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Supporting Information for
Self-Forming Double-Crosslinked Hydrogels by the Marriage of Catechols and Enzyme Mimetic Polymers

Yaqing Chen, Erik Misselwitz, Asger Holm Agergaard, Amanda Andersen, Carsten Pedersen, and Henrik Birkedal*

Department of Chemistry and iNANO-Interdisciplinary Nanoscience Centre, Aarhus University, Gustav Wieds Vej 14, 8000 Aarhus, Denmark

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Section S1: Experimental details

1. Materials

Poly(allylamine hydrochloride) (PAAm, MW 150 kDa, 40% aqueous solution) was purchased from Polyscience, Inc. *l*-Histidine (His), *l*-3,4-dihydroxyphenylalanine (DOPA), copper(II) chloride dihydrate, zinc chloride (>98%), 1-ethyl-3-(3-dimethylaminopropyl)carbodiimide (EDC), n-hydroxysuccinimide (NHS), trifluoroacetic acid (TFA), dimethyl sulfoxide (DMSO), and dialysis membrane (MWCO: 3.5 kD) were all purchased form Sigma-Aldrich and used without further purification.

2. Polymer synthesis

1) Synthesis of *g*-His-PAAm

The polymer of *g*-His-PAAm (histidine grafted polyallylamine) with a low grafting density (*LGD*) ~12% was synthesized based on the carbodiimide coupling chemistry using water-soluble cross-linkers stabilized with NHS, through a procedure adapted from a previous report by Krogsgaard *et al*.[1] and Hwang *et al*.[2] 1.60 g PAAm (17.1 mmol, 1 equiv.) and 827.96 mg *l*-histidine (3.4 mmol, 0.2 equiv.) were dissolved in 30 mL demineralized water, followed by pH adjustment to ~6.0 by 5 M HCl. Next, 1.59 g EDC (10.3 mmol, 0.6 equiv.) was dissolved in 1.6 mL demineralized water and pH adjusted to ~5.5 by 10% TFA. 78.72 mg NHS (0.7 mmol, 0.04 equiv.) was dissolved in 1.6 mL demineralized water and pH adjusted to ~ 5.5 by 1 M NaOH. Afterwards, the EDC solution was added to the mixture of PAAm and *l*-histidine. After 15 min, the NHS solution was added. The final pH of the reaction mixture was adjusted to 6.0 by addition of 1 M NaOH or 1 M HCl. The solution reacted for 24 h in a closed flask at ambient temperature. The synthesized polymer was purified by dialysis using dialysis membranes (MWCO 3.5 kDa) against demineralized water for around 8 days. The completion of purification was proven by UV-VIS spectroscopy of dialysis water showing no absorption peak within 200-800 nm. After purification, the polymer was dried by rotary evaporation or freeze dryer to give a yellow powder after grinding.

g-His-PAAm with a high grafting density (*HGD*) ~58% was synthesized following the same procedure as above, but the amount of *l*-histidine, EDC, and NHS was adjusted accordingly. Specifically, 1 equiv. of *l*-histidine, 3 equiv. of EDC and 0.2 equiv. of NHS were used. The grafting densities of histidine in the synthesized *g*-His-PAAm were determined by ^{1}H NMR spectroscopy (*vide infra*).

2) Synthesis of *g*-DOPA-PAAm

The polymer of *g*-DOPA-PAAm (DOPA grafted polyallylamine) with a grafting density of ~20% was synthesized using EDC/NHS coupling in the mixed solvent of DMSO and water. The synthesis procedure was adapted from Krogsgaard *et al*.[1] 5.00 g PAAm (53.4 mmol, 1 equiv.) was dissolved in 10 mL demineralized water for 15 min, then 490 mL DMSO solvent was slowly added under stirring to reach the total solvent volume of 500 mL. The PAAm solution was continuously bubbled with argon for 15 min. Subsequently, 10.54 g *l*-DOPA (53.4 mmol, 1 equiv.) was added to the reaction mixture. Next, 9.95 g EDC (64.1 mmol, 1.2 equiv.) and 7.38 g NHS (64.1 mmol, 1.2 equiv) was sequentially added to the reaction mixture of DOPA and PAAm. The reaction mixture reacted overnight at ambient temperature with stirring in a light protected flask (wrapped with Tinfoil) and a nitrogen protected atmosphere connected to a nitrogen balloon. The synthesized polymer was purified by dialysis using dialysis membranes (MWCO 3.5 kDa) against 5 mM HCl for around 7 days. The completion of purification was proven by UV-VIS spectroscopy of dialysis water showing no absorption peak within 200-800 nm. After purification, the polymer was concentrated by rotary evaporation and then dried by freezer dryer to give a brown yellow powder after grinding. The DOPA grafting density of *g*-DOPA-PAAm was determined by ^{1}H NMR spectroscopy (*vide infra*).

3. Hydrogel formation

1) Formation of single network (SN) by metal-coordination

a. 20 wt% Cu:*g*-His-PAA (*LGD*)

The metal-coordinate network of 20 wt% Cu:*g*-His-PAAm was formed by firstly dissolving 50 mg *g*-His-PAAm (*LGD*) in 120 μL demineralized water with pH adjusted to 7 by addition of 43 μL HCl solution. 26.55 μL 1M $CuCl_2$ solution (molar ratio of copper to histidine is at 1:3) was then added with violent stirring by a magnetic bar. Finally, the pH was adjusted by

addition of 10.45 µL NaOH solution to reach the requested pH 6 and total solvent volume of 200 µL by stirring with a spatula. Once the $CuCl_2$ droplet made contact with the polymer solution, the polymer solution started to turn sticky and viscous and the color immediately changed to blue due to the formation of tris-His/Cu species. After mixing the components for ~1 min, homogeneous networks were obtained. The pH was measured using a FieldScout SoilStik pH meter.

b. 20 wt% Zn:*g*-His-PAAm (*LGD*)

The metal-coordinate network of 20 wt% Zn:*g*-His-PAAm (molar ratio of zinc to histidine at 1:3) was formed by dissolving 50 mg *g*-His-PAAm (*LGD*) in 120 µL demineralized water with pH adjustment to 7 by 43 µL HCl solution. Then 26.55 µL 1M $ZnCl_2$ was added, followed by the final pH adjustment to 6 with total solvent volume of 200 µL. The complex of Cu:*g*-His-PAAm was sticky and viscous and showed light yellow color.

c. Zn:*g*-His-PAAm (*HGD*)

The metal-coordinate network of 5 wt%, 10 wt% and 20 wt% of Zn:*g*-His-PAAm was prepared by dissolving 10 mg, 20 mg, 40 mg *g*-His-PAAm (*HGD*) in demineralized water, adding 14,15 µL, 28.3 µL, 56.6 µL of 1 M $ZnCl_2$ solution, with total solvent volume of 190 µL, 180 µL, 160 µL, respectively, and pH of 6. The corresponding molar ratio of zinc to histidine is 1:3. The 10 wt% Zn:*g*-His-PAAm was a soft yellow gel. The 5 wt% sample was a liquid, while the 20 wt% sample underwent syneresis.

d. 10 wt% hydrogel of (Zn+Cu):*g*-His-PAAm (*HGD*)

The 10 wt% hydrogel of *g*-His-PAAm (*HGD*) complexing with two types of metal ions was prepared by dissolving 40 mg *g*-His-PAAm (*HGD*) in 280 µL demineralized water, adding 56.6 µL of 1 M mixed metal(II) solution (90% $ZnCl_2$ and 10% $CuCl_2$, containing 50.94 µL 1M $ZnCl_2$ and 5.66 µL 1M $CuCl_2$). Additional water and NaOH was added to reach the requested pH 6 and final solvent volume of 360 µL. The 10 wt% (Zn+Cu):*g*-His-PAAm was a light purple hydrogel.

