Regioselective Reductive Coupling of Alkynes and Aldehydes Leading to Allylic Alcohols

Kazuhiko Takai,* Shuji Sakamoto, and Takahiko Isshiki
Department of Applied Chemistry, Faculty of Engineering,
Okayama University, Tsushima, Okayama 700-8530, Japan

Experimental Conditions: Unless otherwise noted, materials were obtained from commercial suppliers and were used without further purification. Dry, oxygen-free dimethylformamide (DMF) was purchased from Kanto Chemicals, Co. Column chromatography was done with silica gel (200 mesh). Distillation of small amounts of products was performed with a Büchi Kugelrohr, and boiling points are indicated by an air bath temperature without correction. FT-IR spectra were obtained on a Nicolet Protégé 460 spectrometer. ^1H and ^{13}C NMR spectra were recorded on a JEOL JNM-LA400 instrument. Chemical shifts are expressed in ppm downfield from internal tetramethylsilane using the δ scale. Elemental analyses were performed by the staff at the Elemental Analyses Center of Kyoto University.

General Procedure: To a mixture of CrCl_2 (0.61 g, 5.0 mmol) and a catalytic amount of NiCl_2 (32 mg, 0.25 mmol) and triphenylphosphine (0.13 g, 0.50 mmol) in DMF (6 mL) was added a solution of an aldehyde (1.0 mmol) in DMF (4 mL) at 25 °C and the mixture was stirred for 10 min. A solution of a terminal alkyne (2.5 mmol) and water (1 M of a DMF solution, 4 mL) in DMF (6 mL) was added at 25 °C to the mixture over period of 4 h. After stirring at 25 °C for additional 4 h, the reaction mixture was poured into brine (30 mL). The mixture was extracted with ether (3 x 20 mL), and organic extracts were dried over anhydrous magnesium sulfate and concentrated. Purification by column chromatography on silica gel gave the desired coupling product.

2-(2-Phenylethyl)-1-undecen-3-ol (4): Bp 145 °C (bath temp, 0.46 Torr); IR (neat): 3355, 3085, 3027, 2927, 2855, 1646, 1604, 1496, 1455, 1076, 1031, 901, 746, 698 cm⁻¹; ¹HNMR (CDCl₃): δ 0.88 (t, *J* = 6.9 Hz, 3H), 1.22-1.33 (m, 12H), 1.38-1.43 (m, 1H), 1.49-1.61 (m, 2H), 2.29 (dt, *J* = 15.3, 8.0 Hz, 1H), 2.42 (dt, *J* = 15.6, 8.0 Hz, 1H), 2.81 (t, *J* = 8.1 Hz, 2H), 4.07 (s, 1H), 4.91 (d, *J* = 1.2 Hz, 1H), 5.06 (s, 1H), 7.15-7.34 (m, 5H); ¹³CNMR (CDCl₃): δ 14.1, 22.7, 25.7, 29.3, 29.5, 29.6, 31.9, 32.9, 34.5, 35.5, 75.7, 109.9, 125.9, 128.3, 128.3, 142.0, 151.5. Anal. Calcd for C₁₉H₃₀O: C, 83.15; H, 11.02. Found: C, 83.31; H, 11.27.

(*E*)-1-Phenyl-3-tridecen-5-ol (5):¹ IR (neat): 3337, 3108, 3086, 3027, 2954, 2855, 1604, 1496, 1454, 1377, 1304, 1131, 1030, 969, 746, 698 cm⁻¹; ¹HNMR (CDCl₃): δ 0.89 (t, *J* = 6.9 Hz, 3H), 1.23-1.31 (m, 12H), 1.34-1.37 (m, 1H), 1.41-1.53 (m, 2H), 2.36 (dt, *J* = 7.8, 7.1 Hz, 2H), 2.70 (t, *J* = 7.6 Hz, 2H), 4.00-4.05 (m, 1H), 5.47 (ddt, *J* = 15.3, 7.1, 1.2 Hz, 1H), 5.67 (dt, *J* = 15.3, 7.1 Hz, 1H), 7.17-7.30 (m, 5H); ¹³CNMR (CDCl₃): δ 14.1, 22.7, 25.4, 29.3, 29.5, 29.5, 31.9, 33.9, 35.6, 37.3, 73.1, 125.8, 128.3, 128.4, 130.9, 133.8, 141.7.

