Development of a Highly γ -Regioselective Metal-Mediated Allylation Reaction in Aqueous Media: New Mechanistic Proposal for the Origin of γ -Homoallylic Alcohols

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Supporting Information

General

Experiments involving moisture and/or air sensitive components were performed in oven-dried glassware. Commercial solvents and reagents were used without further purification with the following exceptions: Hexane, dichloromethane, ethyl acetate were fractionally distilled. Aldehydes were distilled before used.

Analytical thin layer chromatography (TLC) was performed using Merck 60 F₂₅₄ precoated silica gel plate (0.2 mm thickness). Subsequent to elution, plates were visualized using UV radiation (254 nm) on Spectroline Model ENF-24061/F 254 nm. Further visualization was possible by staining with basic solution of potassium permanganate or acidic solution of ceric molybdate, followed by heating on a hot plate.

Flash chromatography was performed using Merck silica gel 60 with freshly distilled solvents. Columns were typically packed as slurry and equilibrated with the appropriate solvent system prior to use.

Infrared spectra were recorded on a BIO-RAD FTS 165 FTIR spectrometer. Liquid samples were examined as film between NaCl and KBr salt plates.

Proton nuclear magnetic resonance spectra (¹H NMR) were recorded on a Bruker ACF 300 and Bruker Avance DPX

300 spectrophotometer (internal reference SiMe_4 and CDCl_3 as solvent). Chemical shifts for ^1H NMR spectra are reported as δ in units of parts per million (ppm) downfield from SiMe_4 (δ 0.0) and relative to the signal of chloroform-*d* (δ 7.26, singlet). Multiplicities were given as: s (singlet); d (doublet); t (triplet); q (quartet); dd (doublets of doublet); ddd (doublets of doublets of doublet); dddd (doublets of doublets of doublets of doublet); dt (doublets of triplet); or m (multiplets). The number of protons (*n*) for a given resonance is indicated by *n*H. Coupling constants are reported as a *J* value in Hz. Carbon nuclear magnetic resonance spectra (^{13}C NMR) are reported as δ in units of parts per million (ppm) downfield from SiMe_4 (δ 0.0) and relative to the signal of chloroform-*d* (δ 77.03, triplet). The proportion of diastereomers and geometric isomers was determined from the integration of ^1H NMR and ^{13}C NMR spectra.

Mass spectral analyses were carried out on a VG 7035 micromass mass spectrophotometer at a source temperature of 200 °C and at an ion current of 70 eV. Mass spectral data were reported in units of mass to charge (*m/e*) and % intensity.

Experimental procedure

A representative procedure for preparation of indium allylation

A mixture of cyclohexane carboxaldehyde (0.11 g, 1 mmol) and indium powder (0.17 g, 100 mesh, 1.5 mmol) in H₂O (0.11 mL, 6 mmol) was added crotyl bromide (0.16 g, 1.2 mmol) slowly at room temperature in 5 mL RBF. The reaction mixtures were stirred for 12 hours followed by heated at 40°C and monitored by TLC until all the α -adduct was converted to its β -regioisomer. Ether was added to dilute the reaction mixture followed by 1 M HCl to quench the reaction. The reaction mixture was extracted with ether. The combined organic layer was washed with brine, and dried over anhydrous magnesium sulfate, filtered and the solvent was removed *in vacuo*. The crude product was purified by column chromatography to afford 85% (143 mg) yield of β -homoallylic alcohol as a colorless oil.

A representative procedure for preparation of tin crotylation

A mixture of cyclohexanecarboxaldehyde (0.120 mL, 1.0 mmol, 1 equiv.), tin powder (0.178 g, 1.5 mmol, 1.5 equiv.) and crotyl bromide (0.125 mL, 1.2 mmol, 1.2 equiv.) in CH₂Cl₂ (0.385 mL, 6 equiv.) and H₂O (0.108 mL,

6 equiv.) was stirred in a 10 mL round bottom flask equipped with a glass septum at room temperature for 48 hours. 50 mL H₂O was added and the reaction mixture extracted with 50 mL portions of ethyl acetate. The combined organic layer was washed with 50 mL brine and 50 mL water and dried over anhydrous magnesium sulfate. The mixture was then filtered and the solvent removed *in vacuo*. The crude product was purified by column chromatography to afford a 78 % (131 mg) yield mixture of (95%) α - and (5%) β -homoallylic alcohols as a colorless oil.

A representative procedure for preparation of zinc crotylation

A mixture of cyclohexanecarboxaldehyde (0.120 mL, 1.0 mmol, 1 equiv.), zinc powder (0.098 g, 1.5 mmol, 1.5 equiv.) and crotyl bromide (0.125 mL, 1.2 mmol, 1.2 equiv.) in CH₂Cl₂ (0.128 mL, 2 equiv.) and H₂O (0.036 mL, 2 equiv.) was stirred in a 5 mL round bottom flask equipped with a glass septum at room temperature for 120 hours (monitored by TLC). The reaction mixture was diluted with 50 mL diethyl ether and then, it was extract with 10 ml of 5% HCl. The ether layer was washed with, 20 mL sodium bicarbonate, followed with 20 mL brine and dried over anhydrous magnesium sulfate. The mixture was then filtered and the solvent removed *in vacuo*. The crude

product was purified by column chromatography to afford a 66% (110 mg) yield mixture of (95%) Δ^2 - and (5%) Δ^3 -homoallylic alcohols as a colorless oil.