2) Formation of double-crosslink (DC) hydrogel

a. Preparation of *g*-DOPA-PAAm polymer solution

20 wt% *g*-DOPA-PAAm polymer solution was prepared by dissolving 50 mg *g*-DOPA-PAAm in 140 µL nitrogen-purged 0.1 M NaOH solution. Additional 60 µL nitrogen-purged NaOH solution or demineralized water was added dropwise to reach the requested pH of 6 and total solvent volume of 200 µL. Similarly, 10 wt% *g*-DOPA-PAAm polymer solution was prepared by dissolving 40 mg *g*-DOPA-PAAm in 175 µL nitrogen-purged 0.1 M NaOH solution, additional 185 µL nitrogen-purged NaOH solution or demineralized water was added dropwise to reach pH 6.

b. 20 wt% DC hydrogel of Cu:*g*-His-PAAm/*g*-DOPA-PAAm (*LGD*)

The first metal-coordination network of 20 wt% Cu:*g*-His-PAAm (*LGD*) at pH 6 was prepared following the same procedure as above (see Hydrogel formation (1)-a) in a small vial. Next, 20 wt% *g*-DOPA-PAAm polymer solution (see Hydrogel formation 2)-a) as the second network was injected by pipette to the prepared Cu:*g*-His-PAAm (*LGD*) network and mixed by a spatula. The molar ratio of DOPA to Cu(II) was 3:1. The mixed two components turned dark blue and formed a tanned hydrogel overtime, driven by the second crosslink of covalent bonding due to the oxidation of DOPA moiety catalyzed by Cu:*g*-His-PAAm.

c. 20 wt% DN sample of Zn:*g*-His-PAAm/*g*-DOPA-PAAm (*LGD*)

The first metal-coordination network of 20 wt% Zn:*g*-His-PAAm (*LGD*) at pH 6 was prepared following the same procedure as above (see Hydrogel formation (1)-b). Next, the prepared 20 wt% *g*-DOPA-PAAm polymer solution (see Hydrogel formation 2)-a) was injected by pipette to the 20 wt% Zn:*g*-His-PAAm coordinated network and mixed by magnetic stirring. The molar ratio of DOPA to Zn(II) was 3:1. The obtained double network (DN) sample was a light-yellow and viscous fluid and no gel formed even after 3 days.

d. 10 wt% DC hydrogel of (Zn+Cu):*g*-His-PAA/*g*-DOPA-PAAm (*HGD*)

The first metal-coordination network of 10 wt% (Zn+Cu):*g*-His-PAAm was prepared following the above protocol (see Hydrogel formation (1)-d). The prepared 10 wt% *g*-DOPA-PAAm polymer solution (see Hydrogel formation 2)-a) as the

second network was injected to the prepared 10 wt% (Zn+Cu):*g*-His-PAAm and mixed by a spatula. The molar ratio of DOPA to Cu(II) was 10:1. A tanned hydrogel was formed overtime induced by the oxidative crosslinking of DOPA moiety under catalytic (Zn+Cu):*g*-His-PAAm.

e. 10 wt% DN sample of Zn:*g*-His-PAAm/*g*-DOPA-PAAm (*HGD*)

The first metal-coordination network of 10 wt% Zn:*g*-His-PAAm was prepared following the above protocol (see Hydrogel formation (1)-c). Next, the 10 wt% *g*-DOPA-PAAm polymer solution (see Hydrogel formation 2)-a) was injected by pipette into the first coordination network and mixed by magnetic stirring. The DN sample was a light-yellow and viscous fluid and no gel formed even after 3 days.

f. Competitive binding experiment by imidazole solution

A competitive binding experiment was conducted by immersing the DC hydrogel, Cu:*g*-His-PAAm/*g*-DOPA-PAAm, in a 150 mM imidazole solution in an Eppendorf tube at pH 6 and gently shaking the tubes. This resulted in the small molecule imidazole competitively chelating copper ions and extracting them from the gel. The DN sample, Zn:*g*-His-PAAm/*g*-DOPA-PAAm was treated in the same way for comparison. The change of the material over a course of 24 h was monitored.

4. Characterization

1) 1H NMR spectroscopy:

Polymer synthesis of *g*-His-PAAm (with *LGD* and *HGD*) and *g*-DOPA-PAAm as well as metal-binding of *g*-His-PAAm with Zn(II) were analyzed by ^{1}H NMR spectroscopy on a Bruker Ascend™ 400 MHz spectrometer equipped with a 5 mm probe at the Interdisciplinary Nanoscience Center at Aarhus University, Denmark. Samples around 20 mg were dissolved in 600 µL D_2O, where pH was adjusted to 6 by diluted DCl or NaOD solutions.

a. Grafting density analysis

The histidine grafting density of *g*-His-PAAm ($g = \frac{n_{histidine}}{n_{monomer}}$) was calculated from the ^{1}H NMR spectra (Figure S1a) following the equation $GD = \frac{I_{His}}{I_{PAAm}/3} \times 100\%$ by the ratio of the integrated area of one proton from the imidazole ring δ = 6.79-7.07 (or δ = 7.59-7.80) to the integrated area of three protons of –CH-CH_2– from the PAAm backbone δ = 2.31-0.74. The histidine grafting density was determined to be 12% for the low grafting density one (denoted as *LGD*), and 58% for the high grafting density one (denoted as *HGD*).

Similarly, the grafting density of *g*-DOPA-PAAm ($g = \frac{n_{DOPA}}{n_{monomer}}$) was calculated from the ^{1}H NMR spectra (Figure S1b) following the equation $GD = \frac{I_{DOPA}/3}{I_{PAAm}/3} \times 100\%$ by the ratio of the integrated area of three protons from the catechol aromatic ring δ = 6.46-7.01 to the integrated area of three protons of –CH-CH_2– from the PAAm backbone δ = 2.25-0.80. The DOPA grafting density was determined to be 20%.

2) UV-VIS spectroscopy

a. Metal-binding test

Metal-binding properties of *g*-His-PAAm or PAAm with Cu(II) were probed by UV-VIS absorption measurements on an Agilent Cary 60 spectrophotometer within the scan range of 200-800 nm in a quartz cuvette at ambient temperature. In the pH titration study, a 3 mg/mL sample of *g*-His-PAAm mixed with $CuCl_2$ solution (with a molar ratio of Cu(II):histidine at 1:3) was prepared, followed by pH adjustment stepwise from pH 3 to pH 10 with addition of NaOH solution (Figure S2a). A reference sample of PAAm mixed with Cu(II) was prepared and measured following the same procedure with the same amount of $CuCl_2$ solution (Figure S2b). In copper titration study, 1 M $CuCl_2$ solution was incrementally added to a *g*-His-PAAm solution (3 mg/mL, 2.11 mL). A constant pH value at 6.0 (± 0.1) was delicately adjusted by addition of NaOH or HCl solution (Figure S2c). The corresponding molar ratio of copper to histidine is 0, 1:10, 1:5, 1:4, 1:3.5, 1:3, 1:2.5, 1:2, 1:1.5, 1:1, 2:1, respectively. The reference sample of PAAm at constant pH 6 was prepared. The amounts of Cu(II) added to PAAm are

identical to those added to the *g*-His-PAAm (Figure S2d). The wavelength at maximum absorbance (λ_{max}) in the *d-d* band region within 500-800 nm was determined by the software of Cary WinUV scan application. Zinc titration at pH 6 for *g*-His-PAAm and PAAm, respectively, was conducted following a similar procedure as described for the copper titration. The characteristic peak for zin-histidine bonding within 220-450 nm was studied.[3] The pH was measured by a Mettler Toledo pH meter connected to a glass electrode.