2-Decyl-1-phenyl-2-propen-1-ol:² IR (neat): 3364, 3085, 3063, 3029, 2925, 2853, 1648, 1603, 1493, 1454, 1377, 1190, 1025, 902, 842, 699 cm⁻¹; ¹HNMR (CDCl₃): δ 0.88 (t, *J* = 6.9 Hz, 3H), 1.19-1.31 (m, 14H), 1.34-1.43 (m, 2H), 1.79-1.88 (m, 2H), 1.95 (dt, *J* = 15.6, 7.9 Hz, 1H), 4.98 (s, 1H), 5.16 (d, *J* = 3.3 Hz, 1H), 5.26 (s, 1H), 7.28-7.38 (m, 5H); ¹³CNMR (CDCl₃): δ 14.1, 22.7, 27.8, 29.3, 29.4, 29.5, 29.55, 29.58, 31.8, 31.9, 77.3, 109.6, 126.7, 127.7, 128.4, 142.2, 151.2.

(*E*)-1-Phenyl-2-tridecen-1-ol:³ IR (neat): 3347, 3103, 3082, 3060, 2926, 2855, 1599, 1494, 1465, 965, 748, 693 cm⁻¹; ¹HNMR (CDCl₃): δ 0.86 (t, *J* = 6.8 Hz, 3H), 1.21-1.28 (m, 14H),

1.34-1.41 (m, 2H), 1.90 (s, 1H), 2.03 (dt, $J = 7.2, 7.0$ Hz, 2H), 5.14 (d, $J = 6.6$ Hz, 1H), 5.63 (dd, $J = 15.3, 6.6$ Hz, 1H), 5.74 (dt, $J = 15.3, 6.6$ Hz, 1H), 7.23-7.36 (m, 5H); ^{13}C NMR (CDCl_3): δ 14.1, 22.7, 29.1, 29.2, 29.3, 29.4, 29.6, 29.6, 31.9, 32.2, 75.2, 126.1, 127.4, 128.4, 132.2, 132.9, 143.4.

1-Cyclohexyl-2-decyl-2-propen-1-ol: Bp 120 °C (bath temp, 0.45 Torr); IR (neat): 3398, 2924, 2852, 1645, 1465, 1450, 1378, 1306, 1261, 1082, 1021, 897, 803, 735, 666 cm^{-1} ; ^1H NMR (CDCl_3): δ 0.88 (t, $J = 6.8$ Hz, 3H), 0.92-1.05 (m, 1H), 1.11-1.29 (m, 18H), 1.41-1.50 (m, 5H), 1.63-1.67 (m, 1H), 1.71-1.79 (m, 2H), 1.88-1.96 (m, 2H), 2.06 (dt, $J = 15.9, 7.9$ Hz, 1H), 3.77 (d, $J = 6.9$ Hz, 1H), 4.88 (d, $J = 3.0$ Hz, 1H), 4.95 (s, 1H); ^{13}C NMR (CDCl_3): δ 14.1, 22.7, 26.1, 26.3, 26.5, 28.0, 28.1, 29.4, 29.59, 29.63, 29.63, 29.7, 29.9, 31.2, 31.9, 41.0, 80.7, 110.3, 151.0. Anal. Calcd for $\text{C}_{19}\text{H}_{36}\text{O}$: C, 81.36; H, 12.94. Found: C, 81.43; H, 13.08.

(E)-1-Cyclohexyl-2-tridecen-1-ol: IR (neat): 3371, 2925, 2853, 1669, 1464, 1450, 1378, 1306, 1261, 1084, 1004, 969, 892, 721, 666 cm^{-1} ; ^1H NMR (CDCl_3): δ 0.88 (t, $J = 6.7$ Hz, 3H), 0.91-1.01 (m, 1H), 1.14-1.43 (m, 21H), 1.64-1.77 (m, 4H), 1.86 (d, $J = 12.6$ Hz, 1H), 2.03 (dt, $J = 7.2, 7.1$ Hz, 2H), 2.17 (s, 1H), 3.76 (t, $J = 6.9$ Hz, 1H), 5.44 (dd, $J = 15.3, 7.5$ Hz, 1H), 5.60 (dt, $J = 15.3, 7.1$ Hz, 1H); ^{13}C NMR (CDCl_3): δ 14.1, 22.7, 26.07, 26.15, 26.6, 28.7, 28.8, 29.16, 29.23, 29.3, 29.5, 29.60, 29.61, 31.9, 32.3, 43.7, 77.7, 131.4, 133.1. Anal. Calcd for $\text{C}_{19}\text{H}_{36}\text{O}$: C, 81.36; H, 12.94. Found: C, 81.20; H, 13.12.

