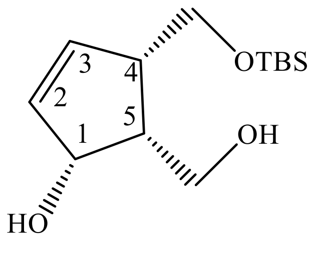
Electronic supplementary materials *Mendeleev Commun.*, 2018, **28**, 546–547

Enantiopure vicinally trisubstituted all-*cis*-bis(hydroxymethyl)cyclopentenols and their derivatives

Airat M. Gimazetdinov, Aidar Z. Almukhametov, Vladimir V. Loza, Leonid V. Spirikhin and Mansur S. Miftakhov

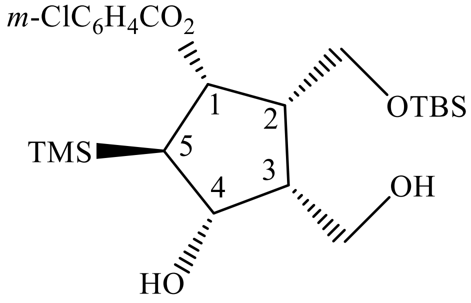
Solvents were purified and dried by standard procedures before use. Reagents were generally the best quality commercial grade and used without further purification unless indicated. All reactions were carried out in oven-dried glassware. TLC was performed using Sorbfil STC-1A (110 µm layer, silica gel 5-17 precoated foil plates). Column chromatography was conducted using 210–280 mesh silica gel. Optical rotations were measured using the sodium D line at 589 nm on a Perkin–Elmer, Model 241 MC polarimeter at 20 °C. IR spectra were recorded on a Shimadzu IR Prestige-21 spectrometer in Nujol mulls or as neat thin films on KBr plates (film) and were reported in reciprocal centimeters (cm^{-1}). ^{1}H and ^{13}C NMR spectra were obtained using a Bruker AM-300 (300 MHz for ^{1}H and 75.47 MHz for ^{13}C) or BrukerAvance III (500 MHz for ^{1}H and 125.77 MHz for ^{13}C) as solutions in CDCl$_3$, CD$_3$OD or *d*-acetone (Aldrich Chemical Company; spectra grade). Chemical shifts are reported in ppm (δ scale) downfield from tetramethylsilane as the internal reference. Splitting patterns are designated as s, singlet; br s, broad singlet; d, doublet, t, triplet; q, quartet; quint., quintet. Mass spectra were recorded on Shimadzu LCMS QP-2010EV (APCI) spectrometer. Elemental analyses were carried on a Euro EA 3000 CHNS-analyzer.

*Compounds **2** and **3**.* A solution of mCPBA (75%, 0.29 g, 1.28 mmol) in CH$_2$Cl$_2$ (20 ml) was added to a solution of olefin **1** (0.20 g, 0.64 mmol) in CH$_2$Cl$_2$ (15 ml) at 0 °C. After stirring for 15 min, the reaction solution was heated to room temperature and stirred for 2 h (TLC monitoring, petroleum ether/ethyl acetate, 1:1). Saturated solution of Na$_2$S$_2$O$_3$ (5 ml) was added, and the mixture was stirred for 1 h. The organic layer was separated and washed with 5% aqueous solution of NaHCO$_3$ (15 ml). The aqueous layer was extracted with CH$_2$Cl$_2$ (3x15 ml), the combined organic extracts were dried over MgSO$_4$ and evaporated under reduced pressure. Column chromatography (petroleum ether/ethyl acetate, 1:1) afforded compounds **2** and **3**.



