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$TiCl_4$-Mediated Nucleophilic Substitution of Propargylic Esters

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Abstract—Direct displacement reactions of propargylic esters are reported. 10 mol% of $TiCl_4$ were used to carry out a nucleophilic substitution. Scope and limitation of this novel reaction are described.

Introduction

The reaction of a metal–carbonyl-complexed triple bond system with nucleophiles represents one of the best known methods for nucleophilic displacement of propargylic systems.[1] The nucleophilic substitution of $Co_2(CO)_8$-complexed propargylic compounds has been named the Nicholas reaction.[2] Recently, Müller et al. have reported the stereoselective substitution of arene–$Cr(CO)_3$-complexed propargylic compounds.[3] Stoichiometric amounts of metal-complexed propargylic esters are required for a complete conversion in both reactions. We have previously described a nucleophilic displacement reaction of propargylic esters in the presence of catalytic amounts of $TiCl_4$.[4] Here we describe our results of the scope and limitation of this novel reaction.

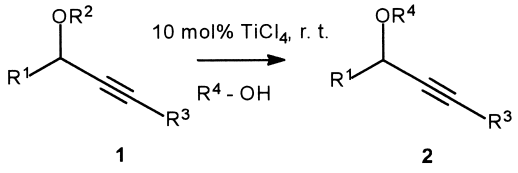
Results and Discussion

Propargylic esters were easily substituted by alcohols in the presence of Lewis acids. Highest yields were obtained by using catalytic amounts of $TiCl_4$ (Scheme 1).

All reactions were carried out at room temperature and the alcohol served in addition as solvent. No significant differences in yields were obtained when propargylic acetates or carbonates were used in displacement reactions for the substrates given in Table 1 (R^2–$COCH_3$ or –COO*i*Bu).

The choice of substituent R^1 is crucial. High yields were obtained with stabilizing substituents (R^1 — phenyl, thiophenyl), whereas no displacement reactions are observed by using alkyl propargylic esters (R^1 — *t*Bu, *n*Pr, entries 13, 14 in Table 1).

In order to determine the scope and limitation of this reaction and to overcome the inflexible diphenylsubstituted propargylic pattern, other stabilizing substituents for R^1 and R^3 were evaluated (Schemes 2 and 3). It was found that



1 **2**

	R^1	R^2	R^3
1a	Ph	Ac	Ph
1b	Ph	*i*Boc	Ph
1c	Ph	Ac	*n*Bu
1d	Ph	*i*Boc	*n*Bu

Scheme 1.

Table 1. Nucleophilic substitution of propargylic esters **1** with different alcohols

Entry	Compound	R^1	R^2	R^3	R^4	Yield (%)
1	**2a**[5]	Ph	Ac	Ph	Me	95
2	**2a**	Ph	*i*Boc	Ph	Me	94
3	**2b**[6]	Ph	Ac	Ph	Et	65
4	**2c**	Ph	Ac	Ph	*i*Pr	59
5	**2d**	Ph	Ac	Ph	*t*Bu	55
6	**2e**	Ph	Ac	Ph	Bn	67
7	**2f**[7]	Ph	Ac	*n*Bu	Me	76
8	**2g**[6]	Ph	Ac	*n*Bu	Et	68
9	**2h**	Ph	Ac	*n*Bu	*i*Pr	42
10	**2i**	Ph	Ac	*n*Bu	Ph	45
11	**2j**	X[a]	Ac	Ph	Me	68
12	**2k**	*n*Pr	Ac	Ph	Me	–
13	**2l**	*t*Bu	Ac	*t*Bu	Me	–
14	**2m**	*n*Pr	Ac	Ph	Me	38[b]

[a] X=thiophenyl.
[b] 10 mol% of Me_3SiOTf was used instead of $TiCl_4$.

Keywords: alkynes; substitution; ethers; catalysis.
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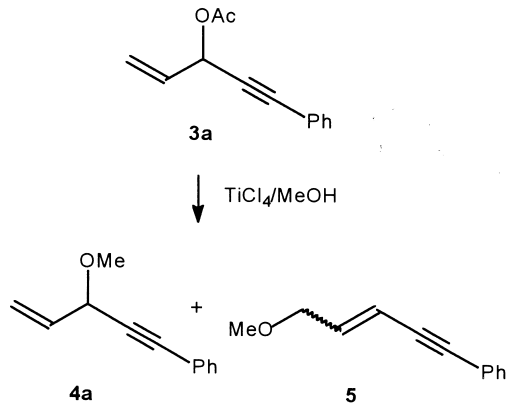


Scheme 2.

allylic substituted propargylic esters in the presence of 10 mol% $TiCl_4$ also underwent this novel displacement reaction with an allylic rearrangement. The *E*- and *Z*-configurated isomers of methyl ether **5** were isolated in 25% yield (***E*-5**:***Z*-5**/5:1; Scheme 2), whereas the methyl ether **4a** was found in 23% yield by using acetate **3a**[12] in this reaction.