1-Cyclohexyl-2-methyl-but-3-en-1-ol

R_f 0.52 (4:1 hexane/ethyl acetate).

^1H NMR (300 MHz, CDCl_3) *anti* isomer: δ 5.85–5.73 (m, 1H), 5.10–5.08 (m, 2H), 3.09 (t, J = 5.6 Hz, 1H), 2.48–2.28 (m, 1H), 1.84–1.08 (m, 11H), 1.03 (d, J = 6.9 Hz, 3H); *syn* isomer: δ 3.19 (t, J = 5.6 Hz, 1H), 2.27–2.19 (m, 1H), 1.84–1.08 (m, 11H), 1.00 (d, J = 6.9 Hz, 3H).

^{13}C NMR (75.4 MHz, CDCl_3) *anti* isomer: δ 140.34, 115.9, 78.8, 40.4, 40.3, 29.9, 27.0, 26.4, 26.4, 26.0, 16.9; *syn* isomer: δ 141.9, 114.4, 78.5, 40.2, 39.7, 29.6, 27.8, 26.3, 26.2, 25.9, 13.0.

FTIR (film) 3586, 3428, 2926, 2828, 1643, 1450, 1111, 1003, 906 cm^{-1} .

HRMS Calcd for $\text{C}_{11}\text{H}_{20}\text{O}$ [M^+]: 168.1514. Found: 168.1515.

1-Cyclohexyl-pent-3-en-1-ol

R_f 0.45 (4:1 hexane/ethyl acetate).

Supporting Information

^1H NMR (300 MHz, CDCl_3) *E* isomer: δ 5.61–5.38 (m, 1H), 3.39–3.29 (m, 1H), 2.24 (t, J = 8.4 Hz, 1H), 2.05 (t, J = 8.4 Hz, 1H), 1.69 (dd, J = 5.6, 0.7 Hz, 3H), 1.87–0.94 (m, 11H). *Z* isomer: δ 1.64 (dd, J = 5.9, 0.7 Hz, 3H)

^{13}C NMR (75.4 MHz, CDCl_3) *E* isomer: δ 128.7, 127.6, 74.9, 42.9, 37.4, 29.0, 28.1, 26.5, 26.2, 26.1, 18.0; *Z* isomer: δ 127.0, 126.6, 75.5, 42.59, 37.46, 31.7, 29.0, 28.1, 26.5, 26.2, 26.1.

FTIR (film) 3591, 3422, 3020, 2925, 2854, 1625, 1448, 1261, 1086, 1065, 1030, 968, 892 cm^{-1} .

HRMS Calcd for $\text{C}_{11}\text{H}_{20}\text{O}$ [M^+]: 168.1514. Found: 168.1520.

4-Methyl-1-phenyl-hex-5-en-3-ol

R_f 0.38 (4:1 hexane/ethyl acetate).

^1H NMR (300 MHz, CDCl_3) *anti* isomer: δ 7.30–7.17 (m, 5H), 5.82–5.68 (m, 1H), 5.14–5.05 (m, 2H), 3.42 (ddd, J = 9.1, 6.0, 3.2 Hz, 1H), 2.86 (ddd, J = 13.9, 10.0, 5.1 Hz, 1H), 2.67 (ddd, J = 13.9, 10.0, 6.0 Hz, 1H), 2.23 (ddq, J = 8.3, 7.0, 6.0 Hz, 1H), 1.89–1.63 (m, 2H), 1.02 (d, J = 6.9 Hz, 3H); *syn* isomer: δ 7.30–7.17 (m, 5H), 5.77 (m, 1H), 5.15–5.08 (m, 2H), 3.53 (ddd, J = 8.9, 4.9, 3.1 Hz, 1H), 2.86 (ddd, J = 14.2, 10.0, 5.1 Hz, 1H), 2.65 (ddd, J

= 14.2, 9.9, 6.5 Hz, 1H), 2.31 (ddq, J = 7.5, 6.7, 4.9 Hz, 1H), 1.82–1.68 (m, 2H), 1.03 (d, J = 6.9 Hz, 3H).

^{13}C NMR (75.4 MHz, CDCl_3) *anti* isomers: δ 142.1, 140.1, 128.3, 125.7, 116.4, 74.0, 44.3, 36.0, 32.1, 16.2; *syn* isomer: δ 142.2, 140.7, 125.7, 128.4, 115.4, 73.9, 44.3, 35.7, 32.4, 14.2.

FTIR (film) 3429, 3084, 3012, 2968, 2930, 2870, 1640, 1603, 1496, 1454, 1218, 1038, 918, 767, 700 cm^{-1} .

HRMS Calcd for $\text{C}_{13}\text{H}_{18}\text{O}$ [M^+]: 190.1357. Found: 190.1365.

1-Phenyl-hept-5-en-3-ol

R_f 0.34 (4:1 hexane/ethyl acetate).

