

Gram-scale Fabrication of Bi@C Nanoparticles through One-step Hydrothermal Method for Dual-Model Imaging Guided NIR-II Photothermal Therapy

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Experimental Section

Instruments

Transmission electronic microscope (TEM, H-600 electron microscope, Hitachi, Japan); Fourier transform infrared (FTIR, Nicolet 520 FTIR spectrometer (Nicolet) equipped with a germanium attenuated total reflection (ATR) accessory, Thermo Fisher Scientific, USA); UV-vis spectrophotometer (UV-1700 Pharma Spectrophotometer, Shimadzu, Japan); ICP-AES (Thermo Scientifici Xseries 2, Thermo Fisher Scientifici, USA).

Biocompatibility and Photothermal Therapy of Bi@C NPs

HeLa cells (5×10^3 cells per well) were incubated in the 96-well plates and incubated in 5% CO₂ at 37 °C for 24 h. After that, the cells were further incubated for another 24 h with Bi@C-suspended medium. Then, the cells were washed for three times with PBS and incubated with 200 μL of MTT solution (0.5 mg mL⁻¹ MTT in PBS, pH 7.4) for another 4 h. After that, the solution was removed and 100 μL of dimethyl sulphoxide (DMSO) was added. The absorbance at 570 nm was recorded by a plate reader. For photothermal therapy, after cells were incubated with Bi@C-suspended medium (0.3 mg mL⁻¹) for 24 h. Then, we used 1064 nm laser (1 W cm⁻²) to irradiate cells for 10 min and cells were further incubated for another 4 h. The survival rate was measured by MTT assay according to above method and observed by CLSM after staining by Calcein AM (8×10^{-8} M) and PI (5×10^{-7} M) for 20 min.

In Vivo Photothermal Therapy

We used the Kunming mice (20-25 g) to acquire tumor models. U14 cells ($\sim 10^6$ in 100 μL PBS) were injected into the right side of the abdomen. When tumors were grow to ~ 100 mm³, we divided the mice into 8 groups, and mice was intravenously injected into PBS (control), Bi NPs, C NPs or Bi@C NPs suspensions in PBS (3.2 mg kg⁻¹), respectively every two days. After 24 h injection, some tumor-bearing mice injected with different solutions were irradiated by 1064 nm laser (1 W cm⁻²) for 10 min. The tumor size (V) was measured and calculated: $V = \text{Length} \times \text{Width}^2 \div 2$. The relative tumor volume was calculated through the following fomula: V/V_0 . On the 15th day, tumors were dissected and weighed.

Thermal Imaging

The tumor-bearing mice were intravenously injected into PBS, Bi, C or Bi@C NPs solution (3.2 mg kg⁻¹). After 24 h, we used the infrared thermal imaging camera to obtain the thermal imaging during the illumination by 1064 nm laser (1.0 W cm⁻²).

Distribution of Bi@C NPs

The tumor-bearing mice were intravenously injected into Bi@C NPs solution (0.2 mL, 0.3 mg mL⁻¹). After 24 h, the mice were dissected and heart, liver, spleen, lung, kidney and tumor were weighted. Then, organs were washed by water to remove the external blood and the organs were cut into pieces and added into 3 mL of the aqua regia for 48 h. The contents of Bi in different organs were measured by ICP-AES.

Blood Circulation of Bi@C NPs

The tumor-bearing mice were intravenously injected into Bi@C NPs solution (0.2 mL, 0.3 mg mL⁻¹). The blood after injection at different time points were obtained through the tail. The blood was weighted and the blood were added into 1 mL of the aqua regia for 48 h and the contents of Bi in the blood were measured by ICP-AES.

CT Imaging

X-ray CT imaging experiments were obtained by CT Scanner (Philips Medical System). Bi@C NPs aqueous solutions with different concentrations of Bi (0, 0.63, 1.25, 2.5, 5 mg mL⁻¹) were placed in 1.5 mL centrifuge tubes for CT imaging. For in vivo CT imaging, when the tumor size attained to ~ 150 mm³, the tumor-bearing mice were intratumoral injected with of Bi@C NPs (Bi content: 5 mg mL⁻¹, 20 μL). After 24 h, CT images were acquired.

