Supporting Information-1 (experimental procedures and spectral data)

Formal Total Synthesis of (±)-Estrone via the Furano Diene Approach

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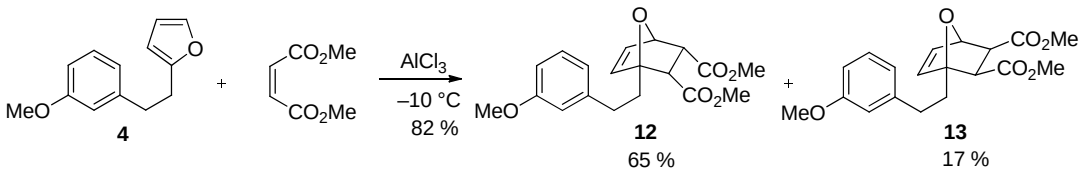
Experimental

General

For product purification by flash column chromatography, silica gel (200~300 mesh) and petroleum ether (PET, bp. 60~90 °C) were used unless otherwise noted. All solvents were purified and dried by standard techniques, and distilled prior to use. Other commercially available reagents were used as received without further purification unless otherwise indicated. All organic extracts were dried over anhydrous sodium sulfate or magnesium sulfate. All moisture-sensitive reactions were carried out under an atmosphere of nitrogen in glassware that had been flame-dried under vacuum. ^{1}H and ^{13}C NMR spectra were recorded on a *Bruker* Avance III 400 or *Varian* Mercury-300 spectrometer with TMS as an internal reference and $CDCl_3$ as solvent, unless otherwise indicated. IR spectra were recorded on a *Nicolet* NEXUS 670 FT-IR spectrometer as liquid film or KBr pellet. EI-MS were obtained on a HP-5988A GC/MS instrument. HRMS were acquired on a *Bruker* Daltonics APEXII 47e FT-ICR spectrometer. Melting points were measured on a *Kofler* hot stage and were uncorrected.

*1. The Diels–Alder cycloaddition of furan **4** with dimethyl maleate*



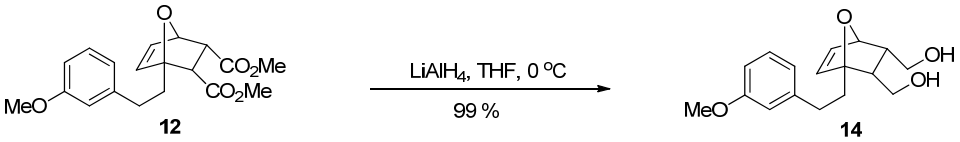
Dimethyl maleate (7.20 g, 52.50 mmol) was introduced into a flask containing powdered $AlCl_3$ (667 mg, 5.00 mmol) at –10 °C under N_2. After the resulting mixture was stirred for 10 min, furano compound **4** (10.10 g, 50.00 mmol) was added via a syringe. The reaction mixture was stirred at –10 °C for 2 days, then extracted with ether, the organic layer was washed successively with water, brine, dried (Na_2SO_4), and concentrated in vacuo. The residue was purified by flash column chromatography (PET : EtOAc = 4 : 1) to give the *endo*-adduct **12** (11.0 g, 65%) as a colorless oil and the *exo*-isomer **13** (3.20 g, 17%) as white plates.

12: R_f = 0.45 (PET : EtOAc = 2 : 1); IR (film): ν_{max} 3002, 2952, 1741, 1604, 1490, 1436, 1259, 1163, 1044, 909, 789, 494 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.20 (1H, t, *J* = 7.6 Hz, ArH), 6.76 (3H, m, ArH), 6.52 (1H, d, *J* = 6.0 Hz, CH=), 6.45 (1H, d, *J* = 6.0 Hz, CH=), 5.11 (1H, d, *J* = 4.4 Hz, OCH), 3.80 (3H, s, OMe), 3.63 (3H, s, OMe), 3.60 (3H, s, OMe), 3.58 (1H, d, *J* = 4.8 Hz, CH), 3.13 (1H, d, *J* = 10.0 Hz, CH), 2.76 (2H, m, CH_2), 2.45 (1H, m, CH_2), 2.15 (1H, m, CH_2) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ171.1, 170.6, 159.6, 143.1, 136.9, 135.2, 129.3, 120.5, 113.9, 111.2, 91.2, 79.4, 55.0, 51.7, 51.7, 51.4, 50.5, 33.5, 30.90 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{19}H_{26}O_6N$ 364.1755, found for $[M+NH_4]^+$ 364.1754

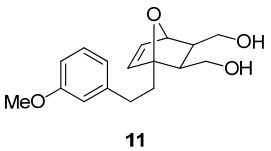
13: R_f = 0.20 (PET : EtOAc = 2 : 1); mp. 109–110 °C; IR (film): ν_{max} 2949, 2844, 1743, 1601, 1436, 1261, 1215, 1159, 1039, 922, 786, 698 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.20 (1H, t, *J* = 7.6 Hz, ArH), 6.76 (3H, m, ArH), 6.47 (1H, d, *J* = 5.6 Hz, CH=), 6.30 (1H, d, *J* = 5.6 Hz, CH=), 5.44 (1H, s, OCH), 3.80 (3H, s, OMe), 3.69 (3H, s, OMe), 3.67 (3H, s, OMe), 2.97 (1H, d, *J* = 9.2 Hz, CH), 2.84 (1H, d, *J* = 9.2 Hz, CH), 2.83–2.80 (1H, m, CH_2), 2.74–2.70 (1H, m, CH_2), 2.21–2.13 (2H, m, CH_2) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ171.6, 171.4, 159.5, 143.0, 137.9, 137.4, 129.3,

120.6, 113.9, 111.2, 91.2, 79.1, 54.9, 52.1, 51.9, 50.0, 49.8, 31.5, 31.4 *ppm*. HRMS (ESI) *m/z*: calcd for $C_{19}H_{26}O_6N$ 364.1755, found for $[M+NH_4]^+$ 364.1748

*2. Preparation of compound **14***

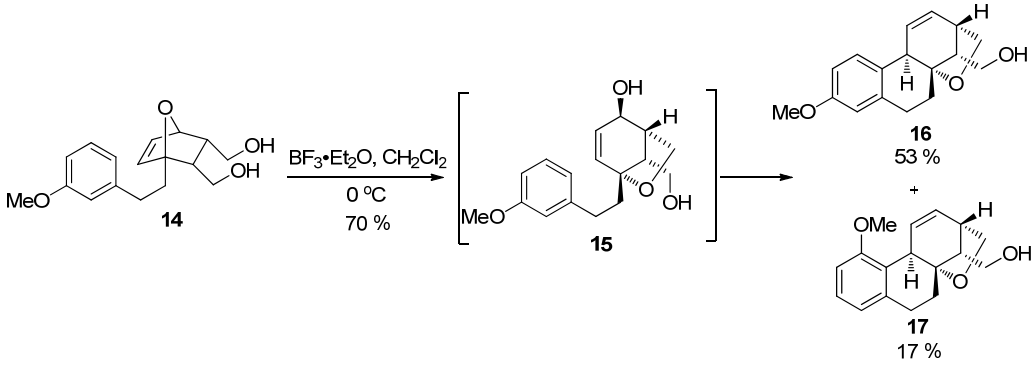


To a suspension of powdered $LiAlH_4$ (1.70 g, 45.00 mmol) in 40 mL of dry THF at 0 °C was added a solution of compound **12** (14.20 g, 41.00 mmol) in dry THF (20 mL) under N_2. After being stirred for 10 min at 0 °C, the reaction mixture was quenched with 5 mL of water, extracted with ether, the organic layer was washed successively with water and brine, dried (Na_2SO_4), and concentrated in vacuo. The residue was purified by flash column chromatography (PET : EtOAc = 1 : 2) to give compound **14** (11.90 g, 99%) as a colorless oil. **14**: R_f = 0.15 (PET : EtOAc = 1 : 2); IR (film): ν_{max} 3359, 2934, 1603, 1490, 1456, 1316, 1258, 1155, 1039, 912, 782, 727, 698, 574 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.20 (1H, t, *J* = 7.6 Hz, ArH), 6.76 (3H, m, ArH), 6.30 (1H, d, *J* = 5.6 Hz, CH=), 6.11 (1H, d, *J* = 5.6 Hz, CH=), 4.80 (1H, d, *J* = 3.6 Hz, OCH), 4.30 (2H, br s, OH), 3.79 (3H, s, OMe), 3.55 (2H, d, *J* = 10.8 Hz, OCH_2), 3.35 (2H, m, OCH_2), 2.78 (2H, m, CH_2), 2.64 (1H, m, CH_2), 2.42–2.25 (2H, m, CH), 2.11 (1H, m, CH_2) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ159.5, 143.4, 136.5, 135.1, 129.3, 120.5, 113.9, 111.1, 90.5, 79.2, 60.8, 60.5, 55.0, 48.4, 46.7, 33.8, 30.9 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{17}H_{26}O_4N$ 308.1856, found for $[M+NH_4]^+$ 308.1864



Compound **11** was prepared by $LiAlH_4$ reduction of compound **13** similarly as above in 98% yield as a colorless oil. **11**: R_f = 0.15 (PET : EtOAc = 1 : 2); IR (film): ν_{max} 3358, 2930, 1602, 1490, 1457, 1259, 1156, 1038, 784, 701 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.20 (1H, t, *J* = 8.0 Hz, ArH), 6.80–6.72 (3H, m, ArH), 6.35 (1H, d, *J* = 5.2 Hz, CH=)), 6.22 (1H, t, *J* = 5.6 Hz, CH=), 4.69 (2H, br s, OH), 4.58 (1H, s, OCH), 3.78 (3H, s, OMe), 3.87–3.68 (4H, m, OCH_2), 2.73–2.66 (2H, m, CH_2), 2.15–1.93 (4H, m) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 159.4, 143.4, 137.7, 135.9, 129.3, 120.5, 113.9, 111.0, 90.4, 80.8, 62.8, 60.0, 54.9, 44.5, 44.1, 31.6, 31.5 *ppm*

*3. Cyclization of compound **14***



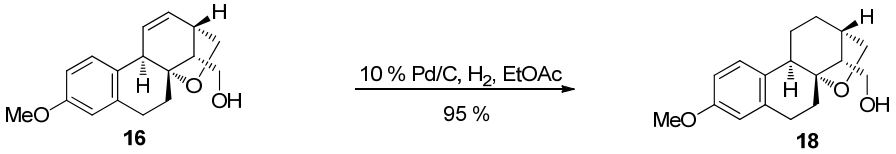
To a solution of compound **14** (2.90 g, 10.00 mmol) in dry CH_2Cl_2 (20 mL) was added BF_3•Et_2O (10.00 mmol, 1.26 mL) at 0 °C under N_2. TLC indicated that compound **15** was the sole intermediary product at 0.5 h, which was transformed gradually into the cyclization products **16** and **17** entirely after 1 h. The reaction mixture was quenched with 2 mL of H_2O, extracted with ether, the organic layer was washed successively with water and brine, dried (Na_2SO_4), and concentrated in vacuo. The residue was purified by flash column chromatography (PET : EtOAc = 5 : 1) to give **16** (1.430 g, 53%) as a colorless oil and **17** (0.476 g, 17 %) as a colorless oil.