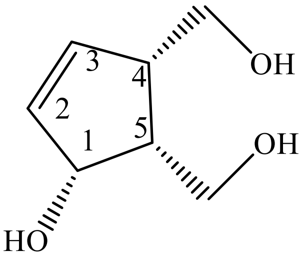
(1R,4S,5R)-4-[tert-Butyl(dimethyl)silyloxymethyl]-5-(hydroxymethyl)cyclopent-2-en-1-ol **2**. Yield 0.11 g (63%), transparent viscous oil; ^{1}H NMR (500 MHz, CDCl$_3$) δ: 6.11 (dt, *J* 1.7, 5.7 Hz, 1H, C^{2}H), 5.48 (dd, *J* 2.3, 5.8 Hz, 1H, C^{3}H), 4.54-4.62 (br.s, 1H, C^{1}H), 4.02 (dd, *J* 8.3, 11.1 Hz, 1H,

$C\underline{H}_{\alpha}H_{\beta}$-OH), 3.85 (dd, *J* 7.2, 11.3 Hz, 1H, $CH_{\alpha}\underline{H}_{\beta}$-OH), 3.69 (dd, *J* 2.3, 10.5 Hz, 1H, $C\underline{H}_{\alpha}H_{\beta}$-OSi), 3.64 (dd, *J* 3.1, 10.5 Hz, 1H, $CH_{\alpha}\underline{H}_{\beta}$-OSi), 3.03-3.10 (br.s, 1H, OH), 2.81-2.86 (m, 1H, C^4H), 2.48 (quint, *J* 7.0 Hz, 1H, C^5H), 2.25-2.40 (br.s, 1H, OH), 0.93 (s, 9H, $(CH_3)_3C$), 0.06 (s, 6H, $(CH_3)_2Si$); ^{13}C NMR (125.76 MHz, $CDCl_3$) δ: 135.58 (C^3), 135.22 (C^2), 74.85 (C^1), 60.68 (CH_2OSi), 60.12 (CH_2OH), 47.10 (C^5), 37.63 (C^4), 25.94 ($(\underline{C}H_3)_3C$), 18.48 ($(CH_3)_3\underline{C}$),-5.53 ($(CH_3)_2Si$); IR (ν/cm^{-1}): 3386, 2955, 2930, 1472, 1256, 1029, 838, 779; MS-ACPI: *m/z* 259 [*M*+H]$^+$; Found (%): C, 60.16; H, 9.96. Calc. for $C_{13}H_{26}O_3Si$ (%): C, 60.34; H, 10.05; R_f (petroleum ether/ethyl acetate, 1:1) 0.6; $[\alpha]_D^{20}$ -39.5 (c 0.9, CH_2Cl_2).



(1R,2S,3R,4S,5R)-2-[tert-Butyl(dimethyl)silyloxymethyl]-4-hydroxy-3-hydroxymethyl-5-(trimethylsilyl)cyclopentyl 3-chlorobenzoate **3**. Yield 0.09 g (29%), transparent viscous oil; ^1H NMR (500 MHz, $CDCl_3$) δ: 7.40, 7.56, 7.90, 7.99 (4H, Ph), 5.23 (dd, *J* 7.1, 8.0 Hz, 1H, C^1H), 4.18 (dd, *J* 3.4, 5.8 Hz, 1H, C^4H), 4.00 (dd, *J* 7.8, 11.3 Hz, 1H, $CH_{\alpha}\underline{H}_{\beta}$-OH), 3.90 (dd, *J* 5.8, 11.3 Hz, 1H, $C\underline{H}_{\alpha}H_{\beta}$-OH), 3.77 (dd, *J* 4.7, 11.0 Hz, 1H, $CH_{\alpha}\underline{H}_{\beta}$-OSi), 3.67 (dd, *J* 3.6, 11.0 Hz, 1H, $C\underline{H}_{\alpha}H_{\beta}$-OSi), 2.56 (dddd, *J* 3.6, 4.7, 6.4, 7.3 Hz, 1H, C^2H), 2.20 (m, 1H, C^3H), 1.48 (dd, *J* 3.4, 8.2 Hz, 1H, C^5H), 0.88 (s, 9H, $(CH_3)_3C$), 0.02 (s, 6H, $(CH_3)_2Si$), 0.01 (s, 9H, $(CH_3)_3Si$); ^{13}C NMR (125.76 MHz, $CDCl_3$) δ: 164.96 (C=O), 127.70, 129.60, 129.81, 131.58, 133.24, 134.66 (Ph), 77.84 (C^1), 73.67 (C^4), 60.37 (CH_2OH), 59.34 (CH_2OSi), 47.02 (C^3), 44.67 (C^2), 42.02 (C^5), 25.78 ($(\underline{C}H_3)_3C$), 18.23 ($(CH_3)_3\underline{C}$), -3.06 c ($(CH_3)_3Si$), -5.69 ($(CH_3)_2Si$); IR (ν/cm^{-1}): 3347, 2954, 2929, 1721, 1291, 1255, 837, 749. MS-ACPI: *m/z* 488 [*M*+H]$^+$; Found (%): C, 56.55; H, 7.87. Calc. for $C_{23}H_{39}O_5Si_2$ (%): C, 56.67; H, 8.0; R_f (petroleum ether/ethyl acetate, 1:1) 0.4; $[\alpha]_D^{20}$ +8.0 (c 0.77, CH_2Cl_2).

