

Tagging alcohols with cyclic carbonate: a versatile equivalent of (meth)acrylate for ring-opening polymerization

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Electronic Supplementary Information

Experimental

Materials and methods.

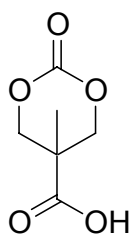
Reagents were available commercially from Aldrich and used as received unless otherwise noted. TU was prepared as previously reported;¹ TU, 4-pyrene-1-butanol (99%) and 1,5,7-triazabicyclo[4.4.0]dec-5-ene (TBD; 98%) were dried by stirring in dry THF with CaH₂, filtering, and removing solvent *in vacuo*; 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU; 98%) was stirred over CaH₂, vacuum distilled, then stored over molecular sieves (3 Å). Melting points of small molecules were determined with a capillary tube melting point apparatus and are uncorrected. Mass spectrometry service (high resolution electrospray ionization, HR-ESI-MS) was provided by Stanford University Mass Spectrometry. ¹H- and {¹H} ¹³C-NMR spectra were obtained on a Bruker Avance 400 instrument operated at 400 MHz and 100 MHz, respectively, using CDCl₃ solutions unless noted otherwise. Gel permeation chromatography (GPC) was performed in THF at 30 °C using a Waters chromatograph equipped with four 5 μm Waters columns (300 mm x 7.7 mm) connected in series with increasing pore size (10, 100, 1000, 10⁵, 10⁶ Å), a Waters 410 differential refractometer for refractive index (RI) detection and a 996 photodiode array detector, and calibrated with polystyrene standards (750 - (2 x 10⁶) g/mol).

Synthesis of **1a**: MTC-OBn²

(i) A mixture of bis-MPA (45.0 g, 0.336 mol), potassium hydroxide (88% assay; 21.5 g, 0.338 mol), and DMF (250 mL) was heated to 100°C for 1 h at which point a homogenous solution was formed. Benzyl bromide (69.0 g, 0.404 mol) was added to the warm solution, and stirring was continued at 100°C for 16 h. The reaction was cooled and the solvent was removed under vacuum. Ethyl acetate (300 mL), hexanes (300 mL), and water (200 mL) were added to the residue. The organic layer was retained, washed with water (200 mL), dried (MgSO₄), and evaporated. The resulting solid was recrystallized from toluene (~1.2 ml/g crude) to give pure benzyl 2,2-bis(methylol)propionate (46 g, 61%).

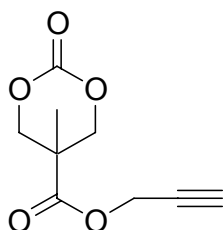
(ii) Benzyl 2,2-bis(methylol)propionate (22.4 g, 0.100 mol) was dissolved in CH₂Cl₂ (300 mL) and pyridine (50 mL, 0.6 mol) and the solution was chilled to -78°C under N₂. A solution of triphosgene (15.0 g, 50.0 mmol) in CH₂Cl₂ was added dropwise over 1 h, at which point the reaction mixture was allowed to warm to room temperature for 2 h. The reaction was quenched by addition of saturated aqueous NH₄Cl (150 mL), after which the organic layer was washed with 1 M aqueous HCl (3 x 200 mL), saturated aqueous NaHCO₃ (1 x 200 mL), dried (MgSO₄), filtered and evaporated to give **2a** as a white solid (pinkish in some preparations) (24.3 g, 97%). Characterization data matched the literature.³ Material for polymerization was purified by recrystallization from ethyl acetate.

1: MTC-OH⁴



A mixture of crude **2a** (24.3 g, 97 mmol), ethyl acetate (250 mL), and Pd/C (10% w/w, 1.6 g) was swirled under H₂ (3 atm) for 24 h. After evacuation of the H₂ atmosphere, THF (250 mL) was added and the mixture was filtered through THF-wetted Celite. Additional THF was used to ensure complete transfer. The collected washings were evaporated to give MTC-OH as a white solid that was used without further purification (15.6 g, 99+%). Characterization matched the literature.

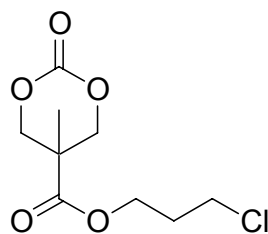
1b (MTC-OCH₂CCH).



