Supplementary Information

Materials: Polyethylene glycol (PEG-200) was purchased from Sinopharm Chemical Reagent Co., Ltd. (China). Bovine serum albumin (BSA) was recieved from Beijing Solarbio Science&Technology Co., Ltd. (China). Singlet oxygen sensor green (SOSG) was bought from Thermo Fisher Scientific (USA). Chlorin e6 (Ce6) was obtained from Frontier Scientific (USA). Fata bovine serum (FBS), penicillin-streptomycin solution were supplied by HyClone (USA). Dulbecco's Modified Eagle's Medium (DMEM) incomplete high glucose medium, cell counting kit-8 (CCK-8) were obtained from Jiangsu Kaiji Biotechnology Co., Ltd. (China). Tris(4,7-diphenyl-1,10-phenanthroline) ruthenium dichloride (II) $[(Ru(dpp)_3)]Cl_2$ was recieved from alfa aesar (China). Dihydrorhodamine123 (DHR-123) was purchased from Jiangsu Kaiji Biotechnology Co., Ltd. (China). Hoechst 33342 was supplied by Beijing Robby Biotechnology Co., Ltd. (China).

Characterizations: The morphology of NPs was observed on a JEOL 2100 transmission electron microscope (TEM, JEOL, Japan). The size distribution of NPs was assessed on a Nano-ZS90 Zetasizer (Malvern, UK). The elemental contents of Mn in the nanozyme and Ca in the CaO_2 NPs were 3.8% and 45.7%, respectively, as determined on an inductively coupled plasma emission ICP-OES spectrometer (ICP-OES, Varian 710-ES, USA). Powder X-ray diffraction patterns were collected on an X-ray diffractometer (ProTT EZRaman A5, USA) with Cu-Kα radiation (λ = 0.1540 nm) at 40 kV.

Quantification of Oxygen generation: In order to quantify the oxygen generation of

CaO_2 upon exposure to water, a JPBJ-608 Dissolved Oxygen Analyzer (Leici, China) was used. Specifically, the oxygen probe was inserted into the aqueous solution containing CaO_2 (0.5 mg/mL) with MnO_2 nanozyme at different concentrations (0, 0.125, 0.25, 0.5 mg/mL) and the oxygen content was measured every 5 min.

Relaxivity of MnO_2: The longitudinal (T_1) phantom images as well as relaxation times of MnO_2 with different Mn concentrations (0, 0.025, 0.05, 0.1, 0.2, 0.4, and 0.8 mM) were recorded on a 7T small animal MR imaging system (Bruker, Germany) using a RARE-T_1+T_2-map sequence with the following parameters: echo time (TE) = 11.00 ms, pulse repetition interval (TR) = 235, 400, 800, 1500, 3000, 5000 ms, acquisition matrix = 256 mm × 256 mm, the flip angle (FA) = 180°, the slice thickness = 1 mm, and the field of view (FOV) = 5.0 × 5.0 cm^2.

Cytotoxicity: The mouse breast cancer cells (4T1) and human umbilical vein endothelial cells (HUVEC) were used as respective tumor and normal cells. Cells were cultured in DMEM high glucose medium containing 10% fetal bovine serum, 1% penicillin, and 1% streptomycin at 37 °C in a CO_2 incubator (Thermo Fisher，USA). The cells in the logarithmic growth phase were seeded in 96-well plates at a concentration of 1×10^5 cells/mL with 100 μL DMEM high glucose medium containing 10% fetal bovine serum. After 24 h, the medium was replaced with 100 μL of fresh medium containing different concentrations of MnO_2, CaO_2 or CaO_2/MnO_2 NPs. After another 24 h or 48 h, the cells were observed under the optical microscope (Nikon, ECLIPSE Ti, Japan). Then CCK-8 assay was performed 1 h later. The absorbance at 450 nm was measured on a Multiskan Spectrum microplate reader

(Thermo Fisher, USA) to calculate the cell viability.