16: IR (film): ν_{max} 3415, 2931, 2872, 1608, 1500, 1462, 1236, 1042, 958, 851 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.15 (1H, d, J = 8.4 Hz, ArH), 6.72 (1H, dd, J_1 = 9.6 Hz, J_2 = 2.4 Hz, ArH), 6.63 (1H, d, J = 2.4 Hz, ArH), 6.20 (1H, m, CH=), 6.07 (1H, dd, J_1 = 9.6 Hz, J_2 = 3.2 Hz, CH=), 4.04 (1H, m, OCH_2), 3.93, (2H, m, OCH_2), 3.78 (3H, s, OMe), 3.55 (1H, t, J = 10.0 Hz, OCH_2), 3.39 (1H, br s, CH), 2.98–2.81(3H, m), 2.08–1.98(3H, m) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 157.5, 136.4, 132.8, 130.8, 127.7, 127.6, 113.1, 112.3, 83.3, 74.6, 60.4, 55.2, 49.7, 45.7, 38.1, 29.7, 28.9 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{17}H_{21}O_3$ 273.1485, found for $[M+H]^+$ 273.1488

17: IR (film): ν_{max} 3420, 2931, 2874, 1579, 1464, 1438, 1249, 1094, 1039, 962, 907, 856 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.08 (1H, t, J = 8.0 Hz, ArH), 6.70 (2H, m, ArH), 6.50 (1H, dd, J_1 = 9.6 Hz, J_2 = 3.2 Hz, CH=), 6.20 (1H, m, CH=), 4.08 (1H, m, OCH_2), 3.95 (2H, m, OCH_2), 3.82 (3H, s, OMe), 3.53 (2H, m, OCH_2), 3.00 (1H, m, CH), 2.76 (2H, m, CH_2), 2.05 (1H, m, CH), 1.96 (2H, m, CH_2) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 157.8, 137.3, 133.2, 128.1, 126.8, 126.5, 121.2 108.3, 83.7, 75.0, 60.5, 55.0, 49.7, 46.9, 36.8, 29.5, 29.4 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{17}H_{21}O_3$ 273.1485, found for $[M+H]^+$ 273.1481

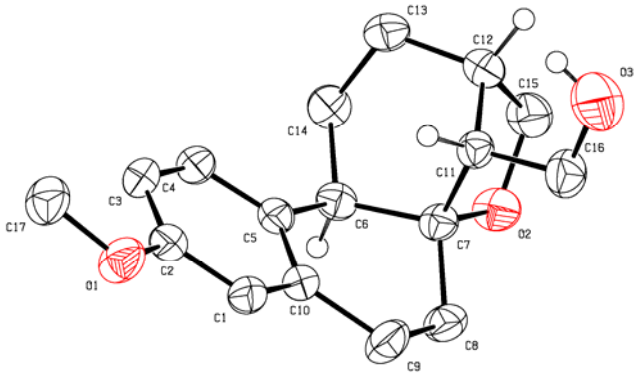
15: IR (film): ν_{max} 3367, 2943, 2880, 1603, 1490, 1458, 1260, 1154, 1038, 908, 783, 733, 696 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ7.22 (1H, t, J = 7.6 Hz, ArH), 6.80 (1H, d, J = 7.6 Hz, ArH), 6.75 (2H, m, ArH), 6.03 (1H, d, J = 9.6 Hz, CH=), 5.87 (1H, dd, J_1 = 9.2 Hz, J_2 = 2.4 Hz, CH=), 4.20 (1H, s, OCH), 4.04 (1H, m, OCH_2), 3.82 (4H, m, OMe & OCH_2), 3.56 (1H, m, OCH_2), 3.38 (1H, d, J = 9.2 Hz, OCH_2), 2.66 (3H, m), 2.32 (2H, m), 2.00 (2H, m, CH_2) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 159.6, 143.2, 136.2, 129.4, 120.5, 114.0, 111.1, 81.3, 70.5, 66.1, 60.6, 60.4, 55.1, 44.0, 43.6, 34.9, 30.7 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{17}H_{26}O_4N$ 308.1856, found for $[M+NH_4]^+$ 308.1860

*4. Preparation of compound **18***



To a solution of **16** (1.36 g, 5.00 mmol) in EtOAc (20 mL) was added 10% Pd/C (136 mg) at room temperature. The reaction flask was evacuated and recharged with H_2 for three times by a H_2 balloon. After 5 h under H_2 atmosphere, the suspension was filtered through Celite and washed with EtOAc. The filtrate was concentrated in vacuo. The residue was purified by flash column chromatography (PET : EtOAc = 2 : 1) to give hydrogenation product **18** (1.30 g, 95%) as colorless solids. R_f = 0.31 (PET : EtOAc = 1 : 2); mp. 152–153 °C; IR (film): υ_{max} 3400, 2928, 2858, 1607, 1492, 1420, 1267, 1247, 1070, 1048, 1026 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.16 (1H, d, J = 8.4

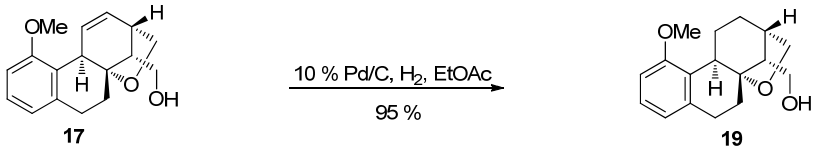
Hz, ArH), 6.70 (1H, d, *J* = 8.4 Hz, ArH), 6.65 (1H, s, ArH), 4.00 (1H, m, OCH_2), 3.91 (1H, d, *J* = 8.0 Hz, OCH_2), 3.78 (4H, m, OCH_2 & OMe), 3.43 (1H, m, OCH_2), 3.00 (2H, m, CH_2), 2.85 (1H, d, *J* = 6.4 Hz, CH_2), 2.48 (1H, s, CH), 2.24 (1H, m, CH_2), 2.15 (1H, m, CH_2), 2.06 (1H, m, CH_2), 1.96 (2H, m, CH_2), 1.80 (1H, m, CH), 1.60 (1H, m, CH_2), 1.48 (1H, m, CH_2) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 157.5, 137.4, 130.7, 125.5, 113.8, 111.4, 84.5, 70.0, 61.0, 55.1, 47.6, 46.0, 37.8, 29.2, 28.7, 27.5, 20.3 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{17}H_{26}O_3N$ 292.1907, found for $[M+NH_4]^+$ 292.1902



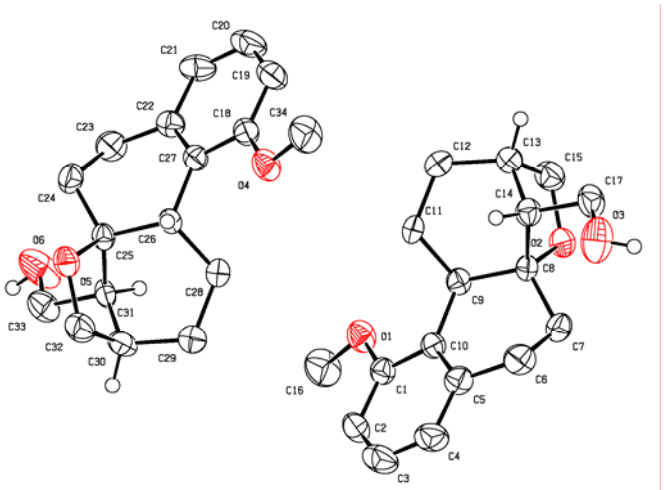
X-ray crystallographic data of Compound ***18***

Empirical formula	$C_{17}H_{22}O_3$	
Formula weight	274.35	
Temperature (K)	294(2)	
Wavelength (Å)	0.71073	
Crystal system	Triclinic	
space group	P1	
Unit cell dimensions	a = 5.4774(11) Å	α =101.285(3)°
	b = 9.2965(18) Å	β = 96.906(3)°
	c = 13.809(3) Å	γ = 92.077(3)°
Volume ($Å^3$)	683.3(2)	
Z	2	
Calculated density (Mg/m^3)	1.333	
Absorption coefficient (mm^{-1})	0.090	
Crystal size (mm^3)	0.18 x 0.22 x 0.26	
θ range	1.52 to 26.41°	
Reflections collected / unique	3880 / 2753	
R_{int}	0.0129	
Data / restraints / parameters	2753 / 0 / 183	
Goodness-of-fit on F^2	1.038	
$R_1(I>2\sigma(I)$	0.0499	
WR_2 (all data)	0.1413	

*5. Preparation of compound **19***



To a solution of **17** (1.36 g, 5.00 mmol) in EtOAc (20 mL) was added 10% Pd/C (136 mg) at room temperature. The reaction flask was evacuated and recharged with H_2 for three times by a H_2 balloon. After 5 h under H_2 atmosphere, the suspension was filtered through Celite and washed with EtOAc. The filtrate was concentrated in vacuo. The residue was purified by flash column chromatography (PET : EtOAc = 2 : 1) to give compound **19** (1.25 g, 95%) as colorless solids. R_f = 0.32 (PET : EtOAc = 1 : 2); mp. 151–152 °C; IR (film): ν_{max} 3423, 2922, 2855, 1581, 1481, 1438, 1246, 1065, 1019, 970, 895, 780, 738 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.06 (1H, t, *J* = 8.0 Hz, ArH), 6.70 (2H, d, *J* = 8.4 Hz, ArH), 4.09 (1H, m, OCH_2), 3.78 (4H, m, OMe & OCH_2), 3.61 (2H, m, OCH_2), 3.10 (1H, m, CH), 2.70 (2H, m, CH_2), 2.50 (1H, t, *J* = 6.4 Hz, CH), 2.23 (2H, m), 2.12 (2H, m), 1.80 (2H, m), 1.60 (1H, m), 1.18 (1H, m) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 157.4, 138.7, 129.5, 126.0, 120.6, 108.3, 85.2, 73.8, 61.5, 55.1, 45.3, 43.3, 35.1, 30.6, 29.4, 28.8, 22.2 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{17}H_{23}O_3$ 275.1642, found for $[M+H]^+$ 275.1646

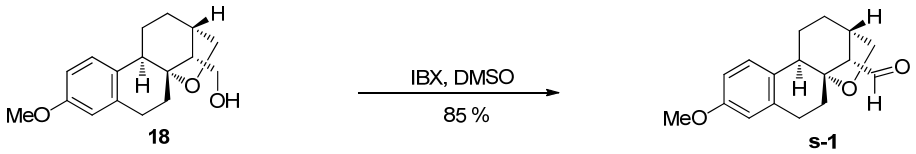


*X-ray crystallographic data of **19***

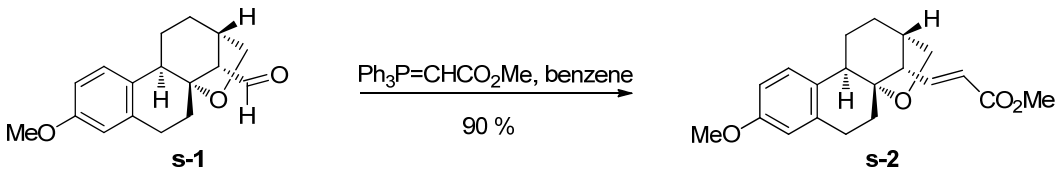
Empirical formula	$C_{17}H_{22}O_3$
Formula weight	274.35
Temperature (K)	294(2)
Wavelength (Å)	0.71073
Crystal system	Orthorhombic
space group	Pca21
Unit cell dimensions	a = 14.159(2) Å α = 90°

	b = 6.4481(12) Å	β = 90°
	c = 30.788(9) Å	γ = 90°
Volume ($Å^3$)	2810.8(11)	
Z	8	
Calculated density (Mg/m^3)	1.297	
Absorption coefficient (mm^{-1})	0.087	
Crystal size (mm^3)	0.16 x 0.32 x 0.38	
θ range	2.65 to 27.18°	
Reflections collected / unique	15370 / 3124	
R_{int}	0.0591	
Data / restraints / parameters	3124 / 1 / 372	
Goodness-of-fit on F^2	1.006	
Extinction coefficient	0.0067(8)	
$R_1(I>2\sigma(I)$	0.0438	
WR_2 (all data)	0.1077	

