Supporting Information

Vanadium-Catalyzed Addition of Propagyl Alcohols and Imines

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General Methods

Unless otherwise noted, all reagents were obtained from commercial suppliers and were used without further purification. Glass equipments were oven- or flame-dried under a stream of nitrogen and anhydrous solvents were transferred by oven-dried syringe or canula. Solvents for chromatography are listed as volume/volume ratios. Flash chromatography employed E. Merck silica gel (Kieselgel 60, 230-400 mesh) and analytical TLC was performed on Merck glass plates coated with silica. Infrared spectra were recorded on a Perkin Elmer FT-IR Paragon 500. ^1H and ^{13}C NMR spectra were obtained using a Varian Inova 500 (500 MHz) or a Varian Mercury 400 (400 MHz). For ^1H NMR spectra, chemical shifts are reported in delta (δ) units in parts per million (ppm) relative to the singlet for chloroform (7.26 ppm) or tetramethylsilane (0 ppm). Splitting patterns are designated as s, singlet; d, doublet; t, triplet; q, quartet; quin, quintet; m, multiplet; and br, broad. Coupling constants are recorded in hertz (Hz). For ^{13}C NMR spectra, chemical shifts are reported in ppm relative to the central line of triplet at 77.0 ppm for chloroform-*d*. Elemental analyses were performed by M-H-W Laboratories, Phoenix, AZ. Mass spectra were provided by the Mass Spectrometry Facility at the University of California-San Francisco. HRMS data are reported as *m/e* (relative intensity) with accurate mass reported for the molecular ion (M^+) or suitable fragments.

[Phenyl-(1-phenylhept-2-ynoxy)-methyl]carbamic acid methyl ester

A flame-dried screw cap reaction vial equipped with a Mininert syringe valve, was flushed with N_2 and charged with tris(triphenylsilyl)vanadate **1a** (44.7 mg, 0.05 mmol) and 1,2-dichloroethane (0.25 mL, 2M). Benzylidene carbamic acid methyl ester (326.1 mg, 2.0 mmol) and then 1-phenyl-2-heptyn-1-ol **2** (188.3 mg, 1.0 mmol) was added using a syringe, and the mixture was stirred at 80 $^\circ\text{C}$. After 48 hours, the solvent was removed in vacuo, and the residue was purified by column chromatography (eluent: Petroleum Ether/EtOAc = 6/1) to give **4** (107.9 mg, 0.307 mmol, Y = 31%) and **5** (199.3 mg, 0.567 mmol, Y = 57%).

Spectral data for **4**: R_f = 0.28 (petroleum ether/EtOAc = 5/1). IR(CDCl_3): ν 3336, 2928, 1712, 1495, 1453, 1238, 1028, 670 cm^{-1} . ^1H NMR (500 MHz, CDCl_3): δ 7.38 – 7.21 (m, 10H), 6.99 (s, 1H), 6.06 (d, J = 8.1 Hz, 1H), 5.66 (d, J = 8.1 Hz, 1H), 3.70 (s, 3H), 2.17–2.05 (m, 1H), 1.80–1.74 (m, 1H), 1.23–1.11 (m, 2H), 0.95–0.87 (m, 2H), 0.61 (t, J = 7.3 Hz,

3H). ^{13}C NMR (75 MHz, CDCl_3) δ 209.9, 156.1, 142.4, 139.3, 135.3, 133.0, 128.7, 128.7, 128.6, 128.5, 127.6, 126.5, 59.6, 52.3, 43.5, 25.4, 21.6, 13.6. Anal. Calc'd for $\text{C}_{22}\text{H}_{25}\text{NO}_3$: C, 75.19; H, 7.17. Found: C, 74.95; H, 7.36.

Spectral data for **5** (mixture of diastereoisomers): R_f = 0.41 (petroleum ether/EtOAc = 5/1). IR(CDCl_3): ν 3322, 2958, 1732, 1496, 1455, 1237, 1023, 698 cm^{-1} . ^1H NMR (500 MHz, CDCl_3): δ 7.56-7.30 (m, 10H), 6.48 (d, J = 9.8 Hz, 0.5H), 6.18 (d, J = 9.8 Hz, 0.5H), 5.55 (s, 0.5H), 5.43 (m, 0.5H), 5.35 (m, 1H), 3.73 (s, 3H), 2.29-2.22 (m, 2H), 1.56-1.35 (m, 4H), 0.93-0.85 (m, 3H). Anal. Calc'd for $\text{C}_{22}\text{H}_{25}\text{NO}_3$: C, 75.19; H, 7.17. Found: C, 75.36; H, 7.31.