b. Oxidation rate measurement of *g*-DOPA-PAAm

Oxidation rate measurement of *g*-DOPA-PAAm (2 mg/mL) under different copper complex at pH 6 was conducted by a PerkinElmer lambda 25 UV/VIS spectrometer at 20 °C equipped with quartz cuvettes (path length: 1 cm). A stock solution of 2 mg/mL *g*-DOPA-PAAm was prepared by dissolving 12 mg *g*-DOPA-PAAm in 6 mL demineralized water and pH adjusted to 6. A stock solution of dilute copper complex of Cu:*g*-His-PAAm with a molar ratio of Cu(II) to histidine at 1:3 was prepared as a catalyst by dissolving 1.7 mg *g*-His-PAAm in 1 mL demineralized water and adding 77 µL 0.1 M $CuCl_2$ solution. Similarly, a stock solution of dilute zinc complex of Zn:*g*-His-PAAm with a molar ratio of Zn(II) to histidine at 1:3 was prepared in the same way as the aforementioned copper system. A blank solution only with DI water was prepared as a reference. Next, 2 mL *g*-DOPA-PAAm stock solution was added in the quartz cuvettes, followed by the addition of 10.77 µL copper catalyst (with a molar ratio of DOPA to Cu(II) at 20:1). The absorbance was measured within the scan range of 200-800 nm right after the sample preparation and every half an hour with a total time interval of 6 hours as shown in Figure S4a. Samples of 2 mL *g*-DOPA-PAAm stock solution mixed with 10.77 µL zinc complex and with 10.77 µL blank solution, respectively, were measured in the same condition (Figure S4b and c).

c. Oxidation rate measurement of dopamine

The oxidation rate of dopamine solution (0.2 mM) mixed with catalyst Cu:*g*-His-PAAm (molar ratio of dopamine to catalyst at 20:1) at pH 6 under different atmosphere condition, i.e. inert gas (by purging with Argon), ambient atmosphere (without treatment), and oxygen rich atmosphere (by purging with oxygen-replenishing compressed air), respectively, was measured by UV-VIS for at least 6 h on an Agilent Cary 60 spectrophotometer in a quartz cuvette. Firstly, a prepared dopamine solution was purged with argon for 20 minutes, followed by the addition of catalyst solution, Cu:*g*-His-PAAm, before measurement. The absorbance of the prepared sample in sealed quartz cuvette was measured within the scan range of 200-800 nm every 10 min with a total time interval of 6 h as shown in Figure S5a. Secondly, absorbance of a prepared dopamine solution with catalyst was placed in an open quartz cuvette without further treatment and measured within the scan range of 200-800 nm every 10 min with a total time interval of 6 h as shown in Figure S5b. Regarding the sample with air purging, a prepared dopamine solution with catalyst was first purged with compressed air for 5 minutes and then the absorbance was measured. This air-purging and absorbance-measurement cycle was conducted every 10 mins with a total time interval of 2 h, followed by 4 cycles of air-purging (55 min) and absorbance-measurement (every 1 h) with a total time interval of 4 h. Additionally, sample absorbance was measured after 2 d after reaction. The spectra are shown in Figure S5c.

3) Rheology

Mechanical properties of samples were probed by dynamic oscillatory rheology using an Anton Paar MCR 501 rheometer equipped with an evaporation hood and a parallel plate setup. All the samples were measured under the plate geometry with a diameter of 8 mm (PP08), except a liquid sample of Cu:PAAm with 20 wt% which was tested by a PP25 measuring system. Amplitude sweeps were conducted by shearing the samples from 0.1%-450% strain at an angular frequency of 1 s^{-1}. Frequency sweeps were performed at a constant amplitude of 10 % (within the range of linear viscoelastic region) and an increasing frequency from 0.1 rad^{-1} to 100 rad^{-1} at 20 °C. Storage modulus (*G'*), loss modulus (*G''*), and tan δ (*G''/G'*) were monitored.

4) SEM and EDS

The microstructure and element analysis of hydrogels were characterized by SEM (scanning electron microscopy) and EDS (energy-dispersive X-ray spectroscopy) performed on a FEI NOVA nanoSEM 600 using 15 keV electrons. Samples of the 20 wt% double-crosslinked hydrogel (Cu:*g*-His-PAAm/*g*-DOPA-PAAm, *LGD*) and double network hydrogel (Cu:*g*-His-PAAm/*g*-DOPA-PAAm, *LGD*) were prepared following the aforementioned Section 3(2). After reaction for 24 hours, samples were freeze-dried and fractured by a spatula. Small pieces of samples (~ 1 mm^2) were collected and placed on a stage with carbon tape and coated by 8 nm Au for use of SEM and EDS characterization.

Section S2: Supporting figures S1-9

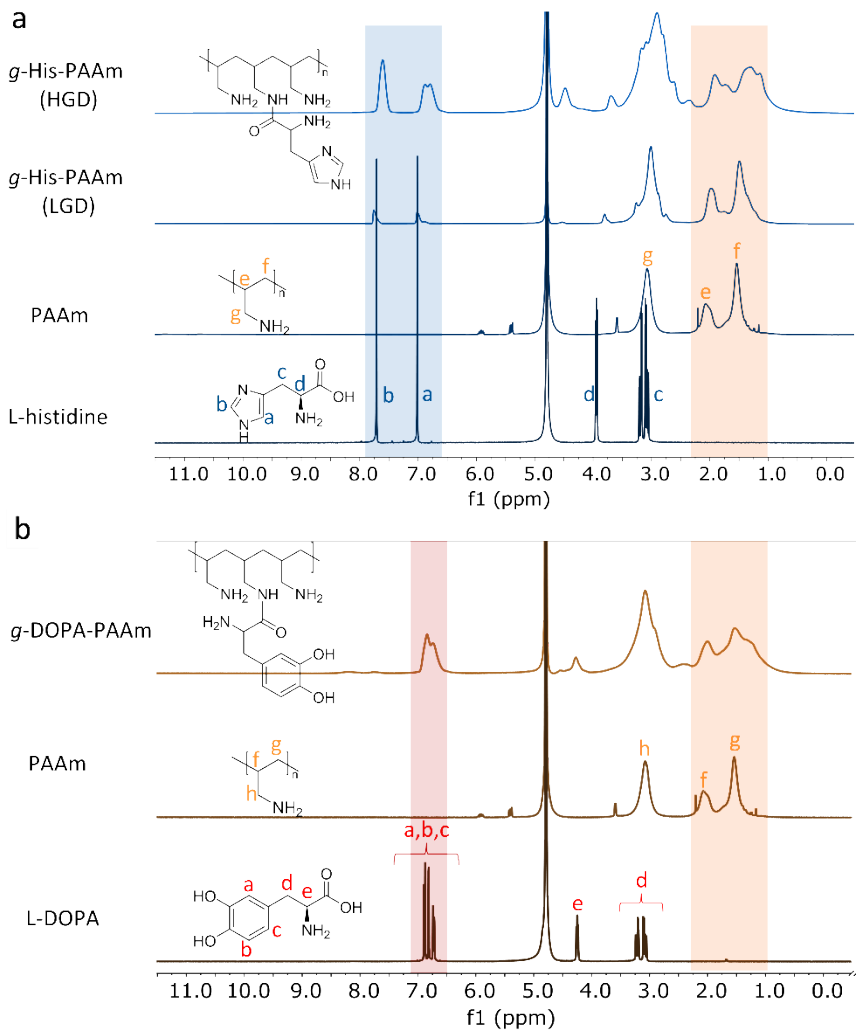

Figure S1. ^{1}H NMR spectra of (a) synthesized *g*-His-PAAm with high grafting density (*HGD*) and low grafting density (*LGD*) compared with pristine polyallylamine (PAAm) and *l*-histidine. The pristine PAAm showed dominant peaks at 3.1, 2.0, 1.5 ppm, where the peaks at 1.5 ppm represent protons from methylene (-CH2) groups while peaks at 2.0 ppm represent protons of methylene linked to amine groups. For synthesized g-His-PAAm, the appearance of characteristic peaks (~7.7 and 7.0 ppm) of imidazole aromatic ring indicates the successful grafting of l-histidine onto PAAm. The histidine grafting density for synthesized polymers with *LGD* and *HGD* was calculated to be 12% and 58%, respectively. (b) Synthesized *g*-DOPA-PAAm compared with pristine PAAm and *l*-DOPA. For synthesized g-DOPA-PAAm, the emergence of peaks in the aromatic region (6.5-7.0 ppm) of *l*-DOPA implies the successful grafting of DOPA onto PAAm (Fig. S1b). The DOPA grafting density for synthesized *g*-DOPA-PAAm was calculated to be 20%.