Animal model establishment: All animal procedures were performed in accordance with the Guidelines for Care and Use of Laboratory Animals of Capital Medical University and approved by the Animal Ethics Committee of Capital Medical University. The mouse subcutaneous tumor model was established using female Balb/c SPF mice weighing about 20 g and male Balb/c SPF nude mice weighing about 20 g as follows. First, 4T1 cells in PBS were prepared in the logarithmic growth phase at a concentration of 2×10^7 cells/mL. Then, 0.1 mL of the cell suspension prepared was subcutaneously injected into the thigh of the mouse, which was experimented when the tumor volume was up to 100 mm^3.

***in vivo* MR imaging**：MnO_2 (5 mg Mn/kg body weight) in 200 μL saline were i.v. injected through tail vein. Then, MR images of the tumor-bearing mice were obtain on a 7 T small MR imaging system (Bruker, Germany) at different time points. T_1 weighted image scanning parameters were set as follows: TR = 300 ms, TE = 8.6 ms, FA = 176.6 deg, FOV = 35 mm × 35 mm, matrix = 256 mm × 256 mm, slice thickness = 1 mm, NEX = 3.

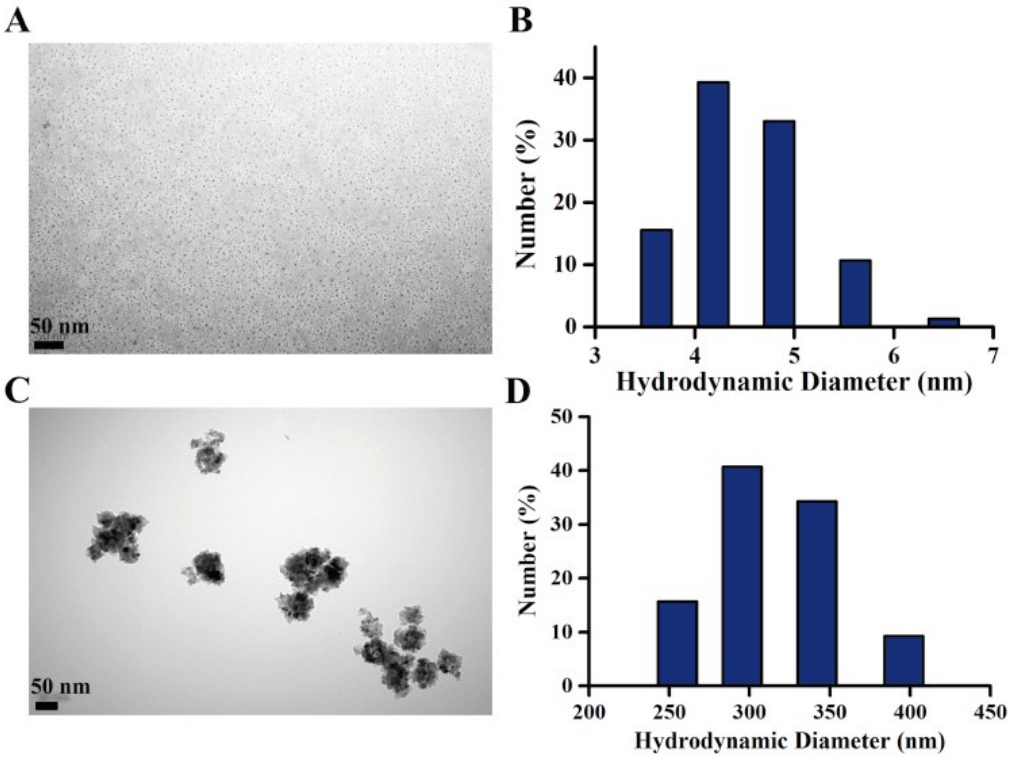

Figure S1. TEM images of MnO_2-BSA NPs (A) and CaO_2-PEG200 NPs (C). Hydrodynamic size distribution of MnO_2-BSA NPs (B) and CaO_2-PEG200 NPs (D).

