Supporting information

Polymeric Quaternary Ammonium Enabled Contact-Active, Long-Acting and Biocompatible Antibacterial Catheters for Overcoming Leaching-Dependent Antimicrobial Additives

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1. Experimental

1.1、Preparation of QPEI-modified TPU (QPEI-TPU)

A total of 1 g of quaternized polyethyleneimine (QPEI) and 100 g of thermoplastic polyurethane (TPU) pellets were accurately weighed and pre-dried separately in a forced-air oven at 40 °C for 8 h to remove residual moisture. This pretreatment step was essential to eliminate trace water that could otherwise induce phase separation or incomplete dissolution during subsequent processing. After drying, the QPEI powder and TPU pellets were co-dissolved in tetrahydrofuran (THF). Ultrasonic agitation followed by continuous magnetic stirring was employed to ensure complete dissolution and homogeneous mixing of the polymer components. The resulting homogeneous solution was carefully poured into a pre-cleaned and dried iron mold (20 cm × 20 cm × 5 cm) to achieve uniform spreading. The mold was then placed in a convection oven and dried at 60 °C for 24 h to allow gradual solvent evaporation and formation of a uniform QPEI–TPU composite film. The obtained film was subsequently transferred to

a vacuum oven and further dried at 60 °C under a vacuum of 0.1 MPa for an additional 24 h to ensure complete removal of residual THF. The dried composite film was then removed from the mold and mechanically cut into small granules (approximately 1–2 mm in diameter) to yield QPEI–TPU masterbatches with a QPEI content of 1 wt.%. Composites containing varying QPEI concentrations were subsequently prepared by blending the masterbatch with pristine TPU at controlled ratios, followed by melt processing using a twin-screw extruder. The extruded QPEI–TPU composite rods with QPEI contents of 0 wt.%, 0.5 wt.%, 1 wt.%, and > 1 wt.% were obtained and cooled to room temperature. The rods were then pelletized and hot-pressed into thin film samples using a flat-plate vulcanizing press. Additionally, medical-grade QPEI–TPU catheters containing 1 wt.% QPEI were fabricated using the same formulation through industrial extrusion at Chengdu Daxan Innovative Medical Tech. Co., Ltd.

1.2 Evaluation of *in vitro* antibacterial performances

Autoclave Sterilization Treatment Assay: The 1 wt.% QPEI-TPU samples were cut into 2 cm×2 cm pieces. Then, the samples were placed in an autoclave and sterilized at 121 °C and 131 kPa for 30 min. The samples were taken out and tested by the film sticking method for its antibacterial property against *S. aureus*.

UV Sterilization Treatment Assay: The QPEI-TPU catheters and commercial TPU catheters were exposed to ultraviolet (UV) irradiation for 24 h. After sterilization, both the QPEI-TPU and commercial TPU catheters were transferred to a fume hood and ventilated at room temperature for 12 h to eliminate potential residual effects. The samples were taken out and tested by the film sticking method for its antibacterial property against *S. aureus*.、*E. coli*、MRSA and *C. albicans.*

Ethylene oxide Sterilization Treatment Assay: The QPEI–TPU catheters and commercial TPU catheters were individually sealed in sterilization pouches that were gas-permeable but bacteria-impermeable, ensuring sufficient spacing between samples to facilitate gas penetration., then placed in an EO sterilizer. The sterilization process was conducted at 55 °C with a relative humidity of 60%, an EO gas concentration of 600 mg/L, and a total exposure time of 3 h. The samples were taken out and tested by

the film sticking method for its antibacterial property against *S. aureus*.、*E. coli*、MRSA and *C. albicans.*

γ -ray *Sterilization Treatment Assay*: The QPEI–TPU catheters and commercial TPU catheters were individually sealed in sterile bags and transferred to a gamma irradiation facility for sterilization. The irradiation dose was set at 25 kGy, and the irradiation process was initiated according to the standard protocol. The samples were taken out and tested by the film sticking method for its antibacterial property against *S. aureus*.、*E. coli*、MRSA and *C. albicans.*

1.3 Statistical analysis. Each assay was performed at least three times, and all quantitative results were presented as mean ± standard deviation.