^1H NMR (300 MHz, CDCl_3) *E* isomers: δ 7.31–7.16 (m, 5H), 5.57 (dq, J = 15.3, 6.3 Hz, 1H), 5.47–5.37 (m, 1H), 3.61 (br m, 1H), 2.86–2.63 (m, 2H), 2.29–2.05 (m, 2H), 1.81–1.58 (m, 2H), 1.69 (d, J = 5.94 Hz, 3H); *Z* isomers: δ 7.28–7.09 (m, 5H), 5.59 (ddq, J = 10.8, 7.2, 0.8 Hz, 1H), 5.36 (dtq, J = 10.8, 7.6, 1.6 Hz, 1H), 3.65–3.55 (m, 1H), 2.75–2.62 (m, 2H), 2.20 (t, J = 7.2 Hz, 2H), 1.73 (dq, J = 13.5, 7.2 Hz, 2H), 1.58 (dd, J = 7.2, 0.8 Hz, 3H)

^{13}C NMR (75.4 MHz, CDCl_3) *E* isomer: δ 142.2, 129.2, 128.5, 128.4, 126.9, 125.8, 70.2, 40.9, 38.4, 32.1, 18.1; *Z*

isomer: δ 142.1, 128.4, 128.4, 127.5, 125.9, 125.8, 70.8, 38.4, 35.1, 32.1, 13.0

FTIR (film) 3568, 3412, 3083, 3064, 3028, 3001, 2963, 2932, 2868, 1640, 1545, 1375, 1000, 914, 748, 700 cm^{-1} .

HRMS Calcd for $\text{C}_{13}\text{H}_{18}\text{O}$ [M^+]: 190.1411. Found: 190.1430.

3-methyl-non-1-en-4-ol

R_f 0.46 (4:1 hexane/ethyl acetate).

^1H NMR (300 MHz, CDCl_3) *anti* isomers: δ 5.79–5.69 (m, 1H), 5.13–5.05 (m, 2H), 3.39 (br, 1H), 2.30–2.28 (m, 1H), 1.52–1.25 (m, 8H), 1.03 (d, J = 6.9 Hz, 3H), 0.89 (t, J = 6.9 Hz, 3H); *syn* isomer: δ 5.85–5.75 (m, 1H), 5.11–5.07 (m, 2H), 3.49 (br s, 1H), 1.52–1.25 (m, 8H), 1.02 (d, J = 6.9 Hz, 3H), 0.89 (d, J = 6.9 Hz, 3H).

^{13}C NMR (75.4 MHz, CDCl_3) *anti* isomer: δ 140.3, 115.9, 74.6, 43.9, 34.1, 31.8, 25.3, 22.5, 16.1, 13.9; *syn* isomer: δ 141.1, 114.0, 74.6, 42.4, 33.9, 31.8, 25.6, 22.5, 16.1, 14.0.

FTIR (film) 3401, 3080, 2958, 2932, 2685, 1639, 1461, 1418, 1378, 1121, 1084, 1002, 912 cm^{-1} .

HRMS Calcd for $\text{C}_{10}\text{H}_{20}\text{O}$ [M^+]: 156.1514. Found: 156.1500.

Dec-2-en-5-ol

R_f 0.41 (4:1 hexane/ethyl acetate).

^1H NMR (300 MHz, CDCl_3) *Z* isomer: δ 5.69–5.59 (m, 1H), 5.48–5.39 (m, 1H), 3.62 (tt, J = 5.9, 5.9 Hz, 1H), 2.27–2.16 (m, 4H), 1.64 (dd, J = 7.1, 0.7 Hz, 3H), 1.46–1.25 (m, 6H), 0.89 (t, J = 7.0 Hz, 3H); *E* isomer: δ 1.60 (dd, J = 7.1, 0.7 Hz, 3H)

^{13}C NMR (75.4 MHz, CDCl_3) *E* isomer: δ 128.8, 127.2, 71.0, 40.6, 36.7, 31.9, 25.3, 22.7, 18.0, 14.0; *Z* isomer: δ 127.2, 126.2, 71.5, 36.8, 35.0, 31.9, 25.5, 22.7, 14.0, 13.0,

FTIR (film) 3400, 3019, 2957, 2930, 2858, 2370, 2345, 1656, 1639, 1459, 1378, 1124, 1030, 968 cm^{-1} .

HRMS Calcd for $\text{C}_{10}\text{H}_{20}\text{O}$ [M^+]: 156.1514. Found: 156.1538.

2-Methyl-1-phenyl-but-3-en-1-ol

R_f 0.42 (4:1 hexane/ethyl acetate).

^1H NMR (300 MHz, CDCl_3) *syn* isomers: δ 7.36–7.24 (m, 5H), 5.83–5.72 (m, 1H), 5.21–5.02 (m, 2H), 4.60 (d, J = 5.5 Hz, 1H), 2.61–2.44 (m, 1H), 2.00 (br s, 1H), 0.87 (d, J = 6.8 Hz, 3H); *anti* isomer: δ 4.35 (d, J = 7.8, 1H), 2.18 (brs, 1H), 1.00 (d, J = 6.8 Hz, 3H).

