Supporting Information

Synthesis of block copolymers containing 3-chloro-2-hydroxypropyl methacrylate by NMP – a versatile platform for functionalization

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S1 General information

Materials

3-Chloro-2-hydroxypropyl methacrylate (≥96.5 %) and 4-vinylbenzyl chloride (90 %) were purchased from *Sigma-Aldrich* (Steinheim, Germany). Styrene (≥ 99 %) was purchased from *Alfa Aesar* (Kandel, Germany) and 1*H*-carbazole was purchased from *Fluka Chemical Corp*. All chemicals were used as received. BlocBuilderMA® was kindly donated by Sylvain Bourrigaud of *Arkema* and used as received. Polymerization inhibitor was removed from monomers by passing over a short column of basic aluminum oxide. All polymerization reactions were degassed by gently bubbling argon through the solution for 30 min prior to heating. All deuterated solvents were purchased from Eurisotop or Deutero. 1-Mesityl-1H-imidazole was synthesized as reported elsewhere.[1]

Characterization

Nuclear magnetic resonance (NMR). Nuclear magnetic resonance (NMR) measurements were performed on the 300 MHz *Bruker (Billerica, USA) AC 300/75 MHz*. The chemical shift for ¹H-NMR experiments is referenced to tetramethylsilane (TMS). The solvent used is always specified and the spectra were referenced to the solvent signal. The obtained NMR spectra were analyzed with the program *MestReNova*.

Size exclusion chromatography (SEC). Size exclusion chromatography (SEC) was carried out on an *Agilent System (1200 series)*, that was equipped with a *PSS* degasser, a *G1310A* pump, a *G1362A* refractive index detector and a *G1315D* diode array detector. Dimethylacetaminde (DMAc) containing

0.21 wt.% LiCl was used as the eluent at a flow rate of 1 mL/min on a *PSS GRAM guard/30/1,000 Å* (10 μm particle size with a separation range from 400 – 1,000,000 g/mol) as stationary phase. The system was calibrated on a polystyrene and poly(methyl methacrylate) standard from *PSS (Mainz, Deutschland)* and the measurement was performed at 40 °C. The analysis of the obtained data was carried out with the program *PSS WinGPC® UniChrom*.

Dynamic light scattering (DLS). Dynamic light scattering was performed with the *ALV/CGS-3 Compact Goniometer System*. The measurement was accomplished under the usage of a laser (λ = 633 nm) at a temperature of 25 °C at a detection angle of 90 °. As correlator the device *ALV/LSE-5004* was utilized. The analysis of the obtained data was carried out with the program *ALV-Correlator 3.0*.

Transmission electron microscopy (TEM). For TEM from aqueous solutions, copper grids were rendered hydrophilic by Ar plasma cleaning for 30 s (*Diener Electronics*). 10 μL of the respective sample solution were applied to the grid and excess sample was blotted with a filter paper. TEM images were acquired with a 200 kV *FEI Tecnai G2 20* equipped with a 4k x 4k *Eagle HS* CCD and a 1k x 1k *Olympus MegaView* camera for overview images. Data processing as well as the determination of the core radius of micelles (individually measuring area of 40 separated and spherical micelles each sample) was performed with the program *ImageJ*. For determining the aggregation number (N_{agg}) the measured core radius (r_{core}) was used as basis:
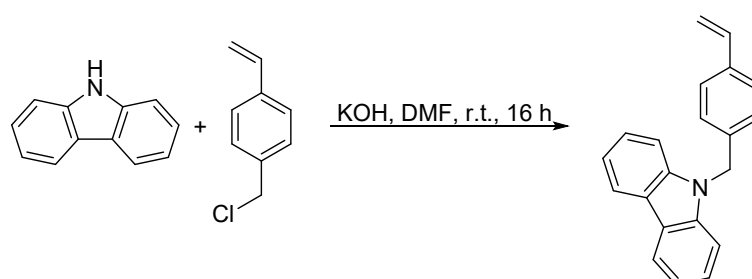
$$N_{agg} = \frac{m_{core}}{m_{PS}^{chain}} = \frac{4\pi N_A \rho_{PS} r_{core}^{3}}{3 M_{PS}^{chain}}$$

with m_{core}: mass of the micellar core; m_{PS}^{chain}: mass of an individual PS chain; N_A: Avogadro constant; ρ_{PS}: density of polystyrene; r_{core}: radius of the micellar core according to TEM; M_{PS}^{chain}: molecular weight of an individual PS chain.