2 Supporting figures

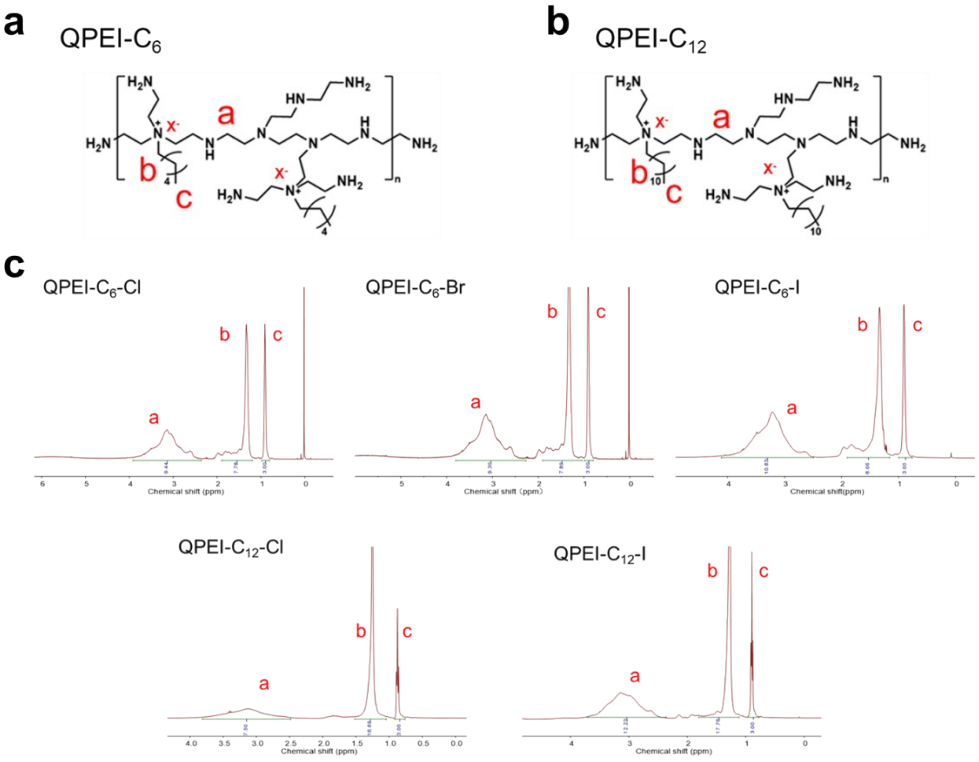

Figure S1 (a) Molecular formula of QPEI-C_6; (b) Molecular formula of QPEI-C_{12}; (c) ^{1}H NMR spectra of various QPEI