^{13}C NMR (75.4 MHz, CDCl_3) *syn* isomer: δ 140.3, 128.1, 127.6, 127.3, 126.8, 116.8, 77.9, 44.6, 16.5; *anti* isomer: δ 142.6, 142.4, 140.6, 128.2, 126.5, 115.5, 77.2, 46.3, 14.0.

FTIR (film) 3405, 3065, 3030, 2974, 2931, 2879, 1637, 1494, 1454, 1418, 1198, 1076, 1021, 914, 762, 701, 681, 631, 548 cm^{-1} .

HRMS Calcd for $\text{C}_{11}\text{H}_{14}\text{O}$ [M^+]: 162.1045. Found: 162.1028.

1-Phenylpent-3-en-1-ol

R_f 0.32 (4:1 hexane/ethyl acetate).

^1H NMR (300 MHz, CDCl_3) *E* isomer: δ 7.36–7.24 (m, 5H), 5.65–5.44 (m, 1H), 5.43–5.32 (m, 1H), 4.68–4.55 (m, 1H), 2.58–2.26 (m, 2H), 1.97 (d, J = 3.3 Hz, 1H), 1.60 (dd, J = 6.8, 0.8 Hz, 3H); *Z* isomer: 2.04 (d, J = 3.0 Hz, 1H), 1.69 (d, J = 1.2 Hz, 3H).

^{13}C NMR (75.4 MHz, CDCl_3) *E* isomer: 144.1, 129.4, 128.3, 127.4, 126.8, 125.8, 73.4, 42.8, 18.0; *Z* isomer: 128.3, 127.5, 127.3, 125.8, 125.7, 125.6, 73.8, 36.8, 12.9.

FTIR (film) 3399, 3029, 2932, 2856, 1604, 1494, 1454, 1439, 1200, 1042, 1029, 968, 759, 700, 551 cm^{-1} .

HRMS Calcd for $\text{C}_{11}\text{H}_{14}\text{O}$ [M^+]: 162.1045. Found: 162.1049.

2,2,4-Trimethyl-hex-5-en-3-ol

R_f 0.5 (4:1 hexane/ethyl acetate).

^1H NMR (300 MHz, CDCl_3) *anti* isomer: δ 6.02–5.83 (m, 1H), 5.09–5.04 (m, 2H), 3.14 (d, J = 2.4 Hz, 1H), 2.59–2.51 (m, 1H), 1.12 (d, J = 7.3 Hz, 3H), 0.96 (s, 9H); *syn* isomer: δ 5.01–4.97 (m, 2H), 3.24 (d, J = 2.4 Hz, 1H), 1.05 (d, J = 6.9 Hz, 3H), 0.94 (s, 9H)

^{13}C NMR (75.4 MHz, CDCl_3) *anti* isomer: δ 140.4, 114.7, 78.9, 39.4, 29.3, 20.7, 16.5. *syn* isomer: δ 144.4, 112.6, 78.9, 39.6, 30.5, 20.6, 16.9.

FTIR (film) 3413.2, 2927.2, 2254.0, 1650.7, 1557.5, 1509.8908.2, 733.4, 651.4.

2,2-Dimethyl-hept-5-en-3-ol

R_f 0.47 (4:1 hexane/ethyl acetate).

^1H NMR (300 MHz, CDCl_3) *E* isomers: δ 5.69–5.31 (m, 2H), 3.17 (dd, J = 10.4, 2.0, 1H), 2.36–2.19 (m, 2H), 1.69 (d, J = 6.4, 3H), 0.90 (s, 9H); *Z* isomers: δ 1.64 (d, J = 6.6 Hz, 3H), 0.94 (m, 9H).

^{13}C NMR (75.4 MHz, CDCl_3) *E* isomer: δ 128.8, 128.3, 78.3, 35.2, 34.4, 25.7, 17.9. *Z* isomer: δ 127.9, 126.7, 79.0, 34.7, 29.4, 26.6, 12.8.

FTIR (film) 3406.4, 3081.2, 2974.0, 2246.3, 1637.6, 1453.9, 1021.3, 912.8, 701.3.

HRMS Calcd for $C_9H_{16}O$ [$M^+ - H$]: 141.1279. Found: 141.1279.

1,4-Diphenyl-but-3-en-1-ol

R_f 0.26 (4:1 hexane/ethyl acetate).

1H NMR (300 MHz, $CDCl_3$) *E* isomer: δ 7.43–7.25 (m, 10H), 6.52 (d, J = 16.0 Hz, 1H), 6.23 (dt, J = 7.6, 16.0 Hz, 1H), 4.82 (t, J = 6.2 Hz, 1H), 2.69 (t, J = 6.7 Hz, 2H), 2.25 (s, 1H)

^{13}C NMR (75.4 MHz, $CDCl_3$) *E* isomer: δ 143.9, 137.2, 133.3, 128.5, 128.4, 127.6, 127.3, 126.1, 125.9, 125.8, 73.7, 43.0

FTIR (film) 3411, 3028, 2926, 2904, 1493, 1453, 1199, 1059, 963, 742, 701, 691 cm^{-1} .

