Pergamon

Tetrahedron 57 (2001) 549–554

TETRAHEDRON

A stereoselective synthesis of silylated polyunsaturated halides from α,β-epoxysilanes

Francesco Babudri, Vito Fiandanese,* Giuseppe Marchese and Angela Punzi

Centro CNR di Studio sulle Metodologie Innovative di Sintesi Organiche, Dipartimento di Chimica, Università di Bari, via Amendola 173, 70126 Bari, Italy

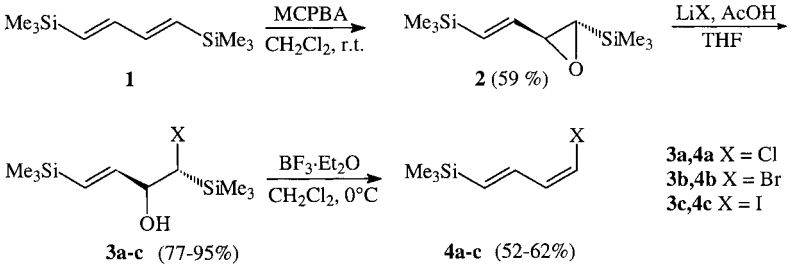
Received 4 August 2000; revised 29 September 2000; accepted 19 October 2000

Abstract—A new synthetic approach to silylated polyunsaturated halides has been developed, starting from the readily available (1*E*,3*E*)-1,4-bis(trimethylsilyl)-1,3-butadiene and (3*E*)-1,4-bis(trimethylsilyl)-3-buten-1-yne. A simple epoxidation reaction, followed by regioselective α-opening of the epoxide ring by metal halides affords the corresponding halohydrins with a high degree of stereoselectivity. A subsequent β-elimination reaction from these compounds leads to (*Z*,*E*)-dienyl halides and to (*Z*)-enyne halides.

1. Introduction

In our recent studies on the synthesis of stereodefined compounds[1] we have devised new methodology for the synthesis of a series of natural compounds[2–7] with a conjugated unsaturated structure starting from unsaturated bis-silyl derivatives. In continuation of these studies, we have explored the possibility of synthesizing mono-silylated and conjugated polyunsaturated halides, with a well-defined stereochemistry, which represent useful building blocks for the construction of polyunsaturated natural compounds.

It is well known that unsaturated silyl derivatives can undergo stereospecific substitution reactions with a variety of electrophiles, but, especially for halogens, both retention and/or inversion of configuration take place, depending on the nature of substituent.[8] Naturally, for bis-silylated derivatives, the direct substitution reaction of one silyl group with halogen is complicated both by chemo- and stereoselective factors. Thus, in order to overcome the difficulty of synthesizing mono-silylated polyunsaturated halides in a stereoselective manner, we now report an effective and stereoselective method for the synthesis of unsaturated halogenoderivatives with a conjugated mono-silylated diene or enyne structure employing α,β-epoxysilanes, prepared from bis-silylated derivatives. Indeed, it is known that α,β-epoxysilanes exhibit a regiochemical preference for α-opening of the epoxide ring with a variety of nucleophiles to produce diastereomerically enriched β-hydroxyalkylsilanes, which can undergo stereospecific *syn* or *anti* β-elimination reactions under basic or acidic conditions, leading to heteroatom-substituted olefins of defined stereochemistry.[9–13]



Scheme 1.

Keywords: silicon and compounds; epoxysilanes; stereoselective synthesis; unsaturated halogenoderivatives.
* Corresponding author. Tel.: +33-080-544-2075; fax: +33-080-544-2129; e-mail: fianda@chimica.uniba.it

0040–4020/01/$ - see front matter
PII: S0040-4020(00)01010-3

Table 1. Conversion of epoxide **2** to dienyl halides **4**

Epoxide	Reaction conditions[a]	Product **3**	Yield (%)	Diastereomeric purity (%)	Reaction conditions[b]	Product **4**	Yield (%)	Isomeric purity (*Z*,*E*/*E*,*E*) %
2	(i)	**3a**	77	96	(iv)	**4a**	52	95/5
2	(ii)	**3b**	84	90	(iv)	**4b**	62	90/10
2	(iii)	**3c**	95	88	(iv)	**4c**	57	86/14

[a] (i) **2**/LiCl/AcOH 1:4:4 in THF at 70°C, reaction time 48 h; (ii) **2**/LiBr/AcOH 1:2:4 in THF at 50°C, reaction time 24 h; (iii) **2**/LiI/AcOH 1:2:4 in THF at r.t., reaction time 5 h.
[b] (iv) **3a–c**/$BF_3{\cdot}Et_2O$ 1:1 in CH_2Cl_2 at 0°C, reaction times 10–20 min.

