# Hyperbranched Poly(*N*-(2-Hydroxypropyl) Methacrylamide) via RAFT Self-Condensing Vinyl Polymerization

Jawaher A. Alfurhood, Hao Sun, Patricia R. Bachler, and Brent S. Sumerlin*

[a]*George & Josephine Butler Polymer Research Laboratory, Center for Macromolecular Science & Engineering, Department of Chemistry , University of Florida, PO box 117200, Gainesville, FL 32611-7200, USA. Email: sumerlin@chem.ufl.edu; Fax: +1 352 392 9741*

## Supporting information

## Materials and measurements

All reagents and solvents were obtained from commercial sources and used as received. All $^{1}$H NMR (500 MHz) and $^{13}$C NMR (500 MHz) spectra were recorded on a Varian Mercury 500 spectrometer with chemical shifts referenced to residual signals from $CDCl_3$ (7.27 ppm) or DMSO-$d_6$ (2.50 ppm). High resolution mass spectrometry (HRMS) was carried out using an Agilent 6220 TOF-MS mass spectrometer in the Direct Analysis in Real Time (DART) mode with the IonSense DART source unless otherwise specified. Gel permeation chromatography (GPC) was conducted in *N*,*N*-dimethylacetamide (DMAc) (with 0.05 M LiCl) at 50 °C with a flow rate of 1.0 mL/min (Pump: Agilent 1260 Infinity Isocratic Pump G1310B, Columns: Guard + two ViscoGel I-series G3078 mixed bed columns, molecular weight range 0–20 × $10^3$ and 0–100 × $10^4$ g $mol^{-1}$). Detection consisted of a Wyatt Optilab T-rEX refractive index detector operating at 658 nm and a Wyatt miniDAWN TREOS laser light scattering detector

(operating at 50 mW, 658 nm, with detection angles of 49°, 90°, and 131°). Molecular weights were determined using poly(methyl methacrylate) (PMMA) standards from 9.88 $\times 10^5$ to 602 g/mol.

**Synthesis of butyl 2-cyanopropan-2-yl- carbonotrithioate**

The synthesis procedure was modified from the procedure reported by Thang et al.[1] 1-Butanethiol (6.68 g, 74.1 mmol) was added drop-wise to a stirred suspension of potassium *tert*-butoxide (8.31 g, 74.1 mmol) in diethyl ether (150 mL) at 5-10 °C. The reaction mixture instantly turned to a white slurry of potassium thiobutanate. Afterwards, the solution was cooled to 0 °C, followed by drop-wise addition of carbon disulfide (5.64 g, 74.1 mmol) to provide a yellow solid, which was collected and used without purification in the next step. Solid iodine (8.62 g, 34.0 mmol) was added in small portions to a suspension of potassium-*S*-butane trithiocarbonate (13.9 g, 68.0 mmol) in diethyl ether (200 mL). The reaction mixture was stirred for 1 h at room temperature and then filtered to remove the white solid of potassium iodide. The filtrate was washed with an aqueous solution of sodium thiosulfate to remove any residual iodine and then dried over sodium sulfate. The solvent was evaporated and bis-(butanesulfyanyl thiocarbonyl)disulfide (8.30 g, 25.0 mmol) was obtained as red oil and characterized by $^1$H NMR spectroscopy. $^1$H NMR (500 MHz, $CDCl_3$): $\delta$ ppm 0.95(t, 6H), 1.45 (m, 4H), 1.7(m, 4H), 3.3(t, 4H).

A solution of the oil product bis-(butanesulfyanyl thiocarbonyl) disulfide (8.30 g, 25.0 mmol) and 4,4'-azobis(4-cyanopentanoic acid) (10.6 g, 37.7 mmol) in ethyl acetate (150 mL) was heated under reflux for 20 h. Evaporation of the reaction mixture followed

by extraction with DI water (5× 100 mL) provided the oily product, butyl 2-cyanopropan-2-yl-carbonotrithioate. $^1$H NMR (500 MHz, $CDCl_3$): $\delta$ ppm 0.95(t, 3H), 1.45 (m, 2H), 1.7(m, 2H), 1.9(s, 3H), 2.40(m, 2H), 2.55 (m, 2H), 3.34 (t, 2H).

