A Dinuclear Zinc Catalyzed Asymmetric Alkynylation of Unsaturated Aldehydes

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Supporting Information

Part A: Experimental Section

General Information:

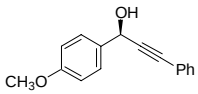
All reactions were performed under a nitrogen atmosphere in oven-dried glassware unless reported otherwise. Solvents were purified on an alumina column solvent purification system. All reagents were purchased commercially and used without further purification unless stated otherwise. Flash chromatography was preformed using silica gel (CM Science, Kieselgel 60, 230-400 mesh, ASTM) and TLC was preformed with glass-backed plates coated with 0.2 mm silica (Merck, DC-Platten, Kieselgel; 60 F_{254}).

Nuclear magnetic resonance (NMR) data were acquired on a Varian Gemini 200 (200 MHz), Mecrury 400 (400 MHz), and Unity 500 (500 MHz) as indicated and chemical shifts are reported in ppm relative to an internal standard. Optical rotation was measured on a Jasco DIP-100 polarimeter in 5 cm cells at the indicated temperature. Infrared (IR) absorption data were acquired on sodium chloride plates on a PerkinElmer Paragon 500 FT-IR spectrometer. HRMS data were acquired by EI.

Representative alkynylation procedure:

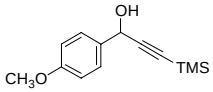
To a solution of Me_2Zn (480 µL, 2.0 M in toluene, 0.96 mmol, 2.95 equiv) in dry toluene (2 mL) was added TMS acetylene (130 µL, 0.92 mmol, 2.8 equiv) at room temperature under an atmosphere of argon. After initial agitation the clear solution stood at room temperature without stirring for 90 minutes, then was transferred via syringe to another test tube containing neat standard diprolinol ligand **1** (20.1 mg, 0.0325 mmol, 0.1 equiv). After 10 minutes the bubbling ceased and aldehyde was added (0.325 mmol). The reaction was sealed and cooled to 4 ˚C for 20-48 hours at which point it was quenched with saturated aqueous NH_4Cl (2mL) and stirred vigorously for 15 minutes. The organic phase was separated and the aqueous phase was extracted with Et_2O (3x10 mL). The organic phases were combined, concentrated and purified by silica gel chromatography.

1-(4-Methoxy-phenyl)-3-phenyl-prop-2-yn-1-ol



Matches published data.[1]
Isolated as a colorless oil. R_f= 0.25 (PE/Et_2O = 2/1)
^{1}H ($CDCl_3$, 500 MHz): δ 7.54 (dm, 8.4 Hz, 2H); 7.47 (dd, *J* = 6.1, 3.0, 2H); 7.33 (d, *J* = 2.1 Hz, 2H); 7.31 (m, 1H); 6.93 (dm, *J* = 8.5 Hz, 2H); 5.65 (d, *J* = 6.1 Hz, 1H); 3.82 (s, *J* = 3H); 2.20 (t, *J* = 5.5 Hz, 1H). ^{13}C ($CDCl_3$, 126 MHz) δ 131.8, 128.7, 128.4, 128.3, 122.6, 114.1, 64.8, 55.4, 28.7. MS (EI, 70 eV): 238 (M^+, 46 %); 222 (68 %); 207 (100 %); 178 (49 %). GCMS (Def-LD): 16.7 min. IR: 3385 (br, OH); 3054, 3001, 2961, 2933, 2836, 2227, 1610 (s), 1511 (s), 1489, 1462, 1442, 1331,1303, 1250. HPLC: Chiralcel OD (hept/*i*PrOH = 80/20): 10.2/15.0 min. $[\alpha]_D$ = +6.4° (c = 0.5, DCM).

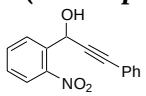
1-(4-Methoxyphenyl)-3-(trimethylsilyl)prop-2-yn-1-ol:



Matches published data.[2]
Isolated as a colorless oil. R_f= 0.40 (PE/Et_2O = 2/1)

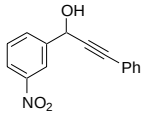
^{1}H ($CDCl_3$, 300 MHz): δ 7.46 (d, *J* = 8.4, 2H); 6.90 (d, *J* = 8.4, 2H); 5.39 (d, *J* = 6.0, 1H); 3.81 (s, 3H); 2.44 (d, *J* = 6.0, 1H); 0.2 (s, 9H). ^{13}C ($CDCl_3$, 76 MHz): 159.7; 132.7; 128.2; 114.0; 105.3; 91.3; 64.5; 55.3; -0.12. IR: 2960, 2901, 2840, 2153, 1639, 1598, 1572, 1510, 1463, 1422, 1316, 1303, 1254, 1164, 1114, 1025, 1005, 845. HPLC: Chiralcel OD (hept/iPrOH = 80/20): 4.9/5.5 min. $[\alpha]_D$ =+ 2.5° (c = 0.52, DCM)

***1-(2-Nitrophenyl)-3-phenylprop-2-yn-1-ol*:**



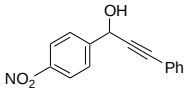
Matches published data.[3]
Isolated as a colorless oil. R_f= 0.30 (PE/Et_2O = 2/1)
^{1}H ($CDCl_3$, 300 MHz): δ 7.99 (ddd, *J* = 1.2, 7.3, 7.4 Hz, 2H); 7.68 (ddd, *J* = 1.2, 7.5, 7.6, 1H); 7.51 (ddd, *J* = 1.2, 7.4, 7.7 Hz, 1H); 7.44 (m, 2H); 7.31 (m, 3H); 6.21 (s, 1H); 3.33 (s, 1H). ^{13}C ($CDCl_3$, 76 MHz): δ 148.2; 135.5; 133.9; 131.9; 129.7; 129.5; 128.9; 128.4; 125.2; 122.0; 87.0; 86.6; 62.0; 51.7. GCMS (Def): 17.4 min. MS (EI, 70 eV): 236 (2 %); 220 (8 %); 190 (62 %); 176 (37 %); 152 (23 %); 129 (27 %); 105 (100 %); 77 (54 %). IR: 3517, 3396, 3075, 3064, 2234, 1609, 1578, 1525, 1490, 1443, 1348, 1181, 1033, 998, 961, 918, 857, 812, 786, 756, 722, 691. HPLC: Chiralcel OD (hept/*i*PrOH = 90/10): 13.9/17.5 min. $[\alpha]_D$ =-12.8° (c = 0.55, DCM)