Results and Discussion

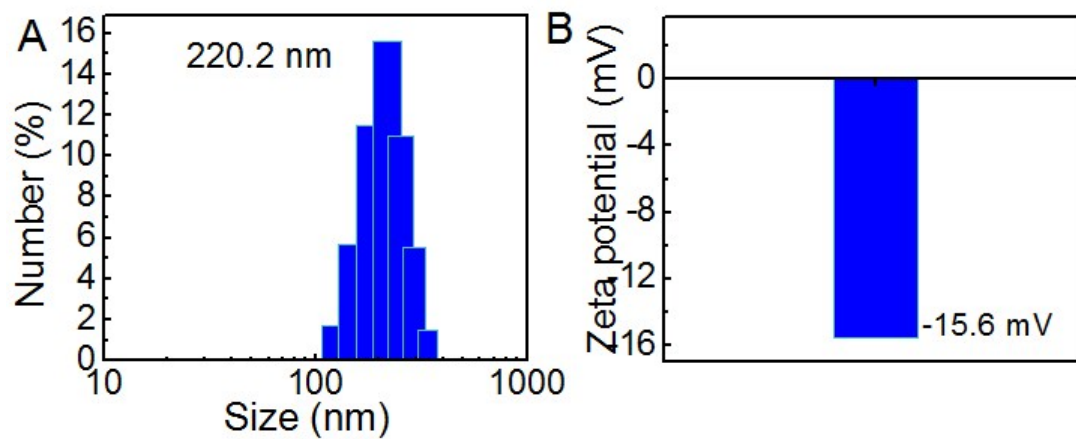


Fig. S1 (A) Hydrodynamic size of Bi@C NPs. (B) Zeta potential of Bi@C NPs.

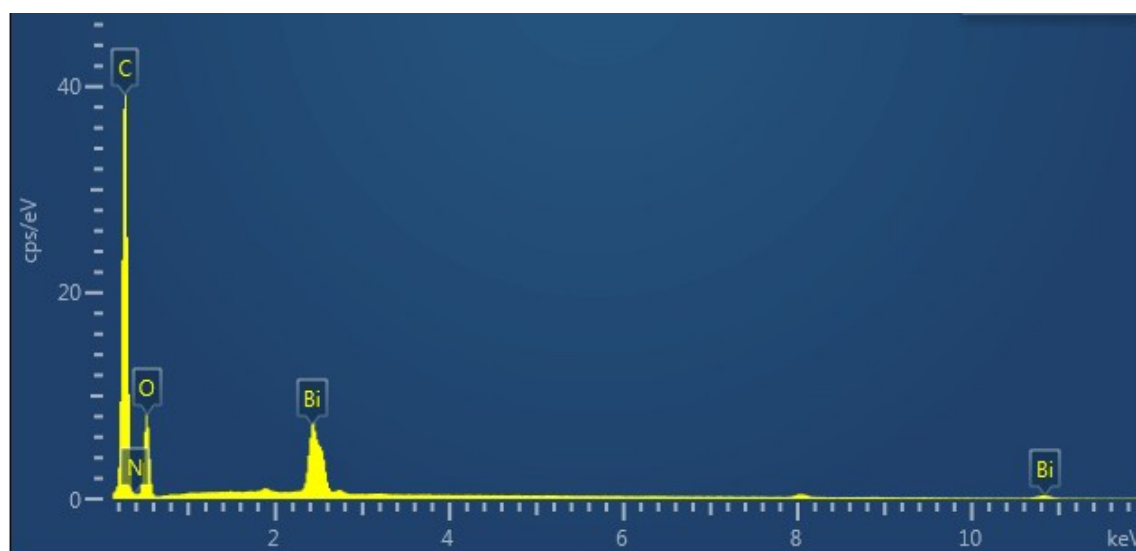


Fig. S2 EDS of Bi@C NPs.

The calculation of photothermal conversion efficiency.

