Supporting Information

Characterization and measurement

Measurement of detachment force of silicone

The magnet was sealed in the PLA shell, as described in Section 2.2.1. Then, a specially designed ring was affixed to the sealed silicone using glue. A hook connected to a push-pull gauge was then threaded through the ring. A motor was used to control the guide rail, slowly pulling the gauge at a speed of 0.1 mm/s until the silicone detached from the microrobot. At this point, the maximum detachment force was recorded. The sections were cut out of the fresh porcine small intestine and large intestine, placed in a 3 cm diameter groove exposing the lumen side and secured using the fixture. Double-sided tape affixed the film sample to the ergometer. The film sample was left in contact with the tissue for 2 minutes with a force of 1.5 N [1]. Subsequently, the film sample was slowly pulled up at a constant speed of 0.1 mm/s. The maximum detachment force was recorded. The measurement results are presented in Fig. S1.

Fourier Transform Infrared Spectroscopy (FTIR) characterization

The chemical groups of materials were analyzed using Fourier transform infrared spectroscopy (Thermerfeld, IS5). In a dry environment, the sample was placed on the crystal surface of the attenuated total reflection (ATR) attachment. The infrared wavenumber range was set from 400 to 4000 cm^{-1} during 32 scans. The results are shown in Fig. S2.

Loss of mass of hydrogel

The weight of hydrogels was measured and recorded as m_1, after which they were placed in PBS solution. The samples were removed at predetermined intervals and dried in a constant temperature drying oven at 50 °C. The weight of samples after complete drying was measured and recorded as m_2, and the mass loss of the hydrogel in the solution can be calculated using the following equation:

$$Q = \frac{m_1 - m_2}{m_1} \times 100\% \quad (1)$$

The results are shown in Fig. S3.

Measuring the adhesion of Eudragit films to PEGDA/PEG hydrogel and PLA

A push-pull gauge was used to measure the adhesion force, and a stepper motor was employed to ensure constant speed during the rise and fall process. A heating platform was used to control the temperature of hydrogel and PLA at 37 ℃. A 1 × 1 cm Eudragit film was fixed to the bottom of the push-pull gauge with double-sided adhesive, and a PLA or PEGDA/PEG hydrogel sheet was placed directly under the gauge and fixed using a fixture. The film remained in contact with the sheets for 20 seconds, and then the film was slowly pulled up at a speed of 0.1 mm/s until the adhesion with the bottom failed. The maximum detachment force was recorded as the adhesion force, with the contact pressure set to 0.6 N for PLA and 0.2 N for PEGDA/PEG hydrogel. The adhesion force between the fully swelling film with PLA

or PEGDA/PEG hydrogel was measured similarly. The results are shown in Fig. S5.

Measuring hydrogel bending properties

The mechanical properties of PEGDA and PEGDA/PEG hydrogels were evaluated using an electronic universal tester machine (LDW-2KN, Shanghai Songdun Instrument Manufacturing Co., Ltd., China). The size of the samples was 16 × 2 × 0.8 cm, and their bending properties were measured through the three-point bending tests after the PEGDA hydrogel was swollen for 12 hours and the PEGDA/PEG hydrogel was swollen for 2 hours. The support span was set to 6 cm, and the applied velocity of the bending load was applied at a constant velocity of 2 mm/min. The results are shown in Fig. S6.

Morphologies of hydrogels

A scanning electron microscope (SIGMA300, Zeiss) with an operating voltage of 10 kV was used to examine the cross-sectional structure of the hydrogels. Before SEM analysis, the hydrogels were rapidly frozen with liquid nitrogen to form amorphous ice and broken with a blade. The broken samples were freeze-dried at 45 ℃ for 24 hours in a freeze dryer (SCIENTZ-10N, Ningbo Scientz Biotechnology Co., Ltd.).

Measurement of dissolution time of enteric-coated capsules

Enteric-coated capsules were purchased from Anhui Huangshan Capsule Co., Ltd., China. Microrobots containing drugs and those without drugs were placed into the enteric capsules. To simulate the pH changes along the gastrointestinal tract, phosphate-buffered saline (PBS) with pH values of 1.2 and 7.4 was sequentially used as the dissolution medium [2]. The capsule was initially placed in a bottle containing 50 mL of PBS (pH 1.2). After incubation for 2 hours, the old solution was removed, and fresh PBS (pH 7.4) was added. The capsule was then incubated for an additional 3 hours. In the experiment, the bottle was placed in a thermostatic water bath oscillator, which was operated at a speed of 150 rpm. The temperature of the water bath was maintained at 37 °C. At pre-selected time intervals, 1 mL of the release medium was collected from the bottle for analysis, and an equal volume of fresh PBS was added following each collection. The experiment was repeated eight times. The results are shown in Fig. S7.

Reference

1 M. Kamba, Y. Seta, A. Kusai and K. Nishimura, *Int. J. Pharm.*, 2002, **237**, 139–149.

2 V. S. Mastiholimath, P. M. Dandagi, S. S. Jain, A. P. Gadad and A. R. Kulkarni, *Int. J. Pharm.*, 2007, **328**, 49–56.

