SUPPORTING INFORMATION

Spiro-Cyclopropanation from Oxoallylsilanes

Asunción Barbero, Pilar Castreño and Francisco J. Pulido*.

Departamento de Química Orgánica, Universidad de Valladolid, 47011 Valladolid, SPAIN

pulido@qo.uva.es

Experimental Section

All reagents were of commercial quality from freshly opened containers or were purified before use. Allene (1,2-propadiene, 99.8%) was supplied by Air-Liquid Spain in lecture bottles. Organometallic reagents were purchased from Aldrich and CuCN from Fluka. The latter was briefly dried in vacuo prior to use. All reactions were carried out under nitrogen and all the glassware carefully dried before use. THF was distilled under N₂ from purple solutions of sodium benzophenone ketyl. The stereochemistry of the compounds has been assigned on the basis of COSY, NOE and NOESY experiments (Bruker AC-300 and ARX-300 apparatus).

Silylcupration of allene and reaction of the intermediate cuprate with α,β -unsaturated carbonyl compounds.

A solution of phenyldimethylsilyllithium (3 mmol) in THF (3 ml) was added by syringe to a stirred suspension of copper(I) cyanide (3 mmol) in THF (5ml) at 0°C. The resulting black mixture was stirred at this temperature for an additional period of 30 min, and then cooled to -40°C. A slight excess of allene was added from a balloon and the mixture was stirred for 1h at

this temperature. $\text{BF}_3 \cdot \text{OEt}_2$ (3 mmol) was added at -40°C to the mixture and was stirred for 5 min at this temperature. Then, the α,β -unsaturated carbonyl compound (3.6 mmol) was added dropwise at -40°C and the resulting mixture was kept at this temperature for 1h. After gentle warming to 0°C the mixture was quenched with saturated ammonium chloride solution (10 ml) and extracted with ether (3x15 ml). The organic layer was dried over MgSO_4 and the solvent rotoevaporated. Purification by flash chromatography gave the oxoallylsilanes **2a-2k** (Ref. 6a and 7).

The Tandem Reaction: Cyclization-Cyclopropanation.

Me_3Al (1.1 ml of a 2M solution in hexane, 2.2 mmol) was added dropwise to a stirred solution of the oxoallylsilane (1.1 mmol) and CH_2I_2 (0.18 ml, 2.2 mmol) in dry CH_2Cl_2 (4 ml) at -60°C . The solution was warmed up slowly and stirred at room temperature for 48 h. Then, a mixture of H_2O (0.12ml, 6.7mmol) and Et_3N (0.4ml) was carefully added at -20°C . The resulting mixture was stirred for an additional 0.5 h at 0°C , filtered through Celite and evaporated under vacuum. The resulting oil was taken up in Et_2O , washed with brine, dried (MgSO_4), and evaporated under vacuum. The residue was chromatographed on a column (silica gel, EtOAc :hexanes) to give the products **3a-3k**.

[5*S**, 7*R**]-5-Methyl-7-phenyl-spiro[2.4]heptan-5-ol (**3a**)

Amorphous white powder. M. p. = $55-57^\circ\text{C}$ (pentane). IR (Cl_4C) 3358, 3058 cm^{-1} . $^1\text{H-NMR}$ (CDCl_3 , 300 MHz): δ 7.38-7.15 (5H, m), 3.13 (1H, t, $J = 9$ Hz), 2.34 (1H, ddd, $J = 13.1$, 9 and 1 Hz), 2.19 (1H, dd, $J = 13.1$ and 9 Hz), 2.34 (1H, br s), 2.03 (1H, d, $J = 12.7$ Hz), 1.82 (1H, d, $J = 12.7$ Hz), 1.53 (3H, s), 0.55-0.50 (1H, m), 0.40-0.29 (2H, m), 0.14-0.06 (1H, m). $^{13}\text{C-NMR}$ (CDCl_3 , 75 MHz): δ 143.0, 128.5, 128.1, 126.1, 78.0, 51.8, 50.5, 49.6, 28.6, 26.2, 11.5, 10.2. MS(EI) m/z : 202 (M^+ , 5%), 184 ($\text{M}^+ - \text{H}_2\text{O}$, 70%), 159, 129. Anal. Calcd for $\text{C}_{14}\text{H}_{18}\text{O}$: C, 83.12; H, 8.97. Found: C, 83.27; H, 9.11.