2-Phenyl-1-undecen-3-ol:⁴ IR (neat): 3415, 3080, 3056, 2924, 2854, 1630, 1574, 1494, 1465, 1378, 1131, 1064, 1027, 908, 777, 698 cm^{-1} ; ^1H NMR (CDCl_3): δ 0.87 (t, $J = 6.9$ Hz, 3H), 1.19-1.28 (m, 11H), 1.42-1.63 (m, 3H), 1.75 (s, 1H), 4.60-4.64 (m, 1H), 5.30 (s, 1H), 5.35 (s, 1H), 7.30-7.40 (m, 5H); ^{13}C NMR (CDCl_3): δ 14.1, 22.6, 25.6, 29.2, 29.4, 29.5, 31.8, 36.0, 73.9, 112.5, 126.9, 127.5, 128.3, 140.1, 152.2.

(E)-1-Phenyl-1-undecen-3-ol:⁵ IR (neat): 3347, 3103, 3082, 3026, 2926, 2855, 1599, 1494, 1465, 965, 748, 693 cm^{-1} ; ^1H NMR (CDCl_3): δ 0.88 (t, $J = 6.6$ Hz, 3H), 1.23-1.45 (m, 12H), 1.55-1.71 (m, 3H), 4.27 (dd, $J = 6.6, 6.3$ Hz, 1H), 6.21 (dd, $J = 15.9, 6.6$ Hz, 1H), 6.56 (d, $J = 15.9$ Hz, 1H), 7.21-7.38 (m, 5H); ^{13}C NMR (CDCl_3): δ 14.1, 22.6, 25.4, 29.2, 29.5, 29.6, 31.8, 37.4, 73.1, 126.4, 127.6, 128.5, 130.1, 132.6, 136.8.

(E)-2-Pentyl-1-phenyl-2-octen-1-ol (6):⁶ IR (neat): 3357, 3089, 3062, 2955, 2927, 2857, 1493, 1455, 1378, 1084, 1008, 700 cm^{-1} ; ^1H NMR (CDCl_3): δ 0.83 (t, $J = 6.9$ Hz, 3H), 0.90 (t, $J = 6.9$ Hz, 3H), 1.14-1.15 (m, 12H), 1.77 (d, $J = 3.3$ Hz, 1H), 1.77-1.86 (m, 1H), 1.93-2.03 (m, 1H), 2.07 (dt, $J = 7.3, 7.2$ Hz, 2H), 5.16 (d, $J = 2.7$ Hz, 1H), 5.61 (t, $J = 7.2$ Hz, 1H), 7.24-7.37 (m, 5H); ^{13}C NMR (CDCl_3): δ 14.0, 14.1, 22.4, 22.6, 27.6, 27.7, 29.2, 29.5, 31.7, 32.1, 78.2, 126.5, 127.3, 127.3, 128.2, 141.2, 142.8.

3-Methylene-6-phenyl-hexane-1,4-diol (7): IR (neat): 3353, 3085, 3026, 2927, 2862, 1645, 1603, 1496, 1454, 1320, 1045, 908, 750, 700 cm^{-1} ; ^1H NMR (CDCl_3): δ 1.84-1.98 (m, 2H), 2.29-2.33 (m, 2H), 2.43 (ddd, $J = 14.0, 8.1, 6.0$ Hz, 1H), 2.64 (ddd, $J = 13.8, 9.1, 6.8$ Hz, 1H), 2.74 (ddd, $J = 13.9, 9.4, 6.4$ Hz, 2H), 3.72 (ddd, $J = 10.4, 8.0, 4.7$ Hz, 1H), 3.82 (dt, $J = 10.5, 5.4$ Hz, 1H), 4.13 (t, $J = 5.4$ Hz, 1H), 4.98 (d, $J = 1.2$ Hz, 1H), 5.12 (s, 1H), 7.17-7.31 (m, 5H); ^{13}C NMR (CDCl_3): δ 32.0, 34.8, 37.1, 62.4, 74.9, 113.7, 125.9, 128.41, 128.43, 141.8, 148.8. Elemental analysis was conducted with its trimethylsilyl ether [bp 60 °C (bath temp, 1.3 Torr)]. Anal. Calcd for $\text{C}_{19}\text{H}_{34}\text{O}_2\text{Si}_2$: C, 65.08; H, 9.77. Found: C, 65.04; H, 9.85.

