

# Novel Photolabile Diblock Copolymers Bearing Truxillic Acid Derivative Junctions

Hong Yang,\*<sup>,†</sup> Lin Jia,<sup>‡</sup> Zhifei Wang,<sup>†,‡</sup> Aurélie Di-Cicco,<sup>‡,§</sup> Daniel Lévy,<sup>‡,§</sup> and Patrick Keller\*<sup>,‡,⊥</sup>

<sup>†</sup>School of Chemistry and Chemical Engineering, Southeast University, Nanjing 211189, China,
 <sup>‡</sup>Institut Curie, Centre De Recherche, CNRS UMR 168, Université Pierre et Marie Curie,
 26 rue d'Ulm 75248 Paris Cedex 05, France, <sup>§</sup>Pict-IbiSA, Institut Curie, Paris, France, and
 <sup>⊥</sup>Department of Chemistry and Biochemistry, University of Colorado, Boulder,
 Colorado 80309-0215, United States

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ABSTRACT: Amphiphilic diblock copolymers, poly(ethylene glycol)-*block*-poly(acrylate), bearing truxillic acid derivatives at the junction point between the two blocks are described. The truxillic acid junction can be selectively cut by UV light, leading to a disassembly of the nano-objects made by self-assembly of the amphiphilic copolymers in water.

## Introduction

Amphiphilic block copolymers have the ability to self-assemble in water to form various nano- or microsized objects,<sup>1</sup> which have potential applications in many domains such as drug delivery,<sup>2</sup> biotechnology,<sup>3</sup> catalysis,<sup>4</sup> and materials chemistry.<sup>5</sup> Recently, polymer micelles and vesicles prepared from amphiphilic block copolymers have received increasing interest because several of their morphological parameters can be modified by the action of external stimuli,<sup>6</sup> either chemical stimuli (pH change,<sup>7</sup> redox reaction,<sup>8</sup> hydrolysis,<sup>9</sup> enzymatic reaction<sup>10</sup>) or physical stimuli (thermal,<sup>11</sup> magnetic,<sup>12</sup> electrical,<sup>13</sup> mechanical (i.e., ultrasound sonication),<sup>14</sup> or photochemical<sup>15</sup>). In particular, stimuli-triggered disassembly could be used to promote reactions locally, such as controlling chemical reactions in microfluidics<sup>16</sup> or in drug delivery.<sup>17</sup>

Light, as a remote stimulus, is an attractive nano-object disassembling driving force, which has been intensively investigated for two obvious advantages: (1) light can be accurately targeted and highly selective; (2) in contrast to chemical stimuli, no acids, bases, or other reagents have to be brought into the system from outside, which in many cases could be technically challenging.

Light-responsive polymer micelles/vesicles can be divided into two main categories, depending on the kind of transformation brought by the photochemical event: (1) The reversible structural changes of the chromophores exposed to light modify the hydrophilic—hydrophobic balances and therefore transform the nanostructures of micelles/vesicles. Typical photochemically induced transition examples use as chromophores azobenzenes (*trans*-to-*cis* isomerization, change of dipole moment, size, and shape),<sup>18</sup> spyrobenzopyran (formation of zwitterionic species),<sup>19</sup> triphenylmethane leucohydroxide (generation of charges),<sup>20</sup> and cinnamoyl (photodimerization).<sup>21</sup> (2) The chromophores actually behave as photolabile covalent junctions between the polymer main body and the sacrificial parts. In this case, the photoirradiation-induced chemical reaction is an irreversible, permanent photocleavage process. For this approach, basically there are two general strategies. One strategy is using the monomer units as the sacrificial parts. For example, *o*-nitrobenzyl acrylates were polymerized to form hydrophobic polymer blocks, which could be photocleaved to become hydrophilic poly(acrylic acid).<sup>22</sup> Another one is to use polymer blocks as the sacrificial parts. The latter is very promising and more efficient potentially, since only one chromophore linker is required, which will need less light power consumption to be cleaved. Up to now, there are only a few examples of such photolabile block copolymers in the literature, based on *o*-nitrobenzyl,<sup>23</sup> 2-nitrophenylalanine,<sup>24</sup> and anthracene<sup>25</sup> photosensitive derivatives (Scheme 1). Herein, we present novel photolabile diblock copolymers bearing  $\alpha$ -truxillic acid derivatives as photocleavable junctions (Scheme 2B).