*6. Preparation of compound **20***

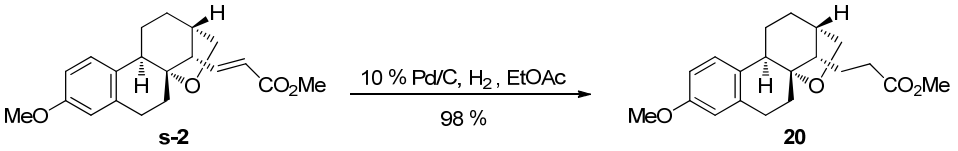


A solution of **18** (1.37 g, 4.15 mmol) in DMSO (10 mL) was treated with IBX (1.1 eq, 1.28 g, 4.60 mmol) at 30 °C and stirred for 30 min, extracted with ether, the organic layer was washed successively with water and brine, dried (Na_2SO_4), and concentrated in vacuo. The residue was purified by flash column chromatography (PET : EtOAc = 10 : 1) to give compound **s-1** (1.15 g, 85%) as white plates. R_f = 0.70 (PET : EtOAc = 3 : 1); mp. 113–115 °C; IR (film): ν_{max} 2926 , 2856, 1717, 1606, 1493, 1457, 1251, 1504, 1036, 970, 911, 881 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 9.82 (1H, d, *J* = 3.6 Hz, CHO), 7.17 (1H, d, *J* = 8.8 Hz, ArH), 6.72 (1H, dd, J_1 = 8.4 Hz, J_2 = 2.8 Hz, ArH), 6.68 (1H, s, ArH), 4.22–4.20 (1H, m, OCH_2), 4.08 (1H, d, *J* = 8.4 Hz, OCH_2), 3.78 (3H, s, OMe), 3.0 (2H, m, CH_2), 2.93 (1H, d, *J* = 6.4 Hz, CH_2), 2.68 (1H, s, CH), 2.43 (1H, d, *J* = 3.6 Hz, CH), 2.44–2.22 (3H, m, CH_2), 2.12 (1H, d, *J* = 8.4 Hz, CH), 1.69–1.63 (1H, m, CH_2), 1.53–1.45 (2H, m, CH_2) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 202.7, 157.9, 136.9, 129.9, 125.7, 113.9, 112.0, 85.5, 71.1, 57.5, 55.1, 45.8, 37.9, 30.2, 28.6, 26.6, 20.2 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{17}H_{24}O_3N$ 290.1751, found for $[M+NH_4]^+$ 290.1757



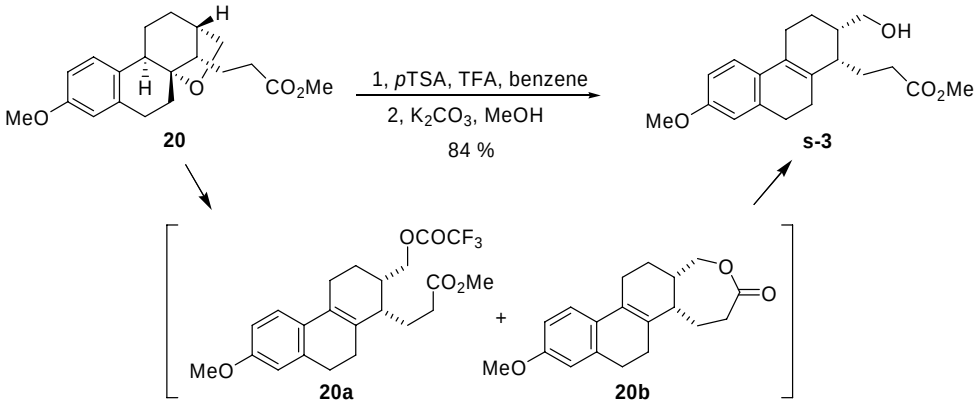
A solution of **s-1** (680 mg, 2.50 mmol) in 15 mL of benzene was added powdered ylide $Ph_3P{=}CHCO_2Me$ (1.67 g, 5.00 mmol). The reaction mixture was heated to 50 °C, stirred for 2 h, cooled to room temperature and extracted with ether. The organic layer was washed successively

with water and brine, dried (Na_2SO_4), and concentrated in vacuo. The residue was purified by flash column chromatography (PET : EtOAc = 3 : 1) to give compound **s-2** (738 mg, 90%) as white plates. R_f = 0.45 (PET : EtOAc = 3 : 1); mp. 127–129 °C; IR (film): ν_{max} 2940, 1722, 1652, 1612, 1574, 1498, 1459, 1436, 1321, 1272, 1240, 1171, 1067, 1045, 985, 915, 874, 791, 731, 587 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.18 (1H, d, J = 8.4 Hz, ArH), 7.00 (1H, dd, J_1 = 15.6 Hz, J_2 = 10.4 Hz, CH=), 6.70 (1H, d, J = 8.4 Hz, ArH), 6.65 (1H, s, ArH), 5.82 (1H, d, J = 15.6 Hz, CH=), 4.15 (1H, m, OCH_2), 4.00 (1H, d, J = 8.4 Hz, OCH_2), 3.76 (3H, s, OMe), 3.72 (3H, s, OMe), 2.93–2.81 (3H, m, CH &OCH_2), 2.39 (1H, d, J = 10.4 Hz, CH), 2.45–2.15 (3H, m, CH & OCH_2), 1.97–1.90 (2H, m, CH_2), 1.63–1.53 (2H, m, CH_2) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 166.4, 157.5, 147.0, 137.3, 130.2, 125.5, 122.4, 113.6, 111.5, 84.9, 70.2, 54.9, 51.3, 49.4, 45.0, 42.3, 30.2, 27.9, 26.9, 20.0 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{20}H_{25}O_4$ 329.1747, found for $[M+H]^+$ 329.1750

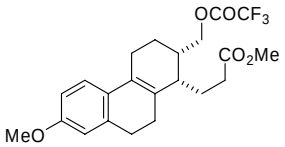


To a solution of **s-2** (1.38 g, 4.20 mmol) in EtOAc (20 mL) was added 10% Pd/C (130 mg) at room temperature. The reaction flask was evacuated and recharged with H_2 for three times by a H_2 balloon. After being stirred for 20 h under H_2 atmosphere, the suspension was filtered through Celite and washed with EtOAc. The filtrate was concentrated in vacuo. The residue was purified by flash column chromatography (PET : EtOAc = 5 : 1) to give compound **20** (1.35 g, 98%) as white plates. R_f = 0.43 (PET : EtOAc = 3 : 1); mp. 105–106 °C; IR (film): ν_{max} 2937, 2877, 1734, 1611, 1497, 1461, 1437, 1367, 1269, 1163, 1070, 1050, 975, 790, 582 cm^{-1}; ^1H NMR (100 MHz, $CDCl_3$): δ 7.15 (1H, d, J = 8.4 Hz, ArH), 6.66 (2H, m, ArH), 4.00 (1H, m, OCH_2), 3.90 (1H, d, J = 8.4 Hz, OCH_2), 3.78 (3H, s, OMe), 3.60 (3H, s, OMe), 2.96 (2H, m, CH_2), 2.90 (1H, d, J = 6.0 Hz, CH), 2.34–2.30 (1H, m, CH), 2.24–2.12 (5H, m), 1.97–1.84 (2H, m, CH_2), 1.61–1.42 (4H, m, CH_2) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 173.7, 157.4, 137.5, 130.8, 125.4, 113.7, 113.3, 85.0, 69.7, 54.9, 51.3, 45.9, 44.6, 38.5, 31.7, 29.2, 28.5, 27.8, 22.2, 20.3 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{20}H_{27}O_4$ 331.1904, found for $[M+H]^+$ 331.1903

*7. Preparation of compound **21***

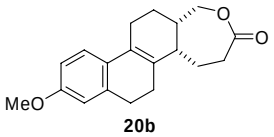


A solution of **20** (330 mg, 1.00 mmol) in 10 mL of benzene was treated with 0.5 mL TFA and *p*-toluenesulfoic acid (60 mg, 0.20 mmol). The reaction mixture was heated to 50 °C, stirred for 1 h, cooled to room temperature and the reaction mixture was quenched by 2 mL of saturated aqueous $NaHCO_3$, extracted with ether, the organic layer was washed successively with water and brine, dried (Na_2SO_4), concentrated in vacuo to give the crude acidolysis product mixture which was used directly in the following step without further purification. The crude product mixture was dissolved in absolute MeOH (5 mL), to which K_2CO_3 (207 mg, 1.50 mmol) was added at room temperature and stirred for 10 min. The reaction mixture was extracted with ether, the organic layer was washed successively with water and brine, dried (Na_2SO_4), and concentrated in vacuo. The residue was purified by flash column chromatography (PET : EtOAc = 5 : 1) to give compound **s-3** (280 mg, 84%) as a colorless oil. R_f = 0.15 (PET : EtOAc = 3 : 1); IR (film): ν_{max} 3438, 2927, 2875, 1734, 1608, 1499, 1252, 1161, 1038, 808 cm^{-1} ; ^1H NMR (400 MHz, $CDCl_3$): δ 7.10 (1H, d, *J* = 8.0 Hz, ArH), 6.68 (2H, m, ArH), 3.78 (3H, s, OMe), 3.67 (3H, s, OMe), 3.65–3.59 (2H, m, OCH_2), 2.71 (2H, t, *J* = 7.6 Hz, CH_2), 2.26–2.25 (7H, m), 2.19–2.13 (1H, m), 1.99–1.85 (2H, m), 1.72–1.65 (2H, m), 1.54–1.48 (1H, m) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$) δ 174.5, 157.8, 137.3, 134.8, 129.0, 126.5, 122.9, 113.2, 110.7, 64.5, 55.1, 51.5, 40.3, 39.3, 33.4, 29.0, 28.9, 25.1, 24.6, 21.0 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{20}H_{27}O_4$ 331.1904, found for $[M+H]^+$ 331.1906



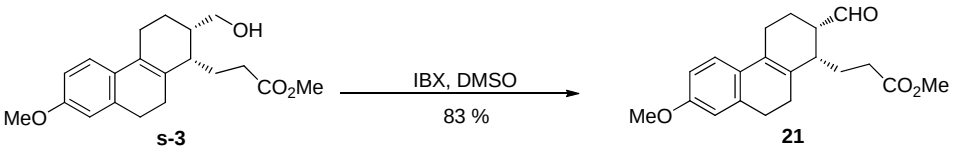
20a

Intermediate **20a**: R_f = 0.80 (PET : AcOEt = 3 : 1); IR (film): ν_{max} 2935, 2837, 1785, 1738, 1608, 1500, 1436, 1353, 1253, 1223, 1163, 1041, 853, 808, 776, 732, 611, 522 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.12 (1H, d, *J* = 8.4 Hz), 6.70 (2H, m), 4.37 (2H, m), 3.79 (3H, s), 3.68 (3H, s), 2.71 (2H, t, *J* = 7.6 Hz), 2.16–2.53 (8H, m), 1.83 (3H, m), 1.65 (1H, m) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 173.6, 158.1, 157.7, 157.2 137.4, 133.4, 128.7, 126.9, 123.1, 113.3, 110.9, 69.7, 55.2, 51.6, 39.5, 36.5, 29.0, 28.5, 24.7, 24.6, 21.1 *ppm*; EIMS *m/z* (%): 426 (M^+, 33), 225 (100), 165 (38), 105 (42), 69 (76).