MTC-OH (1.6 g, 10 mmol) was dissolved in THF (50 mL) with 3 drops of DMF. A solution of oxalyl chloride (1.3 g, 10 mmol) in THF (20 mL) was added, and the solution was stirred under a flow of N₂ for 1 h before volatiles were removed under vacuum to leave a slowly crystallizing white solid. ¹H-NMR analysis of the residue indicated quantitative conversion to the acyl chloride. The solid was redissolved in THF (25 mL) and a solution of propargyl alcohol (0.56 g, 10 mmol) and triethylamine (1.1 g, 11 mmol) in THF was added in a single portion, causing a white precipitate to form immediately. The mixture was stirred for 3 h before it was filtered and the filtrate evaporated. Purification by column chromatography (silica, 1:1 ethyl acetate/hexanes) provided the desired product as an oil that slowly solidified to a white solid, mp 70-72°C. Yield: 1.0 g (51%). ¹H-NMR: δ 4.80 (d, *J* = 2.4 Hz, 2H, OCH₂CCH), 4.72 (d, *J* = 10.8 Hz, 2H, CH_aH_b), 4.24 (d, *J* = 10.8 Hz, 2H, CH_aH_b), 2.55 (t, *J* = 2.4 Hz, 1H, OCH₂CCH), 1.38 (s, 3H, CCH₃). ¹³C-NMR: δ 170.8,

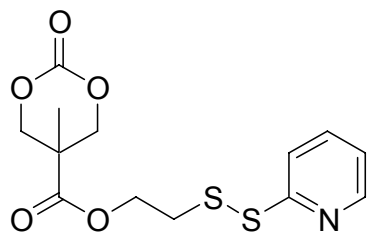
147.7, 76.8, 76.4, 73.2, 53.9, 40.6, 17.8. HR-ESI-MS: m/z calculated for $C_9H_{10}O_5 + Na$ 221.0426; found 221.0435.

1c: MTC- $OCH_2CH_2CH_2Cl$



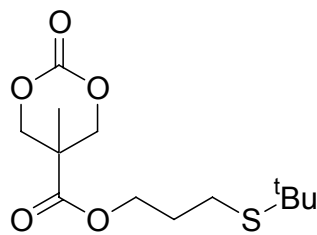
This compound was prepared by the same procedure used for **1b** on a 12.5 mmol scale, using 3-chloropropanol as the alcohol and pyridine in place of triethylamine. For purification, the crude product was redissolved in CH_2Cl_2 (200 mL), the solution was washed with water (3 x 150 mL), the organic layer was retained and dried over $MgSO_4$, and the solvent was removed *in vacuo* to give the product as a clear oil; after standing for several days it formed crystals, mp 34-37°C. Yield: 2.1 g, 70%. 1H -NMR: δ 4.62 (d, J = 10.8 Hz, 2H, CH_aH_b), 4.31 (t, J = 6.0 Hz, 2H, OCH_2CH_2), 4.15 (d, J = 10.8 Hz, 2H, CH_aH_b), 3.55 (t, J = 6.0 Hz, 2H, CH_2Cl), 2.08 (quin, J = 6.0 Hz, 2H, $CH_2CH_2CH_2$), 1.27 (s, 3H, CCH_3). ^{13}C -NMR: δ 171.4, 147.8, 73.4, 63.4, 41.2, 40.7, 31.5, 17.9. HR-ESI-MS: m/z calculated for $C_9H_{13}ClO_5 + Na$ 259.0350, found 259.0353.

1d: MTC- $OCH_2CH_2SS(2-Py)$



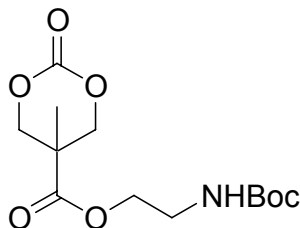
This compound was prepared by the same procedure used for **1b** on half-scale (5 mmol), using *S*-2-pyridyl-*S'*-2-hydroxyethyl disulfide (0.94 g, 5.0 mmol) as the alcohol,⁵ and was purified by column chromatography (silica, 1:1 ethyl acetate/hexanes) to give the product as a waxy solid, mp 64-65°C. Yield: 0.70 g (47%). 1H -NMR: δ 8.49 (m, 1H, ArH), 7.67 (m, 2H, ArH), 7.14 (m, 1H, ArH), 4.70 (d, J = 10.8 Hz, 2H, CH_aH_b), 4.49 (t, J = 6.4 Hz, 2H, $COOCH_2$), 4.21 (d, J = 10.8 Hz, 2H, CH_aH_b), 3.08 (t, J = 6.4 Hz, 2H, SCH_2), 1.35 (s, 3H, CCH_3). ^{13}C -NMR: δ 171.3, 159.5, 150.2, 147.8, 137.6, 121.5, 120.4, 73.3, 64.1, 40.7, 37.3, 18.0. HR-ESI-MS: m/z calculated for $C_{13}H_{15}NO_5S_2 + Na$ 352.0290; found 352.0294.