Our design was inspired by a well-studied photochemical system: the cinnamic acid-truxillic acid reversible photochemical [2 + 2] cycloaddition reaction (Scheme 2A).<sup>26</sup> Cinnamic acid forms, under illumination with ultraviolet light source with wavelengths above 260 nm, a dimer, truxillic acid,<sup>27</sup> which is stable at elevated temperature and under a wide range of wavelengths of UV light. The cyclobutane ring of truxillic acid is however photolabile under deep-UV light, below 260 nm, giving back the original cinnamic acid. This [2 + 2] photodimerization of the cinnamic acid is in fact very similar to the [4 + 4] photodimerization of the anthracene developed by Goldbach et al.<sup>25</sup>

Our strategy, starting from  $\alpha$ -truxillic acid, was to first synthesize an ATRP (atom transfer radical polymerization)<sup>28</sup> macroinitiator by functionalizing an  $\alpha$ -truxillic acid–ATRP small molecule initiator with the hydrophilic poly(ethylene glycol) block via ester or amid bonds, and then to prepare the hydrophobic block via ATRP reaction, to create novel photolabile diblock copolymers (Scheme 3).

### **Experimental Section**

**Materials and Instrumentation.** MeO-PEG<sub>2000</sub>-OH was purchased from Aldrich Inc. MeO-PEG<sub>2000</sub>-NH<sub>2</sub> was purchased from Polysciences Inc. The catalyst Cu<sup>1</sup>Br (98%, Aldrich) was purified as described previously.<sup>29</sup> Monomer *n*-butyl acrylate

<sup>\*</sup>Corresponding authors: Tel 86 25 52090619, Fax 86 25 52090616, e-mail pkuyh9@gmail.com (H.Y.); Tel 33 1 56246762, Fax 33 1 40510636, e-mail patrick.keller@curie.fr (P.K.).





Scheme 2. Principle and Design of Applying α-Truxillic Acid Derivatives as Photocleavable Junctions



Scheme 3. Synthesis of Diblock Copolymers<sup>a</sup>



<sup>*a*</sup> Reagents and conditions: (i) NEt<sub>3</sub>, DCM; (ii) UV, solid state; (iii) 1: (COCl)<sub>2</sub>, DCM; 2: NEt<sub>3</sub>, **5**, DCM; (iv) 1: (COCl)<sub>2</sub>, DCM; 2: NEt<sub>3</sub>, PEG-XH, DCM; (v) CuBr, PMDETA, 1,4-dioxane, 70 °C.

(*n*-BA) and cyclohexyl acrylate (99%, Aldrich) were filtered through a short column of neutral  $Al_2O_3$  before use. Dichloromethane, 1, 4-dioxane, and N,N',N',N''-pentamethyldiethylenetriamine were

distilled from  $CaH_2$  under argon. THF was distilled from sodium benzophenone ketyl under argon. Other chemical reagents were used without further purification. All nonaqueous reactions were



Figure 1. (A) <sup>1</sup>H NMR spectra of PEG-O-macroinitiator. (B) <sup>1</sup>H NMR spectra of PEG-NH-macroinitiator.

conducted in oven-dried glassware under a dry argon atmosphere. All flash chromatography was performed using a Macherey-Nagel MN Kieselgel 60 (0.063–1.2 mm).

All <sup>1</sup>H NMR spectra were obtained using a Bruker HW300 MHz spectrometer and recorded in CDCl<sub>3</sub> (internal reference 7.26 ppm). The molecular weights and the molecular weight distributions of all the polymers were measured by size exclusion chromatography (SEC) using two Waters Styragel HR 5E columns, a Waters 4110 differential refractometer ( $\lambda = 930$  nm), and a Waters 486 UV detector, in line with a Wyatt miniDAWN light scattering instrument (Ar laser,  $\lambda = 690$  nm). THF was used as the eluent at 1 mL/min.