5, 7, 7-Trimethyl-spiro[2.4]heptan-5-ol (**3b**)

Colorless oil. IR (film) 3389, 3050 cm^{-1} . ^1H -NMR (CDCl_3 , 300 MHz): δ 1.89 (2H, d, $J = 13.1$ Hz), 1.81 (2H, s), 1.71 (2H, d, $J = 13.1$ Hz), 1.36 (3H, s), 0.89 (3H, s), 0.82 (3H, s), 0.55-0.50 (1H, m), 0.44-0.26 (3H, m). ^{13}C -NMR (CDCl_3 , 75 MHz): δ 78.1, 57.6, 51.4, 38.1, 29.9, 29.5, 27.4, 27.2, 8.5, 6.7. MS(EI) m/z : 154 (M^+ , 4%), 139 ($\text{M}^+ - \text{Me}$, 29%), Anal. Calcd for $\text{C}_{10}\text{H}_{18}\text{O}$: C, 77.87; H, 11.76. Found: C, 78.11; H, 11.95.

[5*R, 6*S**, 7*R**]-5,6,7-Trimethyl-spiro[2.4]heptan-5-ol (3c)**

Colorless oil. IR (film) 3370, 3068 cm^{-1} . ^1H -NMR (CDCl_3 , 300 MHz): δ 2.42 (1H, quint, $J = 7.1$ Hz), 1.92 (1H, quint, $J = 7.2$ Hz), 1.84 (1H, d, $J = 13.7$ Hz), 1.67 (1H, d, $J = 13.7$ Hz), 1.25 (3H, s), 0.83 (3H, d, $J = 7.2$ Hz), 0.62 (3H, d, $J = 7.3$ Hz), 0.61-0.55 (1H, m), 0.49-0.42 (1H, m), 0.33-0.24 (1H, m), 0.15-0.12 (1H, m). ^{13}C -NMR (CDCl_3 , 75 MHz): δ 82.4, 51.5, 51.4, 40.6, 26.4, 24.1, 13.0, 12.8, 11.6, 10.8. MS(EI) m/z : 154 (M^+ , 5%), 139 ($\text{M}^+ - \text{Me}$, 20%), 126, 121, 108.

[5*S, 7*S**]-7-Isopropyl-5-methyl-spiro[2.4]heptan-5-ol (3d)**

Colorless oil. IR (film) 3338, 3089 cm^{-1} . ^1H -NMR (CDCl_3 , 300 MHz): δ 1.96 (1H, d, $J = 12$ Hz), 1.8-1.65 (4H, m), 1.54-1.46 (1H, m), 1.43 (3H, s), 1.29 (1H, dd, $J = 12$ and 1.3 Hz), 0.88 (3H, d, $J = 6.8$ Hz), 0.79 (3H, d, $J = 6.9$ Hz), 0.67-0.61 (1H, m), 0.49-0.37 (2H, m), 0.32-0.26 (1H, m). ^{13}C -NMR (CDCl_3 , 75 MHz): δ 77.5, 52.1, 47.8, 42.0, 28.4, 22.7, 21.5, 17.3, 15.9, 7.7. Anal. Calcd for $\text{C}_{11}\text{H}_{20}\text{O}$: C, 78.51; H, 11.98. Found: C, 78.80; H, 12.21.

[1*S, 6*R**, 7*R**]-7-Methyl-9-spirocyclopropyl-bicyclo[4.3.0]nonan-7-ol (3e) OH rayado**

Colorless oil. IR (film) 3351, 3095 cm^{-1} . ^1H -NMR (CDCl_3 , 300 MHz): δ 2.05 (1H, d, $J = 13.1$ Hz), 1.93 (1H, q, $J = 5.8$ Hz), 1.84-1.73 (1H, m), 1.70-1.66 (2H, m), 1.60 (1H, d, $J = 13.1$ Hz), 1.52-1.26 (5H, m), 1.38 (3H, s), 0.90-0.84 (2H, m), 0.66-0.60 (1H, m), 0.45-0.41 (1H, m), 0.38-0.24 (2H, m). ^{13}C -NMR (CDCl_3 , 75 MHz): δ 79.6, 50.5, 49.3, 42.0, 29.1, 24.8, 24.0, 23.6, 23.0, 20.5, 13.3, 10.0. MS(EI) m/z : 180 (M^+ , 9%), 162 ($\text{M}^+ - \text{H}_2\text{O}$, 100%), 165.