1-(3-Nitrophenyl)-3-phenylprop-2-yn-1-ol:



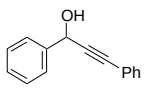
Matches published data.[3]
Isolated as a colorless oil. R_f= 0.30 (PE/Et_2O = 2/1)
^{1}H ($CDCl_3$, 300 MHz): δ 8.49 (s, 1H); 8.19 (dm, *J* = 8.1, 2H); 7.95 (d, *J* =7.8, 1H); 7.57 (t, *J* = 7.8, 1H); 7.47 (m, 2H); 7.34 (m, 3H); 5.79 (d, *J* = 5.4, 1H); 2.68 (d, *J* = 5.4, 1H). ^{13}C ($CDCl_3$, 76 MHz): δ 148.4; 142.7; 132.8; 131.8; 129.6; 129.1; 128.5; 123.3; 121.8; 87.7; 87.5; 63.9. IR: 3386 (br, OH), 3082, 2864, 2356, 2220, 1584, 1528 1489, 1443, 1349, 1193, 1093, 1034, 999, 974, 916, 803. GCMS (Def-LD): 18.4 min. MS (EI, 70 eV): 252 (100 %); 236 (66 %); 219 (47 %); 206 (75 %); 189 (29 %); 178 (98 %); 165 (14 %); 152 (17 %); 129 (44 %); 103 (25 %); 77 (29 %). HPLC: as benzoate; Chiralcel OD (hept/iPrOH = 99/1): 19.1/21.6 min. $[\alpha]_D$ =-11.5° of benzoate (c = 0.4, DCM).

1-(4-Nitrophenyl)-3-phenylprop-2-yn-1-ol:



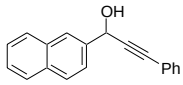
Matches published data.[4]
Isolated as an amorphous white solid. R_f= 0.30 (PE/Et_2O = 2/1).
IR: 3388 (br, OH), 3109, 3079, 2854, 2452, 2230, 2198, 1599, 1519, 1490, 1443, 1348, 1286, 1186, 1108, 1034, 1014, 998, 965, 918, 856, 804. ^{1}H ($CDCl_3$, 300 MHz): δ 8.24 (d, *J* = 8.7, 2H); 7.77 (d, *J* = 8.7, 2H); 7.46 (dd, *J* = 2.4,5.9 Hz, 2H); 7.34 (m, 3H); 5.79 (s, 1H); 2.72 (s, 1H). ^{13}C ($CDCl_3$, 76 MHz): δ 147.8; 147.4; 131.8; 129.1; 128.5; 127.5; 123.9; 121.7; 87.7; 87.4; 64.1. HPLC: Chiralcel OD (hept/iPrOH = 80/20): 9.7/29.3 min. $[\alpha]_D$ =+11.1° (c = 1.0, DCM)

1,3-Diphenylprop-2-yn-1-ol:



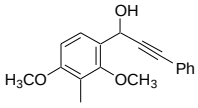
Matches published data.[4]
Isolated as a colorless oil. R_f= 0.30 (PE/Et_2O = 2/1)
GCMS (Def-LD): 15.1 min. MS (EI, 70 eV): 207 (100 %); 191 (29 %); 179 (78 %); 165 (42 %); 152 (14 %); 129 (33 %); 102 (35 %); 77 (31 %). IR: 3533, 3345, 3062, 3032, 2877, 2336, 2229, 1953, 1884, 1808, 1598, 1571, 1489, 1453, 1443, 1383, 1280, 1190, 1070, 1030, 998, 961, 917, 821. ^{1}H ($CDCl_3$, 300 MHz): δ 7.60 (dm, *J* = 7.3 Hz, 2H); 7.46 (dd, *J* = 2.4, 7.5 Hz, 2H); 7.39 (m, 2H); 7.33-7.28 (m, 4H); 5.67 (d, *J* = 5.7 Hz, 1H); 2.46 (d, *J* = 5.8 Hz, 1H). ^{13}C ($CDCl_3$, 76 MHz): δ 140.7; 131.8; 128.7; 128.5; 128.4; 126.8; 122.5; 88.8; 86.7; 65.1. HPLC: Chiralcel OD (hept/iPrOH = 90/10): 12.0/20.3 min. $[\alpha]_D$ =+4.9° (c = 1.0, DCM).

1-(Naphthalen-2-yl)-3-phenylprop-2-yn-1-ol:



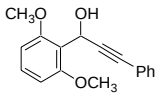
Matches published data.[3]
Isolated as an amorphous white solid. R_f= 0.35 (PE/Et_2O = 2/1).
IR: 3242 (br, OH), 3054, 2916, 2221, 1598, 1508, 1489, 1442,1363, 1272, 1169, 1123, 1012, 980, 944, 903. GCMS (Def-LD): 20.3 min. MS (EI, 70 eV): 258 (100 %); 241 (52 %); 229 (71 %); 215 (16 %); 155 (17 %); 129 (54 %); 102 (13 %); 77 (10 %). HPLC: Chiralcel OD (hept/iPrOH = 80/20): 9.5/21.7 min. ^{1}H ($CDCl_3$, 300 MHz): δ 8.02 (s, 1H); 7.84 (m, 3H); 7.69 (dd, *J* =1.6, 8.7 Hz, 1H); 7.47 (dd, *J* = 3, 6.4 Hz, 4H); 7.30 (dd, *J* = 1.5, 5.6 Hz, 3H); 5.82 (d, *J* = 5.6 Hz, 1H); 2.57 (d, *J* = 5.6 Hz, 1H). ^{13}C ($CDCl_3$, 76 MHz): δ 138.0; 133.3; 133.2; 131.8; 128.7; 128.4; 128.3; 127.8; 126.4; 125.6; 124.7; 122.4; 88.8; 87.0; 65.3. $[\alpha]_D$ =-10.4° (c = 1.0, DCM).