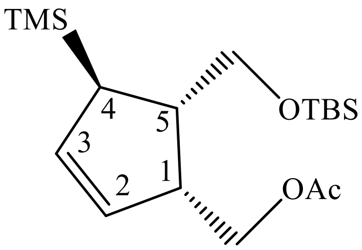
(1R,4S,5R)-4,5-Bis(hydroxymethyl)cyclopent-2-en-1-ol **4**.



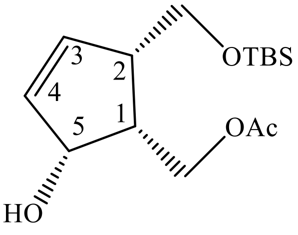
Method A. To a stirred solution of ester **3** (0.10 g, 0.21 mmol) in THF (25 ml) at room temperature was added TBAF (1 *M* THF solution, 0.3 ml, 0.30 mmol). The reaction course was monitored by TLC (petroleum ether/ethyl acetate, 1:1), and after 4 h the solution was evaporated under reduced pressure. Purification of products by column chromatography (chloroform/methanol, 10:1) afforded 0.03 g (89%) of title compound a colorless oily liquid. ^1H NMR (500 MHz, $CDCl_3$) δ: 6.07 (dt, *J* 2.0, 5.7 Hz, 1H, C^2H), 5.92 (dd, *J* 2.7, 5.7 Hz, 1H, C^3H), 4.63 (dd, *J* 2.3, 6.1 Hz, 1H, C^1H), 3.97 (dd, *J* 7.8, 11.0 Hz, 1H, $CH_{\alpha}\underline{H}_{\beta}O$), 3.89 (dd, *J* 6.5, 11.2 Hz, 1H, $C\underline{H}_{\alpha}H_{\beta}O$), 3.59-3.68 (m, 2H, $C'H_2O$), 2.90-3.90 (br. s, 3H, OH), 2.82-2.85 (m, 1H, C^4H), 2.43 (quint., *J* 7.3 Hz, 1H, C^5H); ^{13}C

NMR (125.76 MHz, $CDCl_3$) δ: 136.13 (C^3), 134.95 (C^2), 75.16 (C^1), 60.11 (CH_2O), 59.41 ($C'H_2O$), 47.18 (C^4), 46.00 (C^5); IR (ν/cm^{-1}): 3327, 2923, 1437, 1069, 1010, 966, 753; MS-ACPI: *m/z* 145 $[M+H]^+$; Found (%): C, 58.21; H, 8.17. Calc. for $C_7H_{12}O_3$ (%): C, 58.33; H, 8.33. R_f (chloroform/methanol, 10:1) 0.25; $[\alpha]_D^{20}$ +8.0 (c 1.04, CH_2Cl_2).

Method B. To a stirred solution of compound **6** (0.10 g, 0.33 mmol) in MeOH (25 ml) at room temperature was added Dowex® resin (0.20 g). The reaction course was monitored by TLC (petroleum ether/ethyl acetate, 1:1), and after 6 h the resin was removed by filtration through a short pad of Celite and washed with EtOAc (3x15 ml). The filtrate was concentrated under reduced pressure and the residue was purified by column chromatography on silica gel (chloroform/methanol, 10:1) to furnish the title compound (0.04 g, 84%) as a colorless oily liquid.