HRMS Calcd for $C_{16}H_{16}O$ [M^+]: 224.1201 Found: 224.1190

3-Phenyl-non-1-en-4-ol

R_f 0.48 (4:1 hexane/ethyl acetate)

1H NMR (300 MHz, $CDCl_3$) *anti* isomers: δ 7.40–7.26 (m, 5H), 6.12 (ddd, J = 16.8, 10.0, 8.8 Hz, 1H), 5.24–5.16 (m,

2H), 3.85–3.78 (m, 1H), 3.24 (dd, $J = 7.2, 1.6$ Hz, 1H), 1.74 (d, $J = 3.2$ Hz, 1H), 1.49–1.17 (m, 8H), 0.84 (t, $J = 6.8$ Hz, 3H); *syn* isomer: δ 6.05 (ddd, $J = 17.2, 9.6, 8.4$ Hz, 1H), 5.15–5.08 (m, 2H), 3.90–3.86 (m, 1H), 3.30 (dt, $J = 8.4, 7.6$ Hz, 1H), 0.88 (t, $J = 6.9$ Hz, 3H).

^{13}C NMR (75.4 MHz, CDCl_3) *anti* isomer: δ 141.7, 138.3, 128.7, 127.9, 126.57, 117.7, 73.9, 57.3, 34.3, 31.7, 25.3, 22.5, 13.9.

FTIR (film) 3457, 3088, 3063, 3033, 2937, 2867, 2866, 1745, 1639, 1603, 1508, 1457, 1389, 1296, 1255, 1124, 1074, 1054 cm^{-1} .

HRMS Calcd for $\text{C}_{15}\text{H}_{22}\text{O}$ [$\text{M}^+ - \text{H}_2\text{O}$]: 200.1564. Found: 200.1567.

1-Phenyl-non-1-en-4-ol

R_f 0.37 (4:1 hexane/ethyl acetate).

^1H NMR (300 MHz, CDCl_3) *E* isomers: δ 7.36–7.17 (m, 5H), 6.46 (d, $J = 16.0$ Hz, 1H), 6.23 (ddd, $J = 16.0, 6.9, 4.2$ Hz, 1H), 3.70 (ddd, $J = 11.4, 6.9, 4.2$ Hz, 1H), 2.44 (m, 1H), 2.29 (m, 1H), 1.82 (br s, 1H), 1.56–1.39 (m, 8H), 0.89 (t, $J = 6.9$ Hz, 3H)

^{13}C NMR (75.4 MHz, CDCl_3) *E* isomer: δ 137.3, 132.9, 128.7, 128.5, 128.1, 127.2, 126.4, 126.0, 71.2, 41.1, 36.8, 31.8, 25.3, 22.6, 14.0.

FTIR 3403, 3088, 3063, 3027, 2929, 2859, 1624, 1604, 1494, 1450, 1080, 1030, 966, 743 cm^{-1} .

HRMS Calcd for $\text{C}_{15}\text{H}_{22}\text{O}$ $[\text{M}^+]$: 218.3467. Found: 218.1669.

1,4-Diphenyl-hex-5-en-3-ol

R_f 0.35 (4:1 hexane/ethyl acetate).

^1H NMR (300 MHz, CDCl_3) *anti* isomer: δ 7.38–7.10 (m, 10H), 6.10 (ddd, J = 14.3, 10.4, 6.9 Hz, 1H), 1.58 (br, 1H), 5.23 (d, J = 10.4 Hz, 1H), 5.22 (d, J = 16.8 Hz, 1H), 3.80 (ddd, J = 11.0, 8.1, 3.4 Hz, 1H), 3.27 (dd, J = 8.9, 8.1 Hz, 1H), 2.83–2.62 (m, 2H), 1.72–1.60 (m, 2H)

^{13}C NMR (75.4 MHz, CDCl_3) *anti* isomer: δ 142.1, 138.3, 128.8, 128.7, 128.5, 128.3, 128.0, 126.7, 125.8, 117.9, 73.2, 57.4, 36.1, 32.0

FTIR (film) 3568, 3447, 3079, 3063, 3028, 2920, 2863, 1949, 1874, 1809, 1637, 1602, 1494, 1255, 1062, 998, 847 cm^{-1} .

HRMS Calcd for $\text{C}_{18}\text{H}_{20}\text{O}$ $[\text{M}^+]$: 252.1514. Found: 252.1510.

1,6-Diphenyl-hex-5-en-3-ol

R_f 0.28 (4:1 hexane/ethyl acetate)

Supporting Information

^1H NMR (300 MHz, CDCl_3) *E* isomer: δ 6.49 (d, J = 15.8 Hz, 1H), 6.22 (dt, J = 15.8, 7.8 Hz, 1H), 3.81–3.70 (m, 1H), 2.84 (dt, J = 14.2, 8.0 Hz, 1H), 2.71 (dt, J = 14.2, 8.0 Hz, 1H), 2.52–2.42 (m, 1H), 2.35 (ddd, J = 14.3, 7.8, 7.8 Hz, 1H), 1.88–1.79 (m, 2H), 1.67 (br, 1H).

^{13}C NMR (75.4 MHz, CDCl_3) *E* isomer: δ 142.0, 137.1, 133.3, 128.5, 128.4, 128.1, 127.3, 126.1, 126.0, 125.8, 70.4, 41.2, 38.5, 32.0.