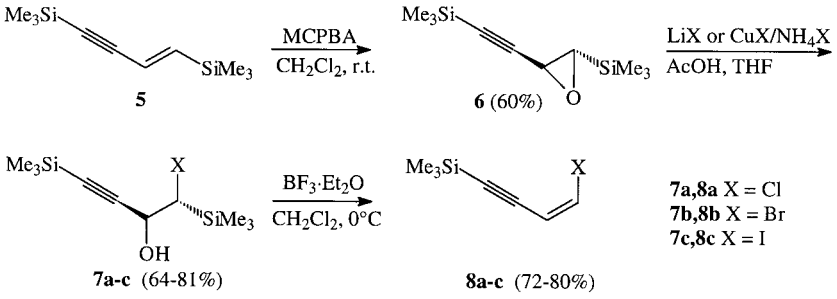
2. Results and discussion

The first step of our methodology (Scheme 1) requires a simple epoxidation reaction of (1*E*,3*E*)-1,4-bis(trimethylsilyl)-1,3-butadiene **1**[14] with *m*-chloroperbenzoic acid (MCPBA) to give the α,β-epoxysilane **2**. The subsequent regio- and stereoselective α-opening of the epoxide ring by lithium halides in the presence of acetic acid[15] affords the corresponding halohydrins **3**. Finally, the reaction of compounds **3** with $BF_3{\cdot}Et_2O$ leads, by a stereospecific *anti* β-elimination reaction, to the unsaturated mono-silylated halogenoderivatives **4** with a (*Z*,*E*) configuration.

The key step of our procedure required the α-opening of the epoxide ring by metal halides under acidic conditions. In order to optimize the reaction, we have performed several reactions with various metal halides (lithium-, sodium-, magnesium- and potassium halides) in the presence of acetic acid,[15] or of silica gel,[16] or of amberlyst 15 resin,[17] and we have found that better results can be obtained using lithium halides in the presence of acetic acid. The reaction was regiospecific and we observed only α ring opening by halide ions under acidic conditions leading, in high yields, to the halohydrins **3** with the halogen group on the carbon bearing the trimethylsilyl group. The reaction was also highly stereoselective and the halohydrins **3a–c** were the main diastereomers. In particular (Table 1), the stereoselectivity of the reaction was dependent on the nature of halide ions (the stereoselectivity followed the order Cl>Br>I). Moreover, in accordance with other works,[15,16] the reactivity of lithium halides was in the order LiI>LiBr>LiCl. Due to the low reactivity of lithium chloride, the reaction required the use of a significant excess of halide (the reaction time can be shortened by using an excess of lithium chloride). Finally, the reactions of the halohydrins **3a–c** with $BF_3{\cdot}Et_2O$ in CH_2Cl_2 at 0°C led to the desired compounds **4a–c** with a (*Z*,*E*) configuration in high isomeric purity, by an *anti* β-elimination process. All isomeric purities were determined by GC/capillary analysis.

Employing the same strategy, the halogenoderivatives **8** were prepared starting from (*E*)-1,4-bis(trimethylsilyl)-3-buten-1-yne **5**[18] (Scheme 2).

Also in this case, the key step required the regioselective α-opening of the bis-silylated propargylic epoxide **6** by metal halides in the presence of acetic acid, but we observed, after several reactions with various metal halides, that the stereoselectivity was strictly dependent on both the halide ion and the metal. Indeed (Table 2), to obtain the halohydrins **7a** and **7b** in high diastereomeric purity (99%) it was necessary to use, respectively, the salts CuCl/NH_4Cl and CuBr/NH_4Br[19] instead of lithium halides. (It is noteworthy that recently[19,20] it has been shown that the



Scheme 2.

Table 2. Conversion of epoxide **6** to dienyl halides **8**

Epoxide	Reaction conditions[a]	Product **7**	Yield (%)	Diastereomeric purity (%)	Reaction conditions[b]	Product **8**	Yield (%)	Isomeric purity (*Z*/*E*) %
6	(i)	**7a**	64	99	(iv)	**8a**	80	99/1
6	(ii)	**7b**	64	99	(iv)	**8b**	72	97/3
6	(iii)	**7c**	81	89	(iv)	**8c**	79	89/11

[a] (i) **6**/CuCl/NH_4Cl/AcOH 1:6:6:12 in THF at 70°C, reaction time 40 h; (ii) **6**/CuBr/NH_4Br/AcOH 1:5:5:10 in THF at 70°C, reaction time 15 h; (iii) **6**/LiI/AcOH 1:2:4 in THF at r.t., reaction time 8 h.
[b] (iv) **7a–c**/$BF_3{\cdot}Et_2O$ 1:1 in CH_2Cl_2 at 0°C, reaction times 10–20 min.

ring opening of propargylic epoxides by nucleophiles led to bromoallenols[19] or to homopropargylic alcohols[20] by the nucleophilic attack on the propargylic position, with a regiochemical preference opposite to that found for our substrates, thus confirming the importance of the presence of the silyl group on the epoxide ring.) The halides **8** were finally obtained in high isomeric purity (89–99%) by reactions of the halohydrins **7** with $BF_3{\cdot}Et_2O$ in CH_2Cl_2 at 0°C. All isomeric purities were determined by GC/capillary analysis.

