Supporting Information

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Controlled Release of Guest Molecules from Mesoporous Silica Particles Based on a pH-Responsive Polypseudorotaxane Motif

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Materials and equipments. 1,1'-Carbonyldiimidazole (CDI), tetraethoxysilane (TEOS), and 3-aminopropyltriethoxysilane (APTES) from Aldrich were used as received. 2-Ethyl-2-oxazoline from Aldrich was purified by vacuum distillation under calcium hydride. Methyl *p*-toluenesulfonate (Aldrich) was purified by vacuum distillation. Succinic anhydride (Aldrich) was recrystallized from n-hexane/acetone (2:8, v/v). Triethylamine (TEA) from Aldrich was purified by distillation under calcium hydride. α -Cyclodextrin, β -cyclodextrin and γ -cyclodextrin from TCI were used as received. All the solvents were purified by literature procedures.^[1] ^1H and ^{13}C NMR spectra were recorded on a Varian UNITY INOVA 400 at 400 and 100 MHz respectively and were referenced to TMS. FT-IR spectra were obtained using Perkin-Elmer System 2000 FT-IR spectrophotometer. Molecular weights and molecular weight distributions were estimated using a GPC equipped with a Waters Associates 410 RI detector, 510 HPLC pump and μ -Styragel columns with pore size of 10^2 , 500, 10^3 , and 10^4 Å. The eluent was THF and the molecular weights were calibrated with polystyrene standards.

Synthesis of amine-terminated poly(2-ethyl-2-oxazoline) (PEtOz-NH₂). A solution of 2-ethyl-2-oxazoline (70.00 g, 706.0 mmol) and methyl *p*-toluenesulfonate (2.19 g, 11.8 mmol) in acetonitrile (300 mL) was stirred at reflux for 30 h under nitrogen. After the reaction was cooled to 0 °C, 0.1 N methanolic ammonia was added to introduce primary amine at the end of the PEtOz chain. The solution was then stirred at room temperature for 3 h under nitrogen. The reaction solution was precipitated into cold diethyl ether. The crude polymer was dissolved in methylene chloride (400 mL), washed twice with a saturated aqueous NaHCO₃ (200 mL), and then washed with distilled water (200 mL). After the organic layer was dried over anhydrous magnesium sulfate, the polymer was then isolated by precipitation into cold diethyl ether (yield 98%).

^1H NMR (CDCl₃): δ 1.93 (m, -COCH₃), 3.38 (s br, -CH₂CH₂- of OZ), 3.55 (s, -CH₂CH₂O-); M_n = 2,500, M_w/M_n = 1.05

Synthesis of amine-terminated poly(ethylenimine) (PEI-NH₂). PEtOz-NH₂ (4.0 g, 0.6 mmol) was dissolved in a mixture of concentrated hydrochloric acid (35%, 30 mL) and distilled water (70 mL). The reaction mixture was stirred at 100 °C for 24 h. The pH was adjusted to 10 by adding NaOH to the solution at 0 °C. The precipitate was collected by centrifugation, washed with distilled water, and then dried in vacuo at 60 °C (yield 90%).

^1H NMR (CDCl₃): δ 1.93 (m, -COCH₃), 3.38 (s br, -CH₂CH₂- of OZ), 3.55 (s, -CH₂CH₂O-); M_n = 1,100 (end group analysis from ^1H NMR spectrum)

Synthesis of Si-MP. Spherical Si-MP was prepared according to reference procedure.^[2] Si-MP was confirmed by powder X-ray diffraction (PXRD) and environmental scanning electron microscopy (E-SEM). The mean diameter of silica particles estimated by E-SEM was 425 nm.

Synthesis of amine-functionalized Si-MP (1). The surface of Si-MP (50 mg) was functionalized with 2 mL of 3-aminopropyltriethoxysilane (APTES) according to the reference procedures.^[3] The particles were separated by centrifugation (5000 rpm, 10 min) and washed three times with ethanol. Particle **1** was characterized by FT-IR and the Ninhydrin test.^[4] The FT-IR spectrum of the particle **1** shows absorption band at 1636 cm⁻¹ due to amine unit on the silica surface. The spectrum also displays a band and at 2927 cm⁻¹ and 2856 cm⁻¹ due to C-H stretching vibrations (Figure S2). The Ninhydrin test revealed the presence of primary amine.^[5,6]

Synthesis of carboxylic acid-functionalized Si-MP (2). The carboxylic acid-functionalized silica particle **2** (20 mg) was obtained by reacting succinic anhydride (0.45 g) with amine-terminated silica particle (**1**) in the presence of TEA (0.45g). The resultant was purified by centrifugation (7000 rpm, 30 min) and washed with ethanol. The particle **2** was characterized by FT-IR (Figure S2).

Synthesis of CDI-activated Si-MP (3) and PEI-functionalized Si-NP (4). The particle **2** was activated by CDI. After reaction, the particle **3** was purified by centrifugation (7000 rpm, 20 min). The activated silica particle **3** was reacted with PEI-NH₂ in PBS solution for 12 h. The particle **4** was characterized by FT-IR (Figure S2).

Figure S1. E-SEM and TEM micrographs for Si-MPs.

Figure S2. FT-IR spectra of particle (A) **1**, (B) **2**, (C) **4**, and (D) a-CD/**4**.

Figure S3. Fluorescence spectra of a) calcein, b) calcein/a-CD, c) calcein/a-CD/PEI, and d) calcein-loaded a-CD/4 at different pH conditions. e) Fluorescence intensity (at 520 nm) of 1) calcein, 2) calcein/a-CD, 3) calcein/a-CD/PEI, and 4) calcein-loaded a-CD/4 at different pH conditions.

The fluorescence intensity of calcein at pH 5.5 and 11 is almost identical even though the fluorescence intensity decreases below pH 4.5. Moreover, the fluorescence intensity of calcein/a-CD and calcein/a-CD/PEI also was similar in the range of our experiment ($5.5 < \text{pH} < 11$).

Figure S3d shows the change in fluorescence intensity of the solutions of calcein-loaded a-CD/4 at different pH conditions. As shown in Figure S3d, at pH 11, weak fluorescence intensity was observed due to self-quenching of calcein molecules in the pore. The fluorescence intensity of the mixture was increased with decreasing pH from 11 to 8. At pH below 8, the fluorescence intensity was not changed, which is due to release of guest molecules from the pore of Si-MP upon dissociation of PEI/CD polypseudorotaxane.^[7-9]

Figure S4. Fluorescence spectra of calcein-loaded β -CD/4 at different pH conditions..

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