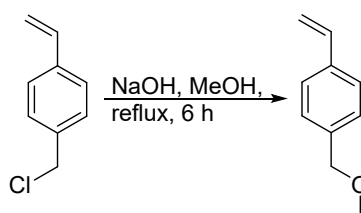# S2 Synthesis

Comonomers

9-(4-Vinylbenzyl)-9H-carbazole (VBC)

Scheme S1: Synthesis of VBC.

9-(4-Vinylbenzyl)-9H-carbazole (VBC) was synthesized according to a modified literature protocol (Section S1).[2] Therefore, in a 250 mL round bottom flask 5.97 g (106.33 mmol) KOH was added to a solution of 10 g (59.81 mmol) 1*H*-carbazole in 160 mL DMF and the mixture was degassed with argon for 15 min. Subsequently, 9.13 g (59.81 mmol) 4-vinylbenzyl chloride was added dropwise and the reaction mixture solution was stirred overnight at room temperature. Afterwards the mixture was diluted with water (700 mL) and precipitating solid was filtered off. The precipitate was dissolved in DCM (500 mL) and washed with water (400 mL). The organic phase was dried over Na_2SO_4 and all volatiles were removed under reduced pressure. The residue was recrystallized from acetone yielding colorless needles as 9-(4-Vinylbenzyl)-9H-carbazole. Yield: 14.6 g (86 %). ^{1}H-NMR: (300.13 MHz, CDCl$_3$, 300.0 K): δ [ppm] 8.18 (d, ^3J(H-H) = 7.8 Hz, 2H, *H*-4, *H*-5 carbazole), 7.50-7.27 (m, 8H, *H*-1, *H*-2, *H*-3, *H*-6, *H*-7, *H*-8 carbazole, *H*-2 styrene), 7.13 (d, ^3J(H-H) = 8.2 Hz, 2H, *H*-3 styrene), 6.69 (dd, ^3J(H-H) = 17.6, 10.9 Hz ,1H, C*H*=CH$_2$), 5.72 (dd, ^3J(H-H) = 17.6 Hz, ^2J(H-H) = 0.9 Hz, 1H, C*H*=C*H*H), 5.53 (s, 2H, -C*H$_2$*-), 5.24 (dd, ^3J(H-H) = 10.9 Hz, ^2J(H-H) =0.9 Hz, 1H, C*H*=CH*H*).

4-(Methoxymethyl)styrene (MMS)

Scheme S2: Synthesis of MMS.

4-(Methoxymethyl)styrene (MMS) was prepared as reported elsewhere (Section S2).[3] Accordingly, in a 250 mL round bottom flask solution of 10.0 g (65.5 mmol) 4-vinylbenzyl chloride in 40 mL MeOH was dropped into a solution of 10.0 g (0.25 mol) NaOH in 100 mL MeOH. The mixture was refluxed under vigorous stirring for 6 h. Subsequently, the reaction mixture was diluted with 200 mL water and extracted with diethyl ether (3 x 100 mL) and *n*-hexane (2 x 50 mL). The combined organic layers were washed saturated NH$_4$Cl solution (1 x 100 mL) and water (1 x 100 mL). The organic phase was dried over MgSO$_4$ and all volatiles were removed under reduced pressure. The obtained pale green-yellow oil was purified *via* vacuum distillation affording a colorless oil as product. For storage 50 mg (450 µmol) hydroquinone was added to inhibit auto polymerization. Yield: 9.52 g (98 %). ^{1}H-NMR: (300.13 MHz, CDCl$_3$, 300.0 K): δ [ppm] 7.41 (d, ^3J(H-H) = 8.2 Hz, 2H, *H*-2), 7.30 (d, ^3J(H-H) = 8.2 Hz, 2H, *H*-3), 6.73 (dd, ^3J(H-H) = 17.6, 10.9 Hz, 1H, -C*H*=CH$_2$), 5.76 (d, ^3J(H-H) = 17.6 Hz, 1H, CH=CH*H*), 5.25 (d, ^3J(H-H) = 11.5 Hz, 1H, C*H*=CH*H*), 4.46 (s, 2H, -C*H$_2$*-O-), 3.39 (s, 3H, -O-C*H$_3$*).

