Stereodivergent Synthesis of (*E*)- and (*Z*)-2-Alken-4-yn-1-ols from 2-Propynoic Acid: A Practical Route via 2-Alken-4-ynoates

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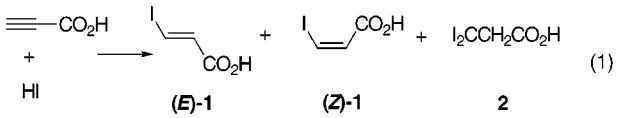
Allylic alcohols and their derivatives play an important role in organic synthesis. For example, they are used as substrates for asymmetric epoxidation,[1] transition metal complex-catalyzed allylic substitution,[2] and Claisen rearrangement.[3] The stereodefined synthesis of allylic alcohols is necessary for such synthetic procedures. 2-Alken-4-yn-1-ols are a versatile and potential synthetic intermediate[4] because of the presence of an enyne and an allylic alcohol sharing the same carbon−carbon double bond. 2-Penten-4-yn-1-ol is used as a starting material for the preparation of 2-alken-4-yn-1-ols.[5] The reaction of epichlorohydrine with sodium acetylide in liquid ammonia reportedly gives 2-penten-4-yn-1-ol, but in an 85:15 mixture of (*E*)- and (*Z*)-2-penten-4-yn-1-ol.[6] Separation of these isomers is necessary for the stereochemical integrity of the alkene. The regioselective reduction of 2,4-alkadiyn-1-ols to (*Z*)-2-alken-4-yn-1-ols mediated by activated zinc has been reported.[7] However, this reduction sometimes gives a mixture of (*E*)- and (*Z*)-2-alken-4-yn-1-ols. The lack of a practical and stereodefined synthesis of 2-alken-4-yn-1-ols from an easily accessible starting material has impeded its utility as a synthetic intermediate. In connection with our ongoing project related to iridium complex-catalyzed allylic substitution,[8] we became interested in developing a practical and stereodefined route to 2-alken-4-yn-1-ols. In this paper, we describe the stereodivergent synthesis of (*E*)- and (*Z*)-2-alken-4-yne-1-ols from 2-propynoic acid.

One efficient route to 2-alken-4-yn-1-ols is the coupling of 3-iodo-2-propen-1-ol with 1-alkynes. This protocol requires the stereodefined synthesis of (*E*)- and (*Z*)-3-iodo-2-propen-1-ol. Hydrostannation of 2-propyn-1-ol followed by iodolysis has been reported to give (*E*)-3-iodo-2-propen-1-ol.[9] However, hydrostannation of 2-propyn-1-ol with tributylstannane gave a mixture of (*E*)-3-tributylstannyl-2-propen-1-ol, (*Z*)-3-tributylstannyl-2-propen-1-ol, and 2-tributylstannyl-2-propen-1-ol. Separation of these isomers prior to iodolysis is necessary.

The hydroiodination of 2-propynoic acid and its derivatives has been studied in detail.[10] If the stereodivergent synthesis of (*E*)- and (*Z*)-3-iodopropenoic acid and/or its derivatives from 2-propynoic acid is possible, coupling of (*E*)- and (*Z*)-3-iodo-2-propenoic acid or its derivatives with 1-alkynes followed by reduction should be a practical route to (*E*)- and (*Z*)-2-alken-4-yn-1-ol from 2-propynoic acid. This route has another advantage. 2-Alken-4-ynoic acid and its derivatives, which are electron withdrawing group substituted enynes, are obtained by this coupling. The 1,6-addition of organocuprates to 2-alken-4-ynoates is reported to be a convenient route to functionalized allenes.[11] The stereodefined synthesis of 2-alken-4-ynoates provides a convenient route to functionalized allenes.

We examined the reaction of 2-propynoic acid with aqueous hydroiodic acid (eq 1). The selectivity of the



(1)

product strongly depended on the reaction conditions. The results are summarized in Table 1. The reaction at 50 °C for 18 h gave a 93:7 mixture of (*E*)- and (*Z*)-3-iodo-2-propenoic acid ((*E*)- and (*Z*)-**1**) in 90% yield (entry 1). 3,3-Diiodopropanoic acid (**2**) was also obtained in 8% yield. Product **2** was formed by hydroiodination of (*E*)- and (*Z*)-**1**. The reaction at room temperature gave a 41:59 mixture of (*E*)- and (*Z*)-**1** in 81% yield (entry 2). This result suggested that (*E*)-**1** was formed by isomerization of the initially formed (*Z*)-**1**.[12] Decreasing the amount of HI and dilution with H_2O increased the selectivity of (*Z*)-**1**. The reaction at 50 °C for 17 h using 1.4 equiv of HI to 2-propynoic acid gave (*Z*)-**1** exclusively in 90% yield (entry 3), and the formation of **2** was suppressed.