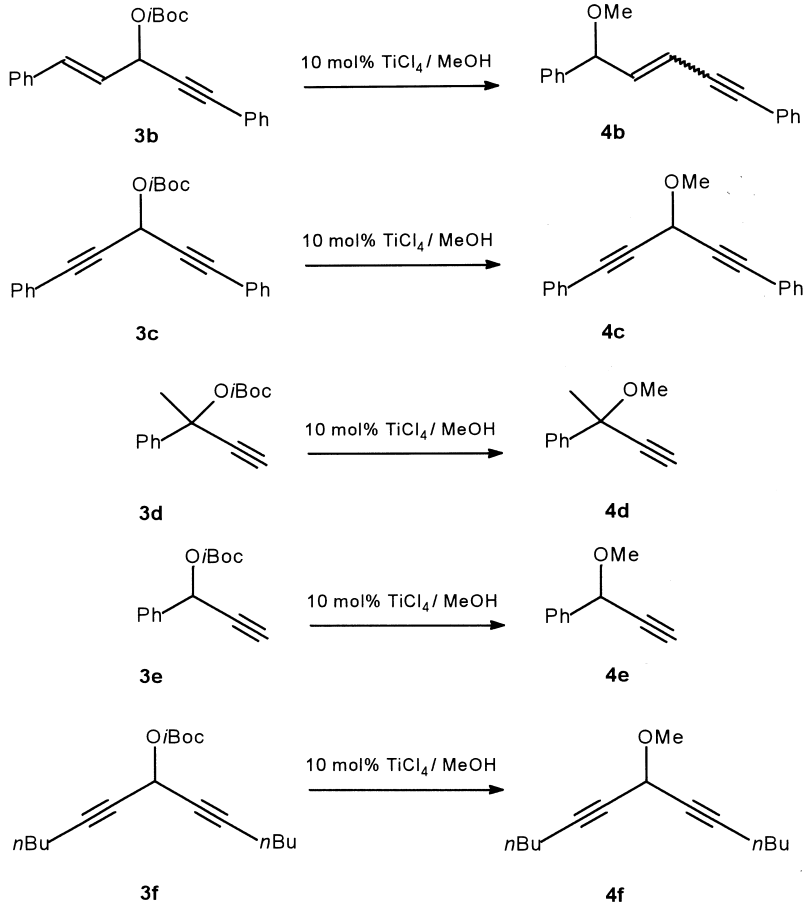
By the use of other cationic stabilizing substrates, one can observe great differences in yields with acetates or carbonates as leaving groups (Scheme 3). In reactions of propargylic acetates, low yields of substitution products were observed. In contrast, high yields were obtained by using the carbonates **3b**–**3f**. For example, methyl ether **4c** was obtained in 90% yield using carbonate **3c**. In displacement reactions using the corresponding acetate, methyl ether **4c** is only isolated in 18% yield. The methyl ethers **4b**–**4f** were obtained in almost quantitative yields. These differences are in contrast to the results given in Table 1.

Cationic transition states play an important role in this novel reaction, as seen by results obtained after reacting substrates with cation-stabilizing substituents. High yields were obtained when R^1 is Ph or thiophenyl (entries 1–11, Table 1). Substitution is not observed when using substrates with alkyl substituents (entries 12, 13, Table 1, R^1 — *n*Pr or *t*Bu).

