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Electronic Supplementary Information

A platinum shell for ultraslow ligand exchange: unmodified DNA adsorbing more stably on platinum than thiol and dithiol on gold

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1. Materials and Methods.

Chemicals. All of the DNA samples were from Integrated DNA Technologies (Coralville, IA) and purified by standard desalting. The DNA sequences and modifications are shown in Table S1. Na_2PtCl_6, $HAuCl_4$, KI, NaCl, $MgCl_2$, sodium ascorbate, 6-mercapto-1-hexanol (MCH), dithiothreitol (DTT) glutathione (GSH), bovine serum albumin (BSA) and KCN were form Sigma-Aldrich. 4-(2-hydroxyethyl)-1-piperazineethanesulfonic acid (HEPES), adenosine, sodium citrate and citric acid were from Mandel Scientific (Guelph, Ontario, Canada). Urea was from Bio Basic Inc. (Markham, Ontario, Canada). DMEM and 1640 cell culture medium were from Fisher Scientific. Human AB serum was from Mediatech Inc. (Manassas, VA, USA). AuNPs (13 nm) were synthesized based on the standard citrate reduction method and the as-prepared AuNP concentration was estimated to be ~10 nM.[S1,2] Milli-Q water was used for all experiments.

Synthesis of PtNPs and Au@Pt NPs. PtNPs (5 nm) were synthesized according to a published procedure.[S3] Briefly, Na_2PtCl_6 (0.2%, 36 mL) was added to boiling water (464 mL). Then, sodium citrate (1%, 11 mL) and citric acid (0.05%) was added. After 1 min, 5.5 mL of a freshly prepared $NaBH_4$ solution (0.08%) containing sodium citrate (1%) and citric acid (0.05%) was quickly injected. After 10 min, the product was cooled down to room temperature. Au@Pt NPs were synthesized following a literature reported procedure.[S4] The above prepared 13 nm AuNPs (10 mL) was mixed with 6 mL Na_2PtCl_6 (1 mM), and the mixture was heated to 80 °C. Then, 3 mL sodium ascorbate (10 mM) was slowly dropped into above mixture under stirring. Finally, the solution was stirred for another 30 min to ensure complete reduction of Na_2PtCl_6.

TEM. TEM measurements were carried out using a Zeiss Libra 200 transmission electron microscope. The sample was prepared by pipetting a drop of the aqueous solution of metal nanoparticle onto a 230 mesh holy carbon copper grid, followed by drying in air before measurement.

DLS. The DLS measurements were conducted using a Zetasizer Nano ZS90 (Malvern) at 25 °C. The concentration of PtNP, AuNP and Au@Pt NP for measurement was 60 nM, 3 nM and 3 nM, respectively. The data were analyzed by Malvern Dispersion Technology Software 4.20.

DNA adsorption kinetics. For salt-dependent and pH-dependent DNA adsorption kinetics, an Alexa Fluor 488-labeled DNA was used (DNA1, Table S1). For salt-dependent study, 2 μL DNA1 (15 μM) was added to 100 μL of the 5 nm PtNPs prepared above in 10 mM HEPES (pH 7.5). Then, 10 μL of NaCl solution with various concentrations was respectively added to each sample, followed by fluorescence monitoring. For pH-dependent DNA adsorption kinetic study, 2 μL citrate buffer (500 mM) of various pH's (3, 4, 5, 6 and 7) was added to 100 μL DNA1 solution (30 nM) to adjust pH. Afterwards, 10 μL of the 5 nm PtNP was added to the solution and fluorescence intensity was monitored to obtain the adsorption kinetic. To study the adsorption kinetics of different DNA bases, 5-mer FAM-labeled DNA homopolymers were employed. Typically, 2 μL DNA (15 μM) was added to 100 μL PtNPs with a brief vortex mixing. Then, 2 μL of citrate·HCl buffer (pH 3, 500 mM) was added to the PtNP solution. At designated time points, 5 μL of the PtNP solution was transferred into 100 μL of HEPES buffer (50 mM, pH 7.5) and fluorescence signal was read by a microplate reader (SpectraMax M3).