Figure

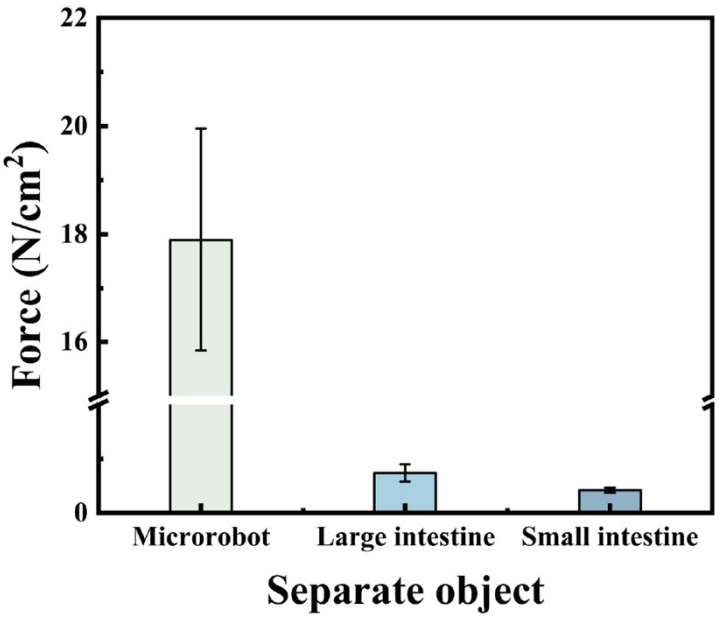

Fig. S1. Detachment force of silicone. (n = 5; Mean ± SD).

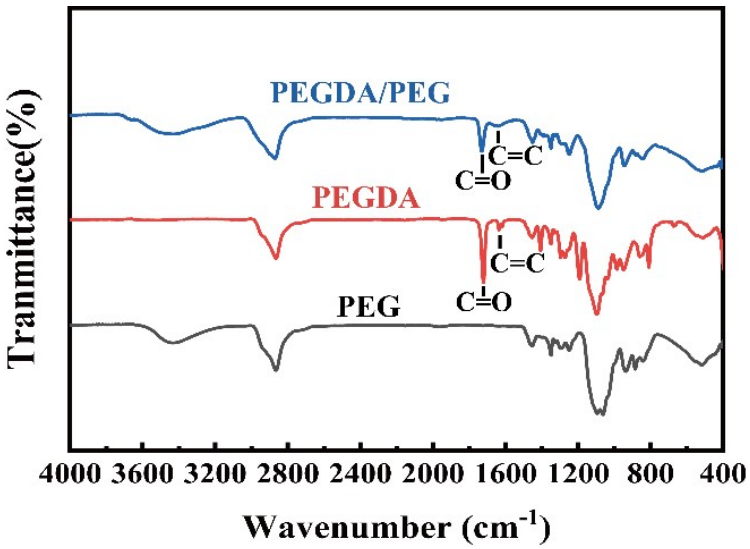

Fig. S2. ATR-FTIR spectra of hydrogels

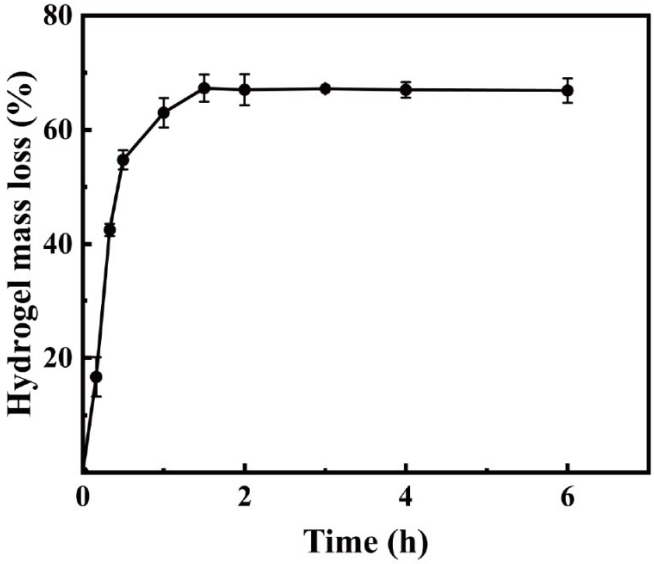

Fig. S3. Mass loss in the first 6 hours of PEGDA/PEG hydrogels. (n = 5; Mean ± SD).

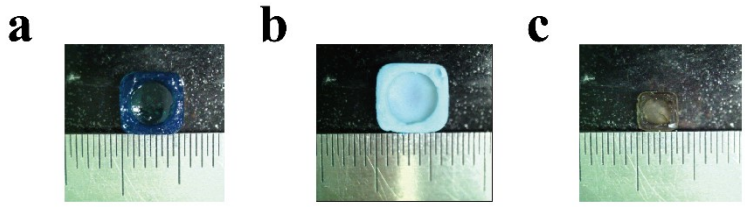

Fig. S4. Morphology of PEGDA/PEG hydrogel. a) Initial state. b) Swelling for 2 hours. c) Swelling for 2 hours and completely drying.