In conclusion, the procedure described here appears to be a useful route to stereodefined polyunsaturated halogeno-derivatives, which, in principle, are useful intermediates in the synthesis of more extended conjugated systems via coupling reactions involving the halogen atom and electrophilic substitution reactions of the silyl group. Moreover, the ready availability of the starting bis-silyl derivatives employed, the mild reaction conditions, the simplicity of the operations involved, and the high selectivity are additional features making the methodology very promising.

3. Experimental

Macherey-Nagel silica gel (60, particle size 0.040–0.063 mm) for flash column chromatography and Macherey–Nagel aluminum sheets with silica gel 60 F_{254} for TLC were used. GC analysis was performed on a Hewlett-Packard 5890 series II gas chromatograph equipped with a SE-30 (methylsilicone, 30 m×0.25 mm id) capillary column. GC–mass spectrometry analysis was performed on a Shimadzu GCMS-QP5000 gas chromatograph-mass spectrometer equipped with a MDN-1 capillary column (methylsilicone, 30 m×0.25 mm id). IR spectra were recorded on a Perkin–Elmer FT-IR 1710 spectrometer. ^{1}H NMR spectra were recorded in deuterochloroform on a Bruker AM 500 spectrometer at 500 MHz and on a Bruker AM 300 spectrometer at 300 MHz. Elemental analyses were recorded on a Carlo Erba EA 1108 elemental analyzer. Solvents were dried before use as follows: methylene chloride was distilled over phosphorus pentoxide, tetrahydrofuran was distilled from sodium.

3.1. Synthesis of products 2–4

3.1.1. (*E*)-1,4-Bis(trimethylsilyl)-3,4-epoxy-1-butene (2). MCPBA (1.72 g, 10.0 mmol) was added at room temperature to a solution of **1** (2.00 g, 10.08 mmol) in CH_2Cl_2 (35 mL). The reaction mixture was stirred for 24 h, quenched with a 2 M aqueous solution of Na_2CO_3 (50 mL), and extracted with petroleum ether (3×50 mL). The organic extracts were washed with a 2 M aqueous solution of Na_2CO_3 (50 mL), then with water (2×50 mL), dried over anhydrous Na_2SO_4 and concentrated under vacuum. Purification by flash chromatography (5% ethyl acetate/petroleum ether) led to the *title compound* **2** (1.27 g, 59% yield) as a colorless oil; [Found: C, 55.9; H, 10.2. $C_{10}H_{22}OSi_2$ requires C, 56.02; H, 10.34%]; ν_{max} (liquid film) 1619, 1261, 1019, 840 cm^{-1}; δ_H (500 MHz, $CDCl_3$) 6.11 (1H, dd, *J*=18.7, 0.6 Hz, =C*H*Si), 5.63 (1H, dd, *J*=18.7, 7.6 Hz, =C*H*CHO), 3.12 (1H, ddd, *J*=7.6, 3.4, 0.6 Hz, =CHC*H*O), 2.15 (1H, d, *J*=3.4 Hz, C*H*Si), 0.04 (18H, s, Si*Me*$_3$); MS *m/z* 199 (1), 147 (2), 133 (2), 111 (25), 73 (100), 59 (8), 45 (20), 43 (8%).

3.1.2. (*E*)-1,4-Bis(trimethylsilyl)-3-hydroxy-4-chloro-1-butene (3a). A THF solution (5 mL) of **2** (0.101 g, 0.47 mmol), LiCl (0.080 g, 1.89 mmol) and acetic acid (0.10 mL, 1.75 mmol) were introduced in a tightly stoppered flask, then the resulting mixture was stirred at 70°C. After reaction completion (48 h) and after cooling at room temperature, the mixture was quenched with a saturated aqueous solution of NH_4Cl (20 mL) and extracted with ethyl acetate (3×20 mL). The organic extracts were washed with water (3×20 mL), dried over anhydrous Na_2SO_4 and concentrated under vacuum. The residue was purified by percolation on florisil column (ethyl ether as eluent) leading to the *title compound* **3a** (0.091 g, 77% yield, diastereomeric purity=96%) as a yellowish oil; [Found: C, 48.0; H, 9.2. $C_{10}H_{23}ClOSi_2$ requires C, 47.87; H, 9.23%]; ν_{max} (liquid film) 3600–3200 (br), 1619, 1250, 992, 840 cm^{-1}; δ_H (500 MHz, $CDCl_3$) 6.07 (1H, dd, *J*=18.7, 5.6 Hz, =C*H*CHOH), 5.94 (1H, dd, *J*=18.7, 1.3 Hz, =C*H*Si), 4.44–4.37 (1H, m, C*H*OH), 3.50 (1H, d, *J*=3.7 Hz, SiC*H*Cl), 2.35 (1H, broad s, CHO*H*), 0.13 (9H, s, Si*Me*$_3$), 0.07 (9H, s, Si*Me*$_3$); MS *m/z* 147 (26), 145 (40), 129 (18), 111 (18), 109 (24), 101 (18), 99 (12), 95 (17), 93 (36), 75 (91), 73 (100), 61 (16), 59 (33), 52 (16), 47 (18), 45 (66), 43 (22%).