**Synthesis of chain transfer monomer (CTM)**

A solution of 4-(butylthiocarbonothioylthio)-4-cyanopentanoic acid (2.4 g, 8.4 mmol, 1.2 equiv.) in dichloromethane (DCM) (20 mL) was cooled to 0 °C prior to the addition of 1-ethyl-3-(3-dimethylaminopropyl)carbodiimide hydrochloride (EDC•HCl) (2.0 g, 11 mmol, 1.5 equiv.). The mixture was stirred for 15 min, followed by the addition of HPMA (1.0 g, 7.0 mmol, 1.0 equiv.) and *N*,*N*-dimethylaminopyridine (DMAP) (0.13 g, 1.1 mmol, 0.15 equiv.) to the reaction mixture. The temperature was raised gradually to room temperature, and the mixture was left stirring for 4 days. Afterwards, the mixture was washed with 5% citric acid. The organic layer was collected and dried over magnesium sulfate. The mixture was then filtered, and the DCM was evaporated *in vacuo*. The remaining oily product was purified by flash chromatography (40:60 ethyl acetate:hexane). $^1$H NMR (500 MHz, DMSO-$d_6$): $\delta$, ppm 0.90(t, 3H), 1.15 (m, 3H), 1.37(m, 2H), 1.62(m, 2H), 1.84(s, 3H), 1.98 (s, 3H), 2.38 (m, 2H), 2.54(m, 2H), 3.19 (m, 2H), 3.34 (m, 2H), 4.93 (m, 1H), 5.32 (s, 1H), 5.61(s, 1H), 8.01(m, 1H). $^{13}$C NMR (DMSO-$d_6$) $\delta$, ppm 13.96, 17.86, 18.8, 20.7, 21.57, 29.51, 29.57, 32.95, 36.33, 37.6.7, 46.86, 69.86, 119.5, 140.03, 168.00, 173.1, 226.2. HRMS (ESI) calcd for $C_{18}H_{28}N_2O_3S_3$ $[M + H]^+$: 417.1335, found: 417.1349.

**Synthesis of hyperbranched PHPMA**

In a typical procedure, HPMA (1.0 g, 7.0 mmol), CTM (0.058 g, 0.14 mmol), and AIBN (4.5 mg, 0.030 mmol) with a ratio of 1/50/0.2 were dissolved in (2.3 mL) of DMAc (monomer concentration was 3 M) in a Schlenk flask. The flask was degassed by 4 cycles of freeze-pump-thaw and then placed in a preheated oil bath at 70 °C. Samples were taken at different reaction times to study the kinetics of polymerization. Each sample was characterized using GPC and $^{1}$H NMR spectroscopy. The polymerization reaction was quenched by placing the flask in an ice bath and exposing it to air. The polymer was purified by precipitation into cold diethyl ether three times.

**Homopolymerization of chain transfer monomer**

Chain transfer monomer (0.60 g, 1.4 mmol) and AIBN (4.8 mg, 0.029 mmol) were dissolved in of DMAc (0.72 mL). The initial concentration of CTM was 2 M in a Schlenk flask. The flask was degassed by 4 cycles of freeze-pump-thaw and then placed in a preheated oil bath at 70 °C. The polymer was purified by precipitation into cold diethyl ether three times.

**Aminolysis of hyperbranched PHPMA**

The polymer (0.20 g, 0.18 mmol of end groups) was dissolved in *N*,*N*-dimethylformamide (DMF) (1 mL). The stirred solution was purged with nitrogen for 15 min followed by addition of hydrazine (0.057 g, 1.8 mmol) and stirred for 30 min. Methyl acrylate (0.152 g, 0.177 mmol) was added to the previous solution and stirred for 2 h. The reaction was quenched by exposure to air, and the resulting polymer was

precipitated into cold diethyl ether. UV-Vis spectroscopy in deionized (DI) water for the polymer before and after aminolysis was conducted to confirm the disappearance of the trithiocarbonate absorption.

**Cloud point determination**

A solution of polymer (5 mg/mL) was prepared in DI water and placed in a quartz cuvette. The sample was heated from 24-80 °C and the absorbance corresponding to each temperature was recorded.