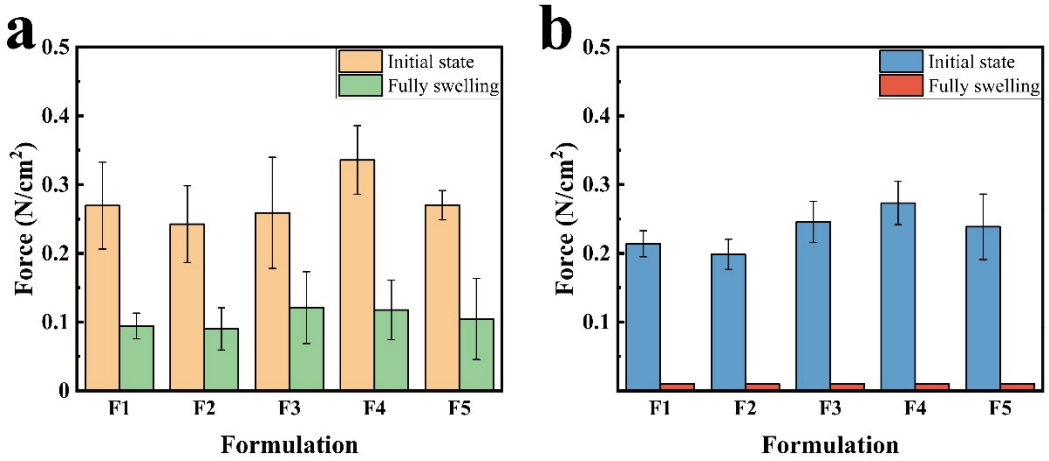

Fig. S5. Adhesion of Eudragit film in the initial and fully swelling state to (a) PLA and (b) PEGDA/PEG hydrogel. (n = 5; Mean ± SD).

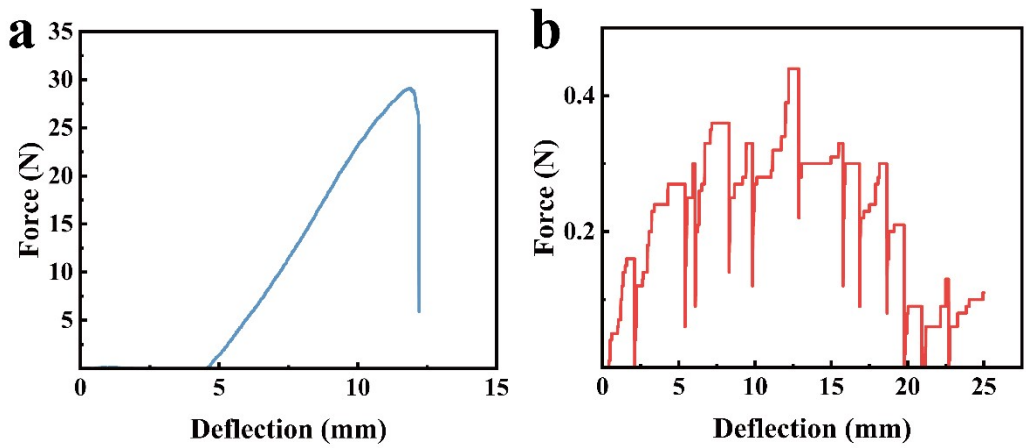

Fig. S6. Load-deflection curves of (a) PEGDA hydrogel and (b) PEGDA/PEG hydrogel in the three-point bending tests.

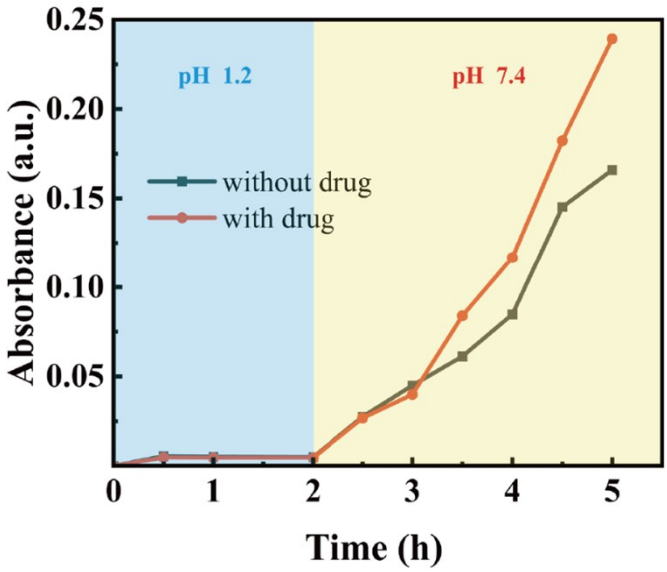

Fig. S7. Absorbance of the solution in which enteric-coated capsules were placed. After being immersed in PBS (pH 7.4) for 1.5 hours, 25% capsules were partially dissolve, resulting in the release of the drug. At this point, the absorbance of the solution containing drug-loaded capsules started to exceed that of the solution without the drug. 75% of capsules began to release their drugs after 2 to 2.5 hours of incubation.