20b

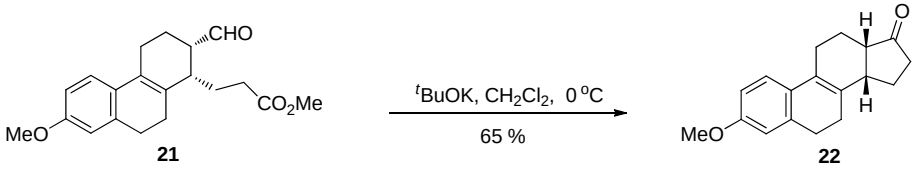
Intermediate **20b**: R_f = 0.20 (PET : AcOEt = 3 : 1); mp. 164–166 °C; IR (film): ν_{max} 2931, 2835, 2250, 1731, 1608, 1571, 1499, 1435, 1395, 1330, 1303, 1279, 1252, 1167, 1070, 1039, 912, 809, 732 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.12 (1H, d, *J* = 8.4 Hz), 6.70 (2H, m), 4.39 (1H, d, *J* = 12.8 Hz), 4.21 (1H, dd, J_1 = 8.8 Hz, J_2 = 5.2 Hz), 3.78 (3H, s), 2.68 (4H, m), 2.50 (2H, m), 2.30 (2H, m), 1.80 (3H, m), 1.65 (3H, m) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 175.5, 158.1, 137.2, 133.3, 128.5, 126.8, 123.1, 113.3, 110.8, 71.2, 55.1, 43.9, 37.2, 32.6, 28.9, 27.5, 25.5, 2.38, 20.4 *ppm*; EIMS *m/z* (%): 298 (M^+, 100), 225 (74), 211 (43), 115 (32).



s-3 **21**

A solution of **s-3** (700 mg, 2.12 mmol) in DMSO (10 mL) was treated with IBX (650 mg, 2.33 mmol) at 30 °C and stirred for 30 min, extracted with ether, the organic layer was washed successively with water and brine, dried (Na_2SO_4), and concentrated in vacuo. The residue was purified by flash column chromatography (PET : EtOAc = 10 : 1) to give compound **21** (580 mg, 83%) as white plates. R_f = 0.60 (PET : EtOAc = 2 : 1); mp. 104–105 °C; IR (film): ν_{max} 2926, 2831, 1733, 1713, 1606, 1497, 1433, 1245, 1198, 1154, 1039, 980, 803 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 9.86 (1H, s, CHO), 7.11 (1H, d, *J* = 8.4 Hz, ArH), 6.69 (2H, m, ArH), 3.78 (3H, s, OMe), 3.66 (3H, s, OMe), 2.73 (2H, t, *J* = 8.0 Hz), 2.67–2.62 (2H, m), 2.56–2.52 (1H, m), 2.44–2.30 (4H, m), 2.30–2.09 (2H, m), 1.90–1.83 (3H, m) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 204.1, 173.2, 158.0, 137.1, 132.9, 128.4, 127.0, 122.9, 113.1, 110.7, 54.9, 51.4, 51.0, 38.6, 32.9, 28.7, 28.2, 26.1, 24.2, 18.1 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{20}H_{24}O_4Na$ 351.1567, found for $[M+Na]^+$ 351.1571

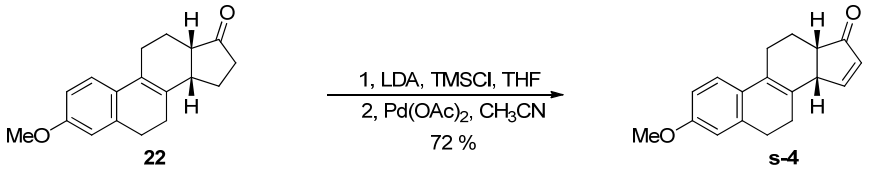
*8. Preparation of compound **22***



21 **22**

To a suspension of solid ^{t}BuOK (103 mg, 0.92 mmol) in 5 mL of dry CH_2Cl_2 at 0 °C was added a solution of compound **21** (75 mg, 0.23 mmol) in dry CH_2Cl_2 (1 mL) under N_2. After being stirred for only 1 min at 0 °C, the reaction was quenched by 0.5 mL of saturated aqueous NH_4Cl, extracted with ether. The organic layer was washed successively with water and brine, dried (Na_2SO_4), and concentrated in vacuo. The residue was purified by flash column chromatography (PET : EtOAc = 15 : 1) to give tetracyclic ketone **22** (36 mg, 65%)[1] as a colorless solid. R_f = 0.44 (PET : EtOAc = 5 : 1); mp. 129–130 °C; IR (film): ν_{max} 2927, 2881, 1736, 1607, 1498, 1430, 1251, 1143, 1041, 812 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.08 (1H, d, *J* = 8.0 Hz, ArH), 6.69 (2H, m, ArH), 3.79 (3H, s, OMe), 2.97 (1H, s, CH), 2.81–2.69 (2H, m, CH_2), 2.47–2.10 (8H, m, CH & CH_2), 2.02–1.92 (2H, m, CH_2), 1.86–1.80 (1H, m, CH_2) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 221.4, 158.1, 137.0, 131.3, 129.1, 128.3, 123.1, 113.3, 110.8, 55.2, 47.4, 41.0, 36.9, 28.7, 26.9, 26.0, 23.1, 20.7 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{18}H_{21}O_2$ 269.1536, found for $[M+H]^+$ 269.1543

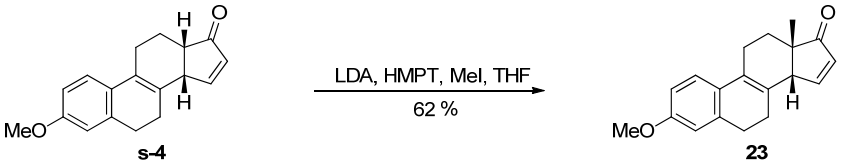
*9. Preparation of compound **23***



22 **s-4**

[1] The *cis* stereochemistry of tetracyclic ketone product **22** was deduced according to: (a) House, H. O.; Rasmusson, G. H. *J. Org. Chem*. **1963**, *28*, 31; (b) Snider, B. B.; Marin, C. P. C. *J. Org. Chem*. **1984**, *49*, 1688.

To a stirred solution of diisopropylamine (0.07 mL) in dry THF (1 mL) was added *n*-BuLi (1.6 M in hexane, 0.25 mL) dropwise at 0 °C under N_2, and the mixture was stirred for 30 min. The resulting LDA solution was cooled to –78 °C, and then a solution of **22** (35 mg, 0.13 mmol) in dry THF (1 mL) was added dropwise via a syringe, stirred for 10 min. A solution of TMSCl (0.07 mL) in THF (1 mL) was added, stirred for 10 min and monitored by TLC. The solvent was evaporated and the resulting suspension was filtered through alumina (1.00 g, PET : EtOAc = 4 : 1). After removing the solvent, the remaining crude silyl ether was taken in dry acetonitrile (1 mL), $Pd(OAc)_2$ (30 mg) was added.[2] The resulting mixture was stirred for 2 h at room temperature and filtered through Celite. The filtrate was concentrated in vacuo. The crude residue was purified by flash column chromatography (PET : EtOAc = 10 : 1) to give dehydrogenated product **s-4** (25 mg, 72%). R_f = 0.30 (PET : EtOAc = 5 : 1); mp. 111–112 °C; IR (film): ν_{max} 2929, 2833, 1705, 1606, 1498, 1251, 1160, 1040, 855, 808 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.71 (1H, dd, J_1 = 5.6 Hz, J_2 = 2.8 Hz, CH=), 7.06 (1H, d, J = 8.0 Hz, ArH), 6.70 (2H, m, ArH), 6.16 (1H, dd, J_1 = 5.6 Hz, J_2 = 2.0 Hz, CH=), 3.79 (3H, s, OMe), 3.62 (1H, br s, CH), 2.89–2.67 (3H, m, CH & CH_2), 2.46–2.35 (2H, m, CH_2), 2.36–2.24 (1H, m, CH_2), 2.18–2.06 (2H, m, CH_2), 1.93–1.86 (1H, m, CH_2) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 212.1, 164.3, 158.2, 136.6, 132.2, 129.9, 128.8, 128.3, 123.4, 113.5, 110.9, 55.3, 47.3, 44.9, 28.6, 27.5, 23.9, 22.4 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{18}H_{19}O_2$ 267.1380, found for $[M+H]^+$ 267.1385



s-4 **23**

To a stirred solution of diisopropylamine (0.26 mL) in dry THF (1 mL) was added *n*-BuLi (1.6 M in hexane, 0.90 mL) dropwise at 0 °C under N_2, and the mixture was stirred for 10 min. The resulting LDA solution was cooled to –78 °C, and then a solution of **s-4** (20 mg, 0.075 mmol) and HMPT (0.2 mL) in dry THF (1mL) was added dropwise via syringe, stirred for 30 min. MeI (0.2 mL, excess) was added. The reaction was allowed to warm to room temperature slowly, stirred for 2 h and monitored by TLC.[3] The reaction was quenched by 0.5 mL of saturated aqueous NH_4Cl, extracted with ether, the organic layer was washed successively with water and brine, dried (Na_2SO_4), and concentrated in vacuo. The residue was purified by flash column chromatography to give compound **23** (13 mg, 62%).[4] R_f = 0.32 (PET : EtOAc = 5 : 1); mp. 113–114 °C; IR (film): ν_{max} 2923, 2851, 1707, 1607, 1499, 1250, 1158, 1039, 812 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.63 (1H, d, J = 8.0 Hz, CH=), 7.08 (1H, d, J = 8.0 Hz, ArH), 6.71 (2H, m, ArH), 6.11 (1H, dd, J_1 = 5.6, J_2 = 2.8 Hz, CH=), 3.80 (3H, s, OMe), 3.15 (1H, s, CH), 2.85–2.75 (2H, m, CH_2), 2.45–2.39 (2H, m, CH_2), 2.32–2.12 (2H, m, CH_2), 1.94–1.89 (1H, m, CH_2), 1.62–1.58 (1H, m, CH_2), 1.20 (3H, s, Me) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 214.5, 162.6, 158.3, 136.7, 130.6, 129.6, 128.6, 128.4, 123.4, 113.6, 111.0, 55.5, 46.9, 31.5, 29.7, 28.7, 27.5, 22.5, 22.3 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{19}H_{21}O_2$ 281.1536, found for $[M+H]^+$ 281.1536

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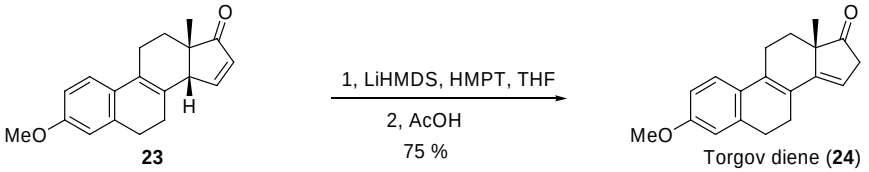
[2] For similar experimental procedures of ketone dehydrogenation via the corresponding enolsilane, see: (a) Singh, V.; Vedantham, P.; Sahu, P. K. *Tetrahedron Lett.* **2002**, *43*, 519; (b) Singh, V.; Vedantham, P.; Sahu, P. K. *Tetrahedron* **2004**, *60*, 8161. (c) Asano, M.; Inoue, M.; Katoh, T. *Synlett* **2005**, 2599.