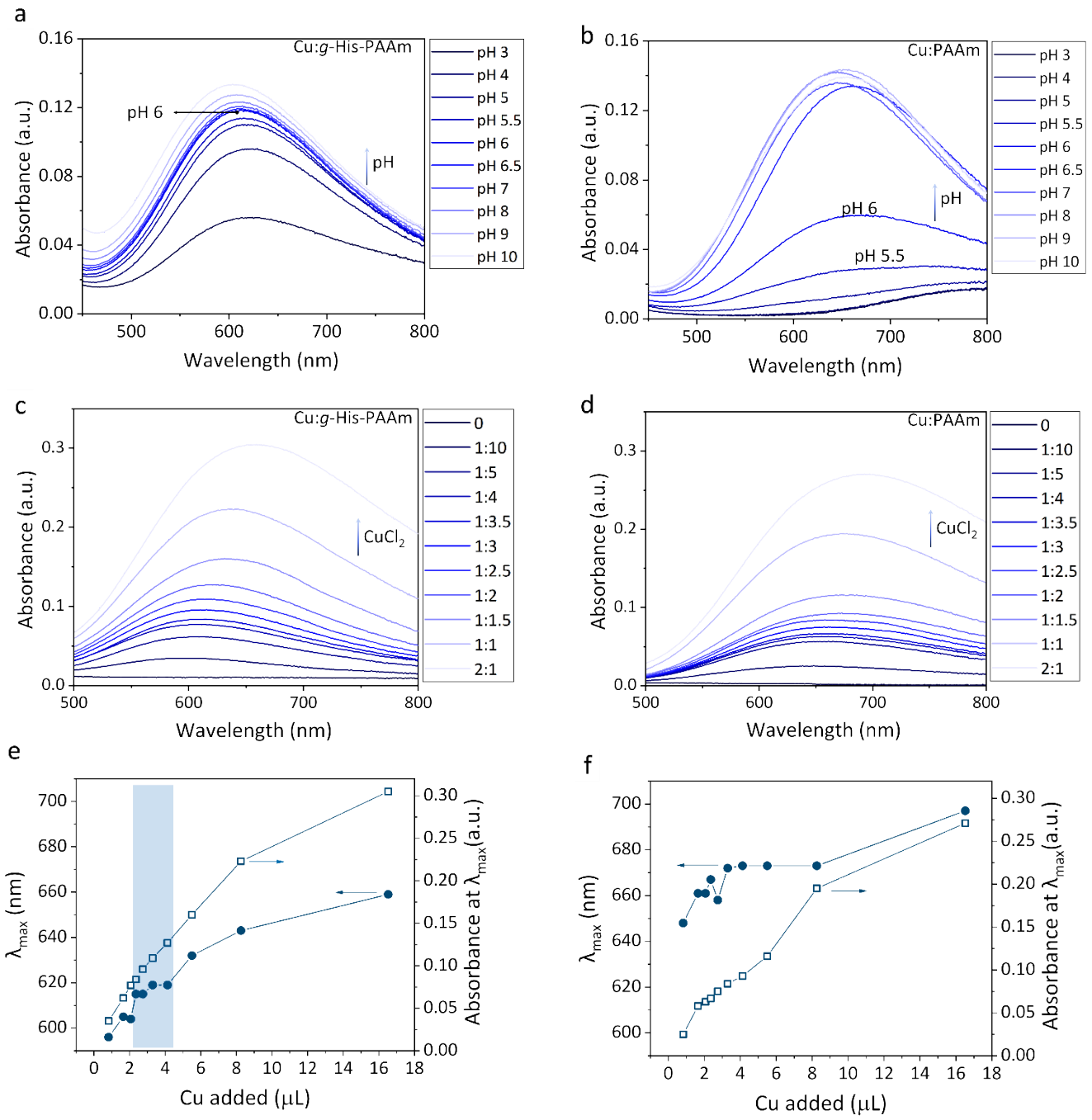

Figure S2. Study on copper complexation by UV-VIS spectroscopy. Absorption profiles of (a) *g*-His-PAAm solution mixed with $CuCl_2$ at a molar ratio of 1:3 of Cu(II):histidine and (b) PAAm solution mixed with the identical amount of $CuCl_2$ of *g*-His-PAAm system at different pH values. Absorption profiles of (c) *g*-His-PAAm and (d) PAAm solution (3 mg/ml) with addition of incremental amounts of $CuCl_2$, the corresponding molar ratios of Cu(II):histidine shown in the top right corner. Plots of wavelength at the maximum absorbance (λ_{max}) and the absorbance at λ_{max} versus the amount of $CuCl_2$ added for (e) *g*-His-PAAm system and for (f) PAAm system, respectively. The amounts of Cu(II) added correspond to the molar ratio of Cu(II):histidine at 0,1:10, 1:5, 1:4, 1:3.5, 1:3, 1:2.5, 1:2, 1:1.5, 1:1, 2:1. The amounts of Cu(II) added to PAAm system are identical to those added to the *g*-His-PAAm system.

As displayed in Figure S2e, there was no clear saturation with the addition of Cu(II) ions, which is consistent with the previous report about copper-imidazole complexes[3]. However, it can be recognized that when the ratio of Cu(II):*g*-His-PAAm is located in the regime of 1:3.5 to 1:2 (in blue shadow), the λ_{max} is relatively constant (615-619 nm), suggesting an almost constant coordination sphere of copper in this metal to ligand ratio.