3.1.3. (1*Z*,3*E*)-1-Chloro-4-trimethylsilyl-1,3-butadiene (4a). $BF_3{\cdot}Et_2O$ (0.05 mL, 0.39 mmol) was added, under nitrogen, at 0°C, to a CH_2Cl_2 solution (7 mL) of **3a** (0.091 g, 0.36 mmol). The reaction mixture was stirred for 15 min at 0°C, then quenched with a saturated aqueous solution of NH_4Cl (20 mL). The resulting mixture was extracted with ethyl acetate (3×20 mL) and the organic phases were washed with water (3×20 mL) and dried over anhydrous Na_2SO_4. The residue obtained by evaporation of the solvent at reduced pressure was purified by percolation on florisil column (ethyl ether as eluent) leading to the *title compound* **4a** (0.030 g, 52% yield, isomeric purity=95%) as a yellowish oil; [Found: C, 52.2; H, 8.2. $C_7H_{13}ClSi$ requires C, 52.31; H, 8.15%]; ν_{max} (liquid film) 1610, 1550, 1281, 1240, 995, 842 cm^{-1}; δ_H (500 MHz, $CDCl_3$) 6.89 (1H, ddd, *J*=18.5, 10.0, 0.9 Hz, C*H*=CHSi), 6.28 (1H, ddd, *J*=10.0, 7.1, 0.9 Hz, C*H*=CHCl), 6.04 (1H, dt, *J*=18.5, 0.9 Hz, =C*H*Si), 5.98 (1H, dt, *J*=7.1, 0.9 Hz, =C*H*Cl), 0.05 (9H, s, Si*Me*$_3$); MS *m/z* 162 (2), 160 (M^+, 4), 147 (20), 145 (57), 119 (11), 109 (38), 95 (35), 93 (100), 81 (8), 79 (17), 73 (17), 59 (69), 45 (31), 43 (43%).

3.1.4. (*E*)-1,4-Bis(trimethylsilyl)-3-hydroxy-4-bromo-1-butene (3b). In a tightly stoppered flask were introduced a solution of **2** (0.101 g, 0.47 mmol) in THF (5 mL), LiBr (0.082 g, 0.94 mmol) and acetic acid glacial (0.10 mL, 1.75 mmol), then the resulting mixture was stirred at 50°C. On completion of the reaction (24 h), a saturated aqueous solution of NH_4Cl was added (20 mL) and the mixture was extracted with ethyl acetate (3×20 mL). The organic extracts were washed with water (3×20 mL), dried over anhydrous Na_2SO_4 and concentrated under vacuum. The resulting crude product was purified by percolation on florisil column (ethyl ether as eluent) affording the *title*

compound **3b** (0.116 g, 84% yield, diastereomeric purity=90%) as a bright yellow oil; [Found: C, 40.8; H, 7.9. $C_{10}H_{23}BrOSi_2$ requires C, 40.66; H, 7.85%]; ν_{max} (liquid film) 3600–3200 (br), 1620, 1250, 991, 840 cm^{-1}; δ_H (300 MHz, $CDCl_3$) 6.05 (1H, dd, *J*=18.7, 5.2 Hz, =C*H*CHOH), 5.93 (1H, dd, *J*=18.7, 0.9 Hz, =C*H*Si), 4.31 (1H, ddd, *J*=5.2, 3.6, 0.9 Hz, C*H*OH), 3.52 (1H, d, *J*=3.6 Hz, SiC*H*Br), 2.67 (1H, broad s, CHO*H*), 0.13 (9H, s, Si*Me*$_3$), 0.05 (9H, s, Si*Me*$_3$); MS *m*/*z* 201 (3), 191 (14), 189 (14), 147 (13), 139 (13), 137 (13), 129 (14), 127 (10), 125 (16), 111 (16), 109 (22), 75 (84), 73 (100), 61 (15), 59 (36), 47 (15), 45 (53), 43 (17%).