[3] For similar experimental procedures, see: (a) Paquette, L. A.; Geng, F. *J. Am. Chem. Soc.* **2002**, *124*, 9199; (b) Geng, F.; Liu, J.; Paquette, L. A. *Org. Lett.* **2002**, *4*, 71.

[4] All spectroscopic data (IR, ^1H NMR and ^{13}C NMR) of synthetic compound **23** are consistent with those of reported in a recent literature: Weimar, M.; Dürner, G.; Bats, J. W.; Göbel, M. W. *J. Org. Chem.* **2010**, *75*, 2718.

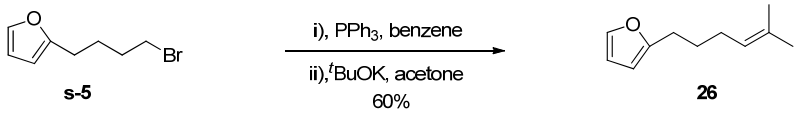
*10. Preparation of Torgov diene **24***[5]



23 Torgov diene (**24**)

To a stirred solution of HMDS (10 eq, 0.05 mL) and HMPT (0.5 mL) in dry THF (1mL) was added *n*-BuLi (1.6M in hexane, 0.17 mL) dropwise at –78 °C under N_2, and the mixture was stirred for 15 min. A solution of compound **23** (8 mg, 0.03 mmol) in dry THF (1 mL) was added dropwise via a syringe. After stirring for 20 min. at –78 °C, the reaction mixture was treated with glacial acetic acid (0.5 mL) and warmed to room temperature gradually. The mixture was poured into a solution of aqueous HCl (1 M, 5 mL), extracted with ether, the organic layer was washed successively with water and brine, dried (Na_2SO_4), and concentrated in vacuo. The residue was purified by flash column chromatography (PET : EtOAc = 15 : 1) to give compound **24** (6 mg, 75%)[6] as colorless solids. R_f = 0.48 (PET : EtOAc = 5 : 1); mp. 106–107 °C; [Lit.[5b] mp. 115–116 °C (MeOH); Lit.[5c] mp. 108–109 °C (MeOH)]; IR (film): ν_{max} 2922, 2852, 1744, 1601, 1461, 1248, 1160, 1041, 800 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.25 (1H, s, ArH), 6.73 (2H, m, ArH), 5.87 (1H, s, CH=), 3.82 (3H, s, OMe), 3.33 (1H, dd, J_1 = 23.2 Hz, J_2 = 2.8 Hz, CH_2), 2.93 (1H, dd, J_1 = 23.2 Hz, J_2 = 2.8 Hz, CH_2), 2.81 (2H, m, CH_2), 2.66–2.59 (3H, m, CH_2), 2.33–2.29 (1H, m, CH_2), 2.07–2.02 (1H, m, CH_2), 1.63–1.59 (1H, m, CH_2), 1.14 (3H, s, Me) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 220.1, 158.7, 146.9, 138.2, 129.9, 128.6, 125.3, 124.1, 114.7, 113.6, 111.1, 55.3, 49.1, 42.0, 29.7, 28.4, 27.3, 23.0, 20.6 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{19}H_{21}O_2$ 281.1536, found for $[M+H]^+$ 281.1543

*11. Preparation of compound **26***



s-5 **26**

A mixture of furano bromide **s-5** (2.03 g, 10.00 mmol)[7] and triphenylphosphine (2.62 g, 10.00 mmol) in 20 mL of benzene was refluxed for 1 day. After cooling to room temperature and filtration, the solids were collected and air-dried to give 2.6 g of white solids, which was suspended in 10 mL of THF and treated with ^{t}BuOK (1.68 g, 15.00 mmol) at 0 ^{o}C. The resulting mixture was stirred for 30 min, to which dry acetone (560 mg, 10.00 mmol) was added at 0 ^{o}C. After stirring for 4 h at room temperature, the reaction mixture was quenched with 5 mL water, extracted with ether, the organic layer was washed successively with water and brine, dried (Na_2SO_4), and concentrated in vacuo. The residue was purified by flash column chromatography (PET) to give compound **26** (492 mg, 80 %) as a colorless oil. R_f = 0.80 (PET); ^1H NMR (400 MHz, $CDCl_3$): δ 7.28 (1H, m, Furan-H), 6.26 (1H, m, Furan-H), 5.96 (1H, m, Furan-H), 5.13 (1H, t, *J* = 7.2 Hz, CH=), 2.61 (2H, t, *J* = 7.6 Hz, CH_2), 2.03 (2H, q, *J* = 7.2 Hz, CH_2), 1.69 (5H, m, Me & CH_2), 1.59 (3H, s, Me) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 156.4, 140.6, 132.0, 124.0, 110.0, 104.6, 28.1, 27.5, 27.4, 25.7, 17.7 *ppm*

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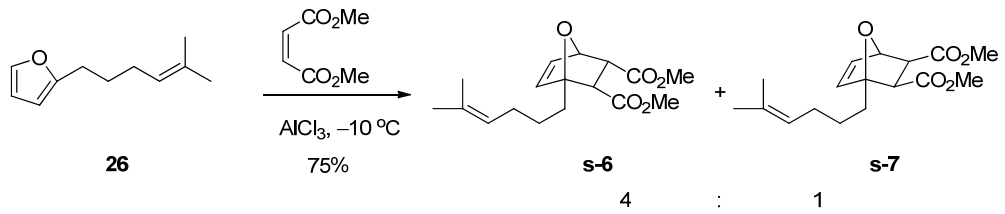
[5] (a) Hu, Q.-Y.; Rege, P. D.; Corey, E. J. *J. Am. Chem. Soc*. **2004**, *126*, 5984; (b) Quinkert, G.; Grosso, M. D.; Döring, A. Döring, W.; Schenkel, R.; Bauch, M.; Dambacher, G. T.; Bats, J. W.; Zimmermann, G.; Dürner, G. *Helv. Chim. Acta*. **1995**, *78*, 1345; (c) Ananchenko, S. N.; Torgov, I. V. *Tetrahedron Lett.* **1963**, *3,* 1553.

[6] All spectroscopic data (IR, ^1H NMR and ^{13}C NMR) of synthetic compound **24** are consistent with those of reported in the literatures.[5]

[7] Prepared according to: Christnreo, G.; Briana, K. *Can. J. Chem*. **1992**, *70*, 2929.

*12. The Diels–Alder cycloaddition of furan **26** with dimethyl maleate*

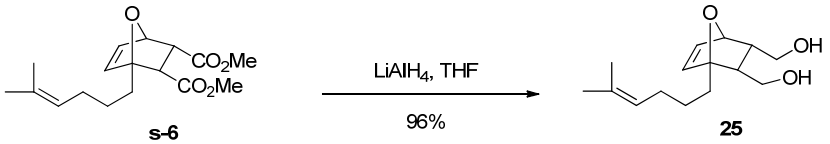


Dimethyl maleate (792 mg, 5.50 mmol) was introduced into a flask containing powdered $AlCl_3$ (133.5 mg, 1.00 mmol) at –10 °C under N_2. The resulting mixture was stirred for 10 min., and compound **26** (802 mg, 5 mmol) was added via a syringe. The reaction mixture was stirred at –10 °C for 2 days, extracted with ether, the organic layer was washed successively with water and brine, dried (Na_2SO_4), and concentrated in vacuo. The residue was purified by flash column chromatography (PET : EtOAc = 5 : 1) to give the endo-adduct **s-6** (951 mg, 60%) as a colorless oil and the exo-isomer **s-7** (230 mg, 15%) as white plates.

s-6: R_f = 0.50 (PET : EtOAc = 2 : 1); IR (film): ν_{max} 3467, 2950, 2859, 1744, 1438, 1202, 1164, 1060, 1011, 930, 714, 496 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 6.47 (1H, d, *J* = 5.6 Hz, CH=), 6.40 (1H, d, *J* = 5.6 Hz, CH=), 5.11 (1H, t, *J* = 7.2 Hz, CH=), 5.05 (1H, dd, J_1 = 4.8, J_2 = 1.6 Hz, OCH), 3.64 (3H, s, OMe), 3.61 (3H, s, OMe), 3.55 (1H, dd, J_1 = 10.0, J_2 = 4.4 Hz, CH), 3.09 (1H, d, *J* = 10.4 Hz, CH), 2.09 (3H, m, CH_2), 1.85 (1H, m, CH_2), 1.68 (3H, s, Me), 1.60 (3H, s, Me), 1.45 (2H, m, CH_2) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 171.0, 170.5, 137.1, 134.7, 131.6, 123.9, 91.6, 79.2, 51.5, 51.2, 50.5, 31.1, 28.0, 25.5, 24.8, 17.5 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{17}H_{32}NO_5N$ 326.1962, found for $[M+NH_4]^+$ 326.1957

s-7: R_f = 0.25 (PET : EtOAc = 2 : 1); mp. 83–84 ºC ; IR (film): ν_{max} 3446, 2951, 2868, 1748, 1437, 1357, 1215, 1162, 1047, 930, 843, 731, 517, 424 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 6.45 (1H, m, CH=), 6.28 (1H, d, *J* = 6.0 Hz, , CH=), 5.40 (1H, d, *J* = 1.6 Hz, OCH), 5.09 (1H, t, *J* = 7.2 Hz, CH=), 3.70 (3H, s, OMe), 3.68 (3H, s, OMe), 2.93 (1H, d, *J* = 8.8 Hz, CH), 2.81 (1H, d, *J* = 8.8 Hz, CH), 2.00 (2H, m, CH_2), 1.83 (3H, m, CH_2),), 1.67 (3H, s, Me), 1.58 (3H, s, Me), 1.45 (1H, m, CH_2) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 171.8, 171.6, 138.2, 137.2, 132.0, 123.8, 91.6, 79.0, 52.1, 51.8, 50.1, 49.9, 29.2, 28.1, 25.6, 25.3, 17.6 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{17}H_{32}NO_5N$ 326.1962, found for $[M+NH_4]^+$ 326.1959