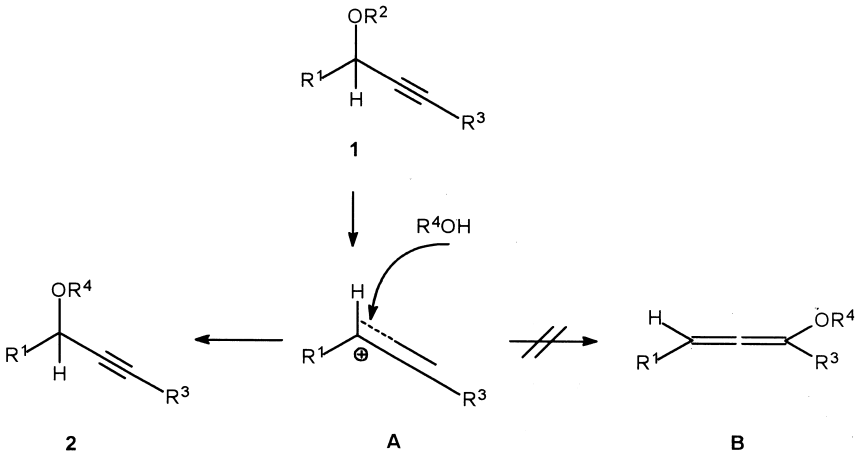
Assuming an irreversible $TiCl_4$-mediated extrusion of the leaving group (acetate or carbonate), a propargylic cation intermediate **A** is formed. Substances derived from the formation of the corresponding allenic system[8] or from rearrangement[9] could not be detected (Scheme 4). We continue our investigations in order to get more insight into the mechanism and to present enantioselective procedures.

Experimental

^1H NMR and ^{13}C NMR spectra were recorded at 300 and 75 MHz, respectively using a AC-300 spectrometer. MS:



Scheme 3.



Scheme 4.

HP 5995 (Hewlett–Packard) spectrometer (70 eV). HRMS: MAT 959 T.

All reactions were carried out under an argon atmosphere in glassware which had been flame-dried under a stream of argon. Solvents were dried and distilled prior to use.

General procedure for the synthesis of propargylic esters

One equivalent of the corresponding acetylene (30 mmol) is dissolved in abs. THF (20.0 ml). The solution was cooled to −78°C and 19 ml (1.01 equiv.) of *n*BuLi (1.6 mol in hexane) is slowly added. One equivalent of the corresponding aldehyde (30 mmol) is added at this temperature and the mixture is allowed stirring and warming up to room temperature overnight. The reaction mixture was poured into aq. saturated NH_4Cl-solution and extracted with 200 ml diethyl ether, dried (Na_2SO_4), filtered and evaporated in vacuum.

The obtained crude products were directly converted into the corresponding actetates (DMAP, pyridine, acetic anhydride) or into the corresponding carbonates (pyridine, chloroformate). The propargylic esters were purified by column chromatography and isolated as oils.

General procedure for the synthesis of 1,4-pentadiynyl esters 3c and 3f

Half equivalent of formic acid methyl ester (10 mmol) is treated with one equivalent of the corresponding lithiated acetylenes (20 mmol). The obtained 1.4-diyn-3-ols were purified by column chromatography.

(1,3-Diphenyl-prop-2-ynyl)-acetate (1a).[10] Yield: 6.77 g (90%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.10–7.60 (m, 10H), 6.62 (s, 1H), 2.04 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 169.88, 137.19, 131.94, 128.98, 128.84, 128.72, 128.30, 127.84, 122.11, 87.07, 85.60, 66.11, 21.16.

(1,3-Diphenyl-prop-2-ynyl)-*i*butylcarbonate (1b). Yield: 8.97 g (97%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.10–7.60 (m, 10H), 6.45 (s, 1H), 3.86 (m, 2H), 1.86 (m, 1H), 0.84 (d, J=7 Hz, 6H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 154.55, 136.69, 131.93, 129.21, 128.90, 128.74, 128.55, 127.89, 122.04, 87.99, 85.06, 74.56, 70.02, 27.81, 18.92. Anal. calcd for $C_{20}H_{20}O_3$: C 77.90; H 6.54, Found: C, 77.45; H, 6.72.

(1-Phenyl-hept-2-ynyl)-acetate (1c).[11] Yield: 5.91 g (86%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.52–7.35 (m, 5H), 6.46 (t, J=2.0 Hz, 1H), 2.27 (dt, J=7.0, 2,0 Hz, 2H), 2.05 (s, 3H), 1.30–1.60 (m, 4H), 0.90 (t, J=7.0 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 169.88, 137.71, 128.72, 128.54, 127.70, 126.53, 88.35, 76.64, 66.06, 30.49, 21.96, 21.17, 18.53, 13.57.

(1-Phenyl-hept-2-ynyl)-*i*butylcarbonate (1d). Yield: 7.39 g (86%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.20–7.60 (m, 5H), 6.22 (t, J=2 Hz, 1H), 1.87 (d, J=7.0 Hz), 1.85 (d, J=7.0 Hz, 2H), 2.20 (dt, J=7.0, 2.0 Hz, 2H), 1.89 (spt, J=7.0 Hz, 1H), 1.20–1.50 (m, 5H), 0.87 (tr, J=7.0 Hz, 3H), 0.86 (d, 3H, J=7 Hz), 0.82 (d, 3H, J=7 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 154.56, 137.18, 128.93, 128.55, 127.76, 89.35, 76.21, 74.35, 69.98, 30.40, 27.77, 21.92, 18.91, 18.54, 13.55. Anal. calcd for $C_{18}H_{24}O_3$: C 74.97; H 8.39. Found: C, 75.00; H, 8.43.