Polymerization reactions

Homopolymerization of 3-chloro-2-hydroxypropyl methacrylate (ClHPMA)

In a 5 mL microwave vial 3.56 mg (9.33 μmol) BlocBuilder MA® were dissolved in 0.50 g (2.80 mmol) 3-chloro-2-hydroxypropyl methacrylate and 2.0 mL 1,4-dioxane. The mixture was stirred under heating at 90 °C for 2 hours. Afterwards, the reaction mixture was cooled down to room temperature and subsequently dropped into 20 mL of n-hexane. The colorless gum-like solid was removed *via* centrifugation and dissolved in methanol. The obtained solution was dialyzed against methanol and afterwards freed from all volatiles under reduced pressure. The residual was dissolved in 1,4-dioxane for freeze-drying, yielding 72 mg of a white powder. ^{1}H-NMR: (300.13 MHz, DMF-d_7, 300.0 K): δ [ppm] 5.70 (s, br, 1H, -CH-OH), 4.27-3.65 (m, br, 5 H, O-CH_2-CH(OH)-CH_2Cl), 2.39-0.73 (m, br, 5 H, -CH_3, polymer backbone). SEC analysis (PMMA standard for calibration): $\overline{M}_n = 35{,}300$ g/mol, Đ = 1.58.

Copolymerization of ClHPMA and styrene

In a 10 mL microwave vial a mixture of 939 mg (5.26 mmol) ClHPMA, 60.9 mg (0.59 mmol) styrene and the respective amount of BlocBuilder MA® (2.78, 5.55, 11.1 mg (7.28, 14.6, 29.1 μmol)) in 3.0 mL 1,4-dioxane was heated at 90 °C. After each time interval (20, 40, 60, 90, 120, 180, 240 min) samples were taken directly from the reaction mixtures and precipitated in n-hexane. The white precipitates were dissolved in a small amount of THF and precipitated again two times in n-hexane. Afterwards, the white precipitates were dissolved in 1,4-dioxane and freeze-dried prior to SEC and NMR analysis.

Copolymerization of ClHPMA and VBC

In a 10 mL microwave vial a mixture of the respective amount of ClHPMA, VBC and BlocBuilder MA® in different amounts of DMF was heated at different temperatures. After each time interval (10, 20, 30, 40, 60, 90, 120 min) samples were taken directly from the reaction mixtures for SEC analysis. Subsequently, the mixture was precipitated in diethyl ether. The white precipitates were dissolved in a small amount of THF and precipitated again two times in diethyl ether. Afterwards, the white precipitates were dissolved in 1,4-dioxane and freeze-dried prior to SEC and NMR analysis. ^{1}H-NMR: (300.13 MHz, DMSO-d$_6$, 300.0 K): δ [ppm] 8.25-8.08 (m, br, 2H, ArH VBC), 7.62-7.11 (m, br, 6H, ArH VBC), 7.09-6.66 (m, br, 4H, ArH VBC) 5.69-5.23 (m, br, 1H, CH-OH ClHPMA) 4.15-3.45 (m, br, 5H, -O-CH_2-CH(OH)-CH_2Cl ClHPMA) 2.07-0.21 (m, br, polymer backbone, -CH-CH_3 ClHPMA).

Table 1: Reaction approaches and batch calculations for the synthesis of P(ClHPMA-*co*-VBC) copolymers.

c(ClHPMA) / mol/L	m (n) BlocBuilder® / mg (μmol)	m (n) ClHPMA / g (mmol)	m (n) VBC / mg (mmol)	m (n) SG1 / mg (μmol)	V DMF / mL	Reaction temperature / °C

1.8	9.53 (30.0)	1.0 (5.60)	31.1 (0.11)	0.85 (3.0)	2.0	90
1.1	4.77 (13.0)	0.5 (2.80)	39.7 (0.14)	0.38 (1.3)	2.0	90
1.1	9.53 (30.0)	1.0 (5.60)	159 (0.56)	0.85 (3.0)	4.5	90
1.1	4.77 (13.0)	0.5 (2.80)	79.3 (0.28)	0.38 (1.3)	2.0	100
1.1	4.77 (13.0)	0.5 (2.80)	79.3 (0.28)	0.38 (1.3)	2.0	110

Copolymerization of ClHPMA and MMS

In a 10 mL microwave vial a mixture of the respective amount of ClHPMA, MMS and BlocBuilder MA®
in different amounts of DMF was heated at different temperatures. After each time interval (10, 20, 30,
40, 60, 90, 120 min) samples were taken directly from the reaction mixtures for SEC analysis.
Subsequently, the mixture was precipitated in diethyl ether. The white precipitates were dissolved in a
small amount of THF and precipitated again two times in diethyl ether. Afterwards, the white
precipitates were dissolved in 1,4-dioxane and freeze-dried prior to SEC and NMR analysis. ^{1}H-NMR:
(300.13 MHz, DMSO-d_6, 300.0 K): δ [ppm] 7.26-6.81 (m, br, 4H, ArH MMS) 5.61-5.23 (m, br, 1H,
CH-OH ClHPMA), 4.43-4.25 (m, br, -CH_2-O- MMS), 4.08-3.45 (m, br, 5H, -O-CH_2-CH(OH)-CH_2Cl
ClHPMA), 3.25 (s, br, -O-CH_3 MMS), 2.06-0.35 (m, br, polymer backbone, -CH-CH_3 ClHPMA).