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Table 1. Hydroiodination of 2-Propynoic Acid[a]

entry	HI/2-propynoicacid	solvent	conditions	yield of **1** (%)[b]	E/Z[c]	yield of **2** (%)[b]
1	2.8	neat	50 °C; 18 h	90	93/7	8
2	3.2	neat	rt; 18 h	81	41/59	6
3[d]	1.4	H_2O	50 °C; 17 h	90	0/100	0

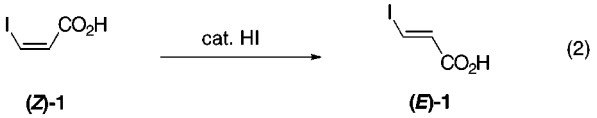
[a] A mixture of 2-propynoic acid (2 mmol) and aqueous hydroiodic acid (55 wt %) was stirred under Ar atmosphere. [b] Isolated yield. [c] Determined by NMR. [d] 2-Propynoic acid (100 mmol), H_2O (30 mL).

Table 2. Synthesis of 2-Alken-4-ynoate 5[a]

entry	ester	alkyne	time (h)	product	yield (%)[b]
1[c]	(*E*)-**4**	1-hexyne	17	(*E*)-**5a**	83
2[d]	(*Z*)-**4**	1-hexyne	15	(*Z*)-**5a**	90
3[e]	(*E*)-**4**	phenylacetylene	3	(*E*)-**5b**	93
4[f]	(*Z*)-**4**	phenylacetylene	3	(*Z*)-**5b**	93
5[g]	(*E*)-**4**	5-chloro-1-pentyne	17	(*E*)-**5c**	80
6[h]	(*Z*)-**4**	5-chloro-1-pentyne	5	(*Z*)-**5c**	81
7[i]	(*E*)-**4**	1-ethynylcyclohexene	3	(*E*)-**5d**	98
8[j]	(*Z*)-**4**	1-ethynylcyclohexene	3	(*Z*)-**5d**	87

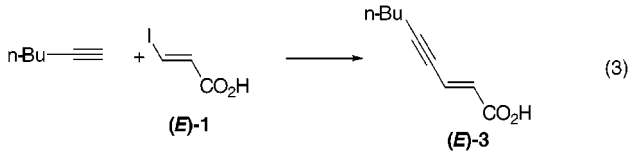
[a] A mixture of **4** (1 equiv), $PdCl_2(PPh_3)_2$ (1 mol%), CuI (0.5 mol%), 1-alkyne (1.1 equiv), and Et_3N (4 mL/**4** mmol) was stirred at 50 °C. [b] Isolated yield. [c] (*E*)-**4** (43 mmol). [d] (*Z*)-**4** (30 mmol). [e] (*E*)-**4** (15 mmol). [f] (*Z*)-**4** (18 mmol). [g] (*E*)-**4** (14 mmol). [h] (*Z*)-**4** (15 mmol). [i] (*E*)-**4** (13 mmol). [j] (*Z*)-**4** (15 mmol).

We examined the isomerization of (*Z*)-**1** to (*E*)-**1** (eq 2).