The morphological analysis of self-assembled aggregates was performed by transmission electron microscopy (TEM) on samples stained by uranyl acetate or by cryogenic transmission electron microscopy (cryo-TEM) on samples fast frozen in liquid ethane. TEM images were recorded using a Philips CM120 electron microscope equipped with a Gatan SSC 1K\_1K CCD camera, and the cryo-TEM images were recorded using a Philips CM 120 kV Lab6. Image acquisition and image analysis were performed at the PICT IBISA Imaging Facility.

at the FIC 1 1015X imaging r acmey. A UV lamp (180 mW cm<sup>-2</sup>,  $\lambda = 365$  nm; ELC-4001light curing unit; Electro-Lite Corp.) and a low-pressure mercury vapor pencil-style lamp (3.5 mW cm<sup>-2</sup>,  $\lambda = 253.7$  nm; inert gas double bore lamp, Jelight Corp.) were used to irradiate the samples to perform the photochemical reactions respectively at different wavelengths. A quartz cell (3.0 cm high, 1.0 cm wide, and 0.1 cm thick) was used to contain sample solutions for irradiation experiments at 254 nm wavelength.

Synthesis of Intermediates 2, 5, and 6 and Macroinitiator 7. The detailed experimental procedures and <sup>1</sup>H NMR spectra of compounds 2, 5, 6, and 7 are listed in the Supporting Information. Typical procedure to prepare the macroinitiators 7: Oxalyl chloride (760  $\mu$ L, 8.71 mmol) was added into a solution of compound 6 (450 mg, 0.87 mmol) in 20 mL of dry THF. One drop of DMF was added into this reaction mixture, which was then allowed to stir for 1 h at room temperature. The reaction mixture was concentrated by rotary evaporation first and then submitted to a high-vacuum oil pump to completely remove the volatiles. The residue was redissolved in 10 mL of dry CHCl<sub>3</sub>. Triethylamine (73 µL, 0.52 mmol), DMAP (11 mg, 0.09 mmol), and MeO-PEG<sub>2000</sub>-OH (830 mg, 0.42 mmol) were added into this resulting solution. The reaction mixture was allowed to stir for 48 h at 60 °C and then poured into a saturated ammonium chloride solution. The resulting solution was extracted by CH<sub>2</sub>Cl<sub>2</sub> (100 mL, twice). The combined organic layers were washed by  $H_2O$  (40 mL, twice), sodium bicarbonate aqueous solution (40 mL, twice), brine (40 mL, once), dried over sodium sulfate, and then concentrated by rotary evaporation to a 2 mL solution, which was precipitated from 100 mL of diethyl ether to give the desired compound, MeO-PEG<sub>2000</sub>-O-macroinitiator (810 mg), as a white solid.

Table 1. Characterization of Amphiphilic Diblock Copolymers

entry	copolymers <sup>a</sup>	$M_n^{\ b}$ (g/mol)	$M_{\rm w}^{\ \ b}\left({\rm g/mol} ight)$	$M_{\rm w}/M_{\rm n}$	$R^{c}$
1	PEG <sub>45</sub> - <sup>O</sup> b-PBA <sub>28</sub>	5130	5900	1.15	33/67
2	PEG <sub>45</sub> - <sup>O</sup> b-PBA <sub>63</sub>	6050	6660	1.10	19/81
3	$PEG_{45}$ - $^{O}b$ - $PCHA_{192}$	11670	13890	1.19	6/94
4	PEG <sub>45</sub> - <sup>N</sup> b-PBA <sub>108</sub>	11400	13680	1.20	12/88
5	PEG <sub>45</sub> - <sup>N</sup> b-PBA <sub>135</sub>	13890	15720	1.13	10/90
6	PEG <sub>45</sub> - <sup>N</sup> b-PCHA <sub>48</sub>	7160	8680	1.21	20/80
7	PEG <sub>45</sub> - <sup>N</sup> b-PCHA <sub>36</sub>	5550	6240	1.13	25/75

<sup>*a*</sup> DP (degree of polymerization) of acrylates was determined by <sup>1</sup>H NMR. <sup>*b*</sup> Molecular weight measurements were analyzed by SEC based on calibration using polystyrene standards. <sup>*c*</sup> *R* represents the ratio of hydrophilic block weight/hydrophobic block weight.