[1*S, 6*R**, 7*S**]-7-Methyl-9-spirocyclopropyl-bicyclo[4.3.0]nonan-7-ol (3e) OH negrita**

Colorless oil. ^1H -NMR (CDCl_3 , 300 MHz): δ 2.57 (1H, m), 2.01 (1H, d, $J = 14$ Hz), 1.81-1.63 (5H, m), 1.57 (1H, d, $J = 14$ Hz), 1.42-1.05 (5H, m), 1.23 (3H, s), 0.64-0.60 (1H, m), 0.54-0.49 (1H, m), 0.32-0.25 (2H, m). ^{13}C -NMR (CDCl_3 , 75 MHz): δ 81.0, 52.2, 49.9, 39.5, 26.4, 24.8, 23.8, 23.5, 22.2, 19.8, 12.5, 11.8. Anal. Calcd for $\text{C}_{12}\text{H}_{20}\text{O}$: C, 79.94; H, 11.18. Found: C, 80.27; H, 11.40.

[1*R, 2*R**, 5*S**]-2-Methyl-4-spirocyclopropyl-bicyclo[3.3.0]octan-2-ol (3f) OH rayado**

Colorless oil. IR (film) 3370, 3062 cm^{-1} . ^1H -NMR (CDCl_3 , 300 MHz): δ 2.39-2.32 (1H, m), 2.19-2.11 (1H, m), 1.90 (1H, d, $J = 12$ Hz), 1.69-1.53 (6H, m), 1.40 (3H, s), 1.35 (1H, d, $J = 12$ Hz), 0.51-0.33 (4H, m). ^{13}C -NMR (CDCl_3 , 75 MHz): δ 79.2, 55.0, 49.4, 49.1, 32.1, 29.2, 27.7, 27.4, 24.1, 14.9, 7.3. Anal. Calcd for $\text{C}_{11}\text{H}_{18}\text{O}$: C, 79.46; H, 10.91. Found: C, 79.75; H, 11.10.

[1*R, 2*S**, 5*S**]-2-Methyl-4-spirocyclopropyl-bicyclo[3.3.0]octan-2-ol (3f) OH negrita**

Colorless oil. ^1H -NMR (CDCl_3 , 300 MHz): δ 2.40 (1H, qd, $J = 8.6$ and 1.9 Hz), 2.13 (1H, ddd, $J = 8.7$, 7.8 and 7.1 Hz), 2.05 (1H, d, $J = 13.1$ Hz), 1.83-1.57 (6H, m), 1.43 (1H, br s), 1.28 (3H, s).

s), 1.09 (1H, dd, $J = 13.1$ and 1.9 Hz), 0.63-0.36 (4H, m). ^{13}C -NMR (CDCl_3 , 75 MHz): δ 81.8, 57.9, 49.2, 47.7, 32.7, 30.8, 27.3, 25.8, 22.9, 17.2, 5.3. MS(EI) m/z : 166 (M^+ , 5%), 148 ($\text{M}^+ - \text{H}_2\text{O}$, 100%), 133, 123.

4-Methyl-3-spirocyclopropyl-bicyclo[2.2.1]heptan-1-ol (3g)

White powder. M. p. = 71-73 °C (hexane). IR (Cl_4C) 3269, 3064 cm^{-1} . ^1H -NMR (CDCl_3 , 300 MHz): δ 2.03-1.95 (1H, m), 1.87 (1H, dd, $J = 11$ and 3.4 Hz), 1.79-1.51 (7H, m), 0.70-0.63 (1H, m), 0.65 (3H, s), 0.37 (1H, ddd, $J = 9.5$, 5.4 and 4.3 Hz), 0.25 (1H, ddd, $J = 10.1$, 6.0 and 4.4 Hz), 0.19-0.14 (1H, m). ^{13}C -NMR (CDCl_3 , 75 MHz): δ 80.9, 50.9, 48.6, 42.5, 36.6, 36.1, 27.8, 15.9, 12.4, 7.6. MS(EI) m/z : 152 (M^+ , 5%), 137, 123. Anal. Calcd for $\text{C}_{10}\text{H}_{16}\text{O}$: C, 78.90; H, 10.59. Found: C, 79.09; H, 10.71.

[1*S*, 3*S*, 6*S*]-3,7,7-Trimethyl-8-spirocyclopropyl-bicyclo[4.3.0]nonan-1-ol (3h)

Colorless oil. $[\alpha]_{\text{D}} = +12.4^\circ$ ($c=0.45$, CHCl_3). IR (film) 3312, 3071 cm^{-1} . ^1H -NMR (CDCl_3 , 300 MHz): δ 2.22 (1H, d, $J = 13.7$ Hz), 1.87 (1H, ddd, $J = 13.0$, 3.8 and 2.2 Hz), 1.76 (1H, ddd, $J = 13.2$, 6.2 and 3.1 Hz), 1.67-1.53 (4H, m), 1.43 (1H, dd, $J = 13.7$ and 1.8 Hz), 1.41-1.35 (1H, m), 1.13 (3H, s), 1.11-0.88 (2H, m), 0.91 (3H, d, $J = 6.5$ Hz), 0.67 (3H, s), 0.55-0.32 (4H, m). ^{13}C -NMR (CDCl_3 , 75 MHz): δ 81.1, 57.7, 48.9, 46.3, 41.1, 33.9, 30.9, 30.1, 28.3, 27.9, 23.4, 22.3, 10.5, 10.2. MS(EI) m/z : 208 (M^+ , 6%), 193, 190. Anal. Calcd for $\text{C}_{14}\text{H}_{24}\text{O}$: C, 80.71; H, 11.61. Found: C, 80.95; H, 11.79.