1-(2,4-Dimethoxy-3-methylphenyl)-3-phenylprop-2-yn-1-ol):



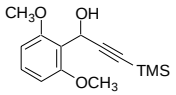
Isolated as an amorphous white solid. R_f= 0.40 (PE/Et_2O = 2/1).
^{1}H ($CDCl_3$, 300 MHz): δ 7.44 (m, 3H); 7.28 (m, 3H); 6.66 (d, *J* = 8.4 Hz, 1H); 5.82 (s, 1H); 3.88 (s, 3H); 3.82 (s, 3H); 2.17 (s, 3H). ^{13}C ($CDCl_3$, 76 MHz): δ 159.2; 157.0; 131.7; 128.4; 128.3; 126.5; 125.6; 122.8; 120.0; 106.1; 89.7; 85.9; 61.7; 61.6; 55.7; 9.3. MS (EI, 70 eV): 282 (33 %); 267 (100 %); 251 (100 %); 235 (12 %); 223 (14 %); 207 (13 %); 178 (23 %); 163 (31 %); 152 (24 %); 115 (28 %). GCMS (EI, Def-LD): 19.02 min. IR: 3406 (br, OH), 3056, 2969, 2940, 2865, 2838, 2225, 1956, 1882, 1677, 1599, 1487, 1463, 1416, 1384, 1269, 1210, 1192, 1165, 1106, 1070, 1008, 935, 915. HPLC: Chiralcel OD (heptane/*i*PrOH = 80/20): 7.5/10.3 min. $[\alpha]_D$ =-2.4° (c = 1.0, DCM).

1-(2,6-Dimethoxyphenyl)-3-phenylprop-2-yn-1-ol:



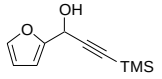
Isolated as an amorphous white solid. R_f= 0.20 (PE/Et_2O = 2/1).
GCMS (Default): 17.7 min. MS (EI, 70 eV): 253 (100 %); 237 (47 %); 165 (22 %); 151 (10 %); 138 (12 %); 115 (14 %); 91 (13 %). IR: 3539, 3009, 2938, 2839, 2361, 1596, 1477, 1436, 1401, 1334, 1292, 1263, 1228, 1174, 1105, 1032, 998, 961. ^{1}H ($CDCl_3$, 300 MHz): δ 7.39 (m, 2H); 7.24 (m, 4H); 6.59 (d, *J* = 8.7 Hz, 2H); 6.12 (d, *J* = 11.4 Hz, 1H); 4.09 (d, *J* = 11.4 Hz, 1H); 3.88 (s, 6H); 2.15 (s, 1H). ^{13}C ($CDCl_3$, 76 MHz): δ 157.6; 131.8; 129.4; 128.1; 128.0; 123.3; 117.7; 104.7; 90.2; 83.0; 57.0; 56.1. HPLC: Chiralcel OD (hept/iPrOH = 90/10): 20.5/27.2 min.

1-(2,6-Dimethoxyphenyl)-3-(trimethylsilyl)prop-2-yn-1-ol:



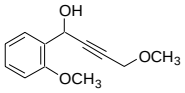
Isolated as an amorphous white solid. R_f= 0.30 (PE/Et_2O = 2/1).
^{1}H ($CDCl_3$, 300 MHz): δ 7.22 (dd, *J* = 8.4,8.5 Hz, 1H); 6.57 (d, *J* = 8.4 Hz, 2H); 5.86 (d, *J* = 11.1 Hz, 1H); 3.90 (d, obscured, 1H); 3.86 (s, 6H); 0.14 (s, 9H). ^{13}C ($CDCl_3$, 76 MHz): δ 157.7; 129.4; 117.8; 106.5; 104.8; 87.2; 56.8; 56.1; 0.04. IR: 3529, 2956, 2840, 2163, 1595, 1477, 1437, 1406, 1333, 1289, 1266, 1249, 1232, 1178, 1108, 1042, 978. HPLC: Chiralcel OD (hept/iPrOH = 90/10): 11.5/15.0 min. $[\alpha]_D$ =-13.5˚ (c = 0.5, DCM).

1-(Furan-2-yl)-3-(trimethylsilyl)prop-2-yn-1-ol:



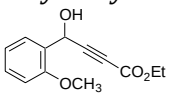
Matches published data.[5]
Isolated as a yellow oil. R_f= 0.65 (PE/Et_2O = 2/1)
^{1}H ($CDCl_3$, 300 MHz): δ 7.41 (m, 1H); 6.45 (d, *J* = 3.3 Hz, 1H); 6.35 (dd, *J* = 2.1,3.3 Hz, 1H); 5.45 (d, *J* = 6.6 Hz, 1H); 2.47 (d, *J* = 6.8 Hz, 1H); 0.21 (s, 9H). ^{13}C ($CDCl_3$, 76 MHz): δ 152.3; 143.2; 110.4; 108.0; 102.3; 91.0; 58.5; -0.2. IR: 3422 (br, OH), 2959, 2895, 2355, 2168, 2127, 1757, 1700, 1684, 1636, 1560, 1461, 1394, 1300, 1250, 1145, 1072, 1051, 1007, 917. HPLC: Chiralcel OD (hept/iPrOH = 90/10): $[\alpha]_D$ =+13.8˚ (c = 0.8, DCM).

4-Methoxy-1-(2-methoxyphenyl)but-2-yn-1-ol:



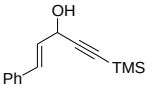
Isolated as a colorless oil. R_f= 0.15 (PE/Et_2O = 2/1)
^1H ($CDCl_3$, 300 MHz): δ 7.54 (dd, *J* = 1.5,7.5 Hz, 1H); 7.31 (ddd, *J* = 1.5, 7.6, 7.8 Hz, 1H); 6.98 (dd, *J* = 7.5,7.7 Hz, 1H); 6.90 (d, *J* = 8.0 Hz, 1H); 5.75 (d, *J* = 6.6 Hz, 1H); 4.18 (d, *J* = 1.5 Hz, 2H); 3.89 (s, 3H); 3.39 (s, 3H); 3.08 (d, 6.4, 1H). ^{13}C ($CDCl_3$, 76 MHz): δ 156.8; 129.8; 128.6; 127.9; 120.9; 110.8; 85.8; 81.8; 61.2; 60.0; 57.6; 55.6. IR: 3406 (br, OH), 2939, 2839, 2360, 2228, 1716, 1645, 1599, 1574, 1490, 1464, 1437, 1357, 1301, 1288, 1248, 1188, 1164, 1102, 1048, 1024, 908. HPLC: Chiralcel AD (hept/iPrOH = 90/10): 15.5/20.0 min. $[\alpha]_D$ =+11.5˚ (c = 1.7, DCM).