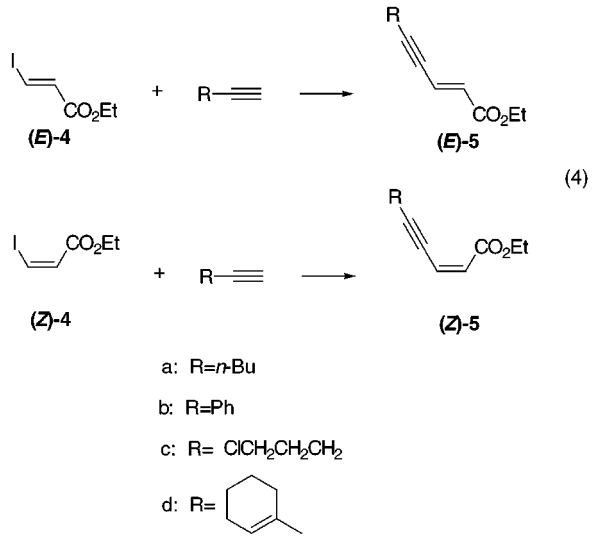


The reaction of (*Z*)-**1** in the presence of a catalytic amount of HI (14 mol %) under refluxing benzene for 5 h gave (*E*)-**1** in 89% yield. Acid (*Z*)-**1** was converted to (*E*)-**1**. Both (*E*)- and (*Z*)-**1** could be obtained in excellent yields from 2-propynoic acid. When H_2SO_4 or HCl was used as a catalyst, no isomerization occurred and the starting material was recovered.

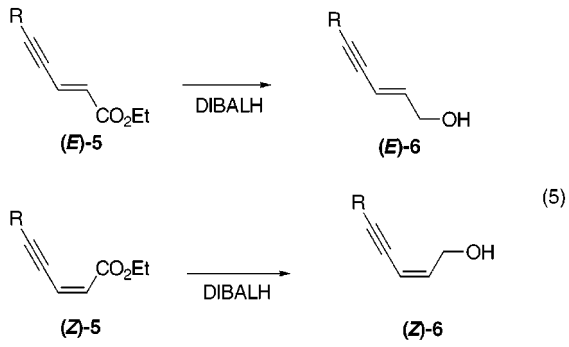
Acid (*E*)- and (*Z*)-**1** showed different reactivities in the coupling with 1-alkyne. The coupling of (*Z*)-**1** with 1-hexyne under Sonogashira conditions[13] did not give the expected product despite the complete consumption of (*Z*)-**1**, whereas (*E*)-**1** coupled with 1-hexyne to give (*E*)-**3** in 63% yield under the same reaction conditions (eq 3).[14]



To obtain both of the expected coupling products, we prepared esters of **1** and subjected them to coupling with 1-alkyne. Esterification of (*E*)- and (*Z*)-**1** with ethanol in the presence of a catalytic amount of H_2SO_4 gave the corresponding esters (*E*)- and (*Z*)-**4** in respective yields of 90% and 88%. Unlike the coupling of acid **1**, both esters **4** coupled smoothly with 1-hexyne (eq 4); the results are



summarized in Table 2. Under Sonogashira conditions, (*E*)- and (*Z*)-**4** coupled with 1-hexyne to give (*E*)- and (*Z*)-**5a** in respective yields of 83% and 90% (entries 1 and 2). The coupling was stereospecific, and both (*E*)- and (*Z*)-**5a** were obtained in stereoisomeric pure form. Various 1-alkynes, including 3-alken-1-yne, could be used for the coupling. The coupling with phenylacetylene and 5-chloro-1-pentyne also gave the coupling products (**5b** and **5c**) in good yields (entries 3−6). The coupling with 1-ethynylcyclohexene gave 2,6-diene-4-ynoate (*E*)- and (*Z*)-**5d** in respective yields of 98% and 87% (entries 7 and 8). Reduction of **5** gave 2-alken-4-yn-1-ol (**6**). Reduction of **5** with $LiAlH_4$ resulted in the formation of a complex mixture of products. Diisobutylaluminum hydride (DIBALH) is a common reagent for the reduction of α,β-unsaturated esters to allylic alcohols.[15] The reduction of **5** with DIBALH was examined. Ester **5** was smoothly reduced to the corresponding allylic alcohol **6** by using 2 equiv of DIBALH at −78 °C (eq 5); the results are summarized



in Table 3. 1,4-, 1,6-, or 1,8-Reduction did not occur. Both (*E*)- and (*Z*)-2-alken-4-yn-1-ols (**6**) were obtained in good yields. The reduction of **5** was stereospecific except in the case of (*Z*)-**5b**, where (*E*)-**6b** was obtained in 3% selectivity (entry 4).