3.1.5. (1*Z*,3*E*)-1-Bromo-4-trimethylsilyl-1,3-butadiene (4b). $BF_3{\cdot}Et_2O$ (0.05 mL, 0.39 mmol) was added, under nitrogen, at 0°C, to a CH_2Cl_2 solution (7 mL) of **3b** (0.116 g, 0.39 mmol). The reaction mixture was stirred for 20 min at 0°C, quenched with a saturated aqueous solution of NH_4Cl (20 mL) and extracted with ethyl acetate (3×20 mL). The organic extracts were washed with water (3×20 mL), dried over anhydrous Na_2SO_4 and concentrated under vacuum. Purification by percolation on florisil column (ethyl ether as eluent) led to the *title compound* **4b** (0.050 g, 62% yield, isomeric purity=90%) as a colorless oil; [Found: C, 40.9; H, 6.5. $C_7H_{13}BrSi$ requires C, 40.98; H, 6.39%]; ν_{max} (liquid film) 1608, 1545, 1280, 1250, 990, 843 cm^{-1}; δ_H (500 MHz, $CDCl_3$) 6.81 (1H, ddd, *J*=18.4, 9.7, 1.0 Hz, C*H*=CHSi), 6.60 (1H, ddd, *J*=9.7, 7.1, 1.0 Hz, C*H*=CHBr), 6.15 (1H, dt, *J*=7.1, 1.0 Hz, =C*H*Br), 6.11 (1H, dt, *J*=18.4, 1.0 Hz, =C*H*Si) 0.07 (9H, s, Si*Me*$_3$); MS *m*/*z* 206 (5), 204 (M^+, 4), 191 (39), 189 (39), 165 (6), 163 (9), 139 (61), 137 (62), 125 (31), 123 (14), 109 (69), 83 (25), 73 (19), 59 (100), 45 (37), 43 (63%).

3.1.6. (*E*)-1,4-Bis(trimethylsilyl)-3-hydroxy-4-iodo-1-butene (3c). A THF solution (5 mL) of **2** (0.101 g, 0.47 mmol), LiI (0.126 g, 0.94 mmol) and acetic acid glacial (0.10 mL, 1.75 mmol) were introduced in a tightly stoppered flask, then the resulting mixture was stirred at room temperature. After 5 h the reaction was completed, and a 10% aqueous solution of sodium thiosulfate was added (20 mL). The resulting mixture was extracted with ethyl acetate (3×20 mL), the organic phases were washed with water (3×20 mL) and dried over anhydrous Na_2SO_4. The residue obtained by evaporation of the solvent at reduced pressure was purified by percolation on florisil column (ethyl ether as eluent). 0.153 g of the *title compound* **3c** (95% yield, diastereomeric purity=88%) were obtained as a yellowish oil; [Found: C, 35.1; H, 6.8. $C_{10}H_{23}IOSi_2$ requires C, 35.08; H, 6.77%]; ν_{max} (liquid film) 3600–3200 (br), 1617, 1250, 990, 841 cm^{-1}; δ_H (500 MHz, $CDCl_3$) 6.04–5.80 (2H, m, C*H*=C*H*), 3.77 (1H, t, *J*=4.2 Hz, C*H*OH), 3.49 (1H, d, *J*=3.6 Hz, SiC*H*I), 2.18 (1H, broad s, CHO*H*), 0.16 (9H, s, Si*Me*$_3$), 0.06 (9H, s, Si*Me*$_3$); MS *m*/*z* 252 (<1), 237 (6), 214 (2), 201 (4), 199 (6), 185 (7), 171 (3), 147 (11), 127 (10), 125 (26), 111 (10), 109 (13), 101 (11), 99 (11), 97 (9), 85 (5), 83 (6), 75 (64), 73 (100), 61 (13), 59 (63), 47 (13), 45 (44), 43 (17%).

3.1.7. (1*Z*,3*E*)-1-Iodo-4-trimethylsilyl-1,3-butadiene (4c). $BF_3{\cdot}Et_2O$ (0.06 mL, 0.47 mmol) was added, under nitrogen, at 0°C, to a CH_2Cl_2 solution (7 mL) of **3c** (0.153 g, 0.45 mmol). The reaction mixture was stirred for 10 min at 0°C, quenched with a saturated aqueous solution of NH_4Cl (20 mL) and extracted with ethyl acetate (3×20 mL). The organic extracts were washed with water (3×20 mL), dried over anhydrous Na_2SO_4 and concentrated under vacuum. Purification by percolation on florisil column (ethyl ether as eluent) led to the *title compound* **4c** (0.065 g, 57% yield, isomeric purity=86%) as a yellowish oil; [Found: C, 33.5; H, 5.2. $C_7H_{13}ISi$ requires C, 33.34; H, 5.20%]; ν_{max} (liquid film) 1604, 1550, 1289, 1249, 991, 840 cm^{-1}; δ_H (500 MHz, $CDCl_3$) 6.69 (1H, dd, *J*=9.5, 7.3 Hz, C*H*=CHI), 6.64 (1H, dd, *J*=17.8, 9.5 Hz, C*H*=CHSi), 6.28 (1H, d, *J*=7.3 Hz, =C*H*I), 6.17 (1H, d, *J*=17.8 Hz, =C*H*Si) 0.12 (9H, s, Si*Me*$_3$); MS *m*/*z* 252 (M^+, 7), 237 (17), 185 (15), 171 (6), 125 (18), 109 (28), 97 (13), 95 (9), 83 (11), 73 (12), 59 (100), 45 (18), 43 (32%).