(1-Vinyl-3-phenyl-prop-2-ynyl)-acetate (3a).[12] Yield: 2.87 g (48%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.20–7.40 (m, 5H), 6.05 (d, J=6.0 Hz, 1H), 5.90 (ddd, J=17.0, 10.0, 6.0 Hz, 1H), 5.54 (brd, J=17.0 Hz, 1H), 5.28 (brd, J=10.0 Hz, 1H), 2.05 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 169.74, 132.97, 131.92, 128.85, 128.56, 122.03, 119.03, 86.94, 84.23, 64.83, 21.07. Anal. calcd for $C_{13}H_{12}O_2$: C, 77.98; H 6.07. Found: C, 77.76; H, 6.29.

3-(*E*)-(1,5-Diphenyl-pent-1-en-4-ynyl)-*i*butylcarbonate (3b). Yield: 1.86 g (20%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.10–7.40 (m, 10H), 6.28 (dd, 1H, J=16, 6 Hz), 6.08 (dd, 1H, J=6, 1.5 Hz), 5.92 (dd, 1H, J=16, 1.5 Hz), 3.95 (m, 2H), 1.90 (m, 1H), 0.87 (d, 6H, J=7 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 154.51, 139.70, 137.72, 128.38, 128.34, 127.14, 122.96, 112.83, 111.93, 86.77, 84.90, 79.05, 74.35, 27.78, 18.91. HRMS: *m*/*z* calcd for $C_{17}H_{13}O$ 233.0966. Found: 233.0955.

[(1-Phenylethynyl-3-phenyl)-prop-2-ynyl]-*i*butylcarbo-

nate (3c). Yield: 2.22 g (67%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.20–7.50 (m, 10H), 6.32 (s, 1H), 3.93 (d, 2H, J=7 Hz), 1.94 (m, 1H), 0.89 (d, 6H, J=7 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 154.00, 132.08, 129.16, 128.31, 121.56, 86.00, 82.30, 74.86, 57.98, 27.81, 18.89. HRMS: *m*/*z* calcd for $C_{17}H_{11}O$ 231.0810. Found: 231.0815.

1-[(1-Phenyl-1-methyl)-prop-2-ynyl]-*i*butylcarbonate (3d). Yield: 1.51 g (20%, from the commercial available alcohol). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.20–7.60 (m, 5H), 3.90 (d, 2H, J=7 Hz), 2.90 (s, 1H), 2.90 (m, 3H), 0.95 (d, 3H, J=7 Hz), 0.94 (d, 6H, J=7 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 152.81, 141.63, 128.43, 128.19, 124.86, 82.53, 77.41, 76.03, 73.95, 32.28, 27.73, 18.85. HRMS: *m*/*z* calcd for $C_{10}H_9O$ 145.0653. Found: 145.0651.

1-(1-Phenyl-prop-2-ynyl)-*i*butylcarbonate (3e). Yield: 6.12 g (88%, from the commercial available alcohol). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.10–7.40 (m, 5H), 6.14 (d, 1H, J=2 Hz), 3.81 (m, 2H), 2.58 (d, 1H, J=2 Hz), 1.80 (spt, 1H, 7 Hz), 0.80 (d, 3H, J=7 Hz), 0.79 (d, 3H, J=7 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 154.40, 135.91, 129.31, 128.73, 127.75, 79.71, 76.35, 74.59, 69.09, 27.75, 18.87. HRMS: *m*/*z* calcd for C_9H_7O 131.0497. Found: 131.0495.

[1-(Hex-1-ynyl)-hept-2-ynyl]-*i*butylcarbonate (3f). Yield: 1.03 g (35%). ^{1}H NMR δ 5.82 (q, 1H, J=2 Hz), 3.89 (d, 2H, J=7 Hz), 2.15 (trd, 4H, J=7, 2 Hz), 1.91 (hpt, 1H, J=7 Hz), 1.15–1.5 (m, 8H), 0.89 (d, 6H, J=7 Hz), 0.83 (t, 6H, J=7 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 154.02, 86.84, 74.27, 74.48, 57.73, 30.17, 27.76, 21.86, 18.84, 18.41, 13.53. HRMS: *m*/*z* calcd for $C_{13}H_{19}O$ 191.1436. Found: 191.1435.