11-Hydroxy-12-(2-phenylethyl)-12-tridecen-2-one: IR (neat): 3428, 3063, 3027, 2929, 2855, 1713, 1646, 1604, 1496, 1454, 1360, 1167, 900, 748, 700 cm^{-1} ; ^1H NMR (CDCl_3): δ 1.24-1.28 (m, 12H), 1.51-1.58 (m, 3H), 2.13 (s, 3H), 2.29 (dt, $J = 15.3, 7.9$ Hz 1H), 2.41 (t, $J = 7.3$ Hz, 2H), 2.42 (dt, $J = 15.3, 8.0$ Hz, 1H), 2.80 (t, $J = 8.2$ Hz, 2H), 4.05-4.09 (m, 1H), 4.92 (d, $J = 1.2$ Hz, 1H), 5.07 (s, 1H), 7.17-7.31 (m, 5H); ^{13}C NMR (CDCl_3): δ 23.8, 25.7, 29.1, 29.3, 29.4, 29.5, 29.8, 32.9, 34.5, 35.5, 43.8, 75.6, 109.9, 125.9, 128.3, 128.3, 142.0, 151.5, 209.3. Elemental analysis was conducted with its trimethylsilyl ether [bp 155 $^\circ\text{C}$ (bath temp, 0.34 Torr)]. Anal. Calcd for $\text{C}_{24}\text{H}_{40}\text{O}_2\text{Si}$: C, 74.17; H, 10.37. Found: C, 74.06; H, 10.56.

(E)-11-Hydroxy-15-phenyl-12-pentadecen-2-one: IR (neat): 3409, 3026, 2928, 2854, 1715, 1496, 1454, 1361, 969, 747 cm^{-1} ; ^1H NMR (CDCl_3): δ 1.20-1.31 (m, 12H), 1.43-1.58 (m, 3H), 2.13 (s, 3H), 2.36 (dt, $J = 7.7, 7.8$ Hz, 2H), 2.41 (t, $J = 7.5$ Hz, 2H), 2.70 (dd, $J = 8.1, 7.2$ Hz, 2H), 4.01 (dt, $J = 6.6, 6.6$ Hz, 1H), 5.46 (dd, $J = 15.3, 6.9$ Hz, 1H), 5.66 (dt, $J = 15.3, 6.6$ Hz, 1H), 7.16-7.29 (m, 5H); ^{13}C NMR (CDCl_3): δ 23.8, 25.3, 29.1, 29.30, 29.35, 29.4, 29.8, 33.9, 35.6, 37.2, 43.8, 73.0, 125.8, 128.3, 128.4, 130.9, 133.9, 141.7, 209.3. Elemental analysis was conducted with its trimethylsilyl ether [bp 150 $^\circ\text{C}$ (bath temp, 0.3 Torr)]. Anal. Calcd for $\text{C}_{24}\text{H}_{40}\text{O}_2\text{Si}$: C, 74.17; H, 10.37. Found: C, 74.29; H, 10.42.

References

1. Inomata, K.; Igarashi, S.; Mohri, M.; Yamamoto, T.; Kinoshita, H.; Kotake, H. *Chem. Lett.* **1987**, 707.
2. Takai, K.; Tagashira, M.; Kuroda, T.; Oshima, K.; Utimoto, K.; Nozaki, H. *J. Am. Chem. Soc.* **1986**, 108, 6048.
3. Kitagawa, K.; Inoue, A.; Shinokubo, H.; Oshima, K. *Angew. Chem. Int. Ed.* **2000**, 39, 2481.
4. Takai, K.; Kimura, K.; Kuroda, T.; Hiyama, T.; Nozaki, H. *Tetrahedron Lett.* **1983**, 24, 5281.
5. Vettel, S.; Vaupel, A.; Knochel, P. *J. Org. Chem.* **1996**, 61, 7473.
6. Takai, K.; Kataoka, Y.; Utimoto, K. *J. Org. Chem.* **1990**, 55, 1707; Inoue, A.; Kitagawa, K.; Shinokubo, H.; Oshima, K. *J. Org. Chem.* **2001**, 66, 4333.