Typical Slow Addition Procedure:

(2-Benzylidene-3-oxo-1-phenylheptyl)carbamic acid methyl ester

Benzylidenecarbamic acid methyl ester (**3**, 81.5 mg, 0.50 mmol), tris[tri(4-chlorophenyl)silyl]vanadate **1b** (30.1 mg, 0.025 mmol) and dichloroethane (250 μl) were placed in a flame-dried screw cap reaction vial equipped with a Mininert syringe valve and the mixture was heated to 80 $^\circ\text{C}$. A mixture of 1-phenyl-2-heptyn-1-ol (**2**, 103.5 mg, 0.55 mmol) and dichloroethane (250 μl) was added to the reaction mixture over the period of 20 hours using a syringe pump. After the mixture was further reacted for 4 hr it was cooled, concentrated and purified by column chromatography on silica (eluent: Petroleum ether/EtOAc = 10/1 $\rightarrow$ 8/1) to give **4** as a yellow oil (161.7 mg, 0.46 mmol, 92 % yield).

(2-Benzoyl-1,3-diphenyl-allyl)-carbamic acid methyl ester

The reaction was carried out according to the general procedure using **2b** (123.6 mg, 0.59 mmol), **3** (88.0 mg, 0.54 mmol) and the catalyst **1b** (30.5 mg, 0.025 mmol). Column chromatography (eluent: Petroleum Ether/EtOAc = 10/1 $\rightarrow$ 6/1) gave **5b** (25 mg, 0.067 mmol, Y = 13%) as a yellow oil and **4b** (143.3 mg, 0.386 mmol, 71 % yield) as a white foamy solid.

5b (mixture of diastereoisomers): R_f = 0.40 (petroleum ether/EtOAc = 5/1). IR(CDCl_3): ν 3401, 3320, 1728, 1493, 1238, 1026, 752, 697. ^1H NMR (500 MHz, CDCl_3): δ 7.64-7.28 (m, 15H), 6.56 (d, J = 9.6 Hz, 0.5H), 6.29 (d, J = 9.6 Hz, 0.5H), 5.48 (d, J = 9.6 Hz, 0.5H), 5.42 (d, J = 9.6 Hz, 0.5H), 3.74 (s, 1.5H), 3.71 (s, 1.5H). ^{13}C NMR (125 MHz, CDCl_3) δ 156.5, 139.2, 138.7, 138.6, 138.5, 131.8, 131.8, 128.6, 128.5, 128.2, 128.1, 127.7, 127.4, 126.1, 126.1, 122.5, 122.5, 87.5, 87.4, 87.1, 86.8, 81.3, 81.1, 69.9, 52.5, 52.4, 29.7.

4b: R_f = 0.24 (petroleum ether/EtOAc = 5/1). Mp 52-55 $^\circ\text{C}$ after recrystallization from petroleum ether. IR(CDCl_3): ν 3330, 3061, 1725, 1653, 1496, 1233, 698 cm^{-1} . ^1H NMR (500 MHz, CDCl_3): δ 7.66 (d, J = 7.6 Hz, 2H), 7.37 (d, J = 7.6 Hz, 2H), 7.36-7.30 (m, 1H), 7.29-7.26 (m, 2H), 7.20-7.15 (m, 3H), 7.10-7.04 (m, 6H), 6.02 (broad d, J = 7.9 Hz, 1H), 5.08 (d, J = 7.9 Hz, 1H), 3.67 (s, 3H). ^{13}C NMR (125 MHz, CDCl_3) δ 199.6, 156.1, 139.1, 136.0, 134.7, 133.6, 133.2, 129.3, 129.0, 128.6, 128.3, 128.2, 128.1, 127.7, 126.8, 60.2, 52.3. Anal. Calc'd for $\text{C}_{24}\text{H}_{21}\text{NO}_3$: C, 77.61; H, 5.70. Found: C, 77.70; H, 5.86.