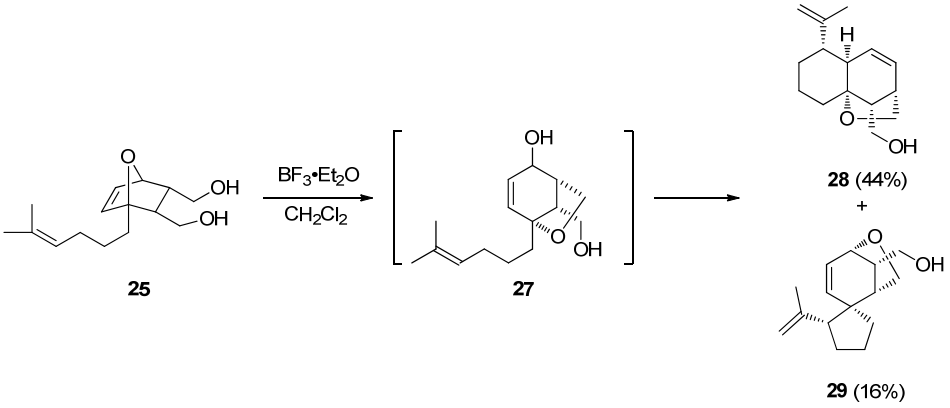
*13. Preparation of compound **25***



To a suspension of powdered $LiAlH_4$ (76 mg, 2.00 mmol) in 10 mL of dry THF at 0 °C was added a solution of compound **s-6** (616 mg, 2.00 mmol) in dry THF (5 mL) under N_2. After being stirred for 10 min at 0 °C, the reaction mixture was quenched with 5 mL of water, extracted with ether, the organic layer was washed successively with water and brine, dried (Na_2SO_4), and concentrated in vacuo. The residue was purified by flash column chromatography (PET : EtOAc =

1 : 2) to give compound **25** (490 mg, 96%) as a colorless oil. R_f = 0.20 (PET : EtOAc = 1 : 2); IR (film): ν_{max} 3374, 2923, 2856, 1442, 1380, 1037, 935, 725, 468 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 6.26 (1H, d, *J* = 5.2 Hz, CH=), 6.11 (1H, d, *J* = 6.0 Hz, CH=), 5.11 (1H, t, *J* = 7.2 Hz, CH=), 4.77 (1H, dd, J_1 = 4.4, J_2 = 1.6 Hz, OCH), 4.02 (2H, s, br., OH), 3.60 (2H, dd, J_1 = 10.8, J_2 = 3.2 Hz, OCH_2), 3.25 (2H, m, OCH_2), 2.77 (1H, m, CH), 2.36 (1H, m, CH), 2.04 (2H, m, CH_2), 1.97 (1H, m, CH_2), 1.81 (1H, m, CH_2), 1.69 (3H, s, Me), 1.60 (3H, s, Me), 1.56–1.42 (2H, m, CH_2) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 137.0, 134.9, 131.8, 124.1, 90.9, 79.1, 61.0, 60.7, 48.5, 46.9, 31.4, 28.2, 25.7, 24.9, 17.7 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{15}H_{28}NO_3$ 270.2064, found for $[M+NH_4]^+$ 270.2059

*14. Cyclization of compound **25***



To a solution of compound **25** (180 mg, 0.71 mmol) in dry CH_2Cl_2 (4 mL) was added $BF_3{\cdot}Et_2O$ (0.09 mL, 0.70 mmol) at 0 °C under N_2. TLC indicated that the intermediary product **27** was formed after 10 min., which was transformed into the eventual cyclization products **28** and **29** after 30 min. The reaction mixture was quenched with 1 mL of H_2O, extracted with ether, the organic layer was washed successively with water and brine, dried (Na_2SO_4), and concentrated in vacuo. The residue was purified by flash column chromatography (PET : EtOAc = 5 : 1) to give **28** (72 mg, 44%) as a colorless oil and **29** (26 mg, 16%) as a colorless oil.

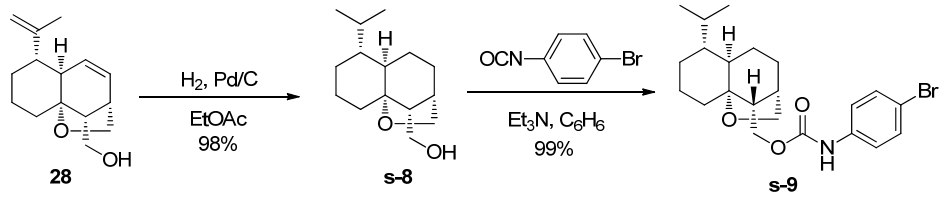
27: R_f = 0.15 (PET : EtOAc = 1 : 2); IR (film): ν_{max} 3351, 2927, 2874, 1741, 1531, 1032, 914, 841, 763, 713, 666, 615, 526 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 5.88 (1H, d, *J* = 9.2 Hz, CH=), 5.78 (1H, s, br., CH=), 5.08 (1H, s, br., CH=), 4.13 (1H, s, br., OH), 4.00 (1H, m, br., OCH), 3.78 (3H, s, br., OCH_2 & OH), 3.34 (2H, m, OCH_2), 2.72 (1H, s, br., CH), 2.26 (1H, s, br., CH), 2.02 (2H, d, *J* = 6.8 Hz, CH_2), 1.69 (3H, s, Me), 1.57 (5H, m, Me & CH_2), 1.35 (2H, m, CH_2) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 136.8, 132.2, 129.0, 123.8, 81.5, 70.5, 66.1, 60.3, 43.8, 43.3, 32.8, 28.3, 25.6, 24.7, 17.7 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{15}H_{24}O_3Na$ 275.1618, found for $[M+Na]^+$ 275.1612

28: R_f = 0.58 (PET : EtOAc = 1 : 2); IR (film): ν_{max} 3405, 2930, 2863, 1644, 1448, 1380, 1054, 1027, 960, 889, 852, 726, 571 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 6.05 (1H, m, CH=), 5.45 (1H, dd, J_1 = 9.6, J_2 = 3.2 Hz, CH=), 4.75 (1H, s, CH_2=), 4.71 (1H, s, CH_2=), 3.95 (1H, m, OCH_2), 3.85 (1H, m, OCH_2), 3.79 (1H, d, *J* = 3.2 Hz, OCH_2), 3.51 (1H, t, *J* = 10.0 Hz, OCH_2), 2.74 (1H, m), 2.30 (1H, t, *J* = 10.0 Hz), 2.04 (1H, m), 1.95 (1H, m), 1.80 (2H, m), 1.69 (3H, s), 1.60 (3H, m), 1.42–1.31 (2H, m) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 146.8, 131.7, 128.7, 111.5, 84.5, 73.6,

60.5, 52.2, 50.9, 45.0, 38.8, 32.7, 31.9, 24.0, 19.1 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{15}H_{26}O_2N$ 252.1958, found for $[M+NH_4]^+$ 252.1952

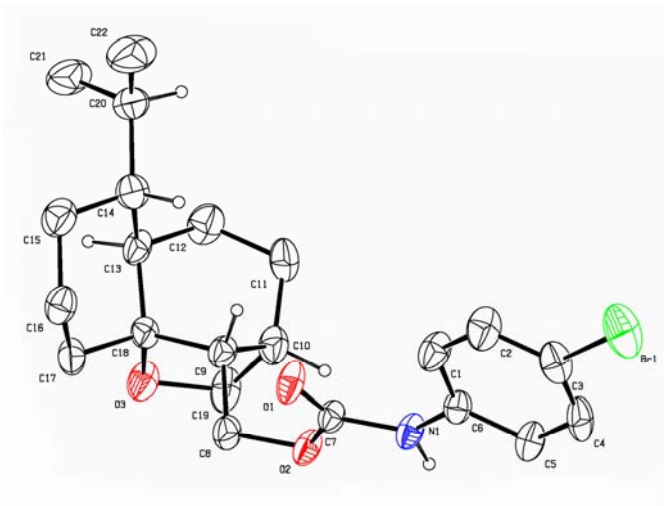
29: R_f = 0.56 (PET : AcOEt = 1 : 2); IR (film): ν_{max} 3380, 2952, 2878, 1710, 1450, 1374, 1222, 1049, 888, 731, 574, 520 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 5.90 (1H, m, CH=), 5.60 (1H, d, *J* = 7.6 Hz, CH=), 4.80 (1H, s, CH_2=), 4.77 (1H, s, CH_2=), 4.22 (1H, d, *J* = 5.6 Hz, OCH), 3.70–3.50 (4H, m, OCH_2), 2.58–2.51 (2H, m), 2.10–1.59 (12H, m) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 147.8, 136.2, 128.1, 112.4, 72.3, 67.7, 63.1, 57.1, 55.0, 46.8, 46.7, 36.9, 30.3, 22.4, 21.5 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{15}H_{23}O_2$ 235.1693, found for $[M+H]^+$ 235.1689

*15. Hydrogenation of compound **28** and derivatization*



To a solution of **28** (234 mg, 1.00 mmol) in EtOAc (20 mL) was added 10% Pd/C (28 mg) at room temperature. The reaction flask was evacuated and recharged with H_2 for three times by a H_2 balloon. After 5 h under H_2 atmosphere, the suspension was filtered through Celite and washed with EtOAc. The filtrate was concentrated in vacuo. The residue was purified by flash column chromatography (PET : EtOAc = 2 : 1) to give compound **s-8** (234 mg, 98%) as a colorless oil. R_f = 0.56 (PET : EtOAc = 1 : 2); IR (film): ν_{max} 3417, 2929, 2868, 1741, 1462, 1367, 1179, 1072, 1031, 987, 959, 894, 843, 794, 656, 554 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 3.93 (1H, m, OCH_2), 3.78 (2H, m, OCH_2), 3.43 (1H, t, *J* = 10.0 Hz, OCH_2), 2.52 (1H, br. s, CH), 2.21 (1H, dd, J_1 = 9.2, J_2 = 5.2 Hz, CH), 1.96–1.35 (13H, m, 3CH & $5CH_2$), 0.90 (3H, d, *J* = 6.8 Hz, Me), 0.69 (3H, d, *J* = 6.8 Hz, Me) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 86.2, 69.2, 60.5, 48.0, 47.4, 42.9, 37.8, 32.9, 28.1, 27.2, 24.0, 23.8, 21.6, 18.8, 14.8 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{15}H_{27}O_2$ 239.2006, found for $[M+H]^+$ 239.2003

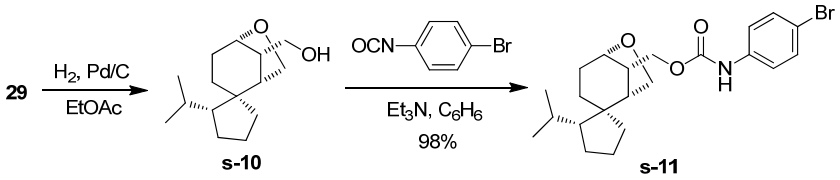
To a solution of compound **s-8** (22 mg, 0.09 mmol) in dry benzene (1 mL) was added 4-bromophenylisocyanate (22 mg, 0.11 mmol) at 0 °C under room temperature, stirred overnight and quenched with 2 mL of H_2O. The reaction mixture was exacted with ether, the organic layer was washed successively with water and brine, dried (Na_2SO_4), and concentrated in vacuo. The residue was purified by flash column chromatography (PET : EtOAc = 10 : 1) to give the corresponding carbamate **s-9** (38 mg, 99%) as colorless solids. R_f = 0.65 (PET : EtOAc = 3 : 1); mp.138–140 ºC; IR (film): ν_{max} 3295, 2955, 2872, 1727, 1534, 1396, 1305, 1222, 1048, 1007, 894, 825, 668, 504 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.40 (2H, d, *J* = 8.8 Hz, ArH), 7.29 (2H, d, *J* = 8.4 Hz, ArH), 6.78 (1H, s, NH), 4.34 (1H, m, OCH_2), 3.96 (2H, m, OCH_2), 3.84 (1H, d, *J* = 8.4 Hz, OCH_2), 2.40 (2H, m), 1.96 (1H, m), 1.70 (4H, m), 1.60 (1H, m), 1.50–0.87 (8H, m), 0.90 (3H, d, *J* = 7.2 Hz, Me), 0.69 (3H, d, *J* = 6.8 Hz, Me) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 153.4, 137.0, 132.0 (2C), 120.2, 116.0, 86.1, 69.1, 63.5, 47.9, 44.5, 42.8, 38.2, 33.0, 27.8, 27.2, 23.9, 23.7, 21.5, 18.7, 14.8 *ppm*