Ethyl 4-hydroxy-4-(2-methoxyphenyl)but-2-ynoate:



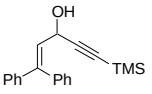
Matches published data.[6]
Isolated as a colorless oil. R_f= 0.20 (PE/Et_2O = 2/1)
^1H ($CDCl_3$, 300 MHz): δ 7.45 (dd, *J* = 1.6, 7.5 Hz, 1H); 7.34 (ddd, *J* = 1.5, 8.1, 7.6 Hz, 1H); 6.98 (ddd, *J* = 1.5, 7.5, 7.8 Hz, 1H); 6.93 (d, *J* = 8.1 Hz, 1H); 5.72 (d, *J* = 7.2 Hz, 1H); 4.23 (q, *J* = 7.0 Hz, 2H); 3.91 (s, 3H); 3.20 (d, *J* = 7.2 Hz, 1H); 1.30 (t, *J* = 7.0 Hz, 3H). ^{13}C ($CDCl_3$, 76 MHz): δ 156.9; 153.5; 130.3; 128.2; 126.9; 121.1; 111.2; 86.3; 69.7; 62.2; 61.4; 55.8; 14.1. IR: 3404 (br, OH), 2924, 2850, 2359, 2332, 2234, 1702, 1598, 1491, 1458, 1437, 1366, 1243, 1165, 1111, 1066, 1017, 749. HPLC: Chiralcel OD (hept/iPrOH = 80/20): 8.9/9.5 min.

1-Phenyl-5-trimethylsilanyl-pent-1-en-4-yn-3-ol



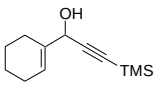
Matches published data.[7]
Isolated as a white solid, (mp = 57-58 ˚C). ^1H NMR (400 MHz, $CDCl_3$) δ 7.40-7.43 (m, 2H), 7.32-7.36 (m, 2H), 7.25-7.29 (m, 1H), 6.77 (dd, J= 16, 1.2 Hz, 1H), 6.29 (dd, J = 16, 6 Hz, 1H), 5.05 (dt, J = 6, 1.2 Hz, 1H), 1.96 (t, J = 6 Hz, 1H), 0.21 (s, 9H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 136.0, 132.0, 128.6, 128.1, 127.8, 126.8, 104.1, 91.3, 66.3, -0.2. IR (neat) 3300 (br, OH), 2960, 2172, 1654, 1496, 1449, 1407, 1251 (s). HPLC (AD column; Hept/*i*PrOH 90/10, 1 mL/min, 254 nm) 6.97/8.79 min. $[\alpha]_D$= +2.16˚ (c 1.05, $CHCl_3$) HRMS—EI (m/z): calcd for $C_{14}H_{18}OSi$: 230.1127; found: 230.1126, 0.6 ppm.

1,1-Diphenyl-5-trimethylsilanyl-pent-1-en-4-yn-3-ol



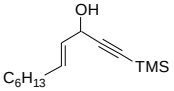
Isolated as a clear yellow oil. ^1H NMR (400 MHz) δ 7.34-7.42 (m, 3H), 7.24-7.31 (m, 7H), 6.15 (d, J = 9.2 Hz, 1H), 4.88 (dd, *J* = 9.2, 4.8 Hz, 1H), 1.90 (d, J= 4.8 Hz, 1H), 0.19 (s, 9H). ^{13}C NMR (100 MHz) δ 144.5, 141.3, 138.4, 129.9, 128.24, 128.20, 128.18, 127.9, 127.8, 127, 105.3, 90.5, 60.6, -0.2. IR (thin film) 3346 (br, OH), 3081, 3059, 3029, 2960, 2899, 2172, 1951, 1890, 1812, 1763, 1627, 1600, 1576, 1493, 1445, 1251 (s). HPLC (AD column; Hept/*i*PrOH 98/2, 1 mL/min, 254 nm) 25.40/30.86 min. $[\alpha]_D$ (c 0.48, $CHCl_3$) = -60.22˚. HRMS—EI (m/z): calcd for $C_{20}H_{22}OSi$: 306.1440; found: 306.1441, 0.5 ppm.

1-Cyclohex-1-enyl-3-trimethylsilanyl-prop-2-yn-1-ol



Isolated as a clear, colorless oil, R_f= 0.50 (PE/Et_2O = 2/1).
^1H ($CDCl_3$, 500 MHz): 5.91 (m, 1H); 4.71 (d, *J* = 6 Hz, 1H); 2.22-2.17 (m, 1H); 2.10-2.04 (m, 3H); 1.97 (d, *J* = 6 Hz, 1H); 1.67 (m, 2H); 1.60 (m, 2H); 0.19 (s, 9H). ^{13}C ($CDCl_3$, 126 MHz): δ 136.7; 125.1; 104.8; 90.6; 67.2; 25.1; 24.2; 22.6; 22.2; -0.07. IR: 3330 (br, OH), 3054, 2959, 2931, 2859, 2838, 2170, 1447, 1437, 1408, 1250, 1175, 1140, 1084, 1034, 988. HPLC: Chiralcel OD (hept/iPrOH = 99.7/0.3); 220 nm: 22.2/24.9 min.

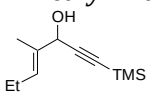
1-Trimethylsilanyl-undec-4-en-1-yn-3-ol



Isolated as a clear, colorless oil, R_f= 0.70 (PE/Et_2O = 2/1).
^1H ($CDCl_3$, 500 MHz): δ 5.88 (ddt, *J* = 1.0, 15.5, 6.5 Hz, 1H); 5.59 (ddt, *J* = 1.5, 5.0, 15.5 Hz, 1H); 4.82 (t, *J* = 6.3 Hz, 1H); 2.07 (q, *J* = 7.0 Hz, 2H); 1.92 (d, *J*

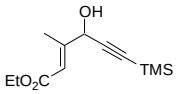
= 6.0 Hz, 1H); 1.39 (m, 2H); 1.33-1.24 (m, 6H); 0.89 (t, *J* = 7.2 Hz, 3H); 0.18 (s, 9H). ^{13}C ($CDCl_3$, 126 MHz): δ 134.4; 128.7; 105.0; 90.6; 63.5; 32.0; 31.7; 28.8; 22.7; 14.2; -0.09. IR: 3321 (br, OH), 2959, 2927, 2857, 2174, 1668, 1467, 1408, 1379, 1302, 1250, 1131, 1091, 1026, 965, 907. HPLC: Chiralcel OD (hept/iPrOH = 96/4); 220 nm: 4.5/5.0 min. $[\alpha]_D$ = -15.9˚ (c = 1.0, DCM). HRMS—EI (m/z): calcd for $C_{13}H_{23}OSi$ $(M\text{-}CH_3)^+$: 223.1518; found: 223.1511, 3.2 ppm.