Table 2: Reaction approaches and batch calculations for the synthesis of P(ClHPMA-*co*-MMS) copolymers.

c(ClHPMA) / mol/L	m (n) BlocBuilder® / mg (μmol)	m (n) ClHPMA / g (mmol)	m (n) MMS / mg (mmol)	m (n) SG1 / mg (μmol)	V DMF / mL	Reaction temperature / °C
1.8	9.53 (30.0)	1.0 (5.60)	84.0 (0.56)	0.85 (3.0)	2.0	90
1.1	4.77 (15.0)	0.5 (2.80)	42.0 (0.28)	0.85 (3.0)	2.0	90
1.1	4.77 (15.0)	0.5 (2.80)	42.0 (0.28)	0.43 (1.5)	2.0	100
1.1	4.77 (15.0)	0.5 (2.80)	42.0 (0.28)	0.43 (1.5)	2.0	110

Polystyrene macroinitiator PS$_{375}$

The synthesis of the polystyrene (PS) macroinitiator was carried out analogously to literature.[4] In a
20 mL microwave vial 36.6 mg (96 μmol) BlocBuilder MA® was dissolved in 5.50 mL (48.0 mmol)
styrene and the solution was heated at 110 °C for 20 h. After cooling down to room temperature the
reaction mixture was dropped into 500 mL of methanol. The precipitating white solid was removed *via*
filtration and dried under reduced pressure. A white powder was obtained as product. Yield: 3.79 g. [1]H-
NMR: (300.13 MHz, CDCl$_3$, 300.0 K): δ [ppm] 7.24-6.29 (m, br, 5H, ArH), 2.29-1.02 (m, br, 3H,
polymer backbone). SEC analysis (PS standard for calibration): M_n = 39,400 g/mol, Đ = 1.15.

Block extension of PS$_{375}$ with ClHPMA and MMS

In a 5 mL-microwave vial 200.0 mg (5.08 µmol) PS$_{375}$, 163.2 mg (914 µmol) ClHPMA, 15.0 mg (102 µmol) MMS and 147.2 µg (0.508 µmol) SG1 were dissolved in 1.3 mL 1,4-dioxane. The mixture was stirred at 110 °C for 20 min and subsequently cooled in a water bath to room temperature. The solution was diluted with 2 mL THF and precipitated in MeOH/water (9:1) three times affording a white powder after freeze-drying (1,4-dioxane as solvent). Yield: 240 mg. ^{1}H-NMR: (300.13 MHz, DMF-d$_7$, 300.0 K): δ [ppm] 7.61-6.58 (m, br, Ar*H* styrene and MMS), 5.97-5.51 (m, br, -CH-O*H* ClHPMA), 4.65-4.52 (m, br, -C*H$_2$*-O- MMS), 4.43-3.76 (m, br, -O-C*H$_2$*-C*H*(OH)-C*H$_2$*Cl ClHPMA), 3.51 (s, br, -O-C*H$_3$* MMS), 2.64-0.74 (m, br, polymer backbone, -CH-C*H$_3$* ClHPMA). SEC analysis (PS standard for calibration): M_n = 55,000 g/mol, Đ = 1.28.