DNA desorption kinetics. The DNA desorption kinetics were measured using the microplate reader. For a typical DNA desorption kinetic study, in each well 5 μL of DNA-nanoparticle conjugations were added to 95 μL HEPES buffer (50 mM, pH 7.5). A small volume of displacement agent was added after 2 min of

background reading and the kinetics of fluorescence enhancement was monitored using the microplate reader.

DNA attachment. The DNA-PtNP and DNA-AuNP conjugations were prepared by a low pH method according to a previous paper.[S5] Typically, 1-2 μL of DNA solution (100 μM) was added to 100 μL of as-prepared particle solutions and mixed via a brief vortex. Then the pH was adjusted to 3 by adding 2 μL of citrate·HCl buffer (500 mM, pH 3). After 10 min incubation, the pH was adjusted back to neutral by adding 6 μL of HEPES buffer (500 mM, pH 7.6). Finally, the mixture was centrifuged at 100,000 (for PtNP) or 15,000 rpm (for AuNP) and the supernatant was removed. The pellet was washed 2-3 times with 50 mM HEPES buffer to completely remove free DNA. The final conjugate was re-dispersed in 5 mM HEPES buffer (pH 7.6) for further use. To attach DNA on Au@Pt NPs, a MCH blocking method was introduced. First, 2 μL DNA stock (100 μM, DNA6 or DNA7) and 1 μL MCH (10 μM) were simultaneously added to 100 μL Au@Pt NPs (3.7 nM). Then 2 μL citrate·HCl buffer (500 mM, pH 3) was added, followed by 3 min incubation. Afterwards, 2 μL MCH (10 mM) was added to completely passivate the particle surface. After 3 min, 6 μL HEPES buffer (500 mM, pH 7.6) was added to adjust pH back to neutral. Then the conjugates were washed 5 times with 50 mM HEPES to completely remove free DNA and MCH, and re-dispersed in 5 mM HEPES (pH 7.6) until further use.

DNA loading capacity quantification. Since PtNPs cannot be dissolved by KCN, and the adsorbed DNA cannot be displaced by adding thiol compounds such as MCH, previously established assays for AuNPs cannot be applied here.[S6,7] Therefore, we developed a new method in this work. DNA loading capacity on PtNPs was quantified by a gel electrophoresis method in this work. The DNA-PtNP conjugations were prepared by the above-mentioned low-pH method. 2% agarose gel was prepared using 10 mM HEPES, pH 7.6 buffer. 20 μL of DNA-PtNP conjugates containing 15% glycerol was loaded and free DNA was separated from PtNPs by running at 120 V for 20 min. The fluorescence intensity of separated free DNA was quantified by a ChemiDoc MP imaging system (Bio-Rad) to calculate the DNA loading capacity.

DNA-directed assembly and melting temperature. DNA6 and DNA7 were respectively attached to Au@Pt NPs with the method described above. Afterwards, 50 μL of each DNA-Au@Pt NP conjugate solution was mixed, and a final of 300 mM NaCl and 200 nM linker DNA were added. After ~30 min incubation at 4 °C, the mixture changed color to purple, indicating formation of Au@Pt NP aggregates. The aggregates were harvested by centrifuge after 1 h incubation, and gently dispersed in 10 mM HEPES containing 50 mM NaCl. To measure the melting property, the aggregate solution was transferred to a quartz micro-cuvette and temperature-dependent UV-vis spectra were monitored on an UV−vis spectrometer (Agilent 8453A). The temperature was contr olled with a circulating water bath and the actual temperature in the cuvette was recorded using a thermometer. The temperature was raised at a rate of ∼1 °C/min with a holding time of 2 min at each temperature.

Table S1. DNA sequences used in this work.