4-Methyl-1-trimethylsilanyl-hept-4-en-1-yn-3-ol



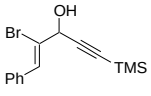
Isolated as a clear, colorless oil, R_f= 0.65 (PE/Et_2O = 2/1). ^{1}H ($CDCl_3$, 500 MHz): δ 5.60 (t, *J* = 7.0 Hz, 1H); 4.73 (d, *J* = 5.5 Hz, 1H); 2.07 (q, *J* =7.0 Hz, 2H); 1.91 (d, *J* = 6.5 Hz, 1H); 1.74 (s, 3H); 0.99 (t, *J* = 7.4 Hz, 3H); 0.18 (s, 9H). ^{13}C ($CDCl_3$, 126 MHz): δ 133.4; 130.4; 104.9; 90.8; 68.6; 21.2; 13.8; 12.1; -0.07. HPLC: Chiralcel OD (hept/iPrOH = 99.7/0.3); 220 nm: 16.8/20.3 min. IR: 3333 (br, OH), 2963, 2935, 2900, 2876, 2173, 1671, 1457, 1408, 1302, 1250, 1023, 1003. $[\alpha]_D$ = -52.5˚ (c = 0.70, DCM) HRMS—EI (m/z): calcd for $C_{11}H_{20}OSi$: 196.1283; found: 196.1275, 4.1 ppm.

4-Hydroxy-3-methyl-6-trimethylsilanyl-hex-2-en-5-ynoic acid ethyl ester



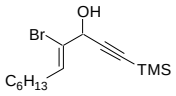
Isolated as a clear, colorless oil, R_f= 0.60 (PE/Et_2O = 2/1). ^{1}H ($CDCl_3$, 400 MHz): δ 6.07 (q, *J* = 1.5 Hz, 1H); 4.79 (s, 1H); 4.17 (q, *J* = 7.5 Hz, 2H); 2.36 (br s, 1H); 2.22 (d, *J* = 1.5 Hz, 3H); 1.28 (t, *J* = 7.5 Hz, 3H); 0.16 (s, 9H). ^{13}C ($CDCl_3$, 101 MHz): δ 166.7, 154.9, 116.3, 102.9, 91.8, 67.2, 60.1, 14.7, -0.2. IR: 3428 (br, OH), 2961, 2902, 2173, 1720, 1701, 1660, 1369, 1345, 1251, 1216, 1149, 1088, 1042, 1012, 941. HPLC: Chiralcel OD (hept/iPrOH = 96/4): 7.4/8.1 min. $[\alpha]_D$ = +16.8˚ (c = 0.37, DCM).

2-Bromo-1-phenyl-5-trimethylsilanyl-pent-1-en-4-yn-3-ol



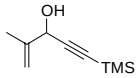
Isolated as a yellow oil. ^{1}H NMR (300 MHz) δ 7.58-7.65 (m, 2H), 7.22-7.39 (3H, m), 5.05 (s, 1H), 2.53 (s, 1H), 0.19 (s, 9H). δ ^{13}C NMR (100 MHz) δ 134.6, 129.7, 129.1, 128.5, 128.2, 125.0, 102.3, 92.7, 68.9, -0.3. IR (thin film) 3357 (br, OH), 2960, 2899, 2177, 1640, 1600, 1492, 1447, 1409, 1251. HPLC (AD column; Hept/*i*PrOH 90/10, 1 mL/min, 254 nm) 5.89/8.64 min. $[\alpha]_D$ = -5.65˚. HRMS—EI (m/z): calcd for $C_{14}H_{17}OSi$ $(M\text{-}Br)^+$: 229.1049; found: 229.1045, 1.6 ppm.

4-Bromo-1-trimethylsilanyl-undec-4-en-1-yn-3-ol



Isolated as a yellow oil. ^{1}H NMR (400 MHz) δ 6.24 (t, J = 7.2 Hz, 1H), 4.90 (d, J = 7.2 Hz, 1H), 2.37 (d, J = 7.6 Hz, 1H), 2.20 (q, J= 7.2 Hz, 2H), 1.37-1.46 (m, 2H), 1.22-1.37 (m, 6H), 0.86-0.92 (m, 3H), 0.19 (s, 9H). ^{13}C NMR (100 MHz) δ 132.4, 126.3, 102.5, 92.0, 67.8, 31.6, 30.9, 28.8, 28.0, 22.5, 14.0, -0.3. IR (thin film) HPLC (AD column; Hept/*i*PrOH 90/10, 1 mL/min, 220 nm) 8.29/10.34 min. $[\alpha]_D$) = -13.30° (c = 1.04, $CHCl_3$). HRMS—EI (m/z): calcd for $C_{14}H_{25}BrOSi$: 318.0837; found: 318.0837, 0.0 ppm.

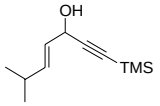
2-Methyl-5-trimethylsilanyl-pent-1-en-4-yn-3-ol



Matches published data.[8]

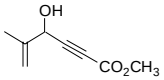
Isolated as a clear oil. ^{1}H NMR (500 MHz) δ 5.18 (s, 1H), 4.93 (s, 1H), 4.78 (d, J = 6 Hz, 1H), 1.91-1.94 (m, 1H), 1.86 (s, 3H), 0.18 (s, 9H). ^{13}C (100 MHz) 143.7, 112.6, 104.3, 89.8, 66.7, 18.1, -0.2. IR (thin film): 3407 (br, OH), 2961, 2175, 1712, 1676, 1646, 1451, 1409, 1376, 1320, 1252. HPLC (AD column; Hept/*i*PrOH 98/2, 1 mL/min, 210 nm) 9.37/8.39 min. $[\alpha]_D$ = -5.20˚ (c = 0.60, $CHCl_3$). HRMS—EI (m/z): calcd for $C_9H_{16}OSi$: 168.0970; found: 168.0970, 0.0 ppm.