(2-Benzylidene-4,4-dimethyl-3-oxo-1-phenyl-pentyl)-carbamic acid methyl ester

The reaction was carried out according to the general procedure using **2c** (113.0 mg, 0.60 mmol), **3** (81.5 mg, 0.50 mmol) and the catalyst **1b** (30.1 mg, 0.025 mmol). Column chromatography (eluent: Petroleum Ether/EtOAc = 11/1 → 9/1) gave **4c** as a light yellow oil (150.8 mg, 0.429 mmol, 86 % yield).

R_f = 0.28 (petroleum ether/EtOAc = 5/1). IR(CDCl₃): $\bar{\nu}$ 3334, 2868, 1727, 1496, 1236, 700 cm⁻¹. ¹H NMR (500 MHz, CDCl₃): δ 7.39-7.35 (m, 4H), 7.32-7.23 (m, 4H), 7.15-7.13 (m, 2H), 6.46 (s, 1H), 5.70 (bd, J = 8.1 Hz, 1H), 5.65 (d, J = 8.1 Hz, 1H), 3.68 (s, 3H), 0.86 (s, 9H). ¹³C NMR (125 MHz, CDCl₃) δ 217.5, 155.9, 142.3, 139.1, 136.0, 129.6, 128.7, 128.4, 128.2, 128.0, 127.5, 58.8, 52.3, 44.7, 27.3. Anal. Calc'd for C₂₂H₂₅NO₃: C, 75.19; H, 7.17. Found: C, 74.95; H, 7.04.

[2-Benzylidene-4-(tert-butyl-dimethyl-silanyloxy)-3-oxo-1-phenyl-butyl]-carbamic acid methyl ester

The reaction was carried out according to the general procedure using **2d** (331.7 mg, 1.20 mmol), **3** (163.1 mg, 1.0 mmol) and the catalyst **1b** (60.2 mg, 0.05 mmol). Column chromatography (eluent: Petroleum Ether/EtOAc = 10/1 → 8/1) gave **4d** as a yellow solid (307.1 mg, 0.699 mmol, 70 % yield).

R_f = 0.32 (petroleum ether/EtOAc = 5/1). Mp 70-72 °C (recrystallization from petroleum ether). IR(CDCl₃): $\bar{\nu}$ 3329, 1709, 1496, 1255, 1129, 838, 700 cm⁻¹. ¹H NMR (500 MHz, CDCl₃): δ 7.36-7.20 (m, 10H), 6.89 (s, 1H), 6.04 (bd, J = 8.1 Hz, 1H), 5.67 (d, J = 8.1 Hz, 1H), 3.91 (d, J = 18.1 Hz, 1H), 3.69 (s, 3H), 3.67 (d, J = 18.1 Hz, 1H), 0.74 (s, 9H), -0.23 (d, J = 7.4 Hz, 6H). ¹³C NMR (125 MHz, CDCl₃) δ 207.6, 156.1, 139.5, 139.0, 135.0, 133.9, 128.7, 128.7, 128.6, 127.8, 126.6, 69.7, 59.4, 52.3, 25.7, 18.3, -5.7, -5.9. HRMS Calc'd for C₂₁H₂₄NO₄Si [M - C₄H₉ (tert-Butyl)]: 382.1475. Meas: 382.1462.

[3-(4-Methoxy-phenyl)-2-pentanoyl-1-phenyl-allyl]-carbamic acid methyl ester

The reaction was carried out according to the typical procedure using **2e** (131.0 mg, 0.60 mmol), **3** (81.5 mg, 0.50 mmol) and the catalyst **1b** (30.1 mg, 0.025 mmol). Column chromatography (eluent: Petroleum Ether/EtOAc = 5/1) gave **4e** as a yellow oil (135.6 mg, 0.355 mmol, 71 % yield).