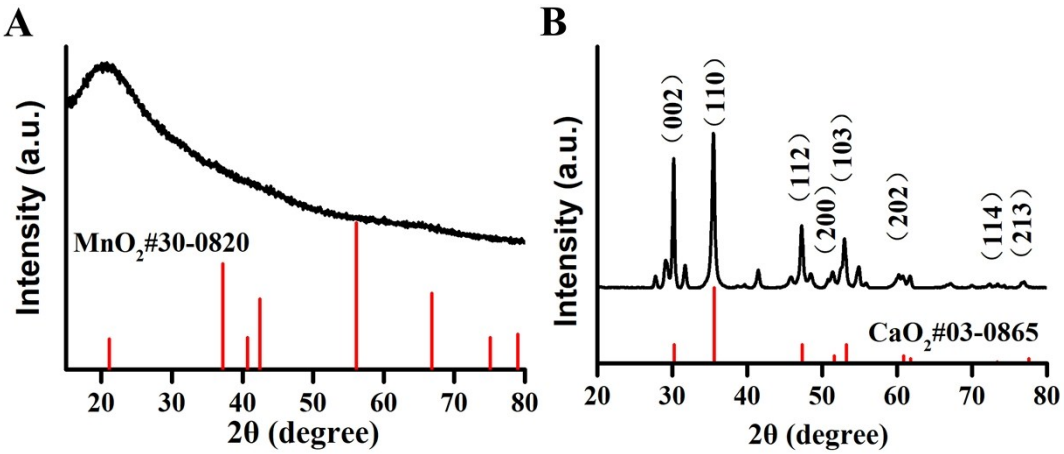

Figure S2. XRD patterns of MnO_2-BSA NPs (A) and CaO_2-PEG200 NPs (B).

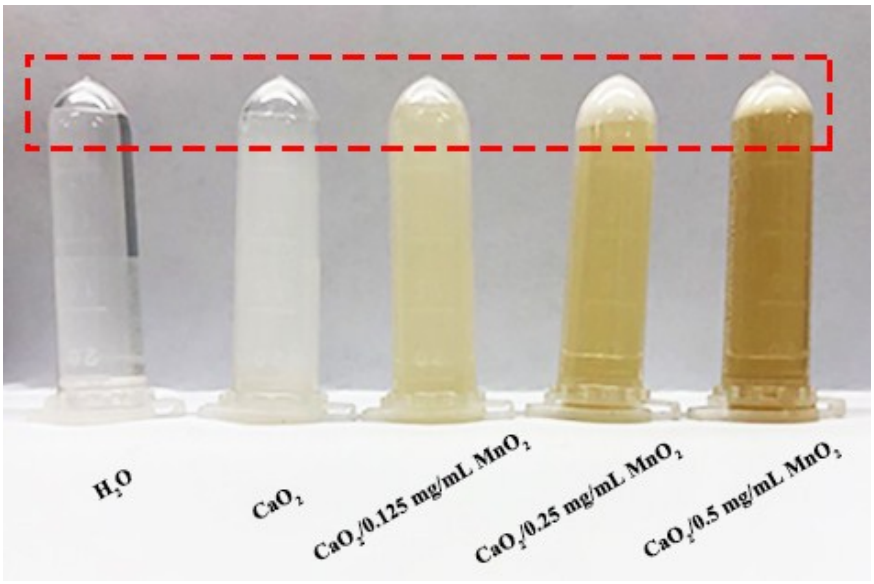

Figure S3. Oxygen bubbles produced from CaO_2 NPs (0.5 mg/mL) in water with or without MnO_2 NPs.