Based on <sup>1</sup>H NMR spectra, MeO-PEG<sub>2000</sub>-O-macroinitiator contained some unreacted PEG<sub>2000</sub>-OH while PEG<sub>2000</sub>-NH-macroinitiator had no PEG<sub>2000</sub>-NH<sub>2</sub> left over.

Synthesis of PEO-*b*-PBA/PCHA Copolymers. Typical procedure: MeO-PEG<sub>2000</sub>-macroinitiator (100 mg, 0.04 mmol), CuBr (11.5 mg, 0.08 mmol), *n*-butyl acrylate (220 mg, 1.72 mmol), 1, 4-dioxane (0.35 mL), and PMDETA (16.7  $\mu$ L, 0.08 mmol) were added into a Schlenk-type flask. The flask was degassed and exchanged with argon via three freeze—thaw cycles and then sealed in a pressure tube which was heated at 70 °C for 18 h. The reaction mixture was diluted with THF and passed through a short basic aluminum oxide column to remove Cu salts. The resulting solution was concentrated by rotary evaporation and a high-vacuum oil pump to remove all the solvent and the unreacted *n*-butyl acrylate, finally providing the corresponding polymer as colorless oil (215 mg).

For MeO-PEG<sub>2000</sub>-O-macroinitiator, in order to remove unreacted PEG-OH, the copolymer was further dialyzed against THF-H<sub>2</sub>O (1:3 volume ratios) solution to remove MeO-PEG<sub>2000</sub>-OH, using a Spectra/Por regenerated cellulose membrane with a molar mass cutoff of 3500 Da, and then lyophilized to give a pure compound. Alternatively, the crude copolymer could also be purified by silica column chromatography (eluting solvents: CH<sub>2</sub>Cl<sub>2</sub>/MeOH, 95/5). However, the trace acids present in regular silica gel decomposed the copolymer into two homopolymers by cutting off the linker. For MeO-PEG<sub>2000</sub>-NH-macroinitiator, the above dialysis–lyophilization step was unnecessary.

Self-Assembly of the Amphiphilic Block Copolymers in Water. The block copolymers were first dissolved in 1,4-dioxane or THF at a concentration of 1.0 mg/mL. Deionized water was then added very slowly (5  $\mu$ L portions) into 1.0 mL of the copolymer solution with gentle shaking. After each addition of water droplet, the solution was left to equilibrate for 5 min. The cycles of water addition and equilibration were stopped after a total amount of 1.5 mL of water has been added. The turbid solution was then dialyzed against deionized water (water

changed every 6 h) for 3 days to remove all the organic solvents, using a Spectra/Por regenerated cellulose membrane with a molar mass cutoff of 3500 Da.

### **Results and Discussion**

Synthesis and Characterization of Amphiphilic Block Copolymers. The amphiphilic diblock copolymers synthesis protocol is shown in Scheme 3. Recrystallized *trans*-cinnamic acid 1 was irradiated in solid state in open air with a UV lamp (180 mW cm<sup>-2</sup>,  $\lambda = 365$  nm; ELC-4001 light curing unit; Electro-Lite Corp.) for 24 h. The corresponding dimer,  $\alpha$ -truxillic acid (2), was first monofunctionalized with



**Figure 2.** (A) Deep-UV illumination of  $\alpha$ -truxillic acid dimethyl ester. (B) <sup>1</sup>H NMR spectra of  $\alpha$ -truxillic acid dimethyl ester: (a) without illumination, (b) 1 h illumination, (c) 2 h illumination, (d) 4 h illumination.

(4-hydroxybutyl)-2-bromo-2-methylpropanoate (5), which was prepared by a simple esterification reaction between 1, 4-butanediol (3) and 2-bromo-2-methylpropionyl bromide (4) and then reacted with monomethoxypoly(ethylene glycol), PEG-OH, or PEG-NH<sub>2</sub> to provide the macroinitiators 7. The macroinitiators were then used in the atom-transfer radical polymerization (ATRP) of different acrylate monomers to give the desired amphiphilic diblock copolymers 8.