General procedure for the $TiCl_4$-mediated displacement reaction

$TiCl_4$ (42 mg, 0.22 mmol) was carefully added to a stirred solution of the corresponding propargylic ester (2.2 mmol) in the corresponding abs. alcohols (5.0 mL). The reaction mixture was stirred for 24 h at rt. The solution was poured into aqu. $NaHCO_3$ solution and extracted several times with diethyl ether. The organic layers were separated, dried (Na_2SO_4), concentrated in vacuum and purified by chromatography. Compounds **2a**–**2m** were isolated as oils. The yields are given in Table 1.

Methyl-(1,3-diphenyl-prop-2-ynyl)-ether (2a).[5] ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.20–7.60 (m, 10H), 5.23 (s, 1H), 3.41 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 138.54, 131.82, 128.56, 128.49, 128.32, 127.54, 122.57, 87.78, 73.53, 55.94.

Ethyl-(1,3-diphenyl-prop-2-ynyl)-ether (2b).[6] ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.05–7.20 (m, 10H), 5.30 (s, 1H), 3.66 (q, 2H), 1.19 (tr, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 138.99, 131.80, 128.52, 128.47, 128.34, 128.28, 127.48, 122.66, 87.32, 71.92, 67.95, 63.94, 15.24.

***i*Propyl-(1,3-diphenyl-prop-2-ynyl)-ether (2c).** ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.20–7.53 (m, 10H), 5.35 (s, 1H), 3.98 (spt,1H, J=6 Hz), 1.21 (d, 3H, J=6 Hz), 1.18 (d, 3H, J=6 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 139.6, 131.8, 128.5, 128.4, 127.4, 122.8, 88.1, 86.6, 69.8, 69.4, 22.9, 21.8. MS: *m*/*z* (relative intensity) 250 (0.05, [M^+]), 207 (0.26), 192 (48%); 191 (1), 189 (0.31), 179 (0.33), 129 (0.39), 105 (0.32), 77 (0.32), 43 (0.25). HRMS: *m*/*z* calcd for $C_{18}H_{18}O$ 251.1436. Found: 251.1427.

***t*Butyl-(1,3-diphenyl-prop-2-ynyl)-ether (2d).** ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.20–7.60 (m, 10H), 5.41 (s, 1H); 1.31 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 140.91, 131.62, 128.47, 128.23, 128.21, 127.81, 127.04, 123.21, 90.68, 85.81, 75.72, 64.63, 28.51. MS: *m*/*z* (relative intensity) 208 (0.13), 191 (0.39), 105 (1), 77 (0.61), 51 (0.25). HRMS: *m*/*z* calcd for $C_{19}H_{20}O$ 264.1514. Found 264.1505.

Benzyl-(1,3-diphenyl-prop-2-ynyl)-ether (2e). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.49–7.88 (m, 15H), 5.70 (s, 1H), 5.04 (d, 1H, J=11.7 Hz), 4.97 (d, 1H, J=11.7 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 138.94, 138.08, 132.01, 128.81, 128.74, 128.62, 128.53, 128.31, 128.04, 127.81, 122.81, 88.12, 87.22, 71.21, 70.36. MS: *m*/*z* (relative intensity) 212 (0.11), 191 (0.05), 121 (0.1), 104 (1), 91 (0.6), 77 (0.8), 65 (0.2), 51 (0.43), 39 (0.15). HRMS: *m*/*z* calcd for $C_{22}H_{18}O$ 298.1358. Found 298.1348.

Methyl-(1-phenyl-hept-2-ynyl)-ether (2f).[7] ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.20–7.60 (m, 5H), 5.07 (tr, 1H, J=2 Hz), 3.40 (s, 3H), 2.29 (dtr, 2H, J=7, 2 Hz), 1.30–1.55 (m, 4H), 0.84 (tr, 3H, J=7 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 139.11, 128.41, 128.28, 127.43, 88.77, 77.52, 73.21, 55.63, 30.75, 22.02, 18.51, 13.62.

Ethyl-(1-phenyl-hept-2-ynyl)-ether (2g).[6] ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.10–8.10 (m, 5H), 5.04 (1H); m 3.60 (s, 1H); 3.40 (m, 1H), 2.17 (tr, 2H), 1.30–1.50 (m, 4H), 1.14 (tr, 3H), 0.83 (tr, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 139.62, 128.37, 128.07, 127.38, 88.12, 78.19, 71.65, 63.54, 30.75, 22.00, 18.58, 15.20, 13.60.