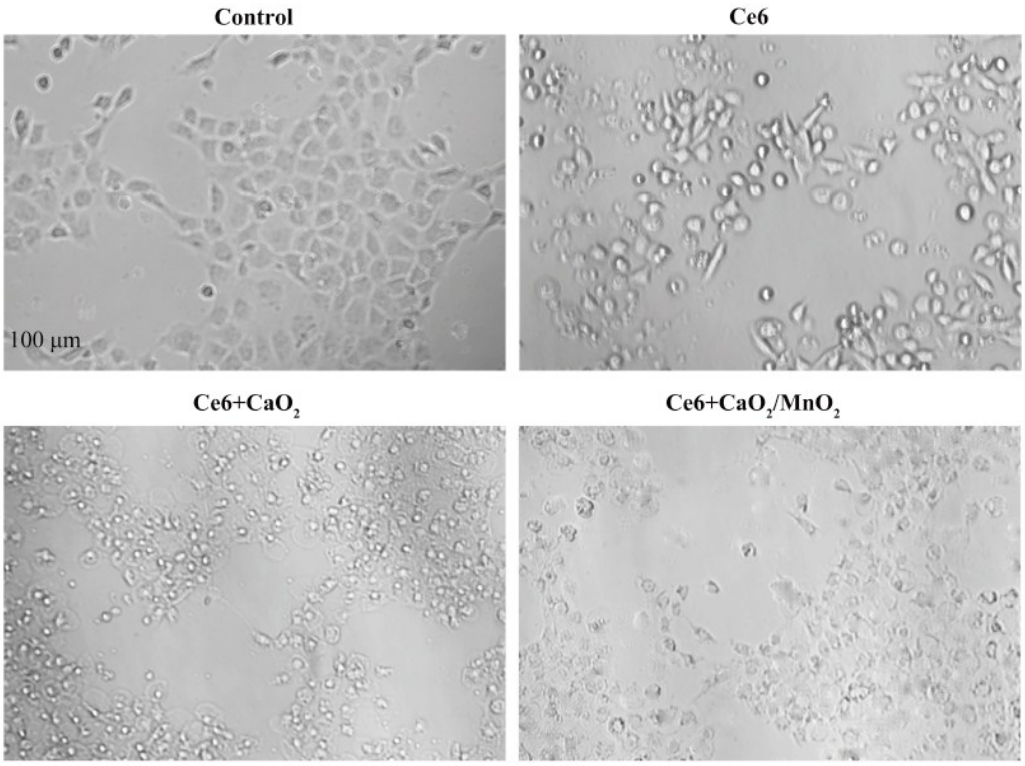

Figure S4. Representative images of 4T1 cell incubated with Ce6, CaO_2 and CaO_2/MnO_2 for 4 h and then received 660 nm laser irradiation (20 mW cm^{-2}, 1 min).

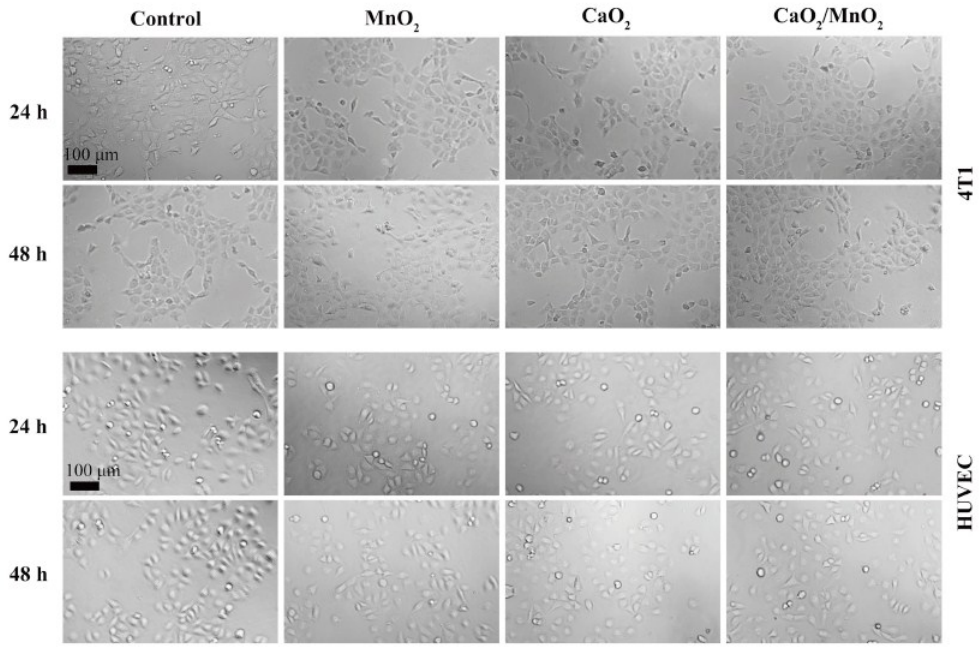

Figure S5. Representative images of 4T1 cell and HUVEC cell incubated with MnO_2, CaO_2 and CaO_2/MnO_2 for 24 and 48 h.