In conclusion, we have developed a stereodivergent route to (*E*)- and (*Z*)-2-alken-4-yn-1-ols from 2-propynoic acid. In view of the ready availability of the starting material and the simplicity of the procedure, 2-alken-4-

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Table 3. Reduction of 2-Alken-4-ynoate 5 to 2-Alken-4-yn-1-ol 6[a]

entry	ester	product	yield (%)[b]
1[c]	(*E*)-**5a**	(*E*)-**6a**	93
2[d]	(*Z*)-**5a**	(*Z*)-**6a**	89
3[e]	(*E*)-**5b**	(*E*)-**6b**	99
4[f]	(*Z*)-**5b**	(*Z*)-**6b**	87[k]
5[g]	(*E*)-**5c**	(*E*)-**6c**	96
6[h]	(*Z*)-**5c**	(*Z*)-**6c**	79
7[i]	(*E*)-**5d**	(*E*)-**6d**	98
8[j]	(*Z*)-**5d**	(*Z*)-**6d**	84

[a] A mixture of **5** (1equiv) and 0.95 M DIBALH in *n*-hexane was stirred at −78 °C for 2 h. [b] Isolated yield. [c] (*E*)-**5a** (43 mmol). [d] (Z)-**5a** (30 mmol). [e] (*E*)-**5b** (16 mmol), DIBALH (2.6 equiv). [f] (*Z*)-**5b** (14 mmol). [g] (*E*)-**5c** (11 mmol). [h] (*Z*)-**5c** (10 mmol). [i] (*E*)-**5d** (10 mmol). [j] (*Z*)-**5d** (11 mmol). [k] (*E*)-**6b** was obtained in 3% yield.

yn-1-ols should be very important in organic synthesis. In addition, this route also gives (*E*)- and (*Z*)-2-alken-4-ynoates, which have wide synthetic applications.

Experimental Section

Materials. All reagents and solvents were dried and purified before use by the usual procedures. $PdCl_2(PPh_3)_2$ was prepared according to the published method.[16] CuI, 2-propynoic acid, and 0.95 M DIBALH in *n*-hexane were purchased.

General Methods. ^{1}H and ^{13}C NMR spectra were measured on a 270 or 400 MHz spectrometer using Me_4Si as an internal standard. Samples were dissolved in $CDCl_3$ solutions. GC analyses were performed using 3 mm × 2 m glass columns packed with either 5% PEG-HT on 60/80 mesh chromosorb w AW-DMCS or 5% OV-17 on 60/80 mesh chromosorb w AW-DMCS. Column chromatography was carried out on 70−230 mesh silica gel. Elemental analyses were performed at the Microanalytical Center of Kyoto University.

(*Z*)-3-Iodo-2-propenoic Acid ((*Z*)-1).[10b] To a solution of 55% aqueous HI (20 mL) and H_2O (30 mL) was added propynoic acid (7.005 g, 100 mmol). The mixture was heated at 50 °C for 17 h. After the mixture cooled to room temperature, ether was added, and the layers were separated. The aqueous layer was extracted with ether, and the combined organic layers were washed with aqueous $Na_2S_2O_3$ and dried ($MgSO_4$). The solvent was evaporated in vacuo. Washing of the residue with *n*-hexane gave (*Z*)-**1** as a pale yellow solid, yield 17.816 g (90%); mp 68−70 °C (lit.[10b] mp 63−64 °C). ^{1}H NMR (270 MHz, $CDCl_3$) δ 6.99 (d, J = 9.2 Hz, 1H), 7.69 (d, J = 9.2 Hz, 1H), 9.94 (br, 1H). ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 98.2, 129.4, 169.7.

(*E*)-3-Iodo-2-propenoic Acid ((*E*)-1).[12a] To a solution of 55% aqueous HI (0.6 mL) and benzene (8 mL) was added (*Z*)-**1** (5.939 g, 30 mmol). The mixture was heated at 80 °C for 5 h. After the mixture cooled to room temperature, ether was added, and the layers were separated. The aqueous layer was extracted with ether, and the combined organic layers were washed with aqueous $Na_2S_2O_3$ and dried ($MgSO_4$). The solvent was evaporated in vacuo. Washing of the residue with *n*-hexane gave (*E*)-**1** as a pale yellow solid, yield 5.286 g (89%); mp 144−147 °C. ^{1}H NMR (270 MHz, $CDCl_3$) δ 6.90 (d, J = 14.8 Hz, 1H), 8.09 (d, J = 14.8 Hz, 1H), 10.0 (br, 1H). ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 103.2, 135.7, 169.4.