*X-ray crystallographic data of Compound **s-9***

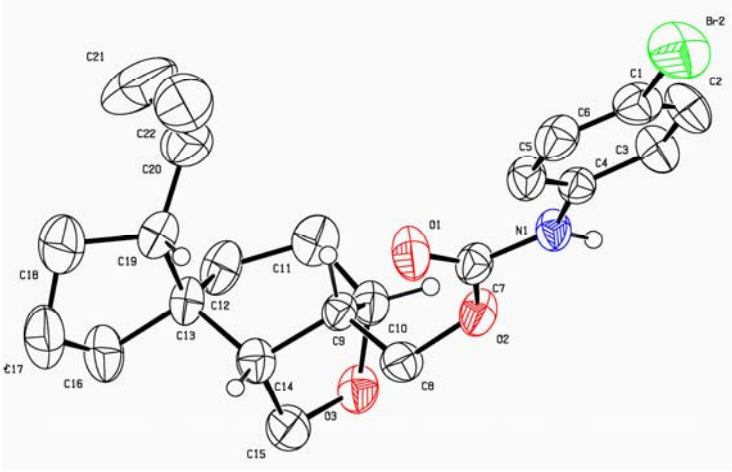
Empirical formula	C_{22} H_{30} Br N O_3
Formula weight	436.38
Temperature (K)	296(2)
Wavelength (Å)	0.71073
Crystal system	Orthorhombic
space group	Pbca
Unit cell dimensions	a = 14.528(2) Å α = 90° b = 13.544(2) Å β = 90° c = 21.691(3) Å γ = 90°
Volume ($Å^3$)	4268.2(10)
Z	8
Calculated density (Mg/m^3)	1.358
Absorption coefficient (mm^{-1})	1.947
Crystal size (mm^3)	0.22 x 0.27 x 0.29
Diffractometer	Bruker APEX-II CCD
θ range	1.88 to 25.20°
Reflections collected / unique	21606 / 3848
R_{int}	0.0736
Data / restraints / parameters	3848 /0 / 250
Goodness-of-fit on F^2	1.031
$R_1(I>2\sigma(I)$	0.0772
WR_2 (all data)	0.2495

*16. Hydrogenation of compound **29** and derivatization*



To a solution of **29** (60 mg) in EtOAc (10 mL) was added 10% Pd/C (15 mg) at room temperature. The reaction flask was evacuated and recharged with H_2 for three times by a H_2 balloon. After 3 h under H_2 atmosphere, the suspension was filtered through Celite and washed with EtOAc. The filtrate was concentrated in vacuo. The residue was purified by flash column chromatography (PET : EtOAc = 2 : 1) to give compound **s-10** (60 mg, 98%) as a colorless oil. R_f = 0.54 (PET : EtOAc = 1 : 2); IR (film): ν_{max} 3404, 2952, 2873, 1742, 1461, 1368, 1206, 1171, 1055, 1030, 861, 490 cm^{-1};^{1}H NMR (400 MHz, $CDCl_3$): δ 4.20 (1H, d, *J* = 4.4 Hz, OCH), 3.89 (1H, d, *J* = 4.8 Hz, OCH_2), 3.71 (2H, m, OCH_2), 3.56 (1H, m, OCH_2), 3.48 (1H, m, OCH_2), 2.18 (1H, t, *J* = 7.2 Hz), 1.90 (2H, m), 1.74 (3H, m), 1.50 (8H, m), 0.92 (3H, d, *J* = 6.0 Hz, Me), 0.86 (3H, d, *J* = 6.0 Hz, Me) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 75.7, 68.6, 63.3, 49.7, 49.6, 48.2, 47.2, 39.0, 32.1, 27.4, 25.2, 24.6, 24.2, 21.9, 18.2 *ppm*; HRMS (ESI) calcd for $C_{15}H_{27}O_2$ 239.2006, found for $[M+H]^+$ 239.2007

Compound **s-11** was prepared similarly as for **s-9** in 98% yield as colorless solids. R_f = 0.65 (PET : EtOAc = 3 : 1); mp.122–124 ºC; IR (film): ν_{max} 3250, 2955, 2874, 1735, 1597, 1540, 1488, 1307, 1228, 1069, 974, 855, 821, 751, 504 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.40 (2H, d, *J* = 8.4 Hz, ArH), 7.28 (2H, m, ArH), 6.74 (1H, br s, NH), 4.19 (1H, d, *J* = 4.0 Hz, OCH), 4.05 (2H, m, OCH_2), 3.78 (1H, d, *J* = 9.2 Hz, OCH_2), 3.76 (1H, m, OCH_2), 2.35 (1H, t, *J* = 7.6 Hz), 1.93–1.25 (13H, m), 0.91 (3H, d, *J* = 6.8 Hz, Me), 0.85 (3H, d, *J* = 6.8 Hz, Me) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 153.3, 137.0, 132.0 (2C), 120.0, 116.0, 75.7, 68.5, 65.5, 49.9, 49.6, 47.4, 45.1, 39.1, 32.0, 27.4, 25.1, 24.8, 24.3, 21.9, 18.2 *ppm*

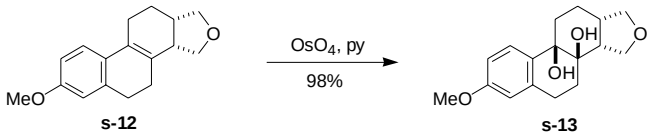


X-ray crystallographic data of Compound ***s-11***

Empirical formula	C_{22} H_{30} Br N O_3
Formula weight	436.38
Temperature (K)	296(2)
Wavelength (Å)	0.71073
Crystal system	Triclinic
space group	P1
Unit cell dimensions	a = 6.460(9) Å α = 83.627(7)° b = 12.2690(17) Å β =81.274(7)° c = 13.6975(18) Å γ = 79.700(8)°

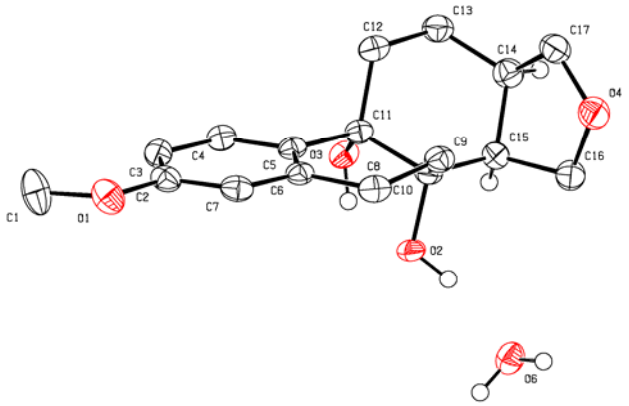
Volume ($Å^3$)	1052.5(2)
Z	2
Calculated density (Mg/m^3)	1.377
Absorption coefficient (mm^{-1})	1.974
Crystal size (mm^3)	0.32 x 0.31 x 0.14
Diffractometer	Bruker APEX-II CCD
θ range	2.36 to 21.16°
Reflections collected / unique	6003 / 4083
R_{int}	0.0239
Data / restraints / parameters	4083 / 0 / 250
Goodness-of-fit on F^2	1.011
$R_1(I>2\sigma(I)$	0.0573
WR_2 (all data)	0.1747

17. Dihydroxylation of compound ***s-12***



s-12 **s-13**

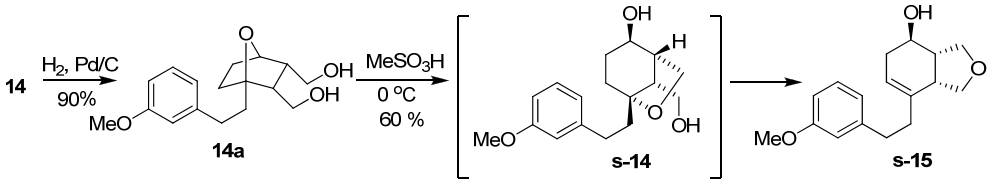
To a solution of compound **s-12** (32 mg, 0.125 mmol) in dry pyridine (0.5 mL) was added OsO_4 (10 mg) at 0 °C under N_2. After stirred for 1 h, the reaction mixture was quenched with 2 mL of saturated $NaHSO_3$, extracted with ether, the organic layer was washed successively with water and brine, dried (Na_2SO_4), and concentrated in vacuo. The residue was purified by flash column chromatography (PET : EtOAc = 2 : 1) to give **s-13** (40 mg, 98%) as white solids. R_f = 0.10 (PET : AcOEt = 1 : 2); IR (film): ν_{max} 3427, 2932, 2868, 1609, 1499, 1252, 1052, 928, 910, 876, 732, 650 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.49 (1H, d, *J* = 9 Hz, ArH), 6.79 (1H, d, *J* = 9 Hz, ArH), 6.59 (1H, s, ArH), 3.96 (1H, d, *J* = 9 Hz, OCH_2), 3.88 (2H, q, *J* = 8.4 Hz, OCH_2), 3.80 (3H, s, OMe), 3.47 (1H, t, *J* = 8.1 Hz, OCH_2), 3.02 (1H, m), 2.58 (4H, m), 2.26 (1H, s), 2.20 (1H, m), 2.00 (4H, m), 1.46 (1H, m) *ppm*; ^{13}C NMR (75 MHz, $CDCl_3$): δ 158.6, 136.1, 134.1, 128.0, 113.2, 112.4, 73.4, 72.8, 70.5, 69.1, 55.2, 47.0, 37.6, 34.2, 28.3, 25.4, 19.2 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{17}H_{21}O_3$ 273.1485, found for $[M–H_2O+H]^+$ 273.1478



X-ray crystallographic data of Compound ***s-13***

Empirical formula	$C_{17}H_{24}O_5$
Formula weight	308.36
Temperature (K)	113(2)
Wavelength (Å)	0.71070
Crystal system	Monoclinic
space group	P21/c
Unit cell dimensions	a = 10.137(9) Å α = 90° b = 7.272(7) Å β = 99.252(11)° c = 20.597(19) Å γ = 90°
Volume ($Å^3$)	1499(2)
Z	4
Calculated density (Mg/m^3)	1.367
Absorption coefficient (mm^{-1})	0.100
Crystal size (mm^3)	0.14 x 0.14 x 0.16
θ range	2.00 to 26.49°
Reflections collected / unique	13868 / 3007
R_{int}	0.0963
Data / restraints / parameters	3007 / 4 / 218
Goodness-of-fit on F^2	1.019
Extinction coefficient	0.032(5)
$R_1(I>2\sigma(I)$	0.0646
WR_2 (all data)	0.2138