6-Methyl-1-trimethylsilanyl-hept-4-en-1-yn-3-ol



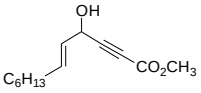
Isolated as a clear oil. ^{1}H NMR (400 MHz) δ 5.84 (ddd, J = 12.4, 5.2, 1.0 Hz, 1H), 5.53 (ddd, J = 12.4, 5.2, 1.1 Hz, 1H), 4.81 (t, J = 5.2 Hz, 1H), 2.32 (m, 1H), 1.96 (d, J = 4.8 Hz, 1H), 1.01 (d, J = 5.2 Hz, 6H), 0.18 (s, 9H). ^{13}C NMR (101MHz) δ 141.0, 125.9, 104.9, 90.6, 63.4, 30.5, 21.97, 21.94, -0.2. IR (thin film): 3333 (br, OH), 2960, 2900, 2871, 2174 (m), 1666, 1630, 1467, 1409, 1384, 1380, 1306, 1251(s). HPLC (AD column; Hept/*i*PrOH 98/2, 1 mL/min, 210 nm) 9.99 min(major), 9.33min(minor). $[\alpha]_D$ = -42.5˚ (c = 2.7, $CHCl_3$). HRMS—EI (m/z): calcd for $C_{11}H_{20}OSi$: 196.1283; found: 196.1294, -5.4 ppm.

4-Hydroxy-5-methyl-hex-5-en-2-ynoic acid methyl ester



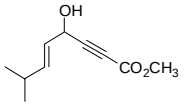
Isolated as a clear oil. ^{1}H NMR (400 MHz) δ 5.19-5.22 (m, 1H), 4.98-5.01 (m, 1H), 4.90 (d, J = 4.8 Hz, 1H), 3.78 (s, 3H), 2.54 (d, J = 6 Hz, 1H), 1.86 (s, 3H). ^{13}C NMR (100 MHz) δ 153.7, 142.0, 113.8, 86.0, 76.9, 65.8, 52.9, 18.1. IR (thin plate) 3422(br, OH), 2922, 229, 1716 (s), 1437. HPLC (AD column; Hept/*i*PrOH 99.7/0.3, 1 mL/min, 220 nm) (major)/(minor) min. $[\alpha]_D$ = -17.3˚ (c =1.42, $CHCl_3$) HRMS—EI (m/z): calcd for $C_8H_{10}O_3$: 154.0623; found: 154.0629, 4.5 ppm.

4-Hydroxy-dodec-5-en-2-ynoic acid methyl ester



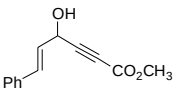
Isolated as a clear oil. ^{1}H NMR (400 MHz) δ 5.91 (dtd, J = 15.6, 6.8, 1 Hz, 1H), 5.57 (ddt, J = 15.6, 6.4, 1.5 Hz, 1H), 4.94 (t, J = 6 Hz, 1H), 3.78 (s, 3H), 2.31-2.41 (m, 1H), 2.06 (q, J = 7.2 Hz, 2H), 1.21-1.43 (m, 8H), 0.87 (t, J= 7.2 Hz, 3H). ^{13}C NMR (100 MHz) δ 153.8, 135.8, 126.6, 86.5, 76.9, 62.6, 52.8, 31.6, 28.8, 28.6, 22.5, 14.0. (thin film) 3414 (br, OH), 2928, 2857, 2238, 1721 (s), 1436. HPLC (AD column; Hept/*i*PrOH 97/3, 1 mL/min, 220 nm) 17.28(major)/15.81(minor) min. $[\alpha]_D$ = +40.1˚ (c = 1.87, $CHCl_3$) . HRMS—EI (m/z): calcd for $C_{11}H_{17}O$ $(M\text{-}CO_2CH_3)^+$: 165.1279; found: 165.1275, 2.4 ppm.

4-Hydroxy-7-methyl-oct-5-en-2-ynoic acid methyl ester



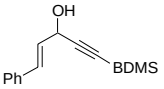
Isolated as a clear oil. ^{1}H NMR (400 MHz) δ 5.87 (ddd, J = 15.2, 6.4, 1.2 Hz, 1H), 5.52 (ddd, J = 15.2, 6.4, 1.3 Hz, 1H), 4.94 (t, J = 6.4 Hz, 1H), 3.78 (s, 3H), 2.46 (d, J = 6.4 Hz, 1H), 2.27-2.38 (m, 1H), 1.00 (d, J = 6.8 Hz, 6H). ^{13}C NMR (100 MHz) δ 153.8, 142.3, 124.0, 86.6, 76.9, 62.6, 52.8, 30.5, 21.8. IR (thin film) 3423 (br, OH), 2959, 2238, 1719, 1560. HPLC (OD column; Hept/*i*PrOH 95/5, 1 mL/min, 220 nm) 11.46(major)/12.50(minor) min. $[\alpha]_D$ = -50.60˚ (c = 1.80, $CHCl_3$). HRMS—EI (m/z): calcd for $C_{10}H_{14}O3$ $(M)^+$: 182.0943; found: 182.0941, 1.2 ppm.

4-Hydroxy-6-phenyl-hex-5-en-2-ynoic acid methyl ester



Isolated as a clear oil. R_f = 0.15 (2:1 PE:Et_2O) ^{1}H NMR (400 MHz) δ 7.24-7.45 (m, 5H), 6.79 (dd, J = 15.6, 1.3 Hz, 1H), 6.27 (dd, J = 15.6, 6 Hz, 1H), 5.17 (td, J = 6, 1.3 Hz, 1H), 3.80 (s, 3H), 2.56 (d, J = 6.8 Hz, 1H). ^{13}C NMR (100 MHz) δ 153.7, 135.5, 133.3, 128.6, 128.5, 126.9, 125.6, 85.8, 77.3, 62.5, 52.9. IR (thin film) 3408 (br, OH), 3028, 2955, 2238, 1954, 1883, 1715, 1495, 1435. HPLC (AD column; Hept/*i*PrOH 90/10, 1 mL/min, 254 nm) 18.18(major)/ 15.86(minor) min. $[\alpha]_D$ = +5.28˚ (c=1.20, $CHCl_3$). HRMS—EI (m/z): calcd for $C_{13}H_{12}O_3$: 216.0708; found: 216.0777, 4.5 ppm.