Name	sequences and modifications (from 5′ to 3′)
A_5	FAM-AAAAA
T_5	FAM-TTTTT
C_5	FAM-CCCCC
G_5	FAM-GGGGG
DNA1	TCACAGATGCGT-Alexa Fluor 488
DNA2	SH-AAAAAAAAACCCAGGTTCTCT-FAM
DNA3	Dithiol-AAAAAAAAACCCAGGTTCTCT-FAM
DNA4	AAAAAAAAACCCAGGTTCTCT-FAM
DNA5	SH-AAAAAAAAACCCAGGTTCTCT
DNA6	AAAAAAAAACCCAGGTTCTCT
DNA7	TCACAGATGCGTAAAAAAAAA
Linker	ACGCATCTGTGAAGAGAACCTGGG
control linker	CCCAGGTTCTCTTCACAGATGCGT

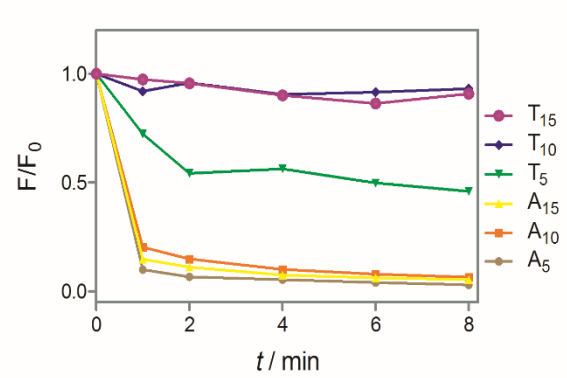

Figure S1. Effect of DNA length on DNA adsorption kinetics by PtNPs at pH 3. The poly-A molecules are not significantly affected by the length and are adsorbed significantly faster than the poly-T DNAs.

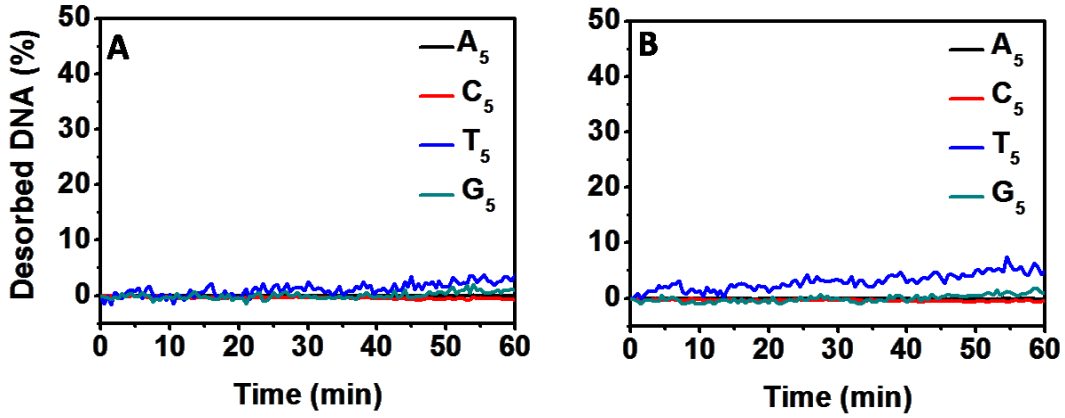

Figure S2. Desorption kinetics of FAM labeled nonthiolated DNA from PtNP after treat with 1 mM adenosine (A) and 0.5 mM guanosine (B).

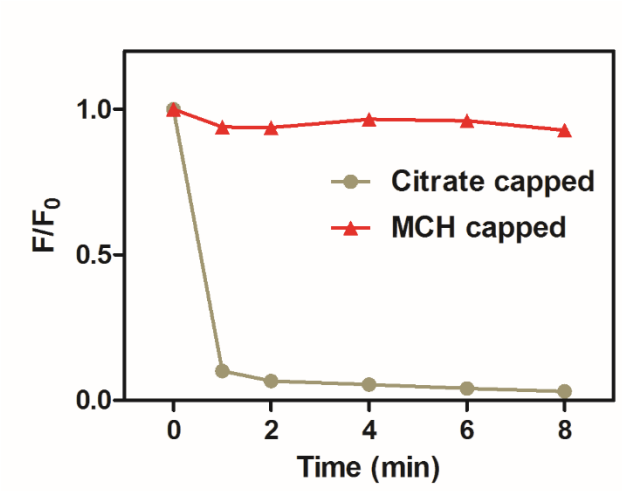

Figure S3. Adsorption kinetic of FAM labeled A_5 DNA on citrate capped and MCH capped PtNP. The lack of adsorption by MCH-capped AuNPs indicates that DNA cannot displace thiol from platinum.

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