3,3-Diiodopropanoic Acid (2). Compound **2** could not be isolated in pure form. Partial ^{1}H NMR spectra was obtained from the mixture of (*E*)- and (*Z*)-**1**. ^{1}H NMR (270 MHz, $CDCl_3$) δ 3.81 (d, J = 7.3 Hz, 2H), 5.25 (t, J = 7.3 Hz, 1H).

(*E*)-2-Nonen-4-ynoic Acid ((*E*)-3). To a mixture of (*E*)-**1** (0.990 g, 5 mmol), $PdCl_2(PPh_3)_2$ (70.2 mg, 0.1 mmol), CuI (9.5 mg, 0.05 mmol), and MeCN (12 mL) were added Et_3N (2.8 mL, 20 mmol) and 1-hexyne (0.509 g, 6.2 mmol). The mixture was stirred at 50 °C for 3 h. After the mixture cooled to room temperature, the solvent was evaporated in vacuo. Ether and H_2O were added to the residue, and the layers were separated. The aqueous layer was extracted with ether, and the combined organic layers were dried ($MgSO_4$). The solvent was evaporated in vacuo. Column chromatography (*n*-hexane/AcOEt 1/1) of the residue gave (*E*)-**3** as a pale yellow solid, yield 0.484 g (63%); mp 49−50 °C. ^{1}H NMR (270 MHz, $CDCl_3$) δ 0.93 (t, J = 7.3 Hz, 3H), 1.43 (sixtet, J = 7.3 Hz, 2H), 1.53 (quintet, J = 6.9 Hz, 2H), 2.40 (td, J = 6.9, 2.3 Hz, 2H), 6.14 (d, J = 15.8 Hz, 1H), 6.85 (dt, J = 15.8, 2.3 Hz, 1H), 10.79 (br, 1H). ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 13.5, 19.5, 21.9, 30.3, 77.8, 102.8, 128.4, 128.8, 171.7. Anal. Calcd for $C_9H_{12}O_2$: C, 71.03; H, 7.95; O, 21.03. Found: C, 70.64; H, 7.94.

Ethyl (*Z*)-3-Iodo-2-propenoate ((*Z*)-4).[10b] A mixture of (*Z*)-**1** (3.959 g, 20 mmol), concentrated H_2SO_4 (0.4 mL), and EtOH (12 mL) was stirred under reflux for 4 h. After the mixture cooled to room temperature, the solvent was evaporated in vacuo. Ether and H_2O were added to the residue, and the layers were separated. The aqueous layer was extracted with ether, and the combined organic layers were dried ($MgSO_4$). The solvent was evaporated in vacuo. Distillation of the residue under reduced pressure gave (*Z*)-**4** as a colorless oil, yield 3.953 g (88%); bp 78−79 °C/10 mmHg. ^{1}H NMR (270 MHz, $CDCl_3$) δ 1.32 (t, J = 7.3 Hz, 3H), 4.25 (q, J = 7.3 Hz, 2H), 6.90 (d, J = 8.9 Hz, 1H), 7.45 (d, J = 8.9 Hz, 1H). ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 14.1, 60.7, 94.6, 129.8, 164.5.

Ethyl (*E*)-3-Iodo-2-propenoate ((*E*)-4).[12a] Bp 74−76 °C/9 mmHg. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.29 (t, J = 7.1 Hz, 3H), 4.20 (q, J = 7.1 Hz, 2H), 6.90 (d, J = 14.8 Hz, 1H), 7.87 (d, J = 14.8 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.1, 60.9, 99.1, 136.6, 164.1.