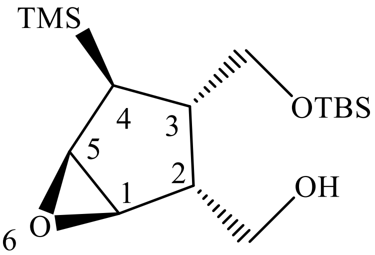
{(1R,4R,5S)-5-[tert-Butyl(dimethyl)silyloxymethyl]-4-(trimethylsilyl)cyclopent-2-en-1-yl}methyl acetate **5**. To a stirred solution of compound **1** (0.22 g, 0.70 mmol) in pyridine (3 ml) at room tmperature was added acetic anhydride (1 ml). The reaction was monitored by TLC (petroleum ether/ethyl acetate, 20:1) and after stirring for 3 h the solution was evaporated under reduced pressure. Column chromatography (petroleum ether/ethyl acetate, 20:1) afforded 0.22 g (87%) of the title compound as a colorless oily liquid. ^1H NMR (500 MHz, *d*-acetone) δ: 5.81 (dt, *J* 2.5, 5.7 Hz, 1H, C^3H), 5.55 (dt, *J* 2.0, 5.7 Hz, 1H, C^2H), 4.32 (dd, *J* 6.5, 10.8 Hz, 1H, $C\underline{H}_{\alpha}H_{\beta}$-OH), 4.10 (dd, *J* 8.1, 10.8 Hz, 1H, $CH_{\alpha}\underline{H}_{\beta}$-OH), 3.72 (dd, *J* 6.9, 9.8 Hz, 1H, $CH_{\alpha}\underline{H}_{\beta}$-OSi), 3.57 (dd, *J* 7.0, 9.8 Hz, 1H, $C\underline{H}_{\alpha}H_{\beta}$-OSi), 3.03-3.12 (m, 1H, C^1H), 2.50-2.58 (m, 1H, C^5H), 1.92-1.96 (m, *J* 2.1 Hz, 1H, C^4H), 2.04 (s, 3H, CH_3CO), 0.95 c (9H, $(CH_3)_3C$), 0.11 (s, 6H, $(CH_3)_2Si$), 0.07 (s, 9H, $(CH_3)_3Si$); ^{13}C NMR (125.76 MHz, $CDCl_3$) δ: 170.06 (C=O), 132.78 (C^3), 127.37 (C^2), 64.36 (CH_2OAc), 63.47 (CH_2OSi), 46.98 (C^1), 43.70 (C^5), 38.41 (C^4), 25.46 ($(\underline{C}H_3)_3C$), 20.05 ($\underline{C}H_3CO$), 17.92 ($(CH_3)_3\underline{C}$), -3.56 ($(CH_3)_3Si$), -6.11 ($(CH_3)_2Si$); IR (ν/cm^{-1}): 2955, 2929, 2897, 2857, 1743, 1472, 1249, 1085, 836, 775, 736. MS-ACPI: *m/z* 357 $[M+H]^+$; Found (%): C, 60.19; H, 9.96. Calc. for $C_{18}H_{36}O_3Si_2$ (%): C, 60.56; H, 10.09. R_f (petroleum ether/ethyl acetate, 20:1) 0.6; $[\alpha]_D^{20}$ +138.5 (c 1.25, CH_2Cl_2).



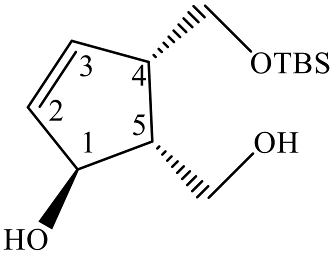
{(1R,2S,5R)-2-[tert-Butyl(dimethyl)silyloxymethyl]-5-hydroxycyclopent-3-en-1-yl}methyl acetate **6**. Allylsilane **5** (0.20 g, 0.56 mmol) was treated as described in the synthesis of compounds **2** and **3** to afford the title compound (0.13 g, 75%) as a transparent viscous oil. ^1H NMR (500 MHz,