Functionalization of PS-*b*-P(ClHPMA-*co*-MMS) with 1-mesityl-1H-imidazole

In a 5 mL microwave vial a solution of 50 mg (1.06 µmol) PS$_{375}$-*b*-P(ClHPMA$_{37}$-*co*-MMS$_8$) and 19.7 mg (106.0 µmol) 1-mesityl-1H-imidazole in 1 mL 1,4-dioxane was degassed by gently bubbling argon through the solution for 30 min before being heated at 150°C for 96 h. Afterwards, the mixture was diluted with 1 mL THF and precipitated three times in *n*-hexane affording a white powder after freeze-drying (1,4-dioxane as solvent). Yield: 51.5 mg. ^{1}H-NMR: (300.13 MHz, DMF-d$_7$, 300.0 K): δ [ppm] 9.81 (s, br, -N=C*H*-N-, MesI), 8.37 (s, br, Ar*H* imidazolium ring), 7.53-6.34 (m, br, ArH styrene, MMS, mesityl), 5.91 (s, br, -CH-O*H* ClHPMA, MesIHPMA), 4.92-4.62 (m, br, -C*H$_2$*-N MesIHPMA), 4.40 (s, br, -C*H$_2$*-O- MMS), 4.25-3.62 (m, br, -O-C*H$_2$*-C*H*(OH)-C*H$_2$*- ClHPMA, MesIHPMA), 3.32 (s, -O-C*H$_3$* MMS), 2.39 (s, Ar-C*H$_3$* (*ortho*-positions) mesityl), 2.33-0.68 (m, br, polymer backbone, -CH-C*H$_3$* ClHPMA, Ar-C*H$_3$* (*para*-position) mesityl). SEC analysis (PS standard for calibration): M_n = 56,700 g/mol, Đ = 1.54.

S3 Micellization procedure

5 mg of block copolymer was dissolved in 2 mL of THF or DMF. 4 mL of methanol or methanol/water (9:1) was added under stirring *via* a syringe pump (42 µL/min). Afterwards the turbid mixture was stirred for one hour. After that time 4 mL of methanol or methanol/water (9:1) was added rapidly and the dispersion was stirred overnight. Subsequently, the mixture was dialyzed against methanol or methanol/water (9:1) (MWCO 12-14 kDA) for at least 4 days with minimum 8 changes of the dialysis methanol.
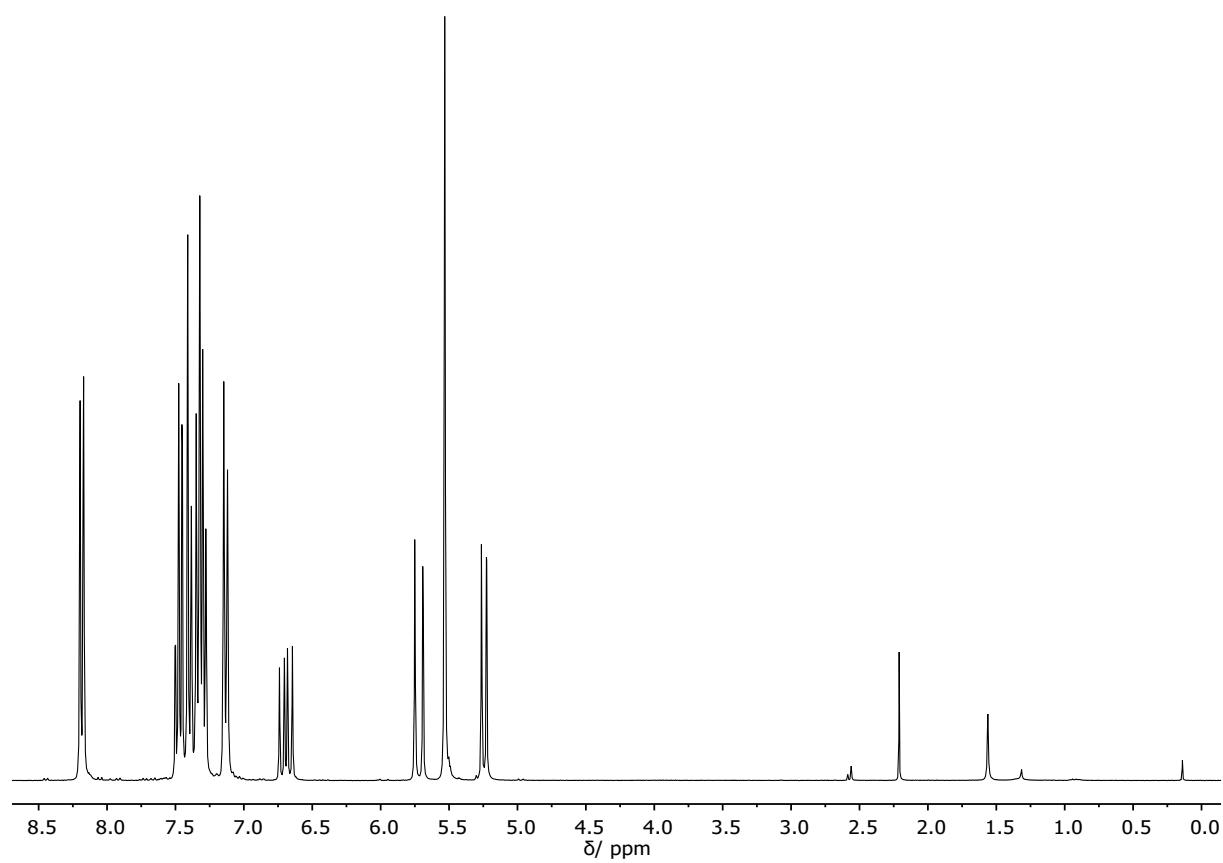
S4 Supplementary figures