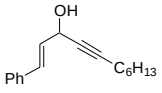
5-(Benzyl-dimethyl-silanyl)-1-phenyl-pent-1-en-4-yn-3-ol



Isolated as a clear oil. ^{1}H NMR (500 MHz) δ 7.38-7.45 (m, 2H), 7.31-7.36 (m, 2H), 7.18-7.30 (m, 3H), 7.06-7.11 (m, 3H), 6.74 (d, J = 15.5 Hz, 1H), 6.27 (dd, J = 15.5, 6 Hz, 1H), 5.02 (t, J = 5.5 Hz, 1H), 2.23 (s, 2H), 2.04 (s, 1H), 0.17 (s, 6H). ^{13}C NMR (126 MHz) δ 138.7, 136.0, 132.1, 128.6, 128.4, 128.2, 128.1, 127.7, 126.8, 124.4, 105.6, 89.8, 63.3, 26.0, 0.0, -2.2. IR (thin film) 3347 (br, OH), 3026, 2960,

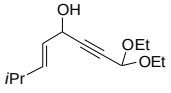
2172, 1946, 1876, 1804, 1651, 1600, 1494, 1451, 1408. HPLC (AD column; Hept/*i*PrOH 90/10, 1 mL/min, 254 nm) 10.52(major)/ 7.63(minor) min. $[\alpha]_D$ = +6.73˚ (c=1.00, $CHCl_3$). HRMS—EI (m/z): calcd for $C_{20}H_{22}OSi$: 306.1440; found: 306.1446, 1.9 ppm.

1-Phenyl-undec-1-en-4-yn-3-ol



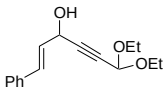
Isolated as a clear yellow oil. ^{1}H NMR (500 MHz) δ 7.38-7.41 (m, 2H), 7.29-7.34 (m, 2H), 7.23-7.28 (m, 1H), 6.75 (d, J = 16 Hz, 1H), 6.30 (dd, J = 16, 6 Hz, 1H), 5.04 (s, 1H), 2.26 (td, J = 7, 2 Hz, 2H), 2.04 (s, 1H), 1.50-1.57 (m, 2H), 1.37-1.44 (m, 2H), 1.24-1.35 (m, 4H), 0.89 (t, J = 7 Hz, 3H). ^{13}C NMR (126 MHz) δ 136.2, 131.4, 128.8, 128.5, 127.9, 126.7, 87.5, 79.1, 63.2, 31.3, 28.55, 28.52, 22.5, 18.8, 14.0. IR (thin film) 3331 (br, OH), 2931, 2858, 2235, 1655, 1496, 1449. HPLC (AD column; Hept/*i*PrOH 90/10, 1 mL/min, 254 nm) 9.42(major)/8.26 (minor) min. $[\alpha]_D$ = 4.75˚ (c=1.00, $CHCl_3$). HRMS—EI (m/z): calcd for $C_{17}H_{22}O$: 242.242.1671; found: 242.1669, 0.8 ppm.

1,1-Diethoxy-7-methyl-oct-5-en-2-yn-4-ol



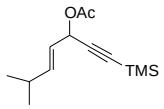
Isolated as a clear colorless oil. ^{1}H NMR (400 MHz) δ 5.83 (ddd, J = 16, 6.4, 1.2 Hz, 1 H), 5.53 (ddd, J = 16, 6.4, 1.4 Hz, 1H), 5.32 (d, J = 1.4 Hz, 1H), 4.88 (d, J = 6.4 Hz, 1H), 3.69-3.78 (m, 2H), 3.54-3.63 (m, 2H), 2.24-2.38 (m, 1H), 2.15 (br s, 1H), 1.23 (t, J = 7.2 Hz, 6H), 0.99 (d, J = 6.8 Hz, 6H). ^{13}C NMR (100 MHz) δ 141.1, 125.5, 91.2, 84.9, 81.0, 62.8, 60.9, 30.5, 21.9, 15.0. IR (thin film) 3422 (br, OH), 2974 (s), 2870, 2364, 2244, 1670, 1466, 1328. $[\alpha]_D$ = -33.5˚ (c=2.28, $CHCl_3$). HPLC (of benzoyl ester): HPLC (AD column; Hept/*i*PrOH 97/3, 1 mL/min, 220 nm) 6.41(major)/5.56 (minor) min HRMS—EI (m/z): calcd for $C_{13}H_{21}O_3$ $(M-H)^+$: 225.1490; found: 225.1485, 2.4 ppm.

6,6-Diethoxy-1-phenyl-hex-1-en-4-yn-3-ol



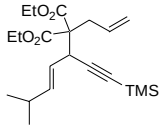
Isolated as a clear yellow oil**.** ^{1}H NMR (400 MHz) δ 7.22-7.41 (m, 5H), 6.76 (d, J = 15.6 Hz, 1H), 6.29 (ddd, J = 15.6, 6, 0.7 Hz, 1H), 5.36 (s, 1H), 5.12 (t, J = 5.2 Hz, 1H), 3.72-3.82 (m, 2H), 3.57-3.65 (m, 2H), 2.32 (br s, 1H), 1.25 (t, J = 7.2 Hz, 6H). ^{13}C NMR (100 MHz) δ 135.9, 132.2, 128.6, 128.2, 127.3, 91.2, 84.2, 81.6, 62.7, 61.0, 15.0. IR (thin film) 3412 (br, OH), 3028, 2977 (s), 2888, 2242, 1952, 1881, 1806, 1723, 1632, 1600, 1579, 1494, 1449. $[\alpha]_D$ = +2.9˚ (c=1.40, $CHCl_3$). HPLC (AD column; Hept/*i*PrOH 90/10, 1 mL/min, 254 nm) 13.54(major)/11.36 (minor) min. HRMS—EI (m/z): calcd for $C_{14}H_{15}O_2$ $(M-OEt)^+$: 215.1072; found: 215.1059, 5.5 ppm.