$CDCl_3$) δ: 6.08 (ddd, *J* 2.0, 2.6, 5.7 Hz, 1H, C^4H), 5.79 (dd, *J* 2.8, 5.7 Hz, 1H, C^3H), 4.43 (ddd, *J* 2.6, 5.9, 11.8 Hz, 1H, C^5H), 4.36 (dd, *J* 6.5, 10.8 Hz, 1H, $CH_\alpha\underline{H}_\beta$-OAc), 4.28 (dd, *J* 7.4, 11.1 Hz, 1H, $C\underline{H}_\alpha H_\beta$-OAc), 3.61 (dd, *J* 2.4, 10.7 Hz, 1H, $CH_\alpha\underline{H}_\beta$-OSi), 3.59 (dd, *J* 2.3, 10.6 Hz, 1H, $C\underline{H}_\alpha H_\beta$-OSi), 2.97 (d, *J* 11.8 Hz, 1H, OH), 2.78 (tdd, *J* 2.4, 2.8, 6.7 Hz, 1H, C^2H), 2.45 (ddd, *J* 6.1, 7.7, 15.3 Hz, 1H, C^1H), 2.07 (s, 3H, CH_3), 0.86 (s, 9H, $(CH_3)_3C$), 0.06 c (6H, $(CH_3)_2Si$); ^{13}C NMR (125.76 MHz, $CDCl_3$) δ: 171.21 (C=O), 135.50 (C^4), 135.06 (C^3), 74.06 (C^5), 62.06 (CH_2OAc), 60.07 (CH_2OSi), 46.97 (C^2), 43.49 (C^1), 25.86 ($(\underline{C}H_3)_3C$), 21.13 ($\underline{C}H_3CO$), 18.48 ($(CH_3)_3\underline{C}$), -5.56 ($(CH_3)_2Si$); IR (ν/cm^{-1}): 3460, 2955, 2930, 2858, 1743, 1472, 1356, 1254, 1033, 838, 780; MS-ACPI: *m/z* 301 [*M*+H]$^+$; Found (%): C, 59.78; H, 9.19. Calc. for $C_{15}H_{28}O_4Si$ (%): C, 59.90; H, 9.32. R_f (petroleum ether/ethyl acetate, 5:1) 0.5; $[\alpha]_D^{20}$ -48.4 (c 1.1, CH_2Cl_2).

Compounds ***2*** *and* ***8***. In a round-bottom flask was placed 0.96 g (11.4 mmol) of solid $NaHCO_3$ and 12 mL of water followed by 18 mL of acetone were added. The resulting mixture was cooled to 0°C and stirred for 20 min. Further was added 0.96 g (1.96 mmol) of Oxone in one portion and stirring was continued at 0°C for 15 min. Then, was added 0.30 g (0.96 mmol) of silane **1** in one portion. Cooling was removed and the reaction mixture was stirred at rt for 1 h. After this time, TLC showed that the reaction was complete (petroleum ether/ethyl acetate, 5:1). The reaction mixture was diluted with 20 mL of water and extracted with EtOAc (3×30 mL). The combined organic layers were dried ($MgSO_4$) and solvent was evaporated in vacuo. Purification of the products by column chromatography (petroleum ether/ethyl acetate, 5:1) afforded products **8** and **2**. *Compound* **2**. Yield 0.23 g (68%), colorless oily liquid. Spectral and analytical data are identical to those described above.