In the above synthetic protocol (Scheme 3), steps i and iii generated difunctional byproducts in addition to the desired monofunctional compounds, which could be easily separated by flash column chromatography since they were all small molecules. However, the synthesis and purification of macroinitiator 7 in step iv was very tedious but was also the key step in the whole work. Our first try was to use the standard DCC/DMAP coupling reaction<sup>30</sup> to form an ester bond linking PEG-OH and compound 6, which resulted in a very low yield. Then, we used oxalyl chloride to activate the carbonyl acid group to form a carbonyl chloride, which was reacted with PEG-OH or PEG-NH<sub>2</sub> (0.5 mol equiv of compound 6). Despite several optimization tests, PEG-Omacroinitiator still had some unreacted PEG-OH inside (Figure 1A; for detailed integration values, see the Supporting Information), which could not be purified in this step. PEG-NH<sub>2</sub>, as a much stronger nucleophile, provided pure PEG-NH-macroinitiator (Figure 1B). Fortunately, the contaminated PEG-OH could be removed in the final stage through a simple dialysis-lyophilization process.

Seven different amphiphilic diblock copolymers were synthesized and characterized (Table 1). The hydrophilic block was always monomethoxylpoly(ethylene glycol) (PEG<sub>45</sub>-OH or PEG<sub>45</sub>-NH<sub>2</sub>, MW 2000, DP 45); the hydrophobic block was either poly(butyl acrylate) or poly(cyclohexyl acrylate). The degrees of polymerization of the poly(acrylate) blocks were determined by <sup>1</sup>H NMR using the integration value of the methylene protons ( $-O-CH_2CH_2-O-$ ) of PEG as the



**Figure 3.** <sup>1</sup>H NMR spectra of  $PEG_{45}$ -<sup>N</sup>*b*-PBA<sub>135</sub> before illumination (A) and after 8 h illumination (B). <sup>1</sup>H NMR spectra of  $PEG_{45}$ -<sup>O</sup>*b*-PBA<sub>28</sub> before illumination (C) and after 8 h illumination (D).



Figure 4. (A) SEC chromatograms of  $PEG_{45}$ -<sup>0</sup>*b*-PBA<sub>28</sub> with increasing UV exposure times. (B) SEC chromatograms of  $PEG_{45}$ -<sup>N</sup>*b*-PBA<sub>108</sub> with increasing UV exposure times.

reference (see the Supporting Information). Herein,  ${}^{O}b$ - represents an ester bond linker between PEG and truxillic acid, while  ${}^{N}b$ - represents an amide bond linker between PEG and truxillic acid.

**Model Molecule Illumination Test.** Before studying the photocleavage of amphiphilic diblock copolymers, a simple model molecule illumination test was performed on a small molecule,  $\alpha$ -truxillic acid dimethyl ester, which is supposed to be capable of being photocleaved into two cinnamic acid methyl ester molecules. Assuming the cyclobutane ring of  $\alpha$ -truxillic acid dimethyl ester might have two random cutoff directions, we should recover both *trans*-cinnamic acid methyl ester and *cis*-cinnamic acid methyl ester (Figure 2A).

The initial concentration of  $\alpha$ -truxillic acid dimethyl ester was 5.0 mg/mL in THF. According to Spectral Database for Organic Compounds SDBS,<sup>31</sup>  $\delta$  3.81, 6.45, and 7.69 belong to *trans*-cinnamic acid methyl ester, while  $\delta$  3.71, 5.96, and 6.97 belong to *cis*-cinnamic acid methyl ester. After 1, 2, and 4 h of irradiation (3.5 mW cm<sup>-2</sup>,  $\lambda$  = 253.7 nm; inert gas double bore lamp, Jelight Corp.), based on the <sup>1</sup>H NMR integration value ratio of three methyl protons ( $\alpha$ -truxillic acid dimethyl ester at  $\delta$  3.30, *trans*-cinnamic acid methyl ester at  $\delta$  3.81, *cis*-cinnamic acid methyl ester at  $\delta$  3.71), we could calculate the molar ratios of the three compounds (Figure 2B and Supporting Information). Interestingly, the molar ratio of *cis*-cinnamic acid methyl ester and *trans*cinnamic acid methyl ester remains constant at 1.3 during the whole illumination.