Ethyl (*Z*)-2-Nonen-4-ynoate ((*Z*)-5a). Typical Procedure for the Coupling of Ethyl 3-Iodo-2-propenoate (4) with 1-Alkyne. To a mixture of (*Z*)-**4** (6.780 g, 30 mmol), $PdCl_2(PPh_3)_2$ (210.6 mg, 0.3 mmol), CuI (28.6 mg, 0.15 mmol), and Et_3N (120 mL) was added 1-hexyne (2.711 g, 33 mmol). The mixture was stirred at 50 °C for 15 h. After the mixture cooled to room temperature, ether and H_2O were added, and the aqueous layer was extracted with ether. The combined organic layers were dried ($MgSO_4$). The solvent was evaporated in vacuo. Column chromatography (*n*-hexane/AcOEt 98/2) of the residue gave (*Z*)-**5a** as a pale yellow oil, yield 4.866 g (90%). ^{1}H NMR (270 MHz, $CDCl_3$) δ 0.93 (t, J = 7.3 Hz, 3H), 1.30 (t, J = 7.3 Hz, 3H), 1.33−1.64 (m, 4H), 2.45 (td, J = 6.9, 2.3 Hz, 2H), 4.22 (q, J = 7.3 Hz, 2H), 6.02 (d, J = 11.5 Hz, 1H), 6.15 (dt, J = 11.5, 2.3 Hz, 1H). ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 13.4, 14.1, 19.6, 21.8, 30.2, 60.1, 77.2, 104.0, 123.8, 127.2, 164.7. Anal. Calcd for $C_{11}H_{16}O_2$: C, 73.30; H, 8.95; O, 17.75. Found: C, 73.48; H, 9.18.

Ethyl (*E*)-2-Nonen-4-ynoate ((*E*)-5a).[11g] ^{1}H NMR (270 MHz, $CDCl_3$) δ 0.92 (t, J = 7.3 Hz, 3H), 1.29 (t, J = 7.3 Hz, 3H), 1.36−1.60 (m, 4H), 2.38 (td, J = 6.6, 2.3 Hz, 2H), 4.20 (q, J = 7.3 Hz, 2H), 6.14 (d, J = 15.8 Hz, 1H), 6.75 (dt, J = 15.8, 2.3 Hz, 1H). ^{13}C NMR (67.8 MHz, $CDCl_3$) δ 13.5, 14.1, 19.4, 21.9, 30.3, 60.5, 77.9, 100.7, 126.0, 129.2, 166.1.

Ethyl (*E*)-5-Phenyl-2-buten-4-ynoate ((*E*)-5b).[11g] ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.31 (t, J = 7.1 Hz, 3H), 4.24 (q, J = 7.1 Hz, 2H),), 6.30 (d, J = 15.8 Hz, 1H), 6.98 (d, J = 15.8 Hz, 1H), 7.31−7.38 (m, 3H), 7.44−7.54 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.2, 60.7, 86.3, 98.2, 122.2, 125.0, 128.4, 129.2, 130.0, 131.9, 165.9.

Ethyl (*Z*)-5-Phenyl-2-buten-4-ynoate ((*Z*)-5b). ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.32 (t, J = 7.1 Hz, 3H), 4.26 (q, J = 7.1 Hz, 2H),), 6.12 (d, J = 11.4 Hz, 1H), 6.35 (d, J = 11.4 Hz, 1H), 7.31−7.36 (m, 3H), 7.51−7.55 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.2, 60.3, 86.3, 101.1, 122.6, 122.7, 128.2, 128.3, 129.1, 132.0, 164.7. Anal. Calcd for $C_{13}H_{12}O_2$: C, 77.98; H, 6.04; O, 15.98. Found: C, 77.80; H, 6.09.

Ethyl (*E*)-8-Chloro-2-octen-4-ynoate ((*E*)-5c). ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.29 (t, J = 7.1 Hz, 3H), 2.01 (quintet, J = 6.5 Hz, 2H), 2.58 (td, J = 6.5, 2.3 Hz, 2H), 3.65 (t, J = 6.5 Hz, 2H), 4.21 (q, J = 7.1 Hz, 2H), 6.16 (d, J = 15.8 Hz, 1H), 6.74 (dt, J = 15.8, 2.3 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.2, 17.1, 31.0, 43.4, 60.6, 78.7, 98.1, 125.5, 129.9, 165.9. Anal. Calcd for $C_{10}H_{13}ClO_2$: C, 59.86; H, 6.53; Cl, 17.67; O, 15.95. Found: C, 59.60; H, 6.59; Cl, 17.70.

Ethyl (*Z*)-8-Chloro-2-octen-4-ynoate ((*Z*)-5c). ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.30 (t, J = 7.1 Hz, 3H), 2.05 (quintet, J = 6.5 Hz, 2H), 2.64 (td, J = 6.5, 2.3 Hz, 2H), 3.73 (t, J = 6.5 Hz, 2H), 4.22 (q, J = 7.1 Hz, 2H), 6.05 (d, J = 11.4 Hz, 1H), 6.12 (dt, J = 11.4, 2.3 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.2, 17.4,

(16) Heck, R. F. *Palladium Reagents in Organic Synthesis*; Academic Press: New York, 1985; p 18.