R_f = 0.19 (petroleum ether/EtOAc = 5/1). IR(CDCl₃): $\bar{\nu}$ 3333, 2958, 1727, 1607, 1511,

1254 cm^{-1} . ^1H NMR (500 MHz, CDCl_3): δ 7.32 – 7.24 (m, 5H), 7.13 (d, J = 8.6 Hz, 2H), 6.94 (s, 1H), 6.85 (d, J = 8.6 Hz, 2H), 6.11 (deformed d, J = 8.4 Hz, 1H), 3.81 (s, 3H), 3.69 (s, 3H), 2.17 – 2.05 (m, 1H), 1.83 – 1.76 (m, 1H), 1.22 – 1.12 (m, 2H), 0.98 – 0.90 (m, 2H), 0.63 (t, J = 7.3 Hz, 3H). ^{13}C NMR (125 MHz, CDCl_3) δ 210.3, 160.0, 156.1, 140.6, 139.5, 133.1, 130.2, 128.6, 127.7, 127.5, 126.4, 113.9, 59.7, 55.3, 52.3, 43.4, 25.5, 21.7, 13.6. HRMS Calc'd for $\text{C}_{23}\text{H}_{27}\text{NO}_4$: 381.1940. Meas: 381.1935.

[3-(4-Fluoro-phenyl)-2-pentanoyl-1-phenyl-allyl]-carbamic acid methyl ester

The reaction was carried out according to the typical procedure using **2f** (123.8 mg, 0.60 mmol), **3** (81.5 mg, 0.50 mmol) and the catalyst **1b** (30.1 mg, 0.025 mmol). (eluent: Petroleum Ether/EtOAc = 6/1) gave **4f** as a light yellow oil (136.5 mg, 0.369 mmol, 74 % yield).

R_f = 0.21 (petroleum ether/EtOAc = 5/1). IR(CDCl_3): $\bar{\nu}$ 3332, 2958, 1727, 1508, 1229 cm^{-1} . ^1H NMR (500 MHz, CDCl_3): δ 7.35 – 7.25 (m, 5H), 7.20 – 7.17 (m, 2H), 7.04 – 7.00 (m, 2H), 6.92 (s, 1H), 6.02 (deformed d, J = 8.1 Hz, 1H), 5.65 (d, J = 8.1 Hz, 1H), 3.70 (s, 3H), 2.08 – 2.03 (m, 1H), 1.83 – 1.77 (m, 1H), 1.23–1.11 (m, 2H), 0.97 – 0.90 (m, 2H), 0.63 (t, J = 7.3 Hz, 3H). ^{13}C NMR (125 MHz, CDCl_3) δ 209.7, 162.8 (d, J^{C-F} = 249.3 Hz), 156.1, 142.6, 139.1, 131.4 (d, J^{C-F} = 12.0 Hz), 130.5, 130.4, 128.7, 127.7, 126.5, 115.6 (d, J^{C-F} = 21.6 Hz), 59.5, 52.3, 43.5, 25.4, 21.7, 13.6. HRMS Calc'd for $\text{C}_{22}\text{H}_{24}\text{FNO}_3$: 369.1740. Meas: 369.1726.

[2-Benzylidene-1-(4-methoxy-phenyl)-3-oxo-heptyl]-carbamic acid methyl ester

The reaction was carried out according to the general procedure using **2** (225.9 mg, 1.20 mmol), **3b** (193.2 mg, 1.00 mmol) and the catalyst **1b** (60.2 mg, 0.05 mmol). Column chromatography (eluent: Petroleum Ether/EtOAc = 10/1 $\rightarrow$ 8/1) gave **4g** as a light yellow oil (249.9 mg, 0.655 mmol, 66 % yield).

R_f = 0.22 (petroleum ether/EtOAc = 5/1). IR(CDCl_3): $\bar{\nu}$ 3332, 2957, 1726, 1512, 1249 cm^{-1} . ^1H NMR (500 MHz, CDCl_3): δ 7.34–7.30 (m, 3H), 7.24 (d, J = 8.7 Hz, 2H), 7.20–7.19 (m, 2H), 6.94 (s, 1H), 6.85 (d, J = 8.7 Hz, 2H), 5.95 (broad d, J = 7.8 Hz, 1H), 3.78 (s, 3H), 3.69 (s, 3H), 2.09–2.04 (m, 1H), 1.87–1.80 (m, 1H), 1.24–1.14 (m, 2H), 0.98–0.88 (m, 2H), 0.62 (t, J = 7.3 Hz, 3H). ^{13}C NMR (125 MHz, CDCl_3) δ 209.9, 159.0, 156.0, 142.8, 135.3, 132.3, 131.4, 128.7, 128.6, 128.5, 127.8, 114.0, 59.0, 55.2, 52.3, 43.5, 25.4, 21.7, 13.6. HRMS Calc'd for $\text{C}_{23}\text{H}_{27}\text{NO}_4$: 381.1940. Meas: 381.1930.