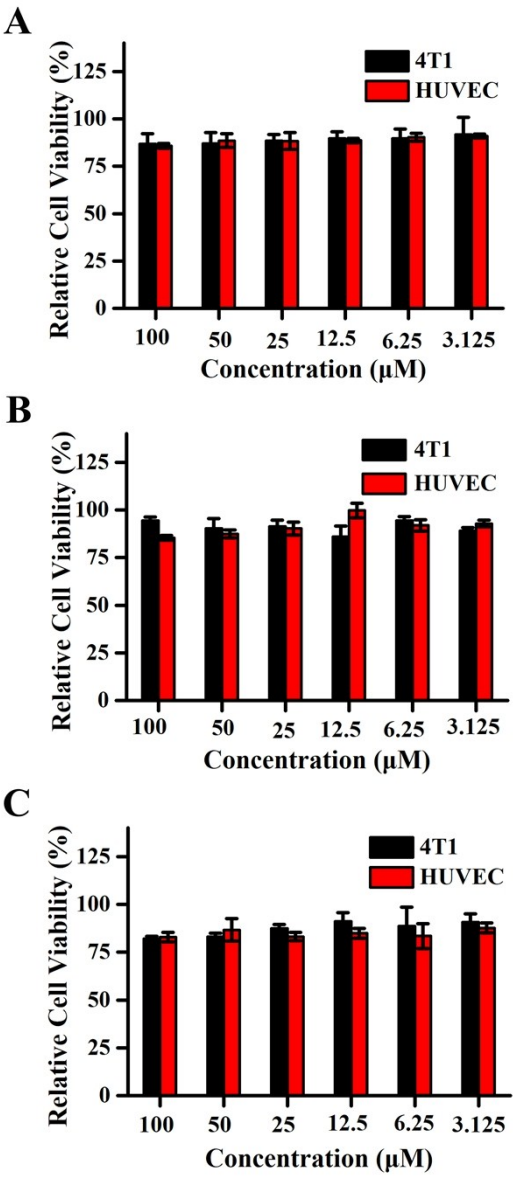

Figure S6. Relative viability of 4T1 and HUVEC incubated with MnO_2 (A), CaO_2 (B) and CaO_2/MnO_2 (C) at different concentrations for 48 h.

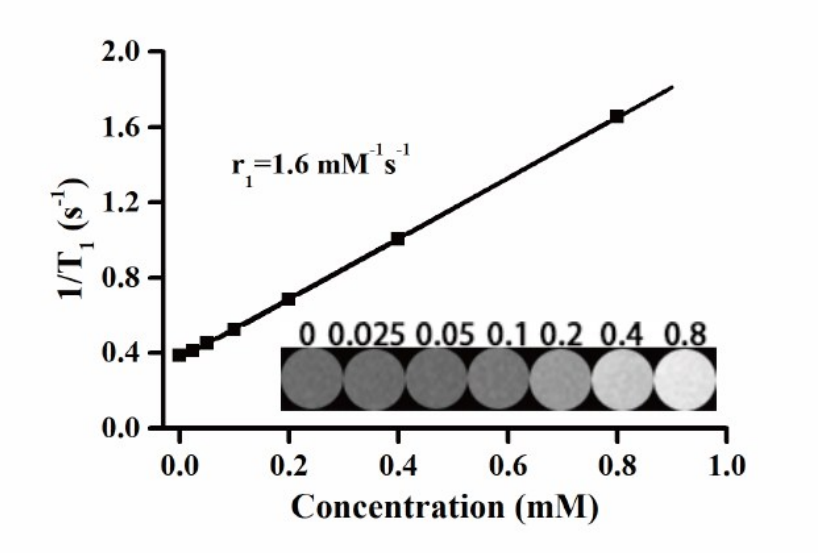

Figure S7. r_1 measurement and corresponding R_1 maps of MnO_2 NPs.