**Photoirradiation of Diblock Copolymers.** We applied proton NMR and size exclusion chromatography (SEC) techniques to study the photocleavage of four amphiphilic diblock copolymers:  $PEG_{45}$ - $^{Ob}$ -PBA<sub>28</sub> (poly(ethylene glycol)-*block*-poly(butyl acrylate)),  $PEG_{45}$ - $^{Nb}$ -PCHA<sub>48</sub> (poly(ethylene glycol)-*block*-poly(cyclohexyl acrylate)),  $PEG_{45}$ - $^{Nb}$ -PBA<sub>135</sub>, and  $PEG_{45}$ - $^{Nb}$ -PBA<sub>108</sub>. The initial concentrations of these amphiphilic diblock copolymers were all of 5.0 mg/mL in THF. Since our available mercury lamp had a very low power intensity of 3.5 mW cm<sup>-2</sup>, we have had to illuminate our copolymer solutions for several hours.

At first, a series of PEG<sub>45</sub>-<sup>N</sup>b-PBA<sub>135</sub> samples were irradiated for 6, 8, 12, and 16 h. We expected to observe the olefin protons of cinnamic group appearing at  $\delta$  7–6 on <sup>1</sup>H NMR spectra. However, as shown in Figure 3A,B, neither olefin protons nor even the aromatic protons were visualized. Then, we realized that our mercury lamp would generate ozone which could destroy all the olefins and even aromatic rings. Meanwhile, since the initial concentrations of PEG<sub>45</sub>-<sup>N</sup>b-PBA<sub>135</sub> was only 5.0 mg/mL, a relatively long hydrophobic block (135 BA units) in the copolymer made the concentration of the  $\alpha$ -truxillic acid linker much lower, which was more susceptible to the trace



**Figure 5.** TEM images of block copolymer self-assemblies. In the 1,4dioxane–H<sub>2</sub>O system:  $PEG_{45^{-}}{}^{N}b$ -PCHA<sub>48</sub> (A) and  $PEG_{45^{-}}{}^{N}b$ -PCHA<sub>36</sub> (E). In the THF–H<sub>2</sub>O system:  $PEG_{45^{-}}{}^{N}b$ -PCHA<sub>48</sub> (B) and  $PEG_{45^{-}}{}^{N}b$ -PCHA<sub>36</sub> (F). (C) and (D) show cryo-TEM images of  $PEG_{45^{-}}{}^{N}b$ -PCHA<sub>48</sub> block copolymer self-assemblies in the 1,4-dioxane–H<sub>2</sub>O system. Scale bar = 100 nm for all the figures.

amount of ozone generated in THF solvent. Thus, a shorter copolymer,  $PEG_{45}$ - $^{O}b$ -PBA<sub>28</sub> dissolved in degassed THF was illuminated for 8 h in inert gas environment. As shown in Figure 3D, olefin protons around  $\delta$  6.5 on <sup>1</sup>H NMR spectra were clearly visualized, peaks that were absent from the original before-illumination sample (Figure 3C).

The photocleavage was also confirmed by SEC. As shown in Figure 4A, when  $PEG_{45}$ - $^{O}b$ -PBA<sub>28</sub> was illuminated for 8 h, it showed a new peak appearing close to the peak of pure PEG<sub>45</sub>-OH. A further cleavage-by-irradiation overtime experiment was performed on  $PEG_{45}$ - $^{N}b$ -PBA<sub>108</sub> (Figure 4B). With increasing times of irradiation, the original peak intensity decreased while the new peak close to the peak of pure PEG<sub>45</sub>-NH<sub>2</sub> increased. Finally, 24 h illumination seemed to completely break all the cyclobutane ring junctions.



**Figure 6.** (A) TEM images of  $PEG_{45}$ -<sup>N</sup>*b*-PCHA<sub>48</sub> self-assembly in water before illumination (scale bar = 50 nm). (B) TEM images of  $PEG_{45}$ -<sup>N</sup>*b*-PCHA<sub>48</sub> self-assembly in water after 6 h illumination (scale bar = 50 nm). (C, D) TEM images of  $PEG_{45}$ -<sup>N</sup>*b*-PCHA<sub>48</sub> self-assembly in water after 24 h illumination (scale bar = 50 nm for C, 1  $\mu$ m for D). (E) DLS size distribution by intensity graph of the formed nano-objects before illumination and after 6 h illumination. (F) SEC chromatograms of  $PEG_{45}$ -<sup>N</sup>*b*-PCHA<sub>48</sub> with increasing UV exposure times.