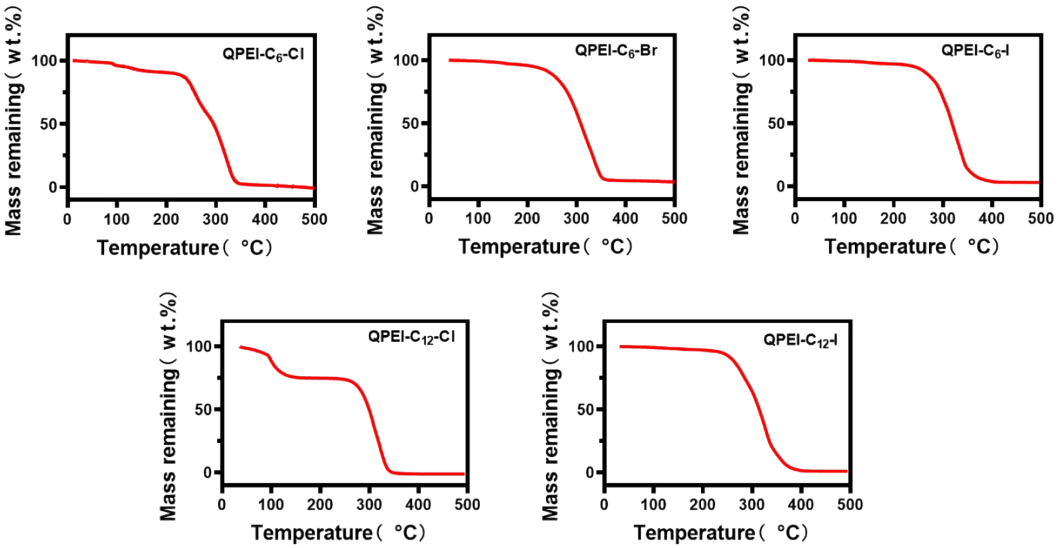

Figure S2 Thermogravimetric analysis curves of various QPEI

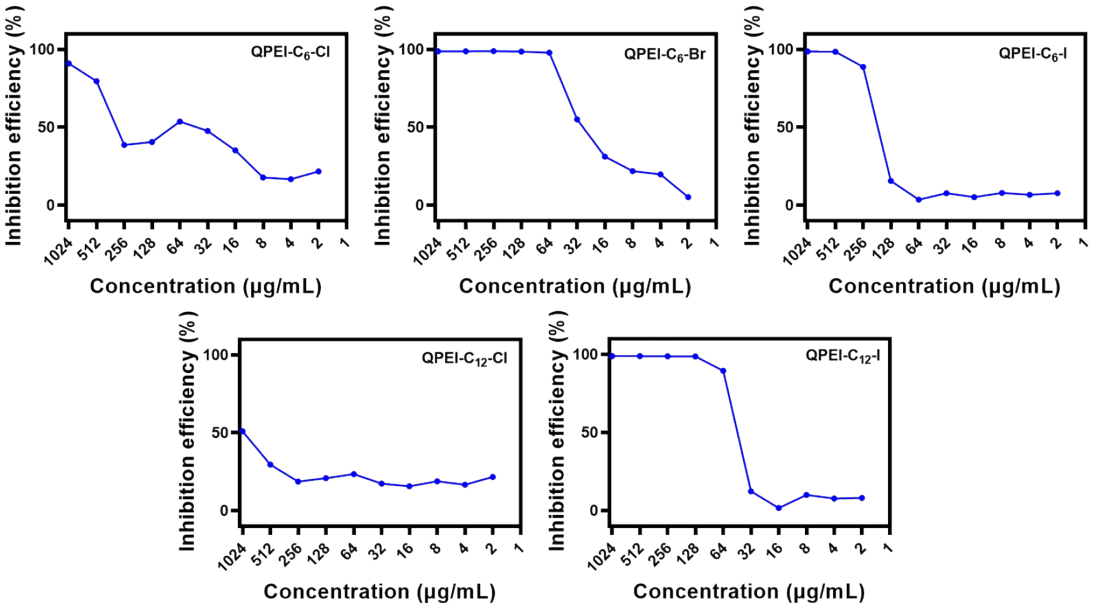

Figure S3 Minimum Bactericidal Concentration of various QPEI

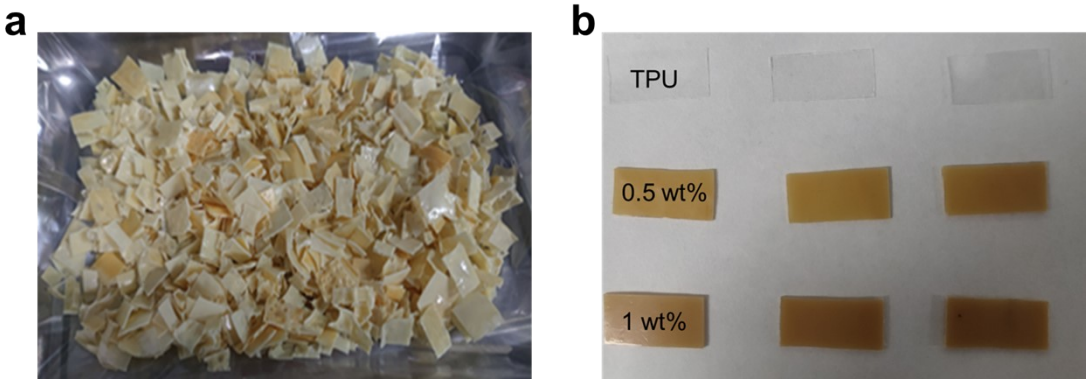

Figure S4 (a) QPEI and TPU blended masterbatch, (b) QPEI-TPU sheets with different blending ratios