Acetic acid 4-methyl-1-trimethylsilanylethynyl-pent-2-enyl ester



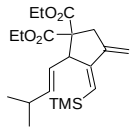
To a vial containing alcohol substrate neat (6-Methyl-1-trimethylsilanyl-hept-4-en-1-yn-3-ol, 110 mg, 0.56 mmol) at 0 ˚C was added acetic anhydride (0.2 mL, 2.1 mmol), then pyridine (60 µL, 0.73 mmol). The reaction stirred for 6 hours at room temperature then diluted with Et_2O (5 mL), quenched with phosphate buffer (4 mL, pH = 4.2), and separated. The organic layer was diluted to 15 mL and again washed with phosphate buffer (3 x 2 mL), dried with $MgSO_4$, filtered, purified by silica gel chromatography (25:1, PE:Et_2O). Product isolated as a clear colorless oil (122 mg, 91%), R_f (5:1, PE:Et_2O) = 0.79. ^{1}H NMR (500 MHz) δ 5.96 (ddd, J = 15.5, 6.5, 1.2 Hz, 1H), 5.86 (d, J = 6.5 Hz, 1H), 5.46 (ddd, J = 15.5, 6.5, 1.3 Hz, 1H), 2.28-2.38 (m, 1H), 2.09 (s, 3H), 1.01 (dd, J = 7, 0.9 Hz, 6H), 0.19 (s, 9H). ^{13}C NMR (126 Hz) δ 169.7, 143.3, 122.0, 101.0, 91.7, 64.7, 30.5, 21.8, 21.2, -0.2. IR (thin film): 2962 (s) , 2873, 2180 (m), 1745 (s), 1668, 1467, 1370, 1251, 1227. $[\alpha]_D$ = -13.7˚ (c=1.83, $CHCl_3$). HRMS—EI (m/z): calcd for $C_{13}H_{22}O_2Si$ $(M)^+$: 238.1389; found: 238.1380, 3.9 ppm.

2-Allyl-2-(4-methyl-1-trimethylsilanylethynyl-pent-2-enyl)-malonic acid diethyl ester



To a stirring suspension of NaH (60% wt/wt in mineral oil, 100 mg, 2.5 mmol) in THF (10 mL, degassed by freeze/pump/thaw) was added neat diethylallyl malonate (437 µL, 2.2 mmol) dropwise. As the suspension stirred for 15 minutes it bubbled and became a clear solution. To a separate flask charged with $Pd_2dba_3CHCl_3$ (43 mg, 0.04 mmol) and PPh_3 (66 mg, 0.25 mmol) was added THF (mL, degassed by freeze/pump/thaw). After the solution stirred for 15 minutes and became a clear yellow solution neat allylic acetate substrate was added (Acetic acid 4-methyl-1-trimethylsilanylethynyl-pent-2-enyl ester, 435 mg, 1.82 mmol). After stirring for 5 minutes the solution containing the substrate and Pd catalyst was transferred *via* cannula to the malonate solution. The reaction was sealed. After 24 hours the reaction was quenched with a phosphate buffer (10 mL, pH= 6.0). The organic layer was separated, dried with $MgSO_4$, filtered, and purified by silica gel chromatography (9:1, PE: Et_2O). Isolated as a clear oil (479 mg, 69%). ^{1}H NMR (500 MHz, $CDCl_3$) δ 5.79-5.89 (m, 1H), 5.72 (ddd, J = 15.5, 7,1.3 Hz, 1H), 5.48 (ddd, J = 15.5, 6.5, 1.3 Hz, 1H), 5.03-5.13 (m, 1H), 4.12-4.21 (m, 4H), 3.75 (d, J = 6.5 Hz, 1H), 2.79 (dd, J = 14.5, 7.5 Hz, 1H), 2.79 (dd, J = 14.5, 7.5 Hz, 1H), 2.72 (dd, J = 14.5, 7 Hz, 1H), 2.23-2.33 (m, 1H), 1.25 (td, J = 7, 2.2 Hz, 6H), 0.96 (d, J = 6.5 Hz, 6H), 0.15 (s, 9H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 169.44, 169.1, 141.4, 133.3, 122.1, 118.6, 103.8, 89.8, 61.3, 61.2, 40.0, 38.0, 30.9, 22.2, 14.1, -0.0. IR (thin film) 2961, 2363, 2174, 1736(s). $[\alpha]_D$ = -54.93˚ (c=2.00, $CHCl_3$). HRMS—EI (m/z): calcd for $C_{21}H_{34}O_4Si$ $(M)^+$: 378.2226; found: 378.2220, 1.6 ppm.

2-(3-Methyl-but-1-enyl)-4-methylene-3-trimethylsilanylmethylene-cyclopentane-1,1-dicarboxylic acid diethyl ester



An NMR tube was charged with $Pd(OAc)_2$ (2.9 mg, 0.013 mmol), *bis*-benzylidene ethylene diamine (3.1 mg, 0.013 mmol), substrate (32.9 mg, 0.087 mmol), and finally C_6D_6 (0.8 mL). The tube was sealed with a cap and parafilm and heated to 60˚C for 16 hours. NMR showed no conversion, and the tube was heated to 100 ˚C for 10 hours. NMR showed full conversion and the reaction was purified by silica gel chromatography without workup (22:1, PE:Et_2O). Isolated as a clear colorless oil (25.4 mg, 77%). ^{1}H NMR (400 MHz, $CDCl_3$) 6.04 (s, 1H), 5.39-5.50 (m, 2H), 5.15 (ddd, J = 15.5, 8.4, 1.1 Hz, 1H), 4.88-4.96 (m, 1H), 4.00-4.26 (m, 5H), 3.25 (dt, J = 16.8, 3.2 Hz, 1H), 2.84 (dd, J = 16.8, 1.3 Hz, 1H), 2.14-2.27 (m, 1H), 1.17-1.30 (m, 6H), 0.89-0.95 (m, 6H), 0.15 (s, 9H). ^{13}C NMR (101 MHz) δ 171.0, 169.1, 155.3, 145.1, 140.9, 124.4, 120.7, 105.9, 62.6, 61,4, 61.2, 52.3, 37.4, 31.2, 22.23, 22.20, 14.1, 14.0, -0.1. IR (thin film): 2959, 2875, 1737 (s), 1466, 1445, 1366, 1248. HPLC (OD-H column; Hept/*i*PrOH 99.5/0.5, 0.8 mL/min, 210 nm) 5.12(minor)/5.52(major) min. $[\alpha]_D$ =-18.1˚ (c=0.50, $CHCl_3$). HRMS—EI (m/z): calcd for $C_{21}H_{34}O_4Si$ $(M)^+$: 378.2226; found: 378.2226, 0.2 ppm.

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