FTIR (film) 3447, 1628, 1408, 1083, 697 cm^{-1} .

HRMS Calcd for $\text{C}_{18}\text{H}_{20}\text{O}$ [M^+]: 252.1514. Found: 252.1530.

1-Cyclohexyl-2-phenyl-but-3-en-1-ol

R_f 0.48 (4:1 hexane/ethyl acetate)

^1H NMR (300 MHz, CDCl_3) *anti* isomer: δ 6.13 (ddd, J = 16.0, 9.0, 6.9 Hz, 1H), 5.20–5.12 (m, 2H), 3.53 (dd, J = 7.6, 6.3 Hz, 1H), 3.44 (dd, J = 8.3, 7.6 Hz, 1H), 1.81–1.10 (m, 11H)

^{13}C NMR (75.4 MHz, CDCl_3) *anti* isomer: δ 142.1, 138.4, 128.6, 127.9, 126.4, 117.5, 78.1, 53.6, 39.6, 30.1, 26.6, 26.4, 26.3, 26.0.

FTIR (film) 3581, 3458, 3458, 3077, 3028, 2925, 2853, 1637, 1601, 1493, 1449, 1260, 1215, 1087, 1037, 989, 916 cm^{-1} .

HRMS Calcd for $C_{16}H_{22}O$ [$M^+ - H_2O$]: 212.1565. Found: 212.1562.

1-Cyclohexyl-4-phenyl-but-3-en-1-ol

R_f 0.44 (4:1 hexane/ethyl acetate).

1H NMR (300 MHz, $CDCl_3$) *E* isomer: δ 6.47 (d, $J = 16.0$ Hz, 1H), 7.36–7.17 (m, 5H), 6.25 (dddd, $J = 16.0, 14.6, 6.9, 4.8$ Hz, 1H), 3.46 (dddd, $J = 12.5, 9.7, 6.9, 4.8$ Hz, 1H), 2.50–2.42 (m, 1H), 2.33–2.23 (m, 1H), 1.87 (d, $J = 12.5$ Hz, 1H), 1.78–1.01 (m, 11H).

^{13}C NMR (75.4 MHz, $CDCl_3$) *E* isomer: δ 137.3, 132.8, 128.5, 127.1, 126.9, 126.0, 75.2, 43.1, 37.9, 29.1, 28.7, 26.5, 26.2, 26.1.

FTIR (film) 3315, 2924, 2852, 2436, 2331, 2643, 1493, 1446, 1341, 1031, 964, 772, 742 cm^{-1} .

HRMS Calcd for $C_{16}H_{22}O$ [M^+]: 230.1670. Found: 230.1653.

2-(Cyclohexyl-hydroxy-methyl)-but-3-enoic acid ethyl ester

R_f 0.36 (4:1 hexane/ethyl acetate).

Supporting Information

^1H NMR (300 MHz, CDCl_3) *anti* isomer: δ 6.02–5.89 (m, 1H), 5.31–5.21 (m, 2H), 4.17 (q, J = 6.9 Hz, 2H), 3.64 (m, 1H), 3.24 (dd, J = 13.2, 9.0 Hz, 1H), 2.74 (d, J = 3.48 Hz, 1H), 2.02–0.99 (m, 11H), 1.27 (t, J = 6.9, 3H); *syn* isomer: δ 5.90–5.78 (m, 1H), 5.25–5.18 (m, 2H), 4.17 (q, J = 6.9 Hz, 2H), 2.57 (d, J = 7.6 Hz, 1H)

^{13}C NMR (75.4 MHz, CDCl_3) *anti* isomer: δ 173.6, 131.9, 119.8, 75.2, 60.8, 52.8, 40.2, 30.0, 28.0, 26.2, 26.0, 25.8, 14.0; *syn* isomer: δ 173.4, 131.9, 118.6, 75.2, 60.8, 53.4, 40.6, 29.0, 26.2, 26.1, 25.9, 25.8, 14.0. FTIR (film) 3451, 2962, 2934, 2865, 1728, 1639, 1463, 1372, 1315, 1249, 1180, 1090, 1032, 923, 768 cm^{-1} .

HRMS Calcd for $\text{C}_{13}\text{H}_{22}\text{O}_3$ [M^+]: 226.1568. Found: 226.1562.

5-Cyclohexyl-5-hydroxy-pent-2-enoic acid ethyl ester

R_f 0.23 (4:1 hexane/ethyl acetate)

^1H NMR (300 MHz, CDCl_3) *E* isomer: δ 7.00 (ddd, J = 16.0, 8.3, 7.6 Hz, 1H), 5.90 (dt, J = 16.0, 1.3 Hz, 1H), 4.19 (q, J = 6.9 Hz, 2H), 3.51 (dt, J = 9.7, 4.1 Hz, 1H), 2.47–2.26 (m, 2H), 1.93 (d, J = 13.2 Hz, 1H), 1.28 (t, J = 6.9 Hz, 3H), 1.85–0.98 (m, 11H).