((1R,2R,3S,4S,5R)-3-(((tert-butyldimethylsilyl)oxy)methyl)-4-(trimethylsilyl)-6-oxabicyclo[3.1.0]hexan-2-yl)methanol **8**. Yield 0.05 g (17%), transparent viscous oil. ^1H NMR (500 MHz, *d*-acetone) δ: 3.76-3.84 (m, 2H, $C\underline{H_2}$-OH), 3.64 (dd, *J* 9.0, 10.4 Hz, 1H, $CH_\alpha\underline{H}_\beta$-OSi), 3.55-3.62 (m, 2H, $C\underline{H}_\alpha H_\beta$-OSi, C^5H), 3.45 (dd, *J* 2.6, 16.4 Hz, 1H, C^1H), 2.82 (s, 1H, OH), 2.32-2.37 (m, 1H, C^2H), 1.93-2.02 (m, 1H, C^3H), 1.25-1.30 (m, 1H, C^4H), 0.89 (s, 9H, $(CH_3)_3C$), 0.11 (s, 6H, $(CH_3)_2Si$), 0.07 (s, 9H, $(CH_3)_3Si$); ^{13}C NMR (125.76 MHz, $CDCl_3$) δ: 62.07 (CH_2OSi), 59.55 (CH_2OH), 59.20 (C^1), 58.45 (C^5), 44.59 (C^2), 40.94 (C^3), 31.95 (C^4), 25.33 ($(\underline{C}H_3)_3C$), 17.81 ($(CH_3)_3\underline{C}$), -2.08 ($(CH_3)_3Si$), -6.12 ($(CH_3)_2Si$); IR (ν/cm^{-1}): 3445, 2954, 2929, 2898, 2857, 1471, 1250, 1099, 837, 776; MS-ACPI: *m/z* 331 [*M*+H]$^+$; Found (%): C, 57.92; H, 10.02. Calc. for $C_{16}H_{34}O_3Si_2$ (%): C, 58.08; H, 10.28. R_f (petroleum ether/ethyl acetate, 5:1) 0.4; $[\alpha]_D^{20}$ +40.0 (c 1.0, CH_2Cl_2).



(1S,4S,5R)-4-[tert-Butyl(dimethyl)silyloxymethyl]-5-(hydroxymethyl)cyclopent-2-en-1-ol **9**. To a stirred solution of epoxide **8** (0.10 g, 0.30 mmol) in MeOH (5 ml) at room temperature was added dropwise solution of acetic acid (0.25 ml) in methanol (5 ml). The reaction was monitored by TLC (petroleum ether/ethyl acetate, 1:1) and after stirring for 56 h the solution was neutralized with saturated $NaHCO_3$ (pH=8). The organic solvent was evaporated under reduced pressure, and the residue was extracted with EtOAc (3×15 ml). The combined organic layers were dried ($MgSO_4$) and the solvent was evaporated in vacuo. Column chromatography (petroleum ether/ethyl acetate, 1:1) afforded 0.07 g (88%) of the title compound as a colorless oily liquid. ^{1}H NMR (500 MHz, $CDCl_3$) δ: 5.93 (d, *J* 5.7 Hz, 1H, C^3H), 5.79 (s, 1H, C^2H), 4.75 (d, *J* 6.8 Hz, 1H, C^1H), 3.90-3,99 (m, 2H, $C\underline{H}_2$-OH), 3.68 (dd, *J* 2.8, 10.7 Hz, 1H, $C\underline{H}_{\alpha}H_{\beta}$-OSi), 3.56 (t, *J* 10.4 Hz, 1H, $CH_{\alpha}\underline{H}_{\beta}$-OSi), 3.10 (br. s, 1H, C^4H), 2.35 (quint., *J* 7.0 Hz, 1H, C^5H), 1.90-2.60 (br. s, 2H, OH), 0.94 (s, 9H, $(CH_3)_3C$), 0.11 (s, 6H, $(CH_3)_2Si$); ^{13}C NMR (125.76 MHz, $CDCl_3$) δ: 135.58 (C^2), 135.22 (C^3), 78.95 (C^1), 63.02 (CH_2OSi), 61.31 (CH_2OH), 53.46 (C^5), 49.12 (C^4), 25.84 ($(\underline{C}H_3)_3C$), 18.22 ($(CH_3)_3\underline{C}$), -5.53 ($(CH_3)_2Si$); IR (ν/cm^{-1}): 3318, 2955, 2928, 2856, 1471, 1255, 1095, 1051, 837, 777; MS-ACPI: *m/z* 259 $[M+H]^+$; Found (%): C, 60.12; H, 9.88. Calc. for $C_{13}H_{26}O_3Si$ (%): C, 60.34; H, 10.05. R_f (petroleum ether/ethyl acetate, 1:1) 0.5; $[\alpha]_D^{20}$ -107.0 (c 0.6, CH_2Cl_2).