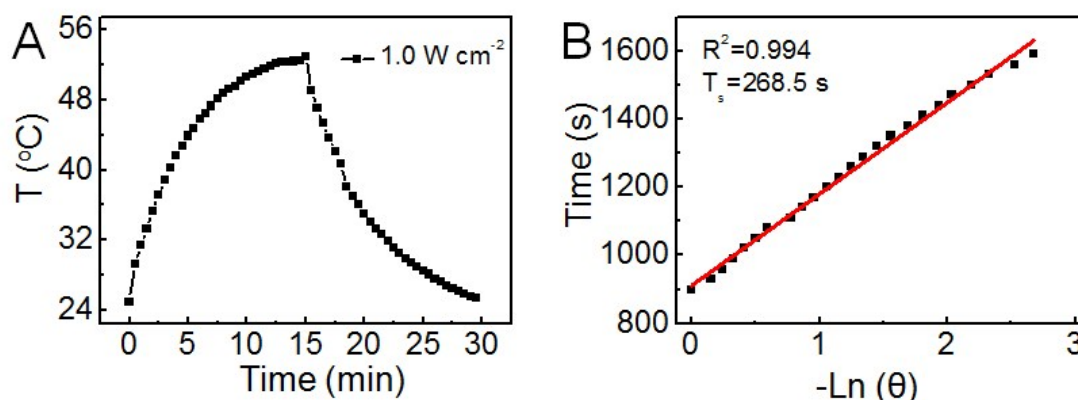


Fig. S3. (A) Photothermal effect of Bi@C NPs (0.4 mg mL^{-1}) under irradiation of 1064 nm laser with the power density of 1.0 W cm^{-2} and the laser was turned off after irradiation of 15 min. (B) The time constant for heat transfer from the system was determined to be $\tau_s = 268.5 \text{ s}$ by applying the linear time data from the cooling period versus negative natural logarithm of the driving force temperature obtained from the cooling stage of (A).

The photothermal conversion efficiency (η) was calculated using following equations.

$$\begin{aligned} T_{\max} - T_{\text{surr}} \\ = 52.6 - 25 \\ = 27.6 \text{ } ^\circ\text{C} \end{aligned}$$

$$T_s = 268.5 \text{ s}$$

$$\begin{aligned} hS &= (\sum m_i C_{p,i}) \div \tau_s \\ &= m(\text{H}_2\text{O}) \times C(\text{H}_2\text{O}) \div \tau_s \\ &= 1 \times 4.2 \div 268.5 \\ &= 15.64 \text{ mW}^\circ\text{C}^{-1} \end{aligned}$$

$$\begin{aligned} Q_{\text{Dis}} &= hS \times (T(\text{H}_2\text{O})_{\max} - T_{\text{surr}}) \\ &= 15.64 \times (28.3 - 25) \\ &= 51.61 \text{ mW} \end{aligned}$$

$$\begin{aligned} \eta &= [hS \times (T_{\max} - T_{\text{surr}}) - Q_{\text{Dis}}] \div [I \times (1 - 10^{-A})] \times 100\% \\ &= 42.32\% \end{aligned}$$

h ($\text{mW m}^{-2} \text{ } ^\circ\text{C}^{-1}$): Heat transfer coefficient;

S (m^2): Surface area of the container;

T_{\max} ($^\circ\text{C}$): Equilibrium temperature;

T_{surr} ($^\circ\text{C}$): Ambient temperature of the surrounding;

Q_{Dis} (mW): The heat from light absorbed by the centrifuge tube walls itself and it was measured independently using a centrifuge tube containing aqueous samples without Bi@C NPs;

I (mW): The incident laser power density;

A_{1064} : The absorbance of Bi@C NPs (0.4 mg mL^{-1}) at 1064 nm.