*18. Cyclization of compound **14a***



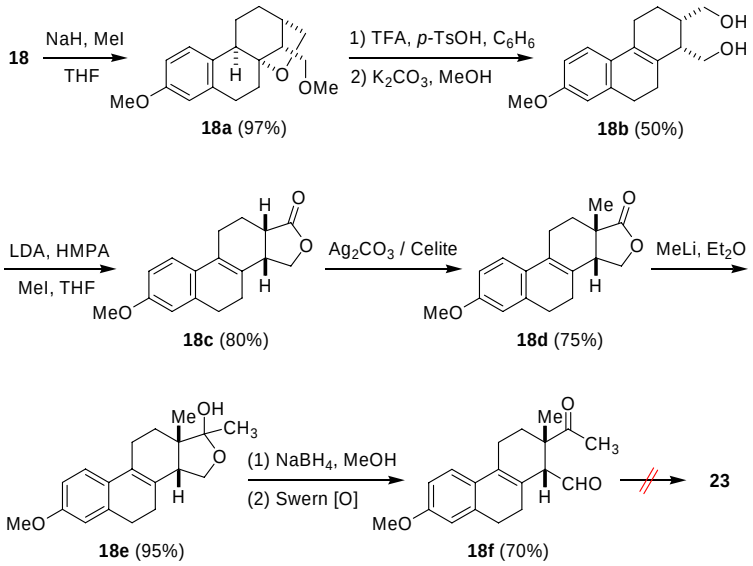
Compound **14a** was prepared by routine catalytic hydrogenation similarly as for compound **18** in 90% yield as a colorless oil. R_f = 0.20 (PET : AcOEt = 1 : 2); IR (film): ν_{max} 3357, 2938, 1603, 1490, 1457, 1316, 1259, 1155, 1044, 966, 902, 785, 699, 572, 460 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.20 (1H, t, *J* = 7.6 Hz, ArH), 6.72 (3H, m, ArH), 4.42 (1H, t, *J* = 5.2 Hz, OCH), 4.07 (1H, br. s, OH), 3.82 (2H, m, OCH_2), 3.78 (3H, s, OMe), 3.59 (2H, m, , OCH_2), 2.76 (2H, m, CH_2), 2.60 (1H, m, CH_2), 2.30 (1H, m, CH_2), 2.05 (2H, m, CH), 1.68 (1H, m, CH_2), 1.53 (1H, m, CH_2), 1.44 (2H, m, CH_2) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 159.6, 143.7, 129.3, 120.6, 113.9, 111.1, 87.9, 78.0, 59.8, 59.7, 55.1, 48.4, 46.4, 36.0, 30.5, 28.8, 26.1 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{17}H_{28}O_4N$ 310.2013, found for $[M+NH_4]^+$ 310.2017

To a solution of compound **14a** (70 mg, 0.24 mmol) in dry CH_2Cl_2 (2 mL) was added $MeSO_3H$ (50 mg, 0.5 mmol) at 0 °C under N_2. After stirring for 1 h, the reaction mixture was quenched with 1 mL of H_2O, extracted with EtOAc, the organic layer was washed successively with water and brine, dried (Na_2SO_4), and concentrated in vacuo. The residue was purified by flash column chromatography (PET : EtOAc = 1 : 2) to give **s-14** (48 mg, 60%) as a colorless oil.

R_f = 0. 15 (PET : AcOEt = 1 : 2); IR (film): ν_{max} 3369, 2931, 1707, 1603, 1490, 1456, 1259, 1153, 1042, 1021, 970, 872, 783, 695, 572 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.18 (1H, t, *J* = 7.6 Hz, ArH), 6.73 (3H, m, ArH), 4.03 (1H, br. s, OCH), 3.93-3.82 (2H, m, OCH_2), 3.78 (3H, s), 3.66 (1H, d, *J* = 8.4 Hz, OCH_2), 3.40 (1H, t, *J* = 10.0 Hz, OCH_2), 2.62 (3H, m), 2.52 (1H, m), 1.97 (1H, m), 1.80 (2H, m), 1.60 (2H, m) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 159.6, 143.8, 129.3, 120.6, 114.1, 111.0, 84.3, 69.2, 68.5, 60.0, 55.1, 45.0, 44.8, 37.2, 32.7, 31.2, 27.0 *ppm*; HRMS (ESI) *m/z*: calcd for $C_{17}H_{28}O_4N$ 310.2013, found for $[M+NH_4]^+$ 310.2009

Compound **s-14** was converted to compound **s-15** if the above cyclization reaction mixture was stirred at room temperature for 4 h, which can be isolated by routine purification procedures as a colorless gum. **s-15**: R_f = 0.35 (PET : EtOAc = 1： 2); IR (film): ν_{max} 3408, 2926, 2869, 1601, 1587, 1489, 1455, 1436, 1259, 1153, 1053 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$): δ 7.20 (1H, t, *J* = 8.0 Hz, ArH), 6.75 (3H, m, ArH), 5.41(1H, q, *J* = 1.2 Hz, CH=), 4.08 (1H, m, OCH_2), 4.02 (1H, m, OCH_2), 3.93 (1H, m, OCH_2), 3.79 (3H, s, OMe), 3.68 (1H, m, OCH), 3.41(1H, t, *J* = 8.4 Hz, OCH_2), 2.87 (1H, m), 2.68 (2H, m), 2.32 (1H, m), 2.09 (3H, m), 2.04 (2H, m) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 159.6, 143.4, 136.8, 129.3, 120.6, 119.1, 114.4, 111.1, 72.3, 71.0, 67.2, 55.1, 45.3, 43.5, 37.7, 34.0, 33.5 *ppm*

*19. Spectroscopic data of intermediates **18a~f***



Compound **18a**: R_f = 0.70 (PET : EtOAc = 2 : 1); IR (film): ν_{max} 2926, 1740, 1608, 1498, 1460, 1240, 1038, 975, 917, 790 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.16 (1H, d, *J* = 8.7 Hz), 6.66 (2H, m), 4.01 (1H, m), 3.95 (1H, m), 3.77 (3H, s), 3.48 (1H, m), 3.29 (3H, m), 3.07 (1H, d, *J* = 8.7 Hz), 3.01 (1H, m), 2.88 (1H, d, *J* = 6.6 Hz), 2.43 (1H, br s), 2.18 (2H, m), 1.96 (3H, m), 1.50 (1H, m) *ppm*; ^{13}C NMR (75 MHz, $CDCl_3$): δ 157.5, 137.5, 130.7, 125.5, 113.7, 111.4, 84.4, 71.3, 70.1, 58.8, 55.1, 45.9, 45.1, 38.3, 29.4, 28.7, 27.4, 20.2 *ppm*

Compound **18b**: R_f = 0.25 (PET : AcOEt = 1 : 2); mp. 132~135 °C; IR (film): ν_{max} 3337, 2924, 2876, 1608, 1498, 1428, 1250, 1155, 1034, 809 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 7.10 (1H, d, *J* = 8.4 Hz), 6.68 (2H, m), 3.78 (3H, s), 3.75 (4H, m), 3.56 (2H, s, br.), 2.68 (2H, m), 2.50 (1H, m),

2.40 (2H, m), 2.30 (2H, m), 2.05 (2H, m), 1.63 (2H, m) *ppm*; ^{13}C NMR (75 MHz, $CDCl_3$): δ 158.1, 137.4, 130.4, 128.8, 128.6, 123.0, 113.3, 110.8, 65.3, 61.3, 55.2, 44.6, 38.8, 29.1, 28.3, 25.4, 21.2 *ppm*; HRMS (ESI) calcd for $C_{17}H_{22}O_3Na$ 297.1461, found for $[M+Na]^+$ 297.1460

Compound **18c**: R_f = 0.45 (PET : AcOEt = 2 : 1); mp. 93~95 °C; IR (film): ν_{max} 2928, 1770, 1608, 1499, 1252, 1153, 1043, 1021, 986, 813, 730, 610 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.10 (1H, d, *J* = 8.4 Hz), 6.72 (2H, m), 4.43 (1H, t, *J* = 7.2 Hz), 4.16 (1H, m), 3.81 (3H, s), 3.21 (1H, s, br.), 2.83 (1H, m), 2.70 (2H, m), 2.05–2.40 (6H, m), 1.85 (1H, m) *ppm*; ^{13}C NMR (75 MHz, $CDCl_3$): δ 178.8, 158.4, 136.8, 130.2, 128.5, 127.0, 123.4, 113.4, 110.9, 70.6, 55.2, 40.1, 38.3, 28.4, 26.8, 22.0, 20.4 *ppm*; HRMS (ESI) calcd for $C_{17}H_{22}O_3N$ 288.1594, found for $[M+NH_4]^+$ 288.1591

Compound **18d**: R_f = 0.48 (PET : AcOEt = 2 : 1); IR (film): ν_{max} 2924, 1768, 1608, 1499, 1457, 1431, 1304, 1252, 1156, 1091, 1021, 866, 813 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.13 (1H, d, *J* = 8.4 Hz), 6.72 (2H, m), 4.51 (1H, t, *J* = 7.8 Hz), 4.10 (1H, t, *J* = 7.2 Hz), 3.80 (3H, s), 2.72 (3H, m), 2.40 (2H, br s), 1.98-2.23 (3H, m), 1.70 (1H, m), 1.25 (3H, s) *ppm*; ^{13}C NMR (75 MHz, $CDCl_3$): δ 181.4, 158.4, 136.7, 128.6, 128.2, 127.1, 123.3, 113.4, 110.9, 69.7, 55.1, 47.1, 40.9, 28.4, 27.6, 27.1, 21.7, 21.3 *ppm*; HRMS (ESI) calcd for $C_{18}H_{24}O_3N$ 302.1751, found for $[M+NH_4]^+$ 302.1747

Compound **18e**: R_f = 0.30 (PET : EtOAc = 2 : 1); mp. 122~127 °C; IR (film): ν_{max} 3386, 2932, 2882, 1608, 1571, 1499, 1464, 1381, 1252, 1153, 1105, 1038, 1010, 929, 871, 813, 732, 644 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.15 (1H, d, *J* = 8.4 Hz), 6.69 (2H, m), 4.33 (1H, t, *J* = 8.0 Hz), 3.80 (3H, s), 3.62 (1H, t, *J* = 8.0 Hz), 2.73 (3H, m), 2.41 (3H, br s), 2.20 (1H, m), 2.09 (1H, m), 1.58 (2H, m), 1.39 (3H, s), 1.03 (3H, s) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 158.0, 136.9, 130.7, 128.8, 124.8, 123.0, 113.5, 110.9, 108.3, 71.7, 55.2, 47.6, 44.9, 28.7, 27.3, 22.4, 21.4, 16.8 *ppm*

Compound **18f**: R_f = 0.30 (PET : EtOAc = 3 : 1); IR (film): ν_{max} 2934, 2835, 1707, 1608, 1571, 1450, 1431, 1252, 1154, 1103, 1140, 992, 929, 877, 812, 613 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$): δ 9.50 (1H, d, *J* = 4.8 Hz), 7.18 (1H, d, *J* = 11.6 Hz), 6.73 (2H, m), 3.80 (3H, s), 2.99 (1H, s, br.), 2.73 (2H, m), 2.59 (2H, m), 2.40 (1H, m), 2.23 (3H, s), 2.18 (1H, m), 2.05 (1H, m), 1.16 (3H, s) *ppm*; ^{13}C NMR (100 MHz, $CDCl_3$): δ 212.7, 197.1, 158.7, 137.5, 129.9, 127.9, 123.4, 123.0, 113.5, 111.1, 60.3, 55.2, 48.9, 28.5, 27.5, 26.6, 25.1, 22.5, 20.9 *ppm*; HRMS (ESI) calcd for $C_{19}H_{23}O_3$ 299.1642, found for $[M+H]^+$ 299.1641