3.2. Synthesis of products 6–8

3.2.1. 1,4-Bis(trimethylsilyl)-3,4-epoxy-1-butyne (6). MCPBA (2.87 g, 16.71 mmol) was added at room temperature to a solution of **5** (1.64 g, 8.35 mmol) in CH_2Cl_2 (40 mL). The reaction mixture was stirred for 16 h, quenched with a 2 M aqueous solution of Na_2CO_3 (50 mL), and extracted with petroleum ether (3×50 mL). The organic extracts were washed with a 2 M aqueous solution of Na_2CO_3 (50 mL), then with water (2×50 mL), dried over anhydrous Na_2SO_4 and concentrated under vacuum. Purification by distillation (Kugelrohr oven temperature 145–150°C, 40 mbar) led to the *title compound* **6** (1.06 g, 60% yield) as a yellowish oil; [Found: C, 56.7; H, 9.4. $C_{10}H_{20}OSi_2$ requires C, 56.53; H, 9.49%]; ν_{max} (liquid film) 2177, 1251, 1020, 845 cm^{-1}; δ_H (500 MHz, $CDCl_3$) 3.08 (1H, d, *J*=3.5 Hz, ≡CC*H*O), 2.34 (1H, d, *J*=3.5 Hz, C*H*Si), 0.09 (9H, s, Si*Me*$_3$), −0.01 (9H, s, Si*Me*$_3$); MS *m*/*z* 212 (M^+<1), 197 (10), 171 (55), 143 (5), 131 (14), 123 (4), 117 (6), 109 (4), 97 (6), 73 (100), 59 (11), 58 (9), 55 (9), 53 (7), 45 (42), 43 (24%).

3.2.2. 1,4-Bis(trimethylsilyl)-3-hydroxy-4-chloro-1-butyne (7a). In a tightly stoppered flask were introduced a solution of **6** (0.100 g, 0.47 mmol) in THF (7 mL), CuCl (0.279 g, 2.82 mmol), NH_4Cl (0.151 g, 2.82 mmol) and acetic acid glacial (0.32 mL, 5.60 mmol). The resulting mixture was stirred at 70°C for 40 h, then, after cooling at room temperature, quenched with a saturated aqueous solution of NH_4Cl (20 mL) and extracted with ethyl acetate (3×20 mL). The organic extracts were washed with water (3×20 mL), dried over anhydrous Na_2SO_4 and concentrated under vacuum. Purification by percolation on florisil column (ethyl ether as eluent) led to the *title compound* **7a** (0.075 g, 64% yield, diastereomeric purity=99%) as a colorless oil; [Found: C, 48.3; H, 8.4. $C_{10}H_{21}ClOSi_2$ requires C, 48.26; H, 8.50%]; ν_{max} (liquid film) 3600–3200 (br), 2173, 1250, 1020, 844 cm^{-1}; δ_H (500 MHz, $CDCl_3$) 4.63 (1H, d, *J*=3.5 Hz, C*H*OH), 3.45 (1H, d, *J*=3.5 Hz, SiC*H*Cl), 1.22 (1H, broad s, CHO*H*), 0.17 (9H, s, Si*Me*$_3$), 0.13 (9H, s, Si*Me*$_3$); MS *m*/*z* 199 (4), 158 (7), 155 (9), 145 (33), 143 (91), 127 (18), 125 (22), 117 (12), 99 (34), 75 (43), 73 (100), 45 (82), 44 (29), 43 (48%).

3.2.3. (*Z*)-1-Chloro-4-trimethylsilyl-1-buten-3-yne (8a).[21] $BF_3{\cdot}Et_2O$ (0.05 mL, 0.39 mmol) was added, under nitrogen, at 0°C, to a CH_2Cl_2 solution (7 mL) of **7a** (0.075 g,

0.30 mmol). The reaction mixture was stirred for 10 min at 0°C, quenched with a saturated aqueous solution of NH_4Cl (20 mL) and extracted with ethyl acetate (3×20 mL). The organic extracts were washed with water (3×20 mL), dried over anhydrous Na_2SO_4 and the solvent was evaporated at reduced pressure. The residue was purified by percolation on florisil column (ethyl ether as eluent) leading to the *title compound* **8a**[21] (0.038 g, 80% yield, isomeric purity=99%); δ_H (500 MHz, $CDCl_3$) 6.38 (1H, d, J=7.5 Hz, =C*H*Cl), 5.87 (1H, d, J=7.5 Hz, ≡CC*H*), 0.20 (9H, s, Si*Me*$_3$); MS *m/z* 160 (3), 158 (M^+, 10), 145 (35), 143 (100), 119 (14), 117 (39), 93 (7), 79 (8), 77 (7), 65 (14), 63 (25), 55 (5), 53 (14), 43 (24%).