NMR spectra
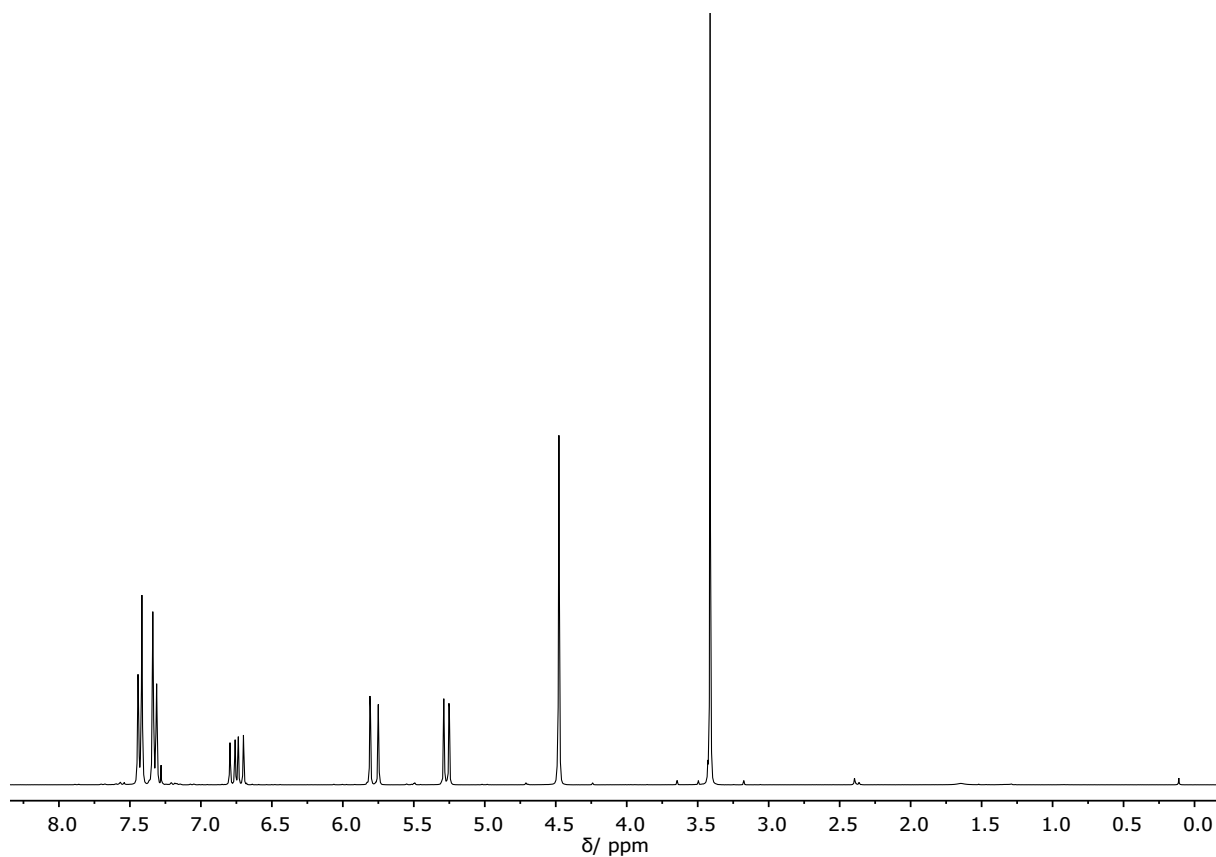

Figure S1: ^{1}H-NMR spectrum of VBC (300.13 MHz, CDCl$_3$, 300.0 K).