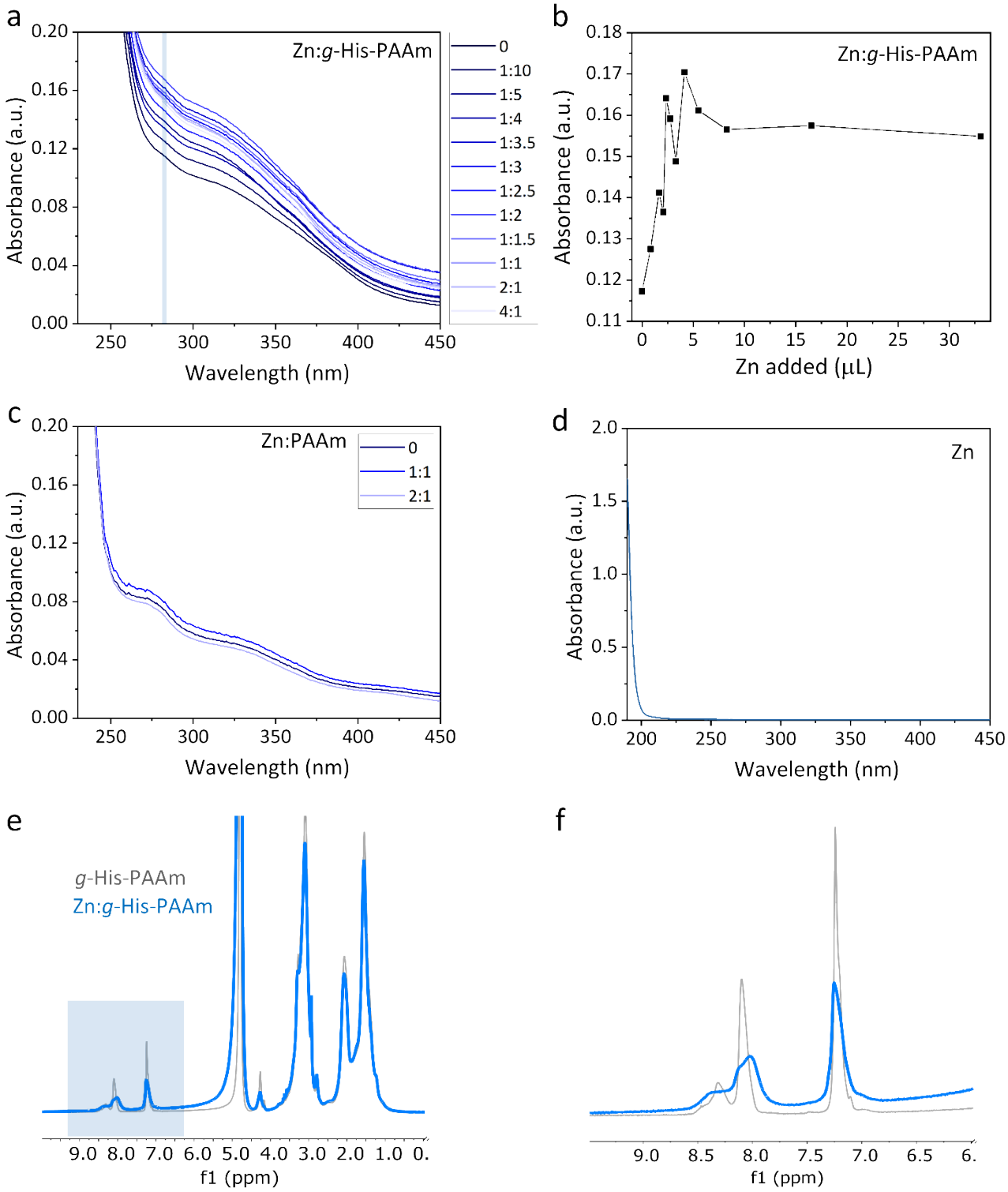

Figure S3. Study on zinc complexation at pH 6 by UV-VIS and NMR spectroscopy. (a) Absorption profiles of g-His-PAAm titrated with $ZnCl_2$ solution, the corresponding molar ratios of Zn(II):histidine shown in the top right corner. (b) Plots of the absorbance variation for g-His-PAAm at 280 nm (shown in the blue ribbon in (a)) versus the volume of titrated 1 M $ZnCl_2$ solution. The amounts of Zn(II) added correspond to the molar ratio of Zn(II):histidine at 0,1:10, 1:5, 1:4, 1:3.5, 1:3, 1:2.5, 1:2, 1:1.5, 1:1, 2:1, 4:1. (c) PAAm solution titrated with $ZnCl_2$ solution, the ratios shown in the top right corner represent the identical amount of $CuCl_2$ added for *g*-His-PAAm system when Zn(II):histidine ratio is 1:1 and 1:2. (d) Absorption profile of $ZnCl_2$ solution at pH~6. (e) ^{1}H NMR spectra of *g*-His-PAAm (in blue) compared with metal coordinate of Zn: *g*-His-PAAm (in grey) with a molar ratio of Zn:histidine at 1:3 at pH 6. pH was adjusted by diluted DCl or NaOD solutions. (f) The zoom-in aromatic region from 9.0 ppm to 6.5 ppm as shown in blue ribbon in (e). The peak broadening of Zn(II):*g*-His-PAAm specifically in the aromatic region at 8.6-6.8 ppm was due to the microenvironmental variation caused by the coordination bonding between the imidazole moiety of *g*-His-PAAm and Zn ions.

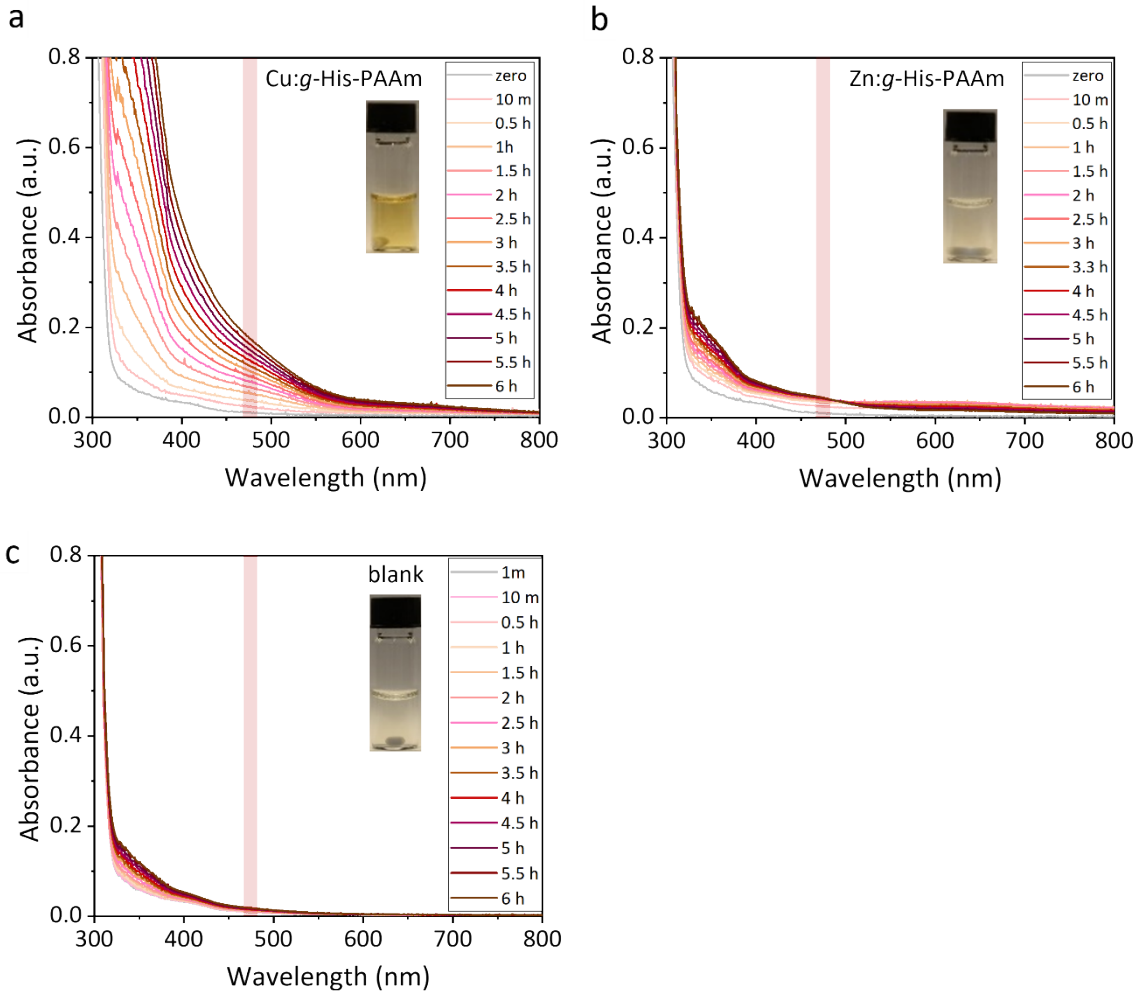

Figure S4. Time dependent UV-VIS absorption profiles of dilute solutions of *g*-DOPA-PAAm mixed with a small amount of (a) complex solution of Cu:*g*-His-PAAm, (b) Zn:*g*-His-PAAm and (c) blank solution without any metal complex. (Molar ratio of metal(II):histidine is 1:3, metal(II):DOPA is 1:20).