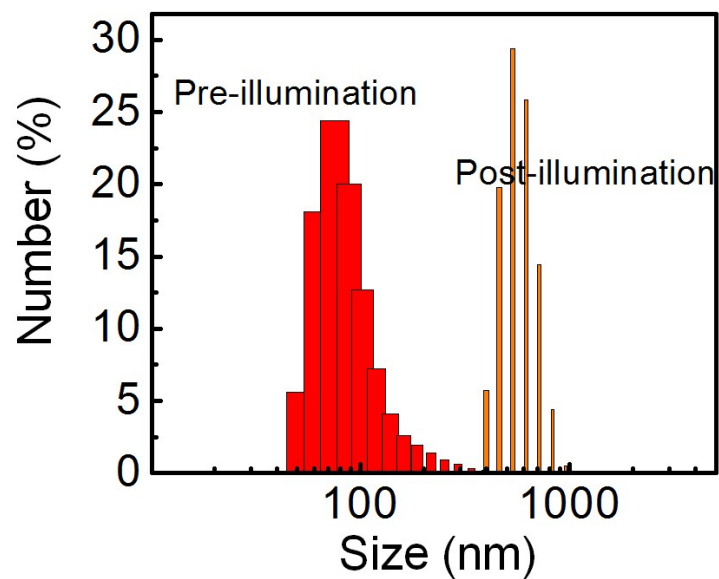


Fig. S4 Hydrodynamic size of fresh prepared of Bi pre- and post- illumination.

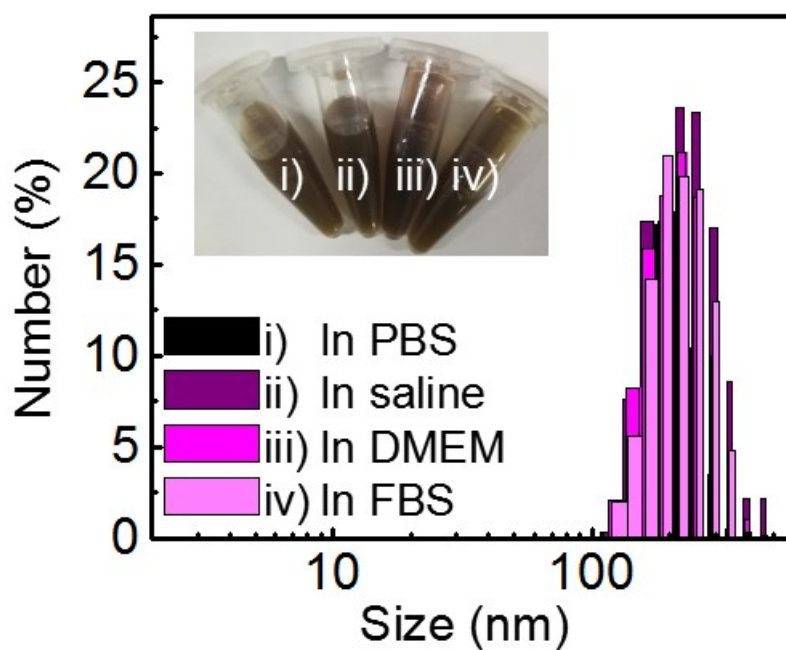


Fig. S5 Hydrodynamic size of Bi@C NPs in PBS, saline, DMEM or FBS after 24 h incubation.

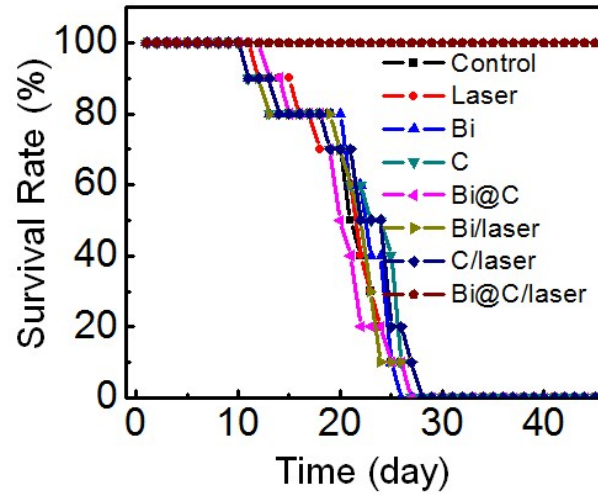


Fig. S6 Survival rate of mice with different treatments.