1e: MTC- $OCH_2CH_2CH_2S^tBu$



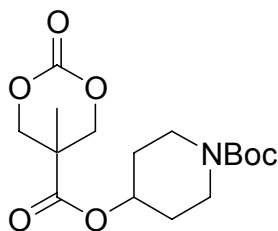
This compound was prepared by the same procedure used for **1b**, using 3-*tert*-butylsulfido-1-propanol (1.48 g, 10 mmol) as the alcohol,⁶ and was purified by column chromatography (silica, 1:1 ethyl acetate/hexanes) to give the product as an oil. Yield: 1.5 g (52%). 1H -NMR: δ 4.62 (d, J = 11.0 Hz, 2H, OCH_aH_b), 4.23 (t, J = 6.4 Hz, 2H, OCH_2CH_2), 4.14 (d, J = 11.0 Hz, 2H, OCH_aH_b), 2.52 (t, J = 7.2 Hz, 2H, SCH_2), 1.89 (m, 2H, $CH_2CH_2CH_2$), 1.27 (s, 3H, CCH_3), 1.25 (s, 9H, $C(CH_3)_3$). ^{13}C -NMR: δ 171.4, 147.8, 73.4, 65.5, 42.6, 40.6, 31.3, 29.1, 24.9, 18.0. HR-ESI-MS: m/z calculated for $C_{13}H_{22}O_5S + Na$ 313.1086; found 313.1086.

1f: *MTC-OCH₂CH₂NHBoc*



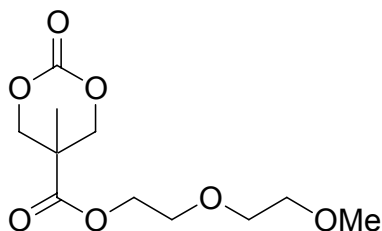
This compound was prepared by the same procedure used for **1b**, using *N*-Boc-ethanolamine (1.6 g, 10 mmol) as the alcohol, and was purified by column chromatography (silica, 1:1 ethyl acetate/hexanes) to give the product as a solid, mp 52-55°C. Yield: (%). ¹H-NMR: δ 4.88 (br, 1H, NH), 4.69 (d, *J* = 10.8 Hz, 2H, CH_aH_b), 4.26 (t, *J* = 5.2 Hz, 2H, OCH₂CH₂), 4.21 (d, *J* = 10.8 Hz, 2H, CH_aH_b), 3.42 (m, 2H, CH₂CH₂NH), 1.44 (s, 9H, C(CH₃)₃), 1.34 (s, 3H, CCH₃). ¹³C-NMR: δ 171.5, 156.3, 148.0, 80.1, 73.4, 65.8, 40.6, 39.8, 28.7, 17.8. HR-ESI-MS: *m/z* calculated for C₁₃H₂₁NO₇ + Na 326.1216; found 326.1216.

1g: *MTC-O-(4-(N-Boc)piperidinyl)*



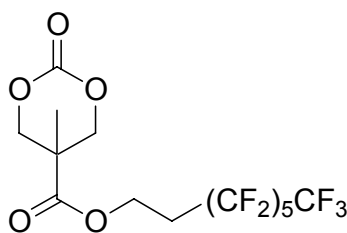
This compound was prepared by the same procedure used for **1b**, using 1-Boc-4-hydroxypiperidine (2.0 g, 10 mmol) as the alcohol, and was purified by column chromatography (silica, 1:1 ethyl acetate/hexanes) to give the product as a white solid, mp 121-123°C. Yield: 1.1 g (32%). ¹H-NMR: δ 5.05 (m, 1H, COOCH), 4.69 (d, *J* = 10.8 Hz, 2H, OCH_aH_b), 4.22 (d, *J* = 10.8 Hz, 2H, OCH_aH_b), 3.65 (m, 2H, NCH_aH_b), 3.30 (m, 2H, NCH_aH_b), 1.87 (m, 2H, NCH₂CH_aH_b), 1.66 (m, 2H, NCH₂CH_aH_b), 1.46 (s, 9H, C(CH₃)₃), 1.33 (s, 3H, CCH₃). ¹³C-NMR: δ 170.9, 155.0, 147.8, 80.3, 73.4, 72.3, 40.8 (br), 30.6, 28.8, 17.8. HR-ESI-MS: *m/z* calculated for C₁₆H₂₅NO₇ + Na 366.1529; found 366.1525.

1h: *MTC-OCH₂CH₂OCH₂CH₂OMe*



This compound was prepared by the same procedure used for **1b**, using diethylene glycol methyl ether (1.2 g, 10 mmol) as the alcohol, and was purified by column chromatography (silica, 1:1 ethyl acetate/hexanes) to give the product as a clear oil. Yield: 0.9 g (34%). ¹H-NMR: δ 4.71 (d, *J* = 10.8 Hz, 2H, CH_aH_b), 4.37 (m, 2H, COOCH₂CH₂), 4.21 (d, *J* = 10.8 Hz, 2H, CH_aH_b), 3.72 (m, 2H, COOCH₂CH₂), 3.62 (m, 2H, OCH₂CH₂O), 3.54 (m, 2H, OCH₂CH₂O), 3.38 (s, 3H, OCH₃), 1.35 (s, 3H, CCH₃). ¹³C-NMR: δ 171.4, 147.9, 73.4, 72.2, 70.9, 69.1, 65.3, 59.4, 40.6, 17.9. HR-ESI-MS: *m/z* calculated for C₁₁H₁₈O₇ + Na 285.0951; found 285.0950.