Figure S2: ^{1}H-NMR spectrum of MMS (300.13 MHz, CDCl$_3$, 300.0 K).
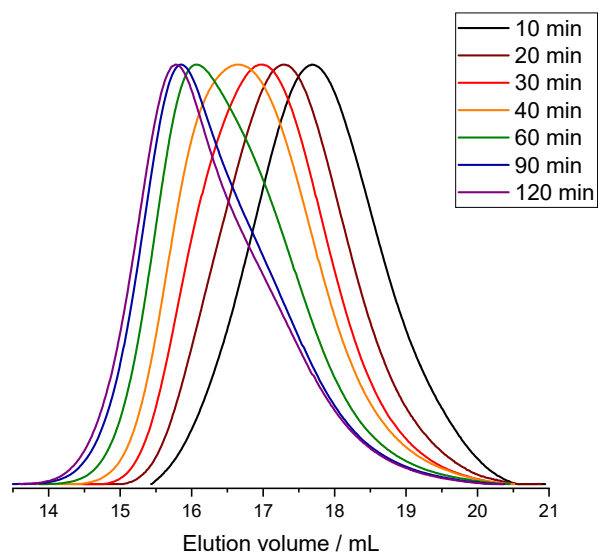
SEC data

Figure S3: Normalized RI SEC elution trace of P(ClHPMA-*co*-VBC) copolymers for different reaction times, M/I = 200:1, 90 °C, 5 mol% VBC, c (ClHPMA) = 1.8 M.

Table S3: Analytical data for kinetic investigations of copolymerizing ClHPMA and VBC at 90 °C.

3 mol% VBC, c (ClHPMA) = 1.8 M			5 mol% VBC, c (ClHPMA) = 1.1 M			10 mol% VBC, c (ClHPMA) = 1.1 M		
t / min	$Đ$[a]	$\bar{M}_n$ / g/mol[a]	t / min	$Đ$[a]	$\bar{M}_n$ / g/mol[a]	t / min	$Đ$[a]	$\bar{M}_n$ / g/mol[a]
10	1.47	25,100	10	1.32	19,500	10	1.24	13,500
20	1.49	29,600	20	1.33	24,900	20	1.25	18,600
30	1.51	34,000	30	1.34	30,000	30	1.26	22,700
40	1.53	38,400	40	1.38	33,700	40	1.27	26,500
60	1.59	43,500	60	1.42	40,300	60	1.30	31,900
90	1.65	45,800	90	1.47	45,800	90	1.37	38,100
120	1.66	47,000	120	1.49	48,000	120	1.38	43,200

[a]SEC analysis, PMMA calibration.

Table S4: Analytical data for kinetic investigations of copolymerizing ClHPMA and VBC at 100 °C and 110°C.

	100 °C		110 °C	
t / min	$Đ$[a]	$\bar{M}_n$ / g/mol[a]	$Đ$[a]	$\bar{M}_n$ / g/mol[a]
10	1.24	20,400	1.18	21,500
20	1.30	28,900	1.27	28,500
30	1.37	33,900	1.32	33,700
40	1.39	36,500	1.38	36,400
60	1.47	40,100	1.45	39,500
90	1.51	42,000	1.51	42,900
120	1.50	43,000	1.52	44,300

[a]SEC analysis, PMMA calibration.

Table S5: Analytical data for kinetic investigations of copolymerizing ClHPMA and MMS at 90 °C.

10 mol% MMS, c (ClHPMA) = 1.8 M			10 mol% MMS, c (ClHPMA) = 1.1 M	
t / min	$Đ$[a]	$\bar{M}_n$ / g/mol[a]	$Đ$[a]	$\bar{M}_n$ / g/mol[a]
10	1.25	14,600	1.19	10,300
20	1.27	20,600	1.21	12,900
30	1.31	25,700	1.23	14,800
40	1.34	30,000	1.24	16,900
60	1.41	38,900	1.25	20,300
90	1.54	48,600	1.28	24,900
120	1.67	56,600	1.31	28,700

[a]SEC analysis, PMMA calibration.

Table S6: Analytical data for kinetic investigations of copolymerizing ClHPMA and MMS at 100 °C and 110°C.

