Electronic Supplementary Material (ESI) for Biomaterials Science

Supporting information

Effects of Nanoparticle Surface Ligands on Protein Adsorption and Subsequent Cytotoxicity

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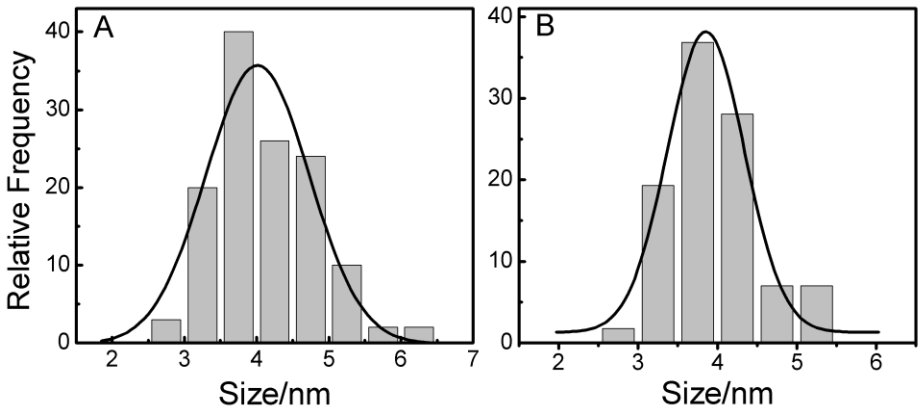

Fig. S1 Size histogram of DPA-QDs (A) and MSA-QDs (B) extracted from several TEM images. The QDs fit to a Gaussian size distribution centered at 4 nm with a standard deviation of 0.60 nm.

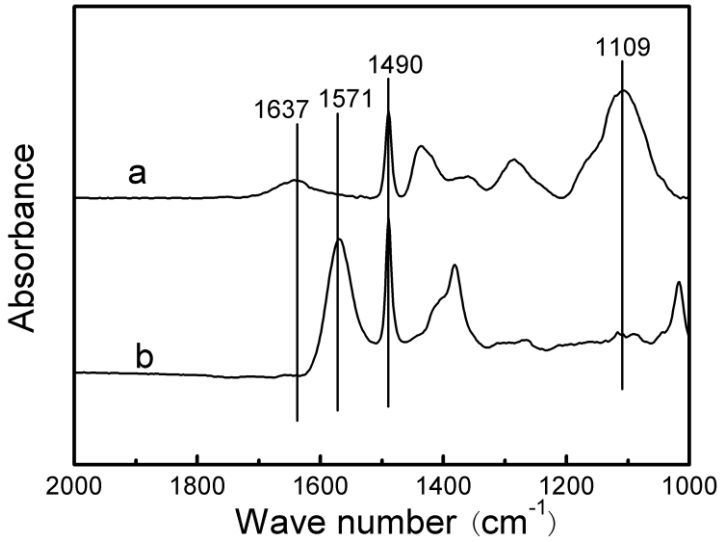

Fig. S2 FT-IR spectra of DPA-QDs (curve a) and MSA-QDs (curve b).

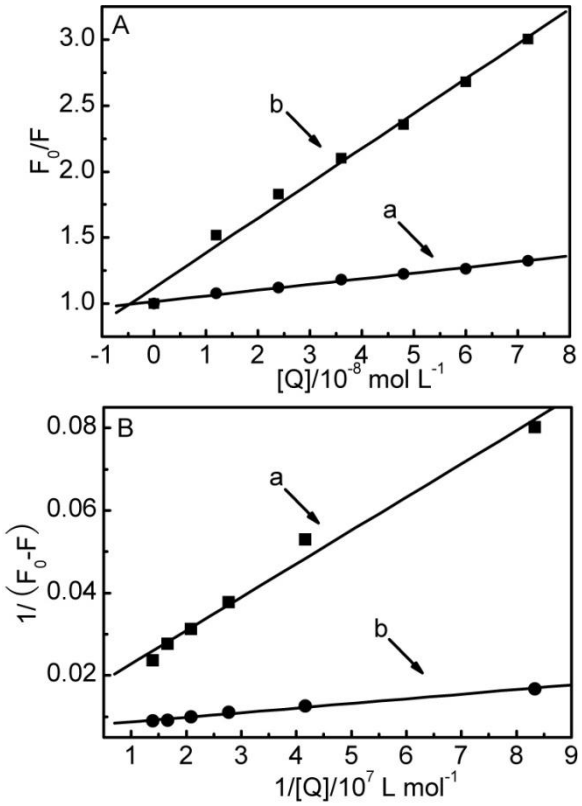

Fig. S3 (A) Stern–Volmer plots for the quenching of HSA by DPA-QDs (a) and MSA-QDs (b) at different concentration. (B) Lineweaver-Burk plots for the quenching of HSA by DPA-QDs (a) and MSA-QDs (b) at different concentration.