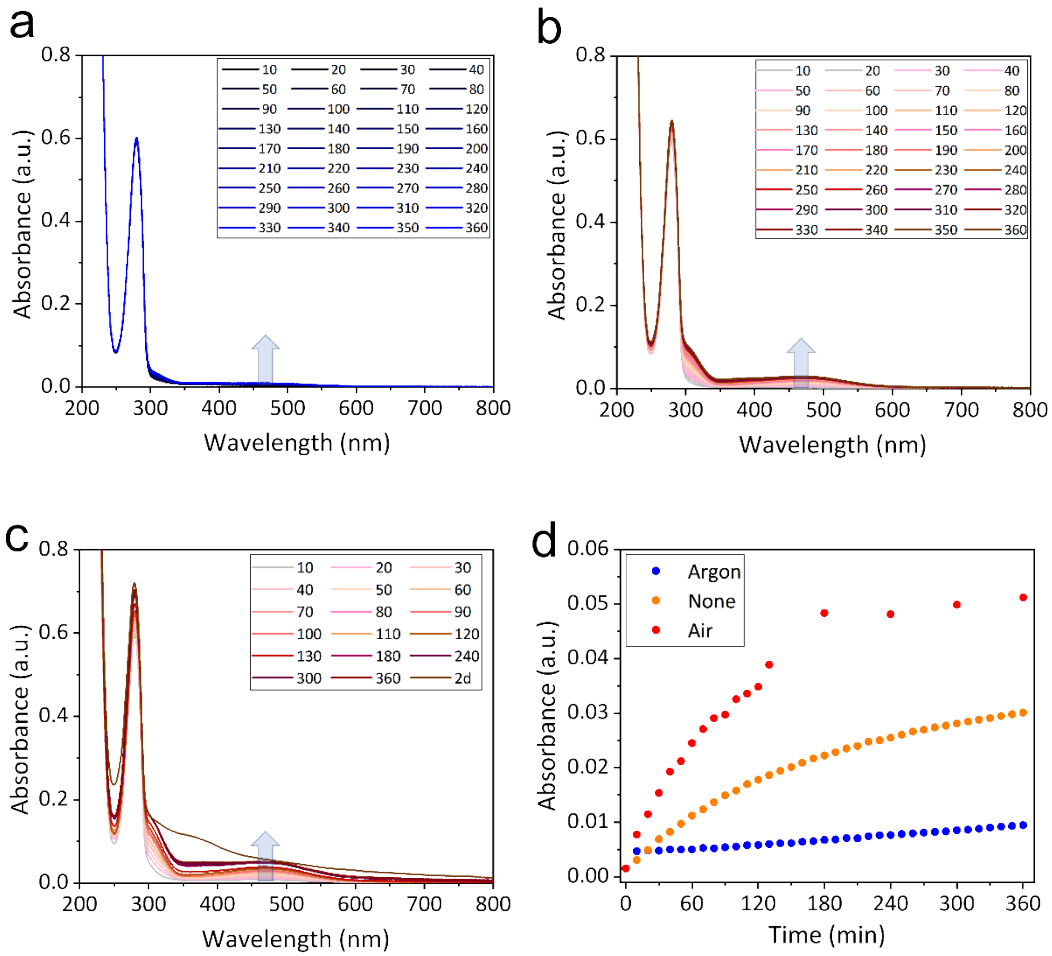

Figure S5. Time dependent UV-VIS absorption profiles of dilute solutions of dopamine mixed with a small amount of copper catalyst, Cu:*g*-His-PAAm, under different atmosphere conditon by purging samples with (a) argon, (b) no treatement and (c) oxygen-replenishing compressed air. (d) Comparison of absorbance at 471 nm versus time for samples under different atmoshpere condition indicating the catalytic activity of copper catalyst by regenerating Cu(II) from Cu(I) by molecular oxygen. pH value is 6. Molar ratio of Cu:dopamine is 1:20.

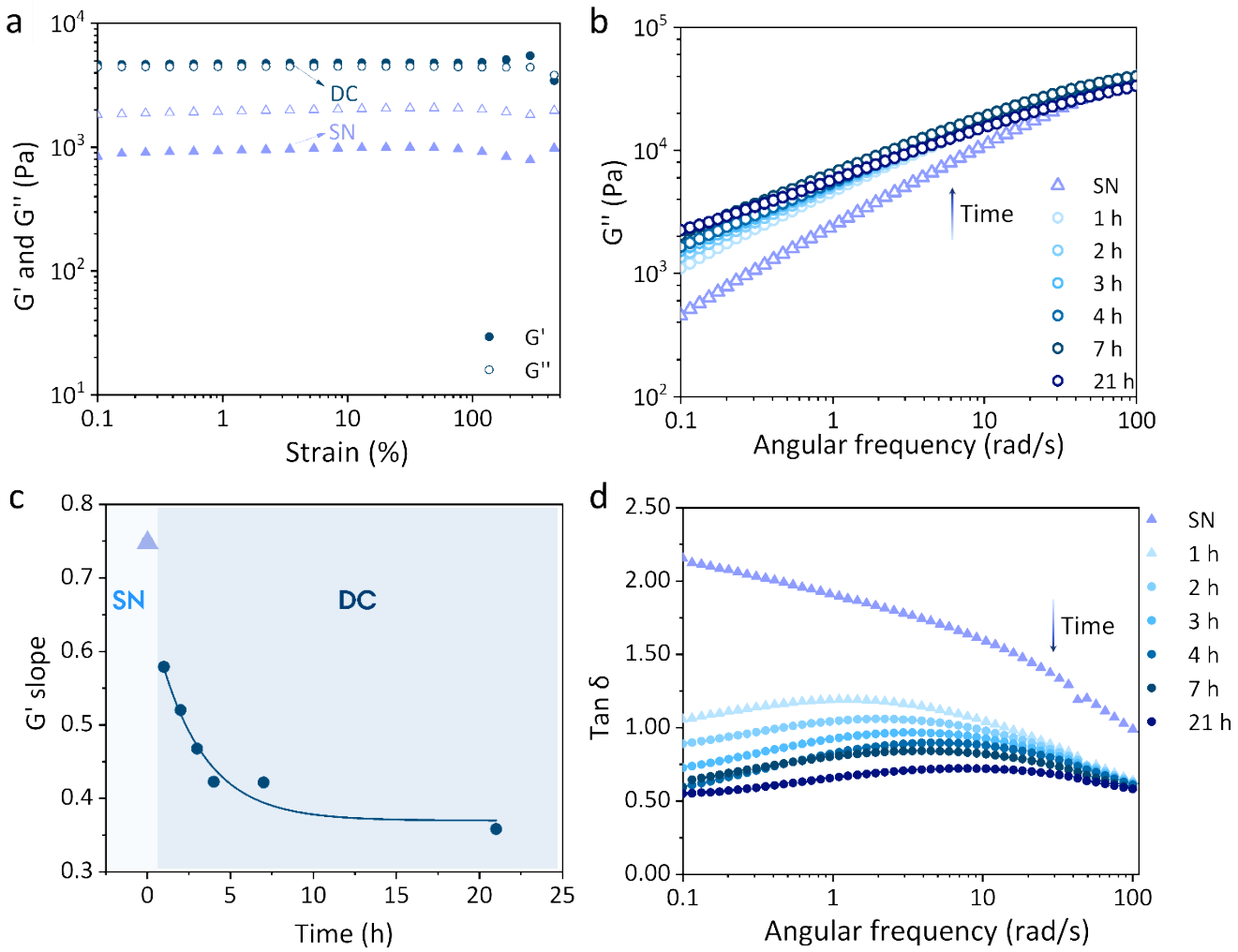

Figure S6. Oscillatory rheological results of the SN and DC samples based on *g*-His-PAAm (*LGD*) and Cu(II). Storage modulus – *G'* in solid circles for DC, in solid triangel for SN, loss modulus – *G''* in open circles for DC, in open triangel for SN. (a) Amplitude sweeps of SN sample Cu:*g*-His-PAAm (in light blue) and DC hydrogel Cu:*g*-His-PAAm/*g*-DOPA-PAAm (in navy blue) under shear strain from 0.1% to 450% at a frequency of 1 s^{-1} indicating a large linear viscoelastic (LVE) region. (b) *G''* of SN (open triangles) and DC samples (open circles) dependent on frequency. (c) The slopes of log(*G'*) vs log(ω) for Figure 2b in manuscript obtained by linear fits within the frequency range 0.1-10 s^{-1} at different reaction time-intervals. The blue line is a fit to the slope vs time values and acts as a guide to the eye. The decreased *G'*-slope against time indicating the formation of a more crosslinked and elastic polymer networks over time. (d) Loss factors (tan δ = *G''/G'*) of SN and DC samples dependent on angular frequency from 0.1 to 100 s^{-1} at a constant strain of 10 % (within LVE region) at different time interval from 1 to 21 hours.