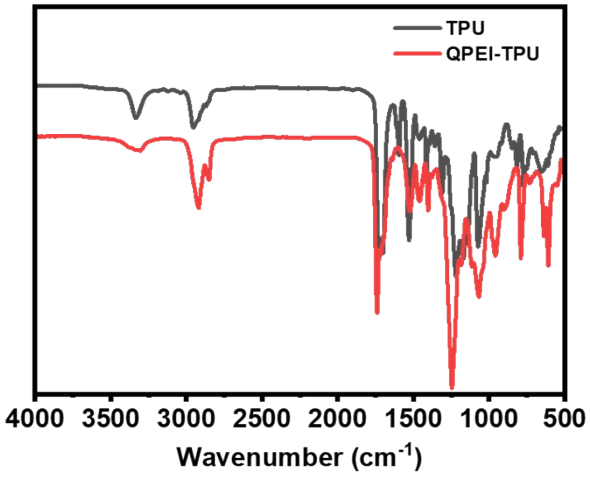

Figure S5 FI-TR spectra of QPEI-TPU catheters and TPU catheters

Figure S6. Subcutaneous implantation infection model on the back of mice

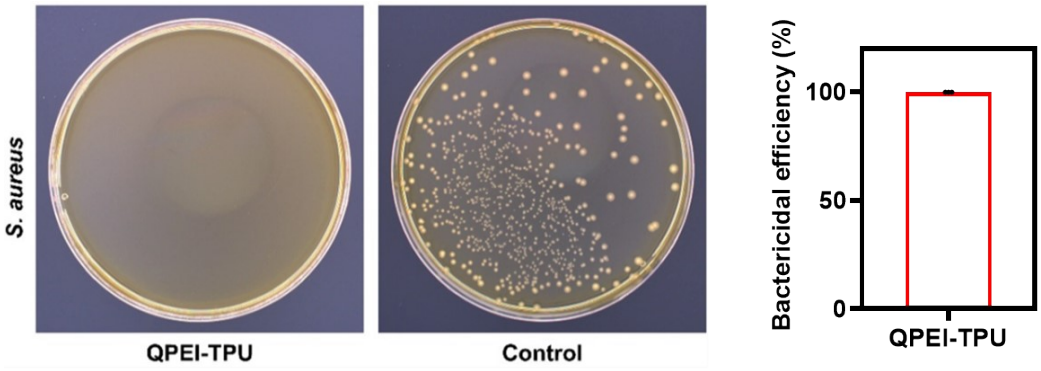

Figure S7. *In vivo* bactericidal rate of QPEI-TPU sheets.

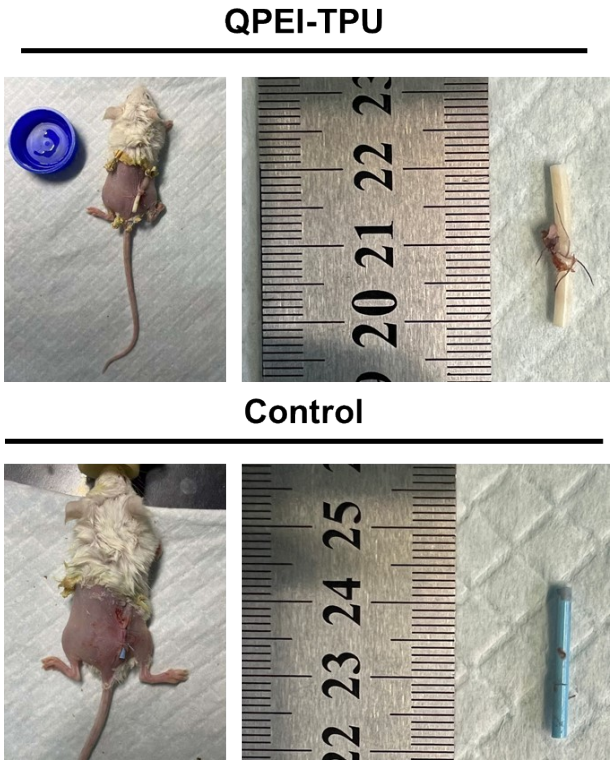

Figure S8. Animal experimental model for catheter-related infections