^{13}C NMR (75.4 MHz, CDCl_3) *E* isomer: δ 166.5, 146.3, 123.2, 74.5, 60.1, 43.1, 36.9, 28.9, 27.7, 26.3, 26.0, 25.9,

14.0. FTIR (film) 3426, 2928, 2854, 1706, 1654, 1449, 1369, 1319, 1266, 1208, 1095, 1041, 979, 893, 771 cm^{-1}

HRMS Calcd for $\text{C}_{13}\text{H}_{22}\text{O}_3$ [M^+]: 226.1568. Found: 226.1566.

6-Cyclohexyl-5,6-dihydro-pyran-2-one

R_f 0.21 (4:1 hexane/ethyl acetate)

^1H NMR (300 MHz, CDCl_3) δ 6.90 (ddd, J = 9.7, 5.5, 2.7 Hz, 1H), 6.01 (dq, J = 9.7, 1.3 Hz, 2H), 4.19 (dddd, J = 11.1, 6.2, 5.5, 4.8 Hz, 1H), 2.37–2.29 (m, 2H), 1.97–1.04 (m, 11H).

^{13}C NMR (75.4 MHz, CDCl_3) δ 164.7, 145.2, 121.4, 82.0, 41.7, 28.2, 28.2, 26.5, 26.2, 25.9, 25.7.

FTIR (film) 3448, 2927, 2854, 1720, 1639, 1450, 1421, 1385, 1252, 1153, 1122, 1085, 1065, 973, 820 cm^{-1} .

HRMS Calcd for $\text{C}_{11}\text{H}_{16}\text{O}_2$ [M^+]: 180.1150. Found: 180.1155.

5-Hydroxy-hex-2-enoic acid ethyl ester

^1H NMR (300 MHz, CDCl_3) *E* isomer: δ 7.02–6.92 (m, 1H), 5.90 (dt, J = 1.4, 15.7 Hz, 1H), 4.19 (t, J = 5.22 Hz, 2H), 3.98–3.23 (m, 1H), 2.40–2.34 (m, 2H), 1.32–1.22 (m, 6H)

^{13}C NMR (75.4 MHz, CDCl_3) *E* isomer: δ 167.1, 145.9, 124.3, 67.2, 60.9, 42.4, 23.7, 14.8

HRMS Calcd for $\text{C}_{11}\text{H}_{16}\text{O}_2$ [$\text{M}^+ - \text{H}_2\text{O}$]: 140.0837. Found: 140.0838.

1-Cyclohexyl-4-methyl-pent-3-en-1-ol

R_f 0.45 (4:1 hexane/ethyl acetate :)

^1H NMR (300 MHz, CDCl_3) δ 5.17 (tq, J = 8.01, 1.38 Hz, 1H), 3.34 (m, 1H), 2.23–2.00 (m, 2H), 1.89–1.84 (m, 1H), 1.74 (s, 3H), 1.64 (s, 3H), 1.43–0.87 (m, 10H).

^{13}C NMR (75.4 MHz, CDCl_3) δ 135.1, 120.7, 75.8, 43.1, 33.0, 29.2, 28.2, 26.6, 26.3, 26.2, 25.9, 18.0.

FTIR (KBr) 3440, 2929, 2118, 1654, 1450, 1358, 1346, 1188, 1045 cm^{-1}

HRMS Calcd for $\text{C}_{12}\text{H}_{21}$ [$\text{M}^+ - \text{OH}$]: 165.1643. Found: 165.1639.

20-((1'*R*)-hydroxy-4'-phenyl-(3'*E*)-buten-1'-yl)-3-oxopregn-4-ene (2k)

R_f 0.59 (2:1 hexane/ethyl acetate)

mp 194.2–195.1 $^{\circ}\text{C}$.

$$[\alpha]_D^{25} = +73.5 \text{ (} c = 0.17, \text{ CHCl}_3 \text{)}$$

^1H NMR (300 MHz, CDCl_3) δ 7.38–7.19 (m, 5H, 25- C_6H_5), 6.49 (d, $J = 16.0$ Hz, 1H, 25- CH), 6.29–6.19 (ddd, $J = 16.0$, 8.01, 5.94 Hz, 1H, 24- CH), 5.73 (s, 1H, 4- CH), 3.80 (dt, $J = 10.5$, 2.43 Hz, 1H, 22- CH), 1.18 (s, 3H, 18- CH_3), 0.99 (d, $J = 6.96$ Hz, 3H, 21- CH_3), 0.75 (s, 3H, 19- CH_3)

^{13}C NMR (75.4 MHz, CDCl_3) δ 199.5, 171.3, 137.2, 132.9, 128.5, 127.6, 127.2, 126.0, 123.8, 72.6, 55.5, 53.8, 53.1, 42.8, 41.2, 39.6, 38.6, 35.7, 35.6, 34.2, 33.9, 32.8, 32.0, 27.4, 24.2, 21.0, 17.3, 12.5, 11.9.

FTIR (KBr) 3415, 3033, 2974, 2941, 2910, 2868, 2853, 1664, 1612, 1276, 1182, 1024, 969, 875, 693 cm^{-1}

HRMS Calcd for $\text{C}_{31}\text{H}_{42}\text{O}_2$ [$\text{M}^+ - \text{H}_2\text{O}$]: 428.30792. Found: 428.30989.