***i*Propyl-(1-phenyl-hept-2-ynyl)-ether (2h).** ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.14–7.39 (m, 5H), 5.07 (s, 1H), 3.85 (q, 1H, J=6.0 Hz), 2.13 (tr, 2H, J=7.2 Hz), 1.22–1.47 (m, 4H), 1.11 (d, 3H, J=6.4 Hz), 1.07 (d, 3H, J=6 Hz), 0.78 (t, 3H, J=7.2 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 140.33, 128.38, 127.91, 127.34, 87.42, 78.91, 69.21, 69.14, 30.76, 21.91, 22.82, 21.71, 18.62, 13.61. MS: *m*/*z* (relative intensity) 231 (0.03, [M+1]), 230 (0.13, [M^+]), 187 (0.14), 171 (0.2), 145 (0.22), 129 (0.51), 115 (0.38), 105 (1), 91 (0.58), 77 (0.61), 57 (0.50), 43 (0.51). HRMS: *m*/*z* calcd for $C_{16}H_{22}O$ 230.1671. Found 230.1672.

Phenyl-(1-phenyl-hept-2-ynyl)-ether (2i). ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.33–7.56 (m, 10H), 5.09 (s, 1H), 2.45 (tr, 2H, J=6 Hz), 1.45–1.64 (m, 4H), 1.09 (tr, 3H, J=7.2 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 155.42, 135.02, 129.81, 129.24, 128.63, 127.91, 126.72, 120.28, 115.56, 85.33, 81.11, 42.61, 31.21, 21.13, 18.72, 13.76. MS: *m*/*z* (relative intensity) 264 (0.15), 221 (0.2), 207 (0.1), 183 (0.1), 95 (0.2), 94 (1), 66 (0.65), 65 (0.6). HRMS: *m*/*z* calcd for $C_{19}H_{20}O$ 264.1514. Found 264.1518.

Methyl-[1-(1-thiophen-2-yl)-hept-2-ynyl]-ether (2j). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.39–7.45 (m, 2H), 7.22–7.28 (m, 4H), 7.16 (ddd, 1H, J=3–4, 1, 1 Hz), 6.92 (dd, 1H, J=5,

3–4 Hz), 5.50 (d, 1H, *J*=1 Hz), 3.41 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 142.12, 131.91, 128.71, 128.43, 126.62, 126.43, 125.91, 122.38, 87.28, 85.93, 68.61, 55.31. MS: *m/z* (relative intensity) 228 (0.16, [M^+]), 213 (0.15), 197 (1), 152 (0.36), 129 (0.6), 111 (0.41), 63 (0.33), 51 (0.31), 45 (0.63), 39 (0.65), 29 (0.32), 15 (0.40). HRMS: calcd for $C_{14}H_{12}OS$ 228.0609. Found 228.0602.

Methyl-[(1-npropyl-3-phenyl)-prop-2-ynyl]-ether (2m). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.40 (m, 2H), 7.20 (m, 3H), 3.40 (tr, 1H, *J*=6–7 Hz), 4.10 (s, 3H), 1.70 (m, 2H), 1.50 (sxt, 2H, *J*=7.8 Hz), 0.90 (tr, 3H, *J*=7.8 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 131.71, 128.21, 122.93, 88.28, 85.85, 71.51, 56.53, 37.81, 18.61, 13.96. MS: *m/z* (relative intensity) 188 (0.05, [M^+]), 157 (0.04), 145 (1), 129 (0.19), 115 (0.34), 102 (0.14), 91 (0.17), 77 (0.13).

Methyl-[(1-vinyl-3-phenyl)-prop-2-ynyl]-ether (4a). Yield: 89 mg (23%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.40 (m, 2H), 7.20 (m, 3H), 5.88 (ddd, 1H, *J*=17, 10, 6 Hz), 5.46 (ddd, 1H, *J*=17, 1, 1 Hz), 5.23 (ddd, 1H, *J*=10, 1, 1 Hz), 4.65 (ddd, 1H, *J*=6, 1, 1 Hz), 3.36 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 134.94, 131.78, 128.52, 128.29, 122.51, 118.07, 87.44, 85.66, 72.09, 55.65. MS: *m/z* (relative intensity) 172 (0.15), 129 (1), 114 (0.1), 105 (0.1), 75 (0.15), 51 (0.1). HRMS: calcd for $C_{12}H_{12}O$ 172.0888. Found 172.0890.

Methyl-(1,5-diphenyl-pent-2-en-4-ynyl)-ether (4b). 371 mg (68% yield) were obtained as a 1:1 mixture of ***E*-4b** and ***Z*-4b**.