3.2.4. 1,4-Bis(trimethylsilyl)-3-hydroxy-4-bromo-1-butyne (7b). In a tightly stoppered flask were introduced a solution of **6** (0.100 g, 0.47 mmol) in THF (7 mL), CuBr (0.337 g, 2.35 mmol) NH_4Br (0.230 g, 2.35 mmol) and acetic acid glacial (0.27 mL, 4.70 mmol), then the resulting mixture was stirred at 70°C. After reaction completion (15 h), the mixture was quenched with a saturated aqueous solution of NH_4Cl (20 mL) and extracted with ethyl acetate (3×20 mL). The organic extracts were washed with water (3×20 mL), dried over anhydrous Na_2SO_4 and concentrated under vacuum. Purification by distillation (Kugelrohr oven temperature 90–100°C, 1 mbar) led to the *title compound* **7b** (0.088 g, 64% yield, diastereomeric purity=99%) as a colorless oil; [Found: C, 41.0; H, 7.3. $C_{10}H_{21}BrOSi_2$ requires C, 40.94; H, 7.21%]; ν_{max} (liquid film) 3600–3200 (br), 2175, 1251, 1022, 843 cm^{-1}; δ_H (500 MHz, $CDCl_3$) 4.56 (1H, d, J=3.4 Hz, C*H*OH), 3.46 (1H, d, J=3.4 Hz, SiC*H*Br), 1.23 (1H, broad s, CHO*H*), 0.19 (9H, s, Si*Me*$_3$), 0.15 (9H, s, Si*Me*$_3$); MS *m/z* 204 (4), 202 (4), 199 (4), 189 (32), 187 (32), 163 (4), 161 (4), 155 (4), 147 (10), 139 (6), 137 (6), 127 (9), 125 (22), 123 (14), 99 (27), 97 (16), 75 (43), 73 (100), 59 (11), 47 (18), 45 (76), 43 (37%).

3.2.5. (*Z*)-1-Bromo-4-trimethylsilyl-1-buten-3-yne (8b).[22] $BF_3{\cdot}Et_2O$ (0.05 mL, 0.39 mmol) was added, under nitrogen, at 0°C, to a CH_2Cl_2 solution (7 mL) of **7b** (0.088 g, 0.30 mmol). The reaction mixture was stirred for 20 min at 0°C, quenched with a saturated aqueous solution of NH_4Cl (20 mL) and extracted with ethyl acetate (3×20 mL). The organic extracts were washed with water (3×20 mL), dried over anhydrous Na_2SO_4 and concentrated under vacuum. Purification by percolation on florisil column (ethyl ether as eluent) led to the *title compound* **8b**[22] (0.044 g, 72% yield, isomeric purity=97%); δ_H (500 MHz, $CDCl_3$) 6.58 (1H, d, J=7.7 Hz, =C*H*Br), 6.30 (1H, d, J=7.7 Hz, ≡CC*H*), 0.20 (9H, s, Si*Me*$_3$); MS *m/z* 204 (13), 202 (M^+, 13), 189 (100), 187 (100), 163 (53), 161 (51), 137 (5), 123 (13), 122 (10), 109 (17), 107 (25), 97 (6), 95 (5), 93 (9), 79 (13), 77 (20), 67 (15), 55 (11), 54 (15), 53 (29), 43 (66%).

3.2.6. 1,4-Bis(trimethylsilyl)-3-hydroxy-4-iodo-1-butyne (7c). In a tightly stoppered flask were introduced a solution of **6** (0.100 g, 0.47 mmol) in THF (5 mL), LiI (0.126 g, 0.94 mmol) and acetic acid glacial (0.10 mL, 1.75 mmol), then the resulting mixture was stirred at room temperature. After reaction completion (8 h), the mixture was quenched with a 10% aqueous solution of sodium thiosulfate (20 mL) and extracted with ethyl acetate (3×20 mL). The organic extracts were washed with water (3×20 mL), dried over anhydrous Na_2SO_4 and concentrated under vacuum. Purification by percolation on florisil column (ethyl ether as eluent) led to the *title compound* **7c** (0.130 g, 81% yield, diastereoisomeric purity=89%) as a thick yellow oil; [Found: C, 35.4; H, 6.2. $C_{10}H_{21}IOSi_2$ requires C, 35.29; H, 6.22%]; ν_{max} (liquid film) 3600–3200 (br), 2170, 1250, 1018, 845 cm^{-1}; δ_H (500 MHz, $CDCl_3$) 4.08 (1H, d, J=3.6 Hz, C*H*OH), 3.40 (1H, d, J=3.6 Hz, SiC*H*I), 1.23 (1H, broad s, CHO*H*), 0.20 (9H, s, Si*Me*$_3$), 0.14 (9H, s, Si*Me*$_3$); MS *m/z* 250 (19), 235 (35), 199 (9), 185 (8), 155 (7), 147 (22), 125 (27), 123 (26), 99 (23), 97 (32), 83 (10), 75 (47), 73 (100), 59 (15), 47 (17), 45 (63), 43 (34%).