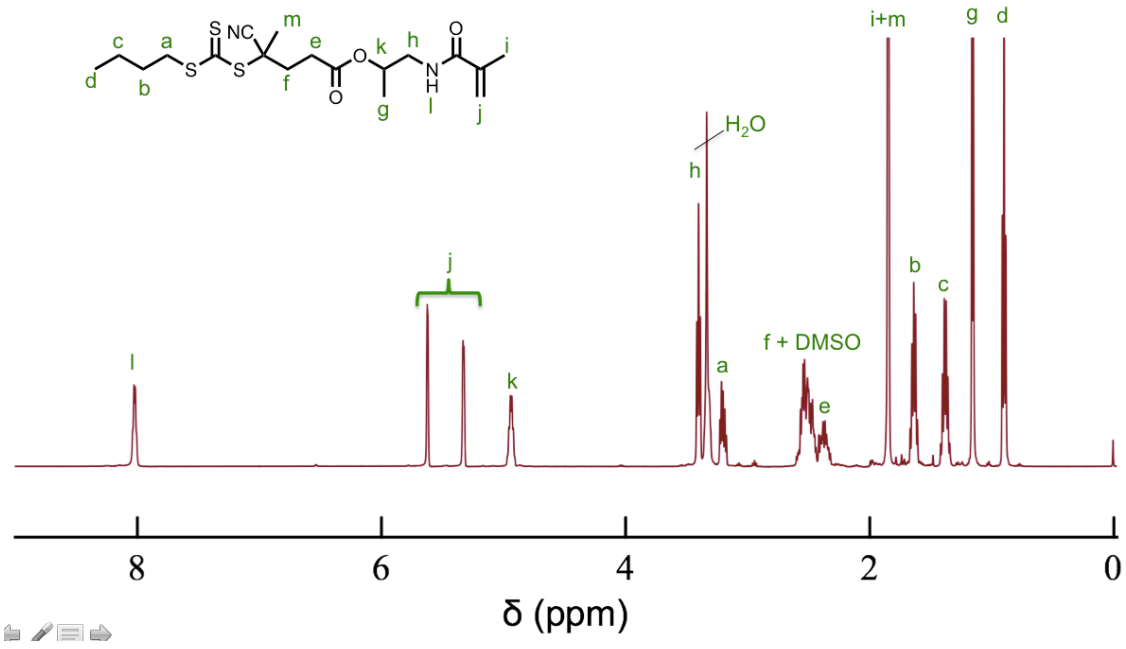


**Figure S1.** $^{1}$H NMR spectrum of the chain transfer monomer (CTM).

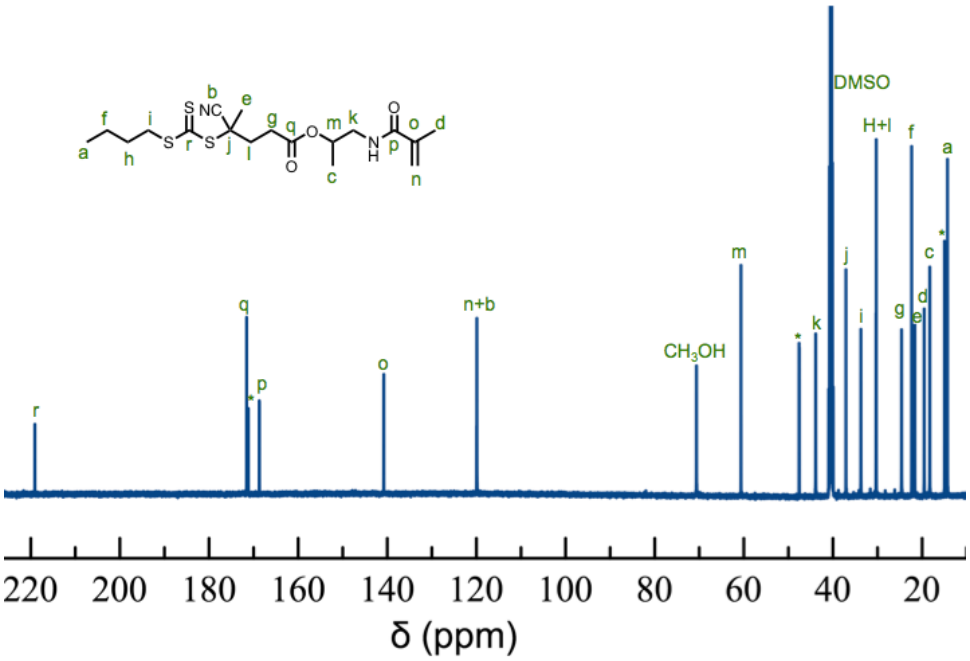


**Figure S2.** $^{13}$C NMR spectrum of the chain transfer monomer (CTM)/* represents residual ethyl acetate.

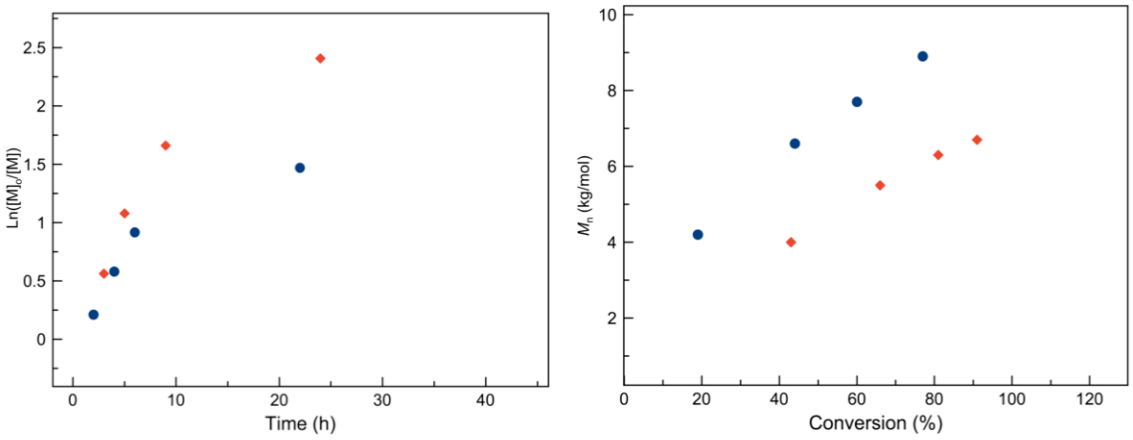


**Figure S3.** (a) Kinetic plot of ln([M]$_0$/[M]) vs. time in RAFT SCVP with [HPMA]:[CTM] ratios of 25:1 (blue) and 10:1 (red). (b) Plot of $M_n$ vs. conversion in RAFT-SCVP with [HPMA]:[CTM] ratios of 25:1 (blue) and 10:1 (red).

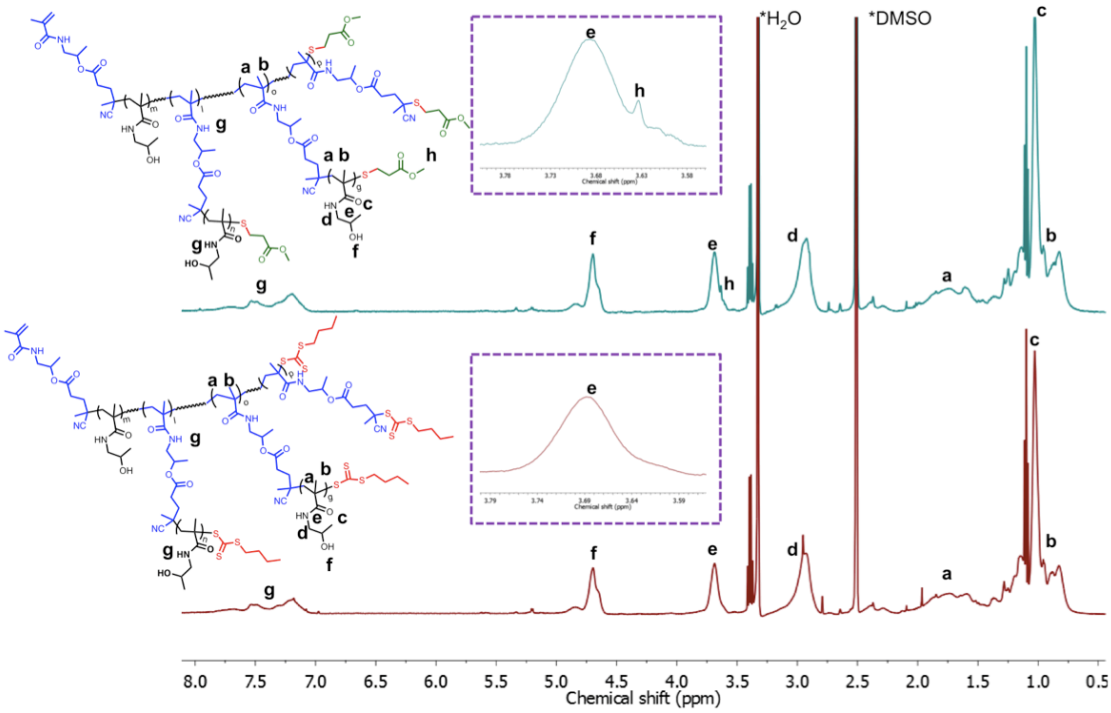


**Figure S4**. $^{1}$H NMR spectra of segmented hyperbranched PHPMA before (bottom, red) and after aminolysis by hydrazine in the presence of methyl acrylate (top, green). The appearance of the signal (*h*, 3.63 ppm) attributed to the terminal methoxy protons indicated Michael addition occurred between the thiols and methyl acrylate.

## References

(1) G. Moad, Y. K. Chong, A. Postma, E. Rizzardo and S. H. Thang, *Polymer*, 2005, **46**, 8458–8468.