31.0, 43.5, 60.2, 78.5, 101.3, 123.3, 128.1, 164.7. Anal. Calcd for $C_{10}H_{13}ClO_2$: C, 59.86; H, 6.53; Cl, 17.67; O, 15.95. Found: C, 59.57; H, 6.54; Cl, 17.76.

Ethyl (*E*)-5-(1-Cyclohexen-1-yl)-2-penten-4-ynoate ((*E*)-5d).[11g] ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.29 (t, J = 7.1 Hz, 3H), 1.57−1.69 (m, 4H), 2.12−2.17 (m, 4H), 4.21 (q, J = 7.1 Hz, 2H), 6.15 (d, J = 15.8 Hz, 1H), 6.23 (quintet, J = 2.0 Hz, 1H), 6.88 (d, J = 15.8 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.2, 21.3, 22.1, 25.9, 28.7, 60.5, 84.1, 100.6, 120.4, 125.6, 128.9, 137.9, 166.0.

Ethyl (*Z*)-5-(1-Cyclohexen-1-yl)-2-penten-4-ynoate ((*Z*)-5d). ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.31 (t, J = 7.1 Hz, 3H), 1.57−1.69 (m, 4H), 2.12−2.22 (m, 4H), 4.22 (q, J = 7.1 Hz, 2H), 6.02 (d, J = 11.4 Hz, 1H), 6.25 (d, J = 11.4 Hz, 1H), 6.28−6.30 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.2, 21.3, 22.1, 25.9, 28.7, 60.1, 84.2, 103.6, 120.8, 123.3, 126.9, 137.8, 164.8. Anal. Calcd for $C_{13}H_{16}O_2$: C, 76.44; H, 7.90; O, 15.67. Found: C, 76.67; H, 8.05.

(*E*)-2-Nonen-4-yn-1-ol ((*E*)-6a).[5] **Typical Procedure for Reduction of Ethyl 2-Alken-3-ynoate (5).** To 0.95 M diisobutylaluminum hydride in *n*-hexane (91 mL) was added dropwise (*E*)-**5a** (7.750 g, 43 mmol). The mixture was stirred at −78 °C for 2 h. The cooling bath was removed, and the mixture was allowed to warm to room temperature. The mixture was poured into 6 M HCl, and the aqueous layer was extracted with ether. The combined organic layers were dried ($MgSO_4$). The solvent was evaporated in vacuo. Column chromatography (*n*-hexane/AcOEt 90/10) of the residue gave (*E*)-**6a** as a colorless oil, yield 5.527 g (93%). ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.92 (t, J = 7.2 Hz, 3H), 1.41 (sixtet, J = 7.2 Hz, 2H), 1.51 (quintet, J = 7.2 Hz, 2H), 1.97 (br, 1H), 2.30 (td, J = 7.2, 1.8 Hz, 2H), 4.16 (d, J = 5.5 Hz, 2H), 5.71 (dt, J = 15.9, 1.8 Hz, 1H), 6.15 (dt, J = 15.9, 5.5 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.9, 19.4, 22.3, 31.2, 63.3, 78.7, 91.7, 111.7, 140.5.

(*Z*)-2-Nonen-4-yn-1-ol ((*Z*)-6a). ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.92 (t, J = 7.3 Hz, 3H), 1.42 (sixtet, J = 7.3 Hz, 2H), 1.52 (quintet, J = 7.3 Hz, 2H), 2.17 (br, 1H), 2.33 (td, J = 7.3, 2.1 Hz, 2H), 4.37 (d, J = 6.3 Hz, 2H), 5.56 (dt, J = 10.8, 2.1 Hz, 1H), 5.99 (dt, J = 10.8, 6.3 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.5, 19.1, 21.9, 30.7, 60.8, 76.2, 96.6, 111.0, 139.9. Anal. Calcd for $C_9H_{14}O$: C, 78.21; H, 10.21; O, 11.58. Found: C, 78.09; H, 10.41.