**Photoirradiation of Self-Assembled Nano-objects.** Our ultimate goal was to observe a UV-light-induced disassembly of the nano-objects made by self-assembly of the amphiphilic block copolymers in water. The ideal scenario was to have an original self-assembled vesicle broken after photoirradiation. In order to get vesicles, we chose to use a much stiffer PCHA (poly(cyclohexyl acrylate)) hydrophobic block instead of PBA (poly(butyl acrylate)) since the cyclohexyl ring system is much more rigid which would help build the hydrophobic shells of vesicles.

On the basis of our previous experiences,<sup>32</sup> when the hydrophilic block/hydrophobic block weight ratio, R, is between 20/80 and 40/60, the block copolymer has better chance to form vesicles in aqueous solution. Thus, PEG<sub>45</sub>-<sup>N</sup>b-PCHA<sub>48</sub>

(R = 20/80) and PEG<sub>45</sub>-<sup>N</sup>b-PCHA<sub>36</sub> (R = 25/75) were chosen for the self-assembly experiments in aqueous solution at a low concentration of 1 mg/mL in deionized water with the aid of 1, 4-dioxane or THF as cosolvent. The morphologies of all the observed nano-objects are shown in Figure 5.

Analysis by TEM with negative staining revealed that  $PEG_{45}$ -<sup>N</sup>*b*-PCHA<sub>48</sub> formed a mixture of spherical micelles and spherical vesicles in the 1,4-dioxane-H<sub>2</sub>O system (Figure 5A). Cryo-TEM showed vesicles as being the minority nano-objects (Figure 5C) while micelles were unfortunately the majority ones (Figure 5D). In the THF-H<sub>2</sub>O system, PEG<sub>45</sub>-<sup>N</sup>*b*-PCHA<sub>48</sub> self-assembled into irregular micelles (Figure 5B). Another copolymer, PEG<sub>45</sub>-<sup>N</sup>*b*-PCHA<sub>36</sub>, appeared as giving almost pure micelles in 1,4-dioxane-H<sub>2</sub>O and THF-H<sub>2</sub>O systems (Figure 5E,F).

Although we did not find monodisperse vesicle morphology in these photolabile amphiphilic block copolymer systems, disassembly of micelles under photoirradiation should still be attractive. When the irregular micelles of PEG<sub>45</sub>-<sup>N</sup>b-PCHA<sub>48</sub> sample self-assembled in THF-H2O (Figure 6A) was illuminated by a deep UV source, the nano-objects were transformed into much smaller polydisperse condensed nanospheres (Figure 6B) after 6 h exposure and became micrometer-sized precipitates (Figure 6C,D) after 24 h exposure. Dynamic light scattering (DLS) and SEC experiments (Figure 6E,F) confirmed these observations. As shown in Figure 6F, 6 h of irradiation did not break all the block copolymers but changed the hydrophilic-hydrophobic balance of the whole system, thus changing the morphology of the nano-objects.<sup>1</sup> However, when all the copolymers were photocleaved after 24 h of irradiation, the pure hydrophobic polymer chains were not stable in aqueous solution, resulting in their precipitation as solid.

### Conclusion

In conclusion, we developed and studied novel photolabile diblock copolymers bearing  $\alpha$ -truxillic acid derivative junctions. Although the photocleavage of these copolymers requires a strong UV source ( $\lambda < 260$  nm) and long irradiation time which is harmful to cells and tissues, these "proof-of-idea" block copolymers could still be attractive candidates for applications in nanoreactors and templates for micro- or nanostructured materials. Furthermore, since  $\alpha$ -truxillic acid derivatives can survive UV irradiation of  $\lambda > 260$  nm, wavelengths that are not supported by *o*-nitrobenzyl groups, multiblock copolymers bearing these two photolabile junctions could be selectively cut off in specific blocks using different wavelengths of light. This will be the subject of a future publication.

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**Supporting Information Available:** Details of the synthesis and characterization; <sup>1</sup>H NMR spectra. This material is available free of charge via the Internet at http://pubs.acs.org.

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