20-((1'*R*)-hydroxy-(3'*E*)-penten-1'-yl)-3-oxopregn-4-ene

R_f 0.61 (2:1 hexane/ethyl acetate)

mp 180.5–181.5 $^{\circ}\text{C}$.

$$[\alpha]_D^{25} = +51.7 \text{ (} c = 0.41, \text{ MeOH) .}$$

^1H NMR (300 MHz, CDCl_3) δ 5.71 (1H, s, 4- CH), 5.61–5.50 (1H, m, 24- CH), 5.46–5.36 (1H, m, 25- CH), 3.61 (1H, dt,

$J = 11.5, 2.4$ Hz, 22-**CH**), 1.68 (3H, d, $J = 6.3$ Hz, 26-**CH**₃), 1.17 (3H, s, 19-**CH**₃), 0.92 (3H, d, $J = 6.6$ Hz, 20-**CH**₃), 0.73 (3H, s, 18-**CH**₃).

¹³C NMR (75.4 MHz, CDCl₃) δ 199.5, 171.4, 128.7, 128.3, 123.7, 72.3, 55.5, 53.8, 53.0, 42.7, 40.8, 39.6, 38.5, 35.7, 35.6, 33.9, 33.6, 32.8, 32.0, 27.3, 24.2, 21.0, 18.0, 17.3, 12.4, 11.9.

FTIR (KBr) 2959, 2935, 2887, 2856, 2362, 2341, 1677, 1223, 1022, 981, 863, 667 cm⁻¹.

HRMS Calcd for C₂₆H₄₀O₂ [M⁺]: 384.3028. Found: 384.3026.

20-((1'*S*)-Hydroxy-(2'*R*)-methyl-3'-buten-1'-yl)-3-oxopregn-4-ene

R_f 0.44 (2:1 hexane/ethyl acetate).

$[\alpha]_D^{25} = +60.9$ ($c = 1.83$, CHCl₃).

¹H NMR (300 MHz, CDCl₃) δ 5.71 (1H, br s, 4-**CH**), 5.57 (1H, ddd, $J = 17.1, 10.1, 8.7$ Hz, 24-**CH**), 5.02 (1H, d, $J = 17.1$ Hz, 25-**CH**₂), 4.97 (1H, dd, $J = 10.1, 1.74$ Hz, 25-**CH**₂), 3.30 (1H, dd, $J = 9.75, 1.41$ Hz, 22-**CH**) 1.17 (3H, s, 19-**CH**₃), 1.09 (3H, d, $J = 6.63$ Hz, 23-**CH**₃), 0.87 (3H, d, $J = 6.60$ Hz, 20-**CH**₃), 0.69 (3H, s, 18-**CH**₃).

^{13}C NMR (75.4 MHz, CDCl_3) δ 199.5, 171.5, 141.0, 123.7, 114.4, 77.2, 55.8, 53.8, 53.7, 52.5, 42.2, 39.6, 38.5, 37.7, 35.6, 33.9, 32.9, 31.9, 27.7, 24.0, 21.0, 18.1, 17.3, 11.8, 11.1.

FTIR (KBr) 3455, 2943, 2869, 1656, 1459, 1378, 1229, 984, 911, 754 cm^{-1} .

HRMS Calcd for $\text{C}_{26}\text{H}_{40}\text{O}_2$ [M^+]: 384.3028. Found: 384.3056.

20-((1'S)-Hydroxy-(2'S)-methyl-3'-buten-1'-yl)-3-

oxopregn-4-ene

R_f 0.44 (2:1 hexane/ethyl acetate).

$[\alpha]_D^{25} = +67.9$ ($c = 0.24$, CHCl_3).

^1H NMR (300 MHz, CDCl_3) δ 5.72 (1H, br s, 4-**CH**), 5.70 (1H, ddd, $J = 17.1, 10.1, 9.06$ Hz, 24-**CH**), 5.14 (1H, d, $J = 17.1$ Hz, 25-**CH**₂), 5.12 (1H, dd, $J = 10.1, 1.74$ Hz, 25-**CH**₂), 3.25 (1H, d, $J = 9.76$ Hz, 22-**CH**) 1.19 (3H, s, 19-**CH**₃), 0.92 (3H, d, $J = 6.62$ Hz, 23-**CH**₃), 0.91 (3H, d, $J = 6.27$ Hz, 20-**CH**₃), 0.73 (3H, s, 18-**CH**₃).

^{13}C NMR (75.4 MHz, CDCl_3) δ 199.5, 171.5, 142.4, 123.7, 116.3, 75.4, 55.7, 53.8, 53.7, 52.4, 42.5, 42.3, 9.6, 38.5, 36.5, 35.6, 33.9, 32.9, 31.9, 27.6, 24.0, 21.3, 17.3, 16.4, 11.8, 11.3.

Supporting Information

FTIR (KBr) 3430, 3347, 3074, 2939, 2870, 1674, 1656,
1612, 1230, 684, 905, 869, 689 cm^{-1} .

HRMS Calcd for $\text{C}_{26}\text{H}_{40}\text{O}_2$ $[\text{M}^+]$: 384.30283. Found: 384.30103.