(1-Benzo[1,3]dioxol-5-yl-2-pentanoyl-3-phenyl-allyl)-carbamic acid methyl ester

The reaction was carried out according to the typical procedure using **2** (113.0 mg, 0.60 mmol), **3c** (103.6 mg, 0.50 mmol) and the catalyst **1b** (30.1 mg, 0.025 mmol). Column chromatography (eluent: Petroleum Ether/EtOAc = 9/2) gave **4h** as a yellow oil (160.0 mg, 0.405 mmol, 81 % yield).

R_f = 0.17 (petroleum ether/EtOAc = 5/1). IR(CDCl₃): $\bar{\nu}$ 3334, 2958, 1727, 1504, 1445, 1238, 1039, 932 cm⁻¹. ¹H NMR (500 MHz, CDCl₃): δ 7.35 – 7.31 (m, 3H), 7.20 – 7.18 (m, 2H), 6.95 (s, 1H), 6.81 (s, 1H), 6.79 (dd, J = 8.1, 1.4 Hz, 1H), 6.76 (d, J = 8.1 Hz, 1H), 6.01 (deformed d, J = 8.2 Hz, 1H), 5.94 (s, 2H), 5.55 (d, J = 8.2 Hz, 1H), 3.69 (s, 3H), 2.11 – 2.07 (m, 1H), 1.89 – 1.82 (m, 1H), 1.29–1.15 (m, 2H), 1.00 – 0.90 (m, 2H), 0.64 (t, J = 7.3 Hz, 3H). ¹³C NMR (125 MHz, CDCl₃) δ 209.8, 156.0, 147.9, 147.0, 142.4, 135.2, 133.4, 132.8, 128.7, 128.5, 119.9, 108.3, 107.2, 101.1, 59.3, 52.3, 43.5, 25.5, 21.7, 13.6. HRMS Calc'd for C₂₃H₂₅NO₅: 395.1733. Meas: 396.1720.

[2-Pentanoyl-3-phenyl-1-(4-trifluoromethyl-phenyl)-allyl]-carbamic acid methyl ester

The reaction was carried out according to the typical procedure using **2** (113.0 mg, 0.60 mmol), **3d** (115.6 mg, 0.50 mmol) and the catalyst **1b** (30.1 mg, 0.025 mmol). Column chromatography (eluent: Petroleum Ether/EtOAc = 10/1) gave **4i** as a yellow oil (159.2 mg, 0.380 mmol, 76 % yield).

R_f = 0.32 (petroleum ether/EtOAc = 5/1). IR(CDCl₃): $\bar{\nu}$ 3329, 2960, 1728, 1504, 1326, 1239, 1166, 1127, 1068 cm⁻¹. ¹H NMR (500 MHz, CDCl₃): δ 7.60 (d, J = 8.4 Hz, 2H), 7.47 (d, J = 8.4 Hz, 2H), 7.36 – 7.33 (m, 3H), 7.21 – 7.19 (m, 2H), 7.08 (s, 1H), 6.23 (deformed d, J = 8.4 Hz, 1H), 5.70 (d, J = 8.4 Hz, 1H), 3.71 (s, 3H), 2.13–2.05 (m, 1H), 1.79–1.73 (m, 1H), 1.22–1.08 (m, 2H), 0.93–0.86 (m, 2H), 0.60 (t, J = 7.3 Hz, 3H). ¹³C NMR (125 MHz, CDCl₃) δ 209.6, 156.1, 143.7, 141.3, 134.9, 129.9 (quartet, J^{C-F} = 32.6 Hz), 129.0, 128.7, 128.6, 126.9, 125.6 (quartet, J^{C-F} = 3.4 Hz), 125.0, 122.9. HRMS Calc'd for C₂₃H₂₄F₃NO₃: 419.1708. Meas: 419.1698.