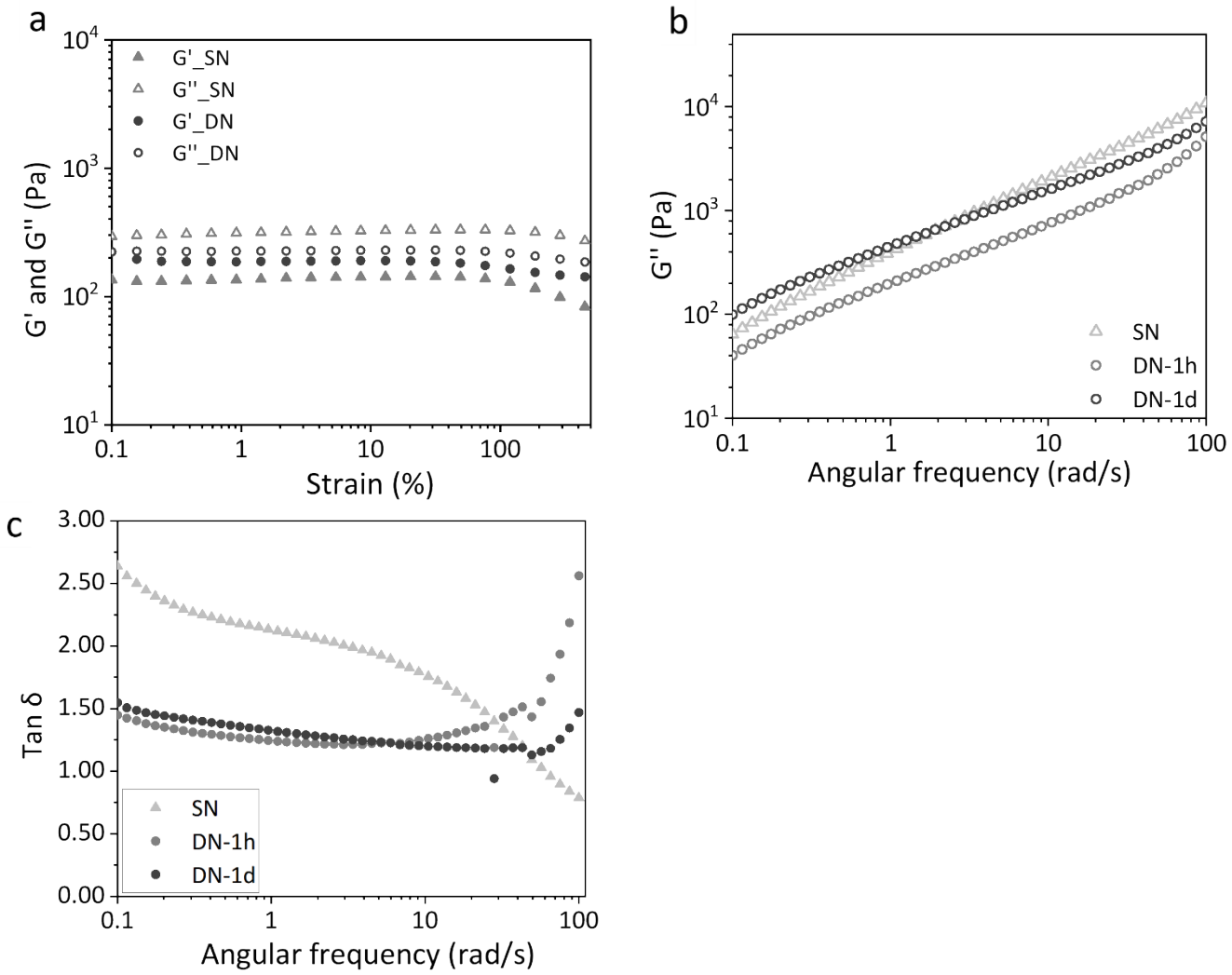

Figure S7. Oscillatory rheological results of the samples based on *g*-His-PAAm (*LGD*) and Zn(II). (a) Amplitude sweeps of SN sample Zn:*g*-His-PAAm (in triangels) and DN sample Zn:*g*-His-PAAm/*g*-DOPA-PAAm (in circles) under shear strain from 0.1% to 450% showing strain dependent *G'* (in solid circles/triangles) and *G''* (in open circles/triangels) at a frequency of 1 s^{-1} indicating a large LVE region. (b) *G''* and (c) loss factors of the SN (in solid triangle) and DN samples (in solid circles) dependent on angular frequency from 0.1 to 100 s^{-1} at a constant strain of 10 % (within LVE region) at different reaction time-interval from 1 hour to 1 day.

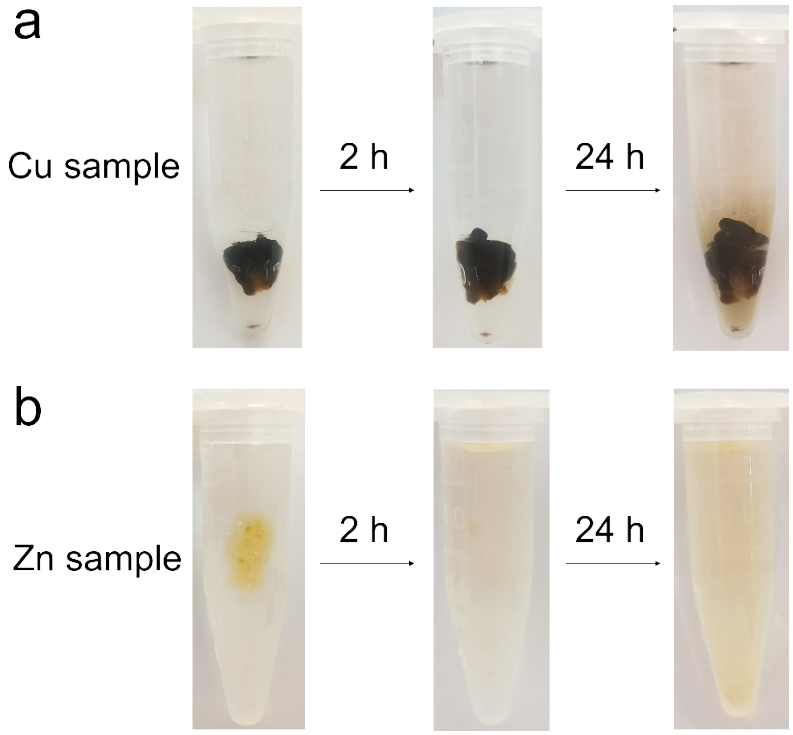

Figure S8. Competitive binding experiments with 150 mM imidazole solution (pH 6) on samples with 20 wt% *LGD* (a) Cu:*g*-His-PAAm/*g*-DOPA-PAAm and (b) Zn:*g*-His-PAAm/*g*-DOPA-PAAm.