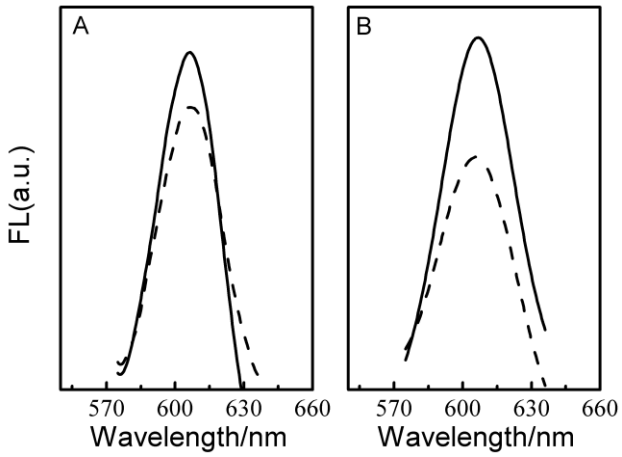

Fig. S4 Fluorescence emission spectra of DPA-QDs (A) and MSA-QDs (B) in the absence (solid line) and presence of HSA (dot line) with 4h incubation time.

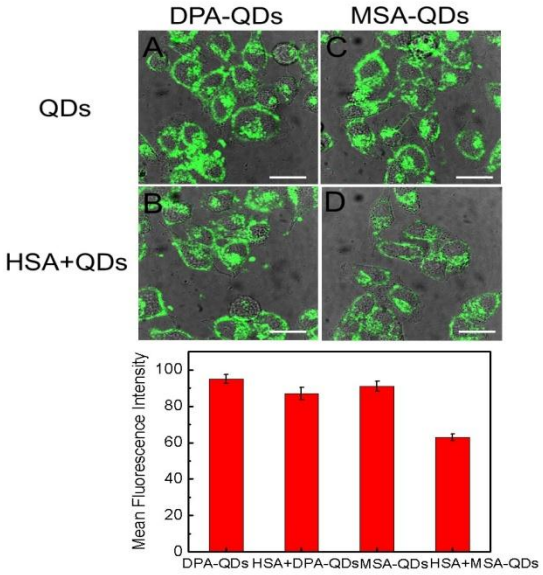

Fig. S5 Confocal images of Hela cells after incubation 30 min with DPA-QDs (A), HSA-DPA-QDs (B), MSA-QDs (C) and HSA-MSA-QDs (D). (E) Mean fluorescence intensity of QDs in Hela cells. Scale bar: 30 μm.

Synthesis of CdSe/ZnS Core/Shell QDs:

Briefly, CdO (102.8 mg), stearic acid (1.2 g), trioctylphosphine oxide (TOPO) (3.35 g) and hexadealamine (HAD) (1.65 g) were mixed and heated to 300 °C under Ar flow. A solution of Se (64 mg Se dissolved in 4 mL tributylphosphine (TOP)) was swiftly injected into the hot solution, and aliquots were taken 1-2 mL into cool toluene. The resulting CdSe QDs were purified and precipitated using acetone, and finally redissolved in $CHCl_3$.

For CdSe/ZnS QDs, zinc acetate and sulfur were used as precursors. The CdSe core solution was mixed with 6 mL OLA and heated to 150-170 °C. Then, the Zn and S precursors were added dropwise to reaction mixture and stiring 15 min. The resulting CdSe/ZnS QDs were purified and precipitated with acetone, and finally stored in $CHCl_3$.

Surface Ligand Exchange with DPA and MSA:

In order to synthetize water-soluble QDs, a 40 mg of DPA (or 80 mg of MSA) was dissolved with 15 mL of 2-propanol (15 mL of a 1:1 (v/v) methanol/dioxane for functionalization with MSA) and the pH was adjusted to 12-13 with tetramethylammonium hydroxide pentahydrate (TMAHP). Then 0.25 mg of OLA-coated CdSe/ZnS QDs was added and the reaction mixture was left stirring at 60-70 °C under a nitrogen atmosphere for 10-20 min. After the reaction was stopped, the exchanged hydrophilic QDs were purified with ethyl acetate. The pellet was centrifuged out and redispersed in PBS.

Calculations of ligand density per QDs

Packing density σ_{PD} was calculated based on the ratio of the mass fractions of S and Zn and defined as:

$$\sigma_{\mathrm{PD}} = \frac{n_{LP}}{n_{NP} SA_{NP}} \qquad \text{(S1)}$$

where n_{LP} and n_{NP} are the number densities of ligands and QDs, respectively, and SA_{NP} is the surface area per QDs. Since the ligand contains one S atom, the value of n_{LP} is obtained from the followig:

$$n_{LP} = \frac{w_s(LP)\rho_{sampe}N_A}{M_s} \tag{S2}$$

where ρ_{sample} is the density of the sample suspension, N_A is the Avogadro constant, and M_S is the molar mass of S, w_S (LP) is the S mass fraction of the ligand, which is obtained from the following equation:

$$w_s(LP) = w_s(T) - \frac{w_{Zn}(NP)M_s}{M_{Zn}} = \frac{w_s(T)M_{Zn} - w_{Zn}(NP)M_s}{M_{Zn}} \tag{S3}$$

where w_S (T) is the total S mass fraction density, which originate in the ligands and QDs, and determined using ICP-AES-MS. w_{Zn} (*NP*) is the S mass fraction of QDs determined using ICP-AES-MS. Similar to n_{LP}, the value of n_{NP} is:

$$n_{NP} = \frac{w_{Zn}\rho_{sample}N_A}{M_{Zn}\theta} \tag{S4}$$

where w_{Zn} is the Zn mass fraction, ρ_{sample} is the density of the sample suspension, N_A is the Avogadro constant, M_{Zn} is the molar mass of Zn, and θ is the number of Zn autom per QDs. Substituting Eqs. S2 and Eqs. S4 into Eq. S1 and rearranging yields

$$\sigma_{PD} = \frac{w_s(LP)M_{Zn}}{w_{Zn}M_sSA_{NP}} \tag{S5}$$

where w_S (LP) is the S mass fraction of ligands, w_S (T) is the total S mass fraction, w_S (NP) is the S mass fraction of QDs, M_{Zn} and M_S is the molar mass of Zn and *S*. For DPA-QDs and MSA-QDs, the radio of packing density of ligand (N) is expressed as:

$$\begin{aligned} N = \frac{\sigma_{PD}(DPA)}{\sigma_{PD}(MSA)} &= \frac{w_s(DPA)M_{Zn}}{w_{Zn}(DPA)M_sSA_{NP}} \times \frac{w_{Zn}(MSA)M_sSA_{NP}}{w_s(MSA)M_{Zn}} \\ &= \frac{w_s(DPA)w_{Zn}(MSA)}{w_s(MSA)w_{Zn}(DPA)} \end{aligned} \tag{S6}$$

where σ_{PD} (DPA) and σ_{PD} (MSA) are the packing density of DPA and MSA ligands, w_S (DPA) and w_S (DPA) are the S mass fraction of DPA and MSA ligands, and w_{Zn} (DPA) and w_{Zn} (MSA) is the Zn mass fraction of DPA-QDs and MSA-QDs.

Substituting Eqs. S5 into Eqs. S6 and rearranging yields

$$N = \frac{\frac{w_s(T-DPA)M_{Zn} - w_{Zn}(DPA)M_s}{M_{Zn}} w_{Zn}(MSA)}{\frac{w_s(T-MSA)M_{Zn} - w_{Zn}(MSA)M_s}{M_{Zn}} w_{Zn}(DPA)} = \frac{\left[w_s(T-DPA)M_{Zn} - w_{Zn}(DPA)M_s\right] w_{Zn}(MSA)}{\left[w_s(T-MSA)M_{Zn} - w_{Zn}(MSA)M_s\right] w_{Zn}(DPA)} \quad \text{(S7)}$$

where w_S (*T-DPA*) and w_S (*T-MSA*) is the total S mass fraction of DPA-QDs and MSA-QDs, M_{Zn} and M_S is the molar mass of Zn and *S*, w_{Zn} (DPA) and w_{Zn} (MSA) is the Zn mass fraction of DPA-QDs and MSA-QDs.

In this work, the values of w_S (*T-DPA*) and w_S (*T-MSA*) is 72.5 μg g^{-1} and 89.90 μg g^{-1}, respectively, and the value of w_{Zn} (*DPA*) and w_{Zn} (*MSA*) is 7.47 μg g^{-1} and 10.11 μg g^{-1}, determined using ICP-AES-MS. The following values can be used in Eq. S7:

w_S (*T-DPA*)=72.50 μg g^{-1}

w_S (*T-MSA*)=89.90 μg g^{-1}

w_{Zn} (*DPA*)= 7.47 μg g^{-1}

w_{Zn} (*MSA*)= 10.11 μg g^{-1}

M_{Zn}=65 g mol^{-1}

M_S =32 g mol^{-1}

Then, Eq. S7 is

$$N = \frac{\left[w_s(T-DPA)M_{Zn} - w_{Zn}(DPA)M_s\right] w_{Zn}(MSA)}{\left[w_s(T-MSA)M_{Zn} - w_{Zn}(MSA)M_s\right] w_{Zn}(DPA)}$$

$$= \frac{(72.5\mu g\cdot g^{-1}\times 65 g mol^{-1} - 7.47\mu g\cdot g^{-1}\times 32 g mol^{-1})\times 10.11\mu g\cdot g^{-1}}{(89.9\mu g\cdot g^{-1}\times 65 g mol^{-1} - 10.11\mu g\cdot g^{-1}\times 32 g mol^{-1})\times 7.47\mu g\cdot g^{-1}}$$

$$= 1.094$$

The DPA/MSA radio on the surface of QDs is around 1.09, equal to 1.0, indicating that the amount of DPA and MSA grafted on QDs is the same. Hence, it is reasonable to compare the two systems.