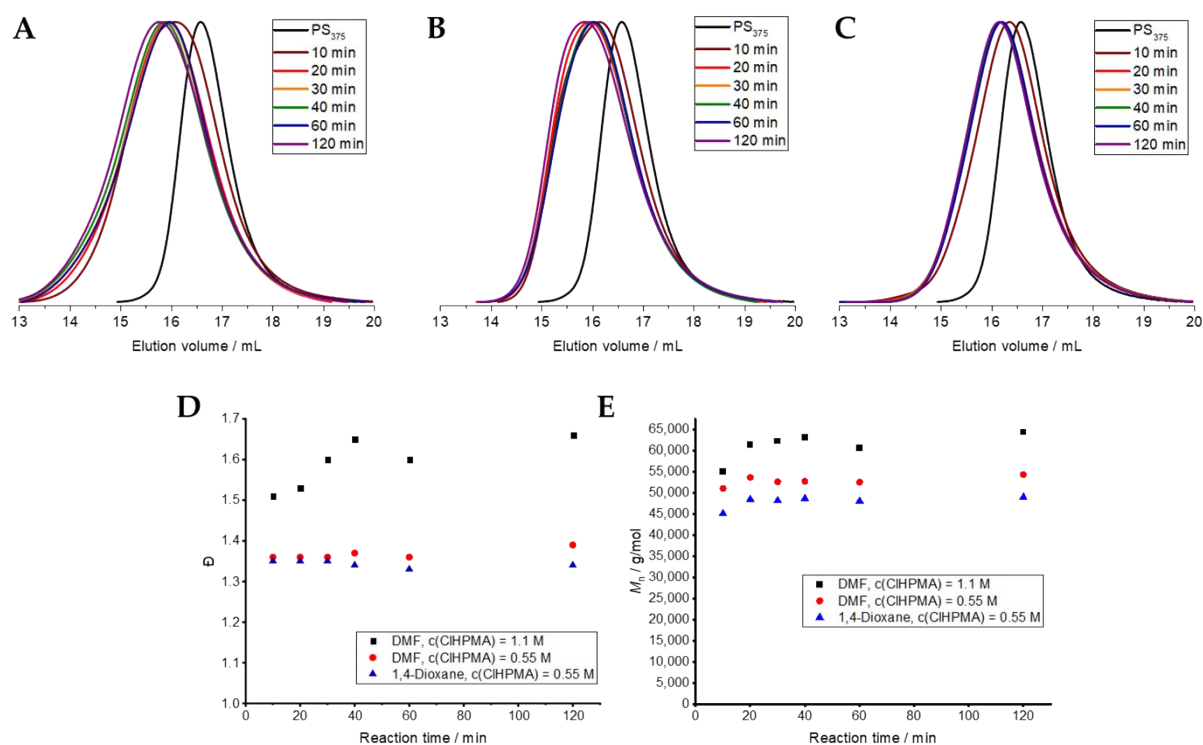|	100 °C		110 °C	
t / min	$Đ$[a]	$\bar{M}_n$ / g/mol[a]	$Đ$[a]	$\bar{M}_n$ / g/mol[a]
10	1.22	16,100	1.28	22,600
20	1.26	21,500	1.43	31,300
30	1.30	25,100	1.53	35,800
40	1.33	27,000	1.56	37,600
60	1.41	32,600	1.62	38,600
90	1.50	36,500	1.61	39,900

| 120 | 1.54 | 38,400 | 1.62 | 39,400 |

Figure S4: Normalized RI SEC elution trace of PS-*b*-P(ClHPMA-*co*-MMS) block copolymers for different reaction times, M/I = 200:1, 10 mol% MMS; (**A**): DMF as solvent, c(ClHPMA) = 1.1 M, (**B**): DMF as solvent, c(ClHPMA) = 0.55 M, (**C**): 1,4-dioxane as solvent, c(ClHPMA) = 0.55 M. (**C**) Apparent average molar mass of PS-*b*-P(ClHPMA-*co*-MMS) copolymers in three kinetic evaluations determined by SEC analysis, DMAc + 0.21 % LiCl as eluent, samples taken directly from reaction mixture. (**D**) Obtained dispersities of PS-*b*-P(ClHPMA-*co*-MMS) copolymers from three kinetic studies, samples taken directly from reaction mixture.

Table S7: Analytical data for kinetic investigations of block extending PS_{375} with ClHPMA and MMS in different solvents and monomer concentrations.

DMF, c (ClHPMA) = 1.1 M			DMF, c (ClHPMA) = 0.55 M			1,4-dioxane, c (ClHPMA) = 0.55 M		
t / min	$Đ$[a]	M_n / g/mol[a]	t / min	$Đ$[a]	M_n / g/mol[a]	t / min	$Đ$[a]	M_n / g/mol[a]
10	1.51	55,100	10	1.36	51,100	10	1.35	45,100
20	1.53	61,500	20	1.36	53,700	20	1.35	48,500
30	1.60	62,300	30	1.36	52,700	30	1.35	48,200
40	1.65	63,200	40	1.37	52,800	40	1.34	48,700
60	1.60	60,700	60	1.36	52,600	60	1.33	48,100
120	1.66	64,400	120	1.39	54,400	120	1.34	49,000

a: SEC analysis, PS calibration.

References

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