 1.70-1.77 (m, 2H), 1.81-1.93 (m, 2H), 2.10-2.17 (m, 1H), 2.23-2.30 (m, 1H), 2.32-2.40 (m, 1H), 2.43 (s, 1H), 2.62-2.73 (m, 2H), 2.84-2.87 (m, 2H), 3.77 (s, 3H), 6.63 (d, $J = 2.7$ Hz, 1H), 6.70 (dd, $J = 8.5, 2.7$ Hz, 1H), 7.15 (d, $J = 8.5$ Hz, 1H); HREI-MS calcd for $\text{C}_{22}\text{H}_{30}\text{O}_3$ MW 342.2195, found m/z 342.2165 (M^+); Anal. Calcd for $\text{C}_{22}\text{H}_{30}\text{O}_3$: C, 77.16; H, 8.83. Found: C, 76.91; H, 9.03.