[1*S**, 7*S**, 8*S**]-7-Isopropyl-8-spirocyclopropyl-bicyclo[4.3.0]nonan-1-ol (3i)

White powder. M. p. = 70-71 °C (hexane). IR (Cl_4C) 3338, 3064 cm^{-1} . ^1H -NMR (CDCl_3 , 300 MHz): δ 1.98-1.87 (1H, m), 1.88 (1H, d, $J = 11.8$ Hz), 1.80 (1H, br s), 1.72-1.43 (7H, m), 1.42-

1.28 (1H, m), 1.18 (1H, d, $J = 11.8$ Hz), 0.90 (3H, d, $J = 7$ Hz), 0.87 (3H, d, $J = 7$ Hz), 0.69-0.61 (1H, m), 0.49-0.45 (1H, m), 0.37-0.26 (2H, m). ^{13}C -NMR (CDCl_3 , 75 MHz): δ 77.0, 52.1, 49.3, 45.6, 34.6, 29.2, 26.1, 21.7, 21.2, 21.1, 18.1, 17.2, 7.9. MS(EI) m/z : 208 (M^+ , 7%), 190, 165 (100), 151, 137.

[1*S, 5*S**]-4-spirocyclopentane-3-spirocyclopropyl-bicyclo[3.3.0]octan-1-ol (3j)**

Colorless oil. IR (film) 3352, 3070 cm^{-1} . ^1H -NMR (CDCl_3 , 300 MHz): δ 2.23 (1H, d, $J = 12.7$ Hz), 1.41 (1H, d, $J = 12.7$ Hz), 2.01-1.2 (15H, m), 0.72 (1H, dt, $J = 12.8$ and 9.1 Hz), 0.52-0.45 (1H, m), 0.29-0.16 (3H, m). ^{13}C -NMR (CDCl_3 , 75 MHz): δ 88.6, 63.0, 53.1, 50.6, 44.1, 38.6, 30.8, 28.4, 28.1, 26.0, 24.1, 23.8, 12.5, 1.1. MS(EI) m/z : 206 (M^+ , 7%), 178 (100), 160, 150. Anal. Calcd for $\text{C}_{14}\text{H}_{22}\text{O}$: C, 81.50; H, 10.75. Found: C, 81.86; H, 10.98.

[1*S, 3*R**, 5*R**, 6*S**]-3-[(Dimethylphenylsilyl)methyl]-5-phenyl-triciclo[4.4.0.0^{3,5}]decan-1-ol (3k)**

Colorless oil. IR (film) 3376, 3058, 3017 cm^{-1} . ^1H -NMR (CDCl_3 , 300 MHz): δ 7.62-7.25 (10H, m), 2.13 (1H, d, $J = 4$ Hz), 2.06 (1H, d, $J = 13.6$ Hz), 1.96-1.90 (2H, m), 1.82 (1H, d, $J = 13.6$ Hz), 1.75-1.54 (3H, m), 1.49 (1H, d, $J = 14.4$ Hz), 1.45-1.32 (3H, m), 1.10 (1H, br s), 0.72 (1H, d, $J = 14.4$ Hz), 0.54 (1H, d, $J = 4$ Hz), 0.49 (3H, s), 0.40 (3H, s), 0.35 (1H, d, $J = 11$ Hz), 0.26 (1H, d, $J = 11$ Hz). ^{13}C -NMR (CDCl_3 , 75 MHz): δ 142.1, 140.1, 133.6, 131.9, 128.8, 127.7, 127.6, 125.9, 78.8, 52.6, 46.2, 41.6, 38.9, 30.8, 29.2, 25.8, 23.8, 23.3, -1.7. MS(EI) m/z : 376 (M^+ , 5%), 358 ($\text{M}^+ - \text{H}_2\text{O}$, 25%), 135 (PhMe_2Si , 100%). Anal. Calcd for $\text{C}_{25}\text{H}_{32}\text{SiO}$: C, 79.73; H, 8.56. Found: C, 80.04; H, 8.85.