(*Z*)-Methyl-(1,5-diphenyl-pent-2-en-4-ynyl)-ether (*Z*-4b). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.10–7.50 (m, 10H), 5.97 (dd, 1H, *J*=11, 9 Hz), 5.97 (dd, 1H, *J*=11, 9 Hz), 5.80 (d, 1H, *J*=11 Hz), 5.29 (d, 1H, *J*=9 Hz), 3.26 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 143.20, 140.86, 131.54, 128.65, 128.46, 128.33, 126.97, 124.41, 123.23, 111.18, 90.49, 87.38, 80.89, 56.63, 56.57. MS: *m/z* (relative intensity) 248 (0.6, [M^+]), 233 (1), 202 (0.4), 131 (0.3), 122 (0.3), 115 (0.3), 105 (0.9), 77 (0.8), 51 (0.3). HR: calcd for $C_{18}H_{16}O$ 248.1201. Found 248.1208.

(*E*)-Methyl-(1,5-diphenyl-pent-2-en-4-ynyl)-ether (*E*-4b). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.10–7.50 (m, 10H), 6.19 (dd, 1H, *J*=16, 6 Hz), 5.88 (dd, 1H, *J*=16, 1 Hz), 5.62 (dd, *J*=6, 1 Hz), 3.33 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 142.91, 140.86, 131.54, 128.60, 128.52, 128.25, 128.01, 127.78, 123.17, 111.06, 95.01, 85.38, 83.62, 56.57.

Methyl-[(1-phenylethynyl-3-phenyl)-prop-2-ynyl]-ether (4c). Yield: 490 mg (90%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.20–7.40 (m, 10H), 5.32 (s, 1H), 3.49 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 133.77, 131.96, 130.21, 128.84, 128.49, 128.32, 122.05, 85.49, 83.89, 60.90, 54.83. MS: *m/z* (relative intensity) 245 (0.2), 218 (0.3), 217 (0.6), 213 (0.4), 202 (1), 105 (0.2), 77 (0.2). HRMS: *m/z* calcd for $C_{14}H_{13}O$ (M−1) 245.0966. Found 245.0967.

Methyl-[(1-phenyl-1-methyl)-prop-2-ynyl]-ether (4d).[13] Yield: 337 mg (96%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.10–7.50 (m, 5H), 3.14 (s, 3H), 2.65 (s, 1H), 1.66 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 142.10, 128.29, 127.85, 125.94, 83.67, 76.38, 75.47, 52.48, 32.56.

Methyl-(1-phenyl-prop-2-ynyl)-ether (4e).[14] Yield: 118 mg (38%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.20–7.50 (m, 5H), 5.00 (d, 1H, *J*=2 Hz), 3.36 (s, 3H), 2.57 (d, 1H, *J*=2 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 137.96, 128.67, 128.54, 127.35, 81.27, 75.80, 72.78, 55.91

Methyl-[(1-hex-1-ynyl)-hept-2-ynyl]-ether (4f). Yield: 285 mg (63%). ^{1}H NMR (300 MHz, $CDCl_3$) δ 4.82 (tr, 1H, *J*=2 Hz), 3.33 (s, 3H), 2.20 (trd, 4H, *J*=7, 2 Hz), 1.40 (m, 8H), 0.84 (tr, 6H, *J*=7 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 85.85, 75.65, 60.22, 54.27, 30.44, 21.89, 18.38, 13.52. MS: *m/z* (relative intensity) 205 (0.05, [M^+]), 191 (0.3), 135 (0.2), 122 (0.2), 121 (0.35), 115 (0.4), 105 (0.4), 91 (1), 85 (0.4), 79 (0.4), 77 (0.6), 57 (0.4). HRMS: *m/z* calcd for $C_{14}H_{21}O$ (M−1) 205.1592. Found 205.1589.

Methyl-(5-phenyl-pent-2-en-4-ynyl)-ether (5). 96 mg (25% yield) were obtained as a 5:1 mixture of ***E*-5** and ***Z*-5**.

(*E*)-Methyl-(5-phenyl-pent-2-en-4-ynyl)-ether (*E*-5). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.30–7.40 (m, 2H), 7.10–7.25 (m, 3H), 6.16 (dt, 1H, *J*=16, 6 Hz), 5.85 (dt, 1H, *J*=16, 2 Hz), 3.91 (dd, 2H, *J*=6, 2 Hz), s 3.26; ^{13}C NMR (75 MHz, $CDCl_3$) δ 139.35, 131.53, 128.36, 128.24, 123.24, 111.75, 105.76, 90.03, 87.39, 72.26, 58.17.