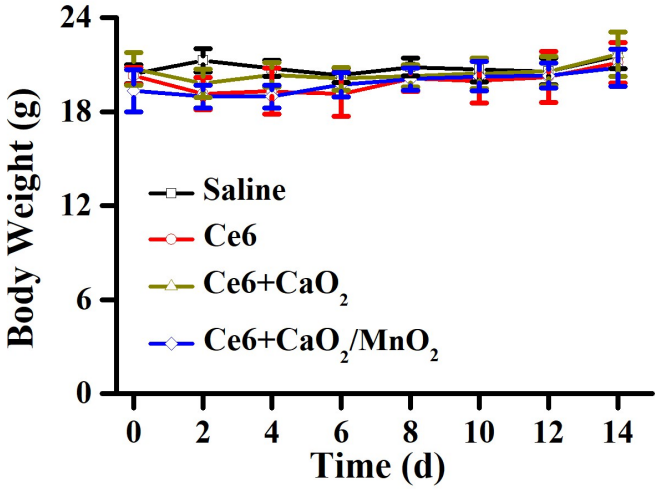

Figure S8. Mouse body weight variations after treatment (n = 5).

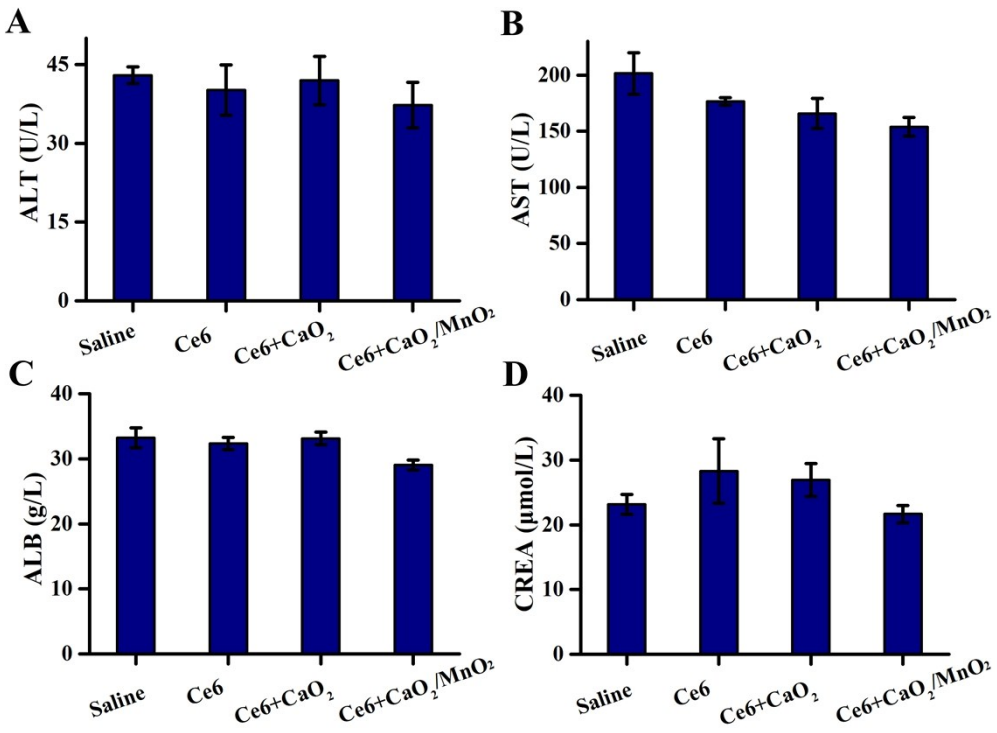

Figure S9. Serum biochemistry test results (n = 3).