(*E*)-5-Phenyl-2-penten-4-yn-1-ol ((*E*)-6b). ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.03 (br, 1H), 4.22 (dd, J = 5.2, 1.8 Hz, 2H), 5.96 (dt, J = 15.9, 1.8 Hz, 1H), 6.32 (dt, J = 15.9, 5.2 Hz, 1H), 7.26−7.30 (m, 3H), 7.40−7.44 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 62.7, 87.3, 90.0, 110.3, 123.1, 128.1, 128.2, 131.4, 141.8. Anal. Calcd for $C_{11}H_{10}O$: C, 83.51; H, 6.37; O, 10.11. Found: C, 83.50; H, 6.37.

(*Z*)-5-Phenyl-2-penten-4-yn-1-ol ((*Z*)-6b). ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.31 (br, 1H), 4.48 (d, J = 6.4 Hz, 2H), 5.78 (dt, J = 10.9, 1.4 Hz, 1H), 6.12 (dt, J = 10.9, 6.4 Hz, 1H), 7.28−7.32 (m, 3H), 7.40−7.44 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 60.9, 85.0, 95.2, 110.5, 122.9, 128.3, 128.4, 131.4, 141.3. Anal. Calcd for $C_{11}H_{10}O$: C, 83.51; H, 6.37; O, 10.11. Found: C, 83.27; H, 6.50.

(*E*)-8-Chloro-2-octen-4-yn-1-ol ((*E*)-6c). ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.98 (quintet, J = 6.6 Hz, 2H), 2.33 (br, 1H), 2.50 (td, J = 6.6, 2.0 Hz, 2H), 3.65 (t, J = 6.6 Hz, 2H), 4.16 (dd, J = 5.6, 2.0 Hz, 2H), 5.70 (dquintet, J = 15.9, 2.0 Hz, 1H), 6.16 (dt, J = 15.9, 5.6 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 16.7, 31.3, 43.6, 62.7, 79.2, 88.8, 110.6, 140.8. Anal. Calcd for $C_8H_{11}ClO$: C, 60.57; H, 6.99; Cl, 22.35; O, 10.09. Found: C, 60.29; H, 7.08; Cl, 22.33.

(*Z*)-8-Chloro-2-octen-4-yn-1-ol ((*Z*)-6c). ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.69 (br 1H), 2.00 (quintet, J = 6.8 Hz, 2H), 2.54 (td, J = 6.8, 2.2 Hz, 2H), 3.66 (t, J = 6.8 Hz, 2H), 4.38 (dd, J = 6.4, 1.3 Hz, 2H), 5.57 (dt, J = 10.8, 1.3 Hz, 1H), 6.03 (dt, J =10.8, 6.4 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 16.9, 31.3, 43.6, 60.8, 76.7, 94.3, 110.9, 140.5. Anal. Calcd for $C_8H_{11}ClO$: C, 60.57; H, 6.99; Cl, 22.35; O, 10.09. Found: C, 60.14; H, 6.78; Cl, 22.22.

(*E*)-5-(1-Cyclohexen-1-yl)-2-penten-4-yn-1-ol ((*E*)-6d). ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.55−1.67 (m, 4H), 2.10−2.15 (m, 4H), 2.22 (br, 1H), 4.18 (dd, J = 5.4, 1.7 Hz, 2H), 5.84 (d, J = 15.9 Hz, 1H), 6.10 (quintet, J = 2.0 Hz, 1H), 6.18 (dt, J = 15.9, 5.4 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.4, 22.2, 25.6, 29.0, 62.8, 84.6, 92.0, 110.9, 120.6, 135.0, 140.5. Anal. Calcd for $C_{11}H_{14}O$: C, 81.44; H, 8.70; O, 9.86. Found: C, 81.19; H, 8.72.

(*Z*)-5-(1-Cyclohexen-1-yl)-2-penten-4-yn-1-ol ((*Z*)-6d). ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.56−1.68 (m, 4H), 2.11−2.16 (m, 5H), 4.39 (dd, J = 6.4, 1.3 Hz, 2H), 5.69 (d, J = 10.8 Hz, 1H), 6.02 (dt, J = 10.8, 6.4 Hz, 1H), 6.12 (quintet, J = 2.0 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.7, 22.5, 26.0, 29.4, 61.2, 82.7, 97.6, 111.1, 120.9, 135.6, 140.4. Anal. Calcd for $C_{11}H_{14}O$: C, 81.44; H, 8.70; O, 9.86. Found: C, 81.15; H, 8.63.

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