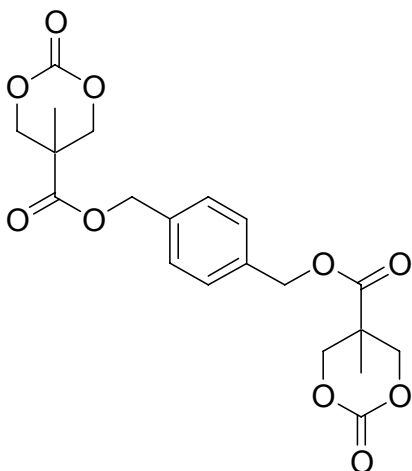
1i: *MTC-OCH₂CH₂(CF₂)₅CF₃*



This compound was prepared by the same procedure used for **1b**, using 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluoro-1-octanol (3.64 g, 10 mmol) as the alcohol, and was purified by column chromatography (silica, 1:1 ethyl acetate/hexanes) to give the product as a white solid, mp 53-55°C. Yield: 1.3 g (26%). ¹H-NMR: δ 4.71 (d, *J* = 10.8 Hz, 2H, CH_aH_b), 4.54 (t, *J* = 6.4 Hz, 2H, COOCH₂), 4.23 (d, *J* = 10.8 Hz, 2H, CH_aH_b), 2.54 (m, 2H, CH₂CH₂CF₂), 1.35 (s, 3H, CCH₃). ¹³C-NMR: δ

171.1, 147.7, 125-105 (br, C-F), 73.1, 58.4, 40.6, 30.6 (t, $J = 21.6$ Hz), 17.7. HR-ESI-MS: m/z calculated for $C_{14}H_{11}F_{13}O_5 + Na$ 529.0297; found 529.0291.

1j: MTC-OCH₂-C₆H₄-CH₂O-MTC



This compound was prepared by the same procedure used for **1b**, using benzene-1,4-dimethanol (0.69 g, 5 mmol) as the alcohol. The product precipitated from THF and was isolated with NEt₃HCl by filtration. Washing of the solid with 1 M HCl(aq) and further filtration gave the product as a white solid, mp >180°C. Yield: 1.04 g (49%). ¹H-NMR (DMSO-*d*₆): δ 7.39 (s, 4H, ArH), 5.23 (s, 4H, ArCH₂), 4.60 (d, $J = 10.8$ Hz, 4H, CH_aH_b), 4.39 (d, $J = 10.8$ Hz, 4H, CH_aH_b), 1.21 (s, 6H, CCH₃). ¹³C-NMR (DMSO-*d*₆): δ 171.8, 147.5, 135.9, 128.1, 72.8, 66.8, (~40 – obscured by solvent), 16.7. HR-ESI-MS: m/z calculated for C₂₀H₂₂O₁₀ 445.1111; found 445.1108.

Example procedure: polymerization of 1a

1a (250 mg, 1 mmol), PyBuOH (5.6 mg, 0.02 mmol), and TU (18.8 mg, 0.05 mmol) were dissolved in dichloromethane (1 mL), and this solution was transferred to a vial containing DBU (7.5 mg, 0.05 mmol) to initiate polymerization. Samples (200 μ L) were taken and quenched with benzoic acid (5-10 mg). After evaporation of solvent, the residues were redissolved in CDCl₃ for NMR analysis or THF for GPC analysis.

Example procedure: copolymerization of TMC with 1b

TMC (160 mg, 1.6 mmol), **1b** (79 mg, 0.4 mmol), PyBuOH (11 mg, 0.04 mmol), and TU (37 mg, 0.1 mmol) were dissolved in dichloromethane (2 mL), and this solution was transferred to a vial containing DBU (15 mg, 0.1 mmol) to initiate polymerization. Samples (200 μ L) were taken and quenched with benzoic acid (5-10 mg). After evaporation of solvent, the residues were redissolved in CDCl₃ for NMR analysis or THF for GPC analysis.

¹ R.C. Pratt, B.G.G. Lohmeijer, D.A. Long, A.P. Dove, H. Li, R.M. Waymouth, J.L. Hedrick *Macromolecules* 2006, **39**, 7863.

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⁴ T.F. Al-Azemi, K.S. Bisht *J. Poly. Sci. A* 2002, **40**, 1267.

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⁶ N.K. Sharma, F. de Reinach-Hirtzbach, T. Durst *Can. J. Chem.* 1976, **54**, 3012.