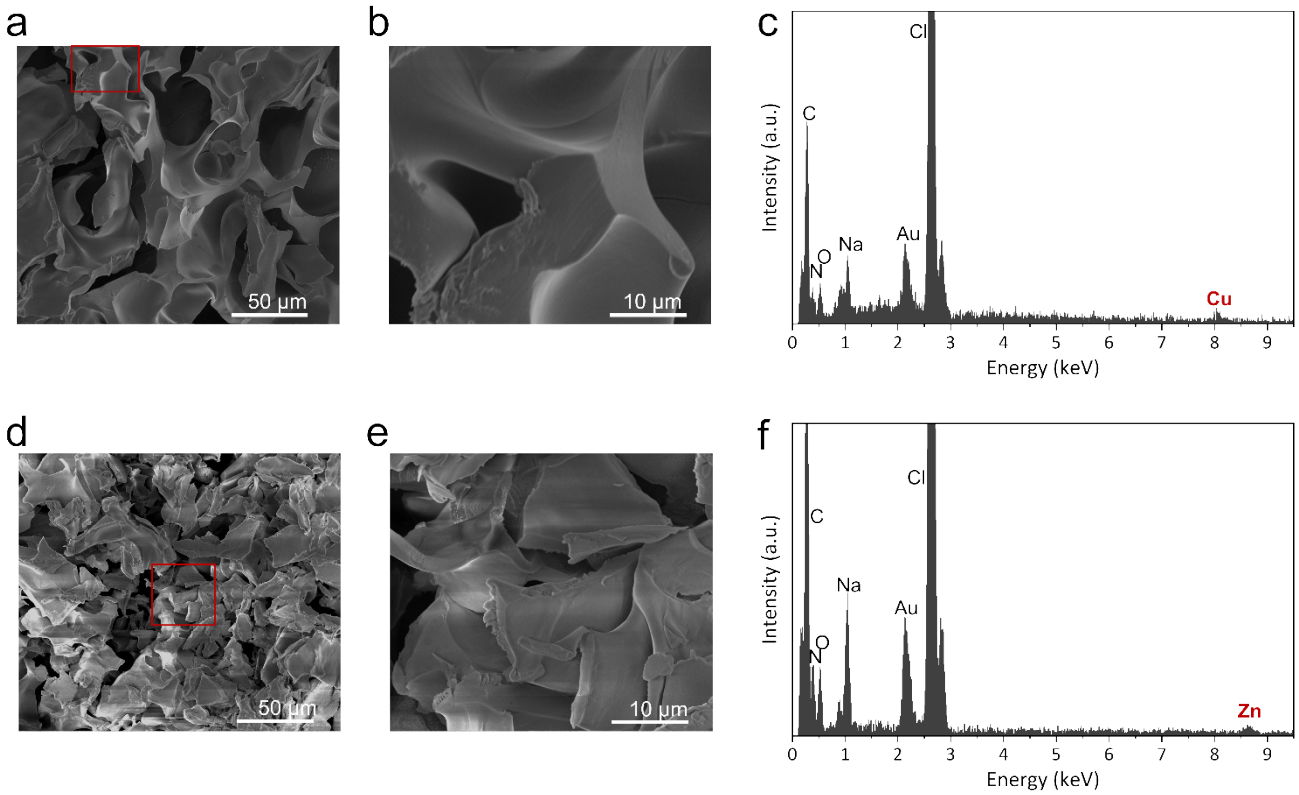

Figure S9. SEM (a, b, d, e) and EDS (c, f) characterization of DC hydrogel, Cu:*g*-His-PAAm/*g*-DOPA-PAAm (a-c) and DN hydrogel, Zn:*g*-His-PAAm/*g*-DOPA-PAAm (d-f). EDS results showed the existence of copper and zinc in the copper containing and zinc containing system, respectively. The spectra shown are sums of spectra measured on three different points randomly chosen on the sample.

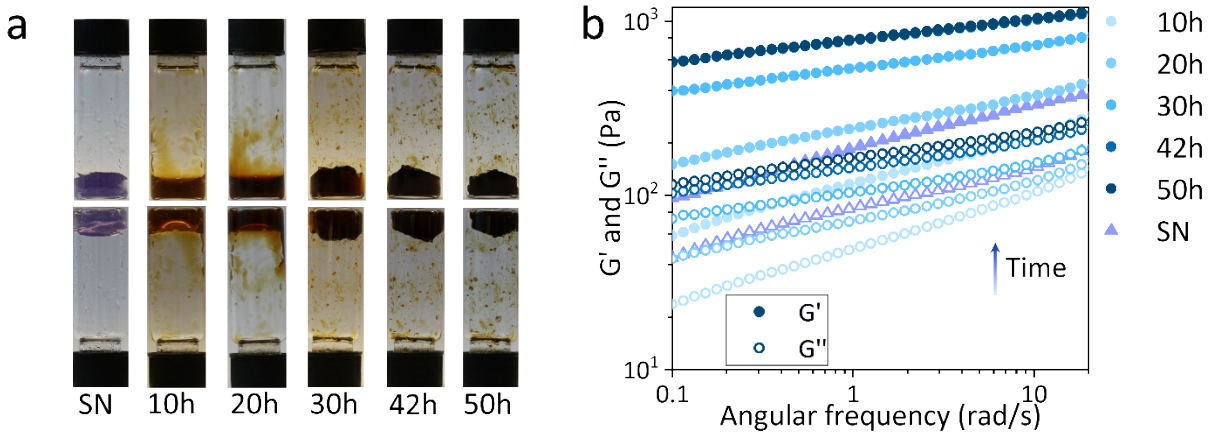

Figure S10. (a) Inverted vial tests of samples including SN hydrogel (Zn+Cu):*g*-His-PAAm (*HGD*), and DC hydrogel (Zn+Cu):*g*-His-PAAm/*g*-DOPA-PAAm (*HGD*)10, 20, 30, 42 and 50 h after formation. b) Rheological frequency sweeps of these hydrogels at a constant strain of 10% (within the LVE range). *G'* in solid circles for DC, and in solid triangel for SN; *G''* in open circles for DC and in open triangel for SN.

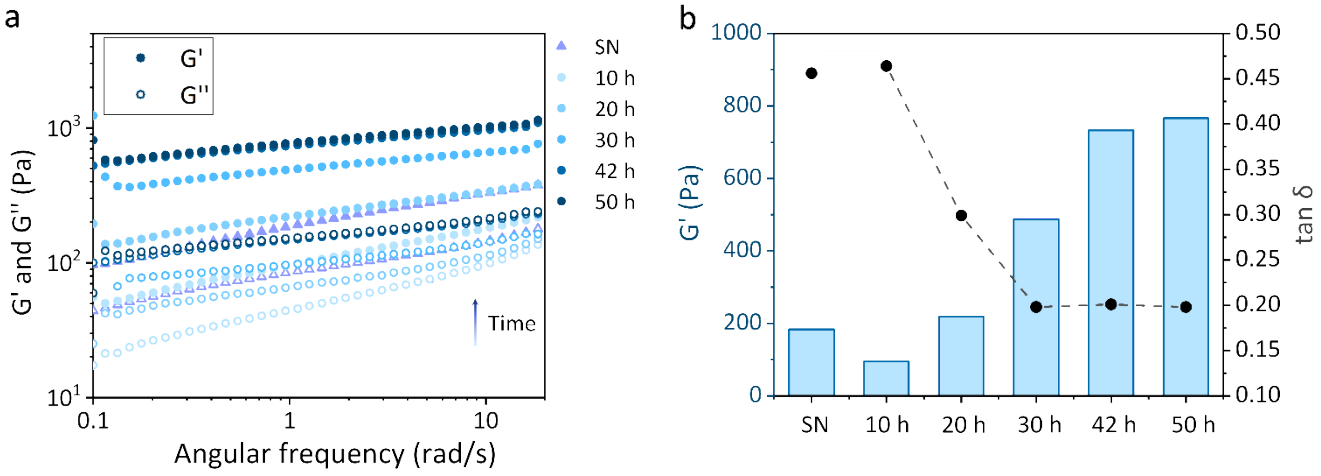

Figure S11. (a) Frequency sweeps 10 wt% SN hydrogel (Zn+Cu):*g*-His-PAAm and 10 wt% DC hydrogel of (Zn+Cu):*g*-His-PAAm/*g*-DOPA-PAAm with *HGD* at a constant strain of 1% showing *G'* (solid circles for DN, solid triangles for SN) and *G''* (open circles for DN, open triangles for SN) (b) *G'* (blue column) and tan δ (*G''*/*G'*, black dotted line) of SN and DC hydrogels after 10, 20, 30, 42, 50 h after formation, respectively, at 1 s^{-1} frequency and a strain of 1%. Compared with Figure S7b, of which freqency sweeps were conducted at 10% strain, the *G'*, *G''* and tan δ evolutions in frequency sweep at 1% in Figure S8a showed very similar trends and values, indicating the similar rhelogical behavior of samples sheared under 10% and 1% strain.

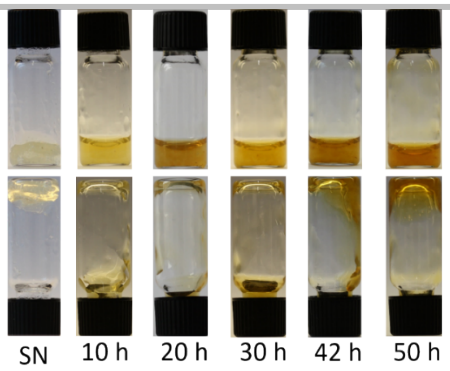

Figure S12. Inverted vial-test of samples of *g*-His-PAAm (*HGD*) with Zn(II) with 10 wt% total polymer concentration and a molar ratio of zinc:histidine at 1:3. From left to right: SN hydrogel Zn:*g*-His-PAAm, DN samples of Zn:*g*-His-PAAm/*g*-DOPA-PAAm prepared after 10, 20, 30, 42 and 50 hours after formation. Hydrogels did not form even after 50 hours, since zinc complex could not catalyze the oxidization of catechol moeity to induce oxidative crosslinking, thereby inhibiting the formataion of hydrogel.

Section S3: References

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