(*Z*)-Methyl-(5-phenyl-pent-2-en-4-ynyl)-ether (*Z*-5). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.10–7.40 (m, 5H), 5.98 (dtr, 1H, *J*=11, 6 Hz), 5.76 (dtr, 1H, *J*=6, 1.5 Hz), 4.2 (dd, 2H, *J*=6, 1.5 Hz), 3.29 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) 139.35, 131.45, 128.22, 122.89, 111.67, 104.86, 95.22, 85.16, 70.23, 55.60. MS: *m/z* (relative intensity) 172 (0.15), 171 (0.2), 156 (0.6), 129 (0.9), 102 (1), 77 (0.4), 51 (0.3). HRMS: *m/z* calcd for $C_{13}H_{14}O$ ($C_{12}H_{12}O+CH_2$) 186.1045. Found 186.1045.

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References

1. Altenbach, H. J. In *Comprehensive Organic Synthesis*; Trost, B. M., Ed.; Pergamon: Oxford, 1991; Vol. 6, pp 829–871 and references cited therein; Tsuji, J.; Mandai, T. *Angew. Chem., Int. Ed. Engl.* **1995**, *34*, 2830–2854; see also Tsuji, J. *Palladium Reagents and Catalysts*; Wiley: New York, 1995; Malleron, J.-L.; Fiaud, J.-C.; Legros, J.-Y. *Handbook of Palladium-Catalyzed Organic Reactions*; Academic: New York, 1997; Brinkmeyer, R. S.; Macdonald, T. L. *J. Chem. Soc., Chem. Commun.* **1978**, 876–877; Macdonald, T. L.; Reagan, D. R. *J. Org. Chem.* **1980**, *45*, 4740–4747.

2. For a review of this reaction and references cited in see Nicholas, K. M. *Acc. Chem. Res.* **1987**, *20*, 207–214. For theoretical investigations of this reaction see Schreiber, S. L.; Klimas, M. T.; Sammakia, T. *J. Am. Chem. Soc.* **1987**, *109*, 5749–5759.

3. Müller, T. J. J.; Netz, A. *Tetrahedron Lett.* **1999**, 3145–3148; Müller, T. J. J.; Ansorge, M.; Polborn, K. *J. Organomet. Chem.*

1999, *578*, 252–259; Müller, T. J. J.; Netz, A. *Organometallics* **1998**, *17*, 3609.
4. Bartels, A.; Mahrwald, R.; Quint, S. *Tetrahedron Lett.* **1999**, *40*, 5989–5990.
5. Bhatt, R. K.; Shin, D.-S.; Falck, J. R. *Tetrahedron Lett.* **1992**, *33*, 4885–4888; Hayashi, M.; Inubushi, A.; Mukaiyama, T. *Bull. Soc. Chem. Jpn* **1988**, *61*, 4037–4042.
6. Mantione, R. *Bull. Soc. Chim. Fr.* **1969**, 4514–4552.
7. Shi, M.; Shouki, K.; Okamoto, Y.; Takamuku, S. *J. Chem. Soc., Perkin Trans. 1* **1990**, 2443–2450.
8. Saucy, G.; Marbet, R.; Lindlar, H.; Isler, O. *Helv. Chim. Acta* **1959**, *42*, 1945–1952; Benn, W. R. *J. Org. Chem.* **1968**, *33*, 3113–3118; Schlossarczyk, H.; Sieber, W.; Hesse, M.; Hannsen, H.-J.; Schmid, H. *Helv. Chim. Acta* **1973**, *56*, 875–944; Denmark, S. E. In *Comprehensive Organic Synthesis*; Paquette, L. A., Ed.; Pergamon, Oxford, 1991; Vol. 5, p. 768.
9. Mahrwald, R.; Schick, H. *Angew. Chem., Int. Ed. Engl.* **1991**, *30*, 593–594.
10. Tabuchi, T.; Inanaga, J.; Yamaguchi, M. *Chem. Lett.* **1987**, 2275–2278.
11. Baldwin, J. E.; Benett, A. R.; Forrest, A. *J. Chem. Soc., Chem. Commun.* **1987**, 250–251.
12. Burgess, K.; Jennings, L. D. *J. Am. Chem. Soc.* **1991**, 6129–6139.
13. Frey, H.; Kaupp, G. *Synthesis* **1990**, 931–934.
14. Padwa, A.; Austin, D.; Gareau, Y.; Kassir, J. M.; Xu, S. *J. Am. Chem. Soc.* **1993**, 2637–2647.