3.2.7. (*Z*)-1-Iodo-4-trimethylsilyl-1-buten-3-yne (8c). $BF_3{\cdot}Et_2O$ (0.05 mL, 0.39 mmol) was added, under nitrogen, at 0°C, to a CH_2Cl_2 solution (7 mL) of **7c** (0.130 g, 0.38 mmol). The reaction mixture was stirred for 10 min at 0°C, quenched with a saturated aqueous solution of NH_4Cl (20 mL) and extracted with ethyl acetate (3×20 mL). The organic extracts were washed with water (3×20 mL), dried over anhydrous Na_2SO_4 and concentrated under vacuum. Purification by percolation on florisil column (ethyl ether as eluent) led to the *title compound* **8c** (0.075 g, 79% yield, isomeric purity=89%) as a yellowish oil; [Found: C, 33.6; H, 4.5. $C_7H_{11}ISi$ requires C, 33.61; H, 4.43%]; ν_{max} (liquid film) 2154, 1578, 1251, 1027, 844 cm^{-1}; δ_H (500 MHz, $CDCl_3$) 6.81 (1H, d, J=8.4 Hz, =C*H*I), 6.60 (1H, d, J=8.4 Hz, ≡CC*H*), 0.22 (9H, s, Si*Me*$_3$); MS *m/z* 250 (M^+, 30), 235 (100), 209 (43), 155 (6), 123 (32), 107 (18), 97 (43), 93 (13), 77 (13), 67 (17), 55 (14), 53 (33), 43 (42%).

Acknowledgements

This work was financially supported in part by the Ministero dell'Università e della Ricerca Scientifica e Tecnologica, Rome, and the University of Bari (National Project 'Stereoselezione in Sintesi Organica. Metodologie ed Applicazioni').

References

1. For reviews, see: Fiandanese, V. *Pure Appl. Chem.* **1990**, *62*, 1987–1992; Fiandanese, V. Conjugated Polyunsaturated Silanes as Versatile Building Blocks in Organic Synthesis. In *Recent Research Developments in Organic Chemistry*; Pandalai, S. G., Ed.; Transworld Research Network, 1999; Vol. 3, pp 177–194.
2. Babudri, F.; Fiandanese, V.; Naso, F. *J. Org. Chem.* **1991**, *56*, 6245–6248.
3. Babudri, F.; Fiandanese, V.; Naso, F.; Punzi, A. *Synlett* **1992**, 221–223.
4. Babudri, F.; Fiandanese, V.; Naso, F.; Punzi, A. *Tetrahedron Lett.* **1994**, *35*, 2067–2070.
5. Babudri, F.; Fiandanese, V.; Marchese, G.; Punzi, A. *Synlett* **1995**, 817–818.
6. Babudri, F.; Fiandanese, V.; Hassan, O.; Punzi, A.; Naso, F. *Tetrahedron* **1998**, *54*, 4327–4336.
7. Babudri, F.; Fiandanese, V.; Marchese, G.; Punzi, A. *Tetrahedron* **2000**, *56*, 327–331.

8. For review, see: Fleming, I.; Barbero, A.; Walter, D. *Chem. Rev.* **1997**, *97*, 2063–2192.
9. For review, see: Hudrlik, P. F.; Hudrlik A. M. *Adv. Silicon. Chem.* **1993**, *2*, 1–89.
10. Hudrlik, P. F.; Tafesse, L.; Hudrlik, A. M. *J. Am. Chem. Soc.* **1997**, *119*, 11689–11690.
11. Cuadrado, P.; González-Nogal, A. M. *Tetrahedron Lett.* **2000**, *41*, 1111–1114.
12. Bassindale, A. R.; Soobramanien, M.-C.; Taylor, P. G. *Bull. Soc. Chim. Fr.* **1995**, *132*, 604–608.
13. Ukaji, Y.; Yoshida, A.; Fujisawa, T. *Chem. Lett.* **1990**, 157–160.
14. Naso, F.; Fiandanese, V. A.; Babudri, F. In *Encyclopedia of Reagents for Organic Synthesis*, Paquette, L. A., Ed.; Wiley: Chichester, 1995; Vol. 1, pp 593–594.
15. Bajwa, J. S.; Anderson, R. C. *Tetrahedron Lett.* **1991**, *32*, 3021–3024.
16. Kotsuki, H.; Shimanouchi, T. *Tetrahedron Lett.* **1996**, *37*, 1845–1848.
17. Federici, C.; Righi, G.; Rossi, L.; Bonini, C.; Chiummiento, L.; Funicello, M. *Tetrahedron Lett.* **1994**, *35*, 797–800.
18. Fiandanese, V.; Marchese, G.; Punzi, A.; Ruggieri, G. *Tetrahedron Lett.* **1996**, *37*, 8455–8458.
19. Bernard, N.; Chemla, F.; Normant, J. F. *Tetrahedron Lett.* **1998**, *39*, 8837–8840.
20. Bernard, N.; Chemla, F.; Normant, J. F. *Tetrahedron Lett.* **1998**, *39*, 6715–6718.
21. Chemin, D.; Linstrumelle, G. *Tetrahedron* **1994**, *50*, 5335–5344.
22. Uenishi, J.; Kawahama, R.; Yonemitsu, O.; Tsuji, J. *J. Org. Chem.* **1998**, *63*, 8965–8975.