(1-Furan-2-yl-2-pentanoyl-3-phenyl-allyl)-carbamic acid methyl ester

The reaction was carried out according to the typical procedure using **2** (113.0 mg, 0.60 mmol), **3e** (76.6 mg, 0.50 mmol) and the catalyst **1b** (30.1 mg, 0.025 mmol). Column chromatography (eluent: Petroleum Ether/EtOAc = 9/1) gave **4j** as yellow oil (75.0 mg, 0.220 mmol, 44 % yield).

R_f = 0.27 (petroleum ether/EtOAc = 5/1). IR(CDCl₃): $\bar{\nu}$ 3329, 2958, 1728, 1503, 1240 cm⁻¹. ¹H NMR (500 MHz, CDCl₃): δ 7.35 – 7.31 (m, 4H), 7.21 – 7.20 (m, 2H), 7.00 (s, 1H), 6.32 (dd, *J* = 3.2, 1.8 Hz, 1H), 6.24 (d, *J* = 3.2 Hz, 1H), 5.95 (deformed d, *J* = 9.0 Hz, 1H), 5.70 (d, *J* = 9.0 Hz, 1H), 3.71 (s, 3H), 2.15–2.10 (m, 1H), 2.05–1.99 (m, 1H), 1.32–1.22 (m, 2H), 1.05–0.98 (m, 2H), 0.68 (t, *J* = 7.3 Hz, 3H). ¹³C NMR (125 MHz, CDCl₃) δ 209.3, 156.0, 152.2, 142.2, 140.2, 135.1, 133.8, 128.7, 128.5, 110.6, 107.1, 54.2, 52.4, 42.8, 25.7, 21.8, 13.6. HRMS Calc'd for C₂₀H₂₃NO₄: 341.1627. Meas: 341.1634.

(2-Benzylidene-3-oxo-1-thiophen-2-yl-heptyl)-carbamic acid methyl ester

The reaction was carried out according to the general procedure using **2** (150.9 mg, 0.80 mmol), **3f** (113.0 mg, 0.67 mmol) and the catalyst **1b** (30.1 mg, 0.025 mmol). Column chromatography (eluent: Petroleum Ether/EtOAc = 10/1 → 8/1) gave **4k** as an orange colored oil (153.5 mg, 0.429 mmol, 86 % yield).

R_f = 0.28 (petroleum ether/EtOAc = 5/1). IR(CDCl₃): $\bar{\nu}$ 3330, 2958, 1728, 1498, 1233, 699 cm⁻¹. ¹H NMR (500 MHz, CDCl₃): δ 7.37–7.33 (m, 3H), 7.23–7.20 (m, 3H), 7.08 (s, 1H), 7.00–6.93 (m, 2H), 6.10 (broad d, *J* = 8.4 Hz, 1H), 5.86 (d, *J* = 8.4 Hz, 1H), 3.71 (s, 3H), 2.19–2.13 (m, 1H), 2.00–1.94 (m, 1H), 1.33–1.21 (m, 2H), 1.02–0.95 (m, 2H), 0.66 (t, *J* = 7.3 Hz, 3H). ¹³C NMR (125 MHz, CDCl₃) δ 209.3, 156.0, 143.9, 141.7, 135.2, 133.9, 128.8, 128.8, 128.5, 127.1, 125.0, 124.9, 56.0, 52.4, 43.5, 25.7, 21.7, 13.6. HRMS Calc'd for C₂₀H₂₃NO₃S: 357.1399. Meas: 357.1397.

(2-Pentanoyl-3-phenyl-1-styryl-allyl)-carbamic acid methyl ester

The reaction was carried out according to the typical procedure using **2** (113.0 mg, 0.60 mmol), **3g** (94.6 mg, 0.50 mmol) and the catalyst **1b** (30.1 mg, 0.025 mmol). Column

Spectra for 4

01/11/15 14:27 unspecified
X: 16 scans, 4.0cm-1

Spectra for 5

Spectra for **4b**

Spectra for 4c

Spectra for **4d**

Spectra for 4e

Spectra for **4f**

Spectra for 4g

Spectra for **4h**

Spectra for 4i

Spectra for 4j

Spectra for **4k**

Spectra for **4l**