



Article Pt Nanoparticles Anchored on NH₂-MIL-101 with Efficient Peroxidase-Like Activity for Colorimetric Detection of Dopamine

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Abstract: Dopamine (DA) is an important catecholamine neurotransmitter that plays a highly relevant role in regulating the central nervous system, and abnormal DA content can cause many immune-related diseases. Hence, it is of significance to sensitively and specifically identify DA for clinical medicine. In this work, Pt/NH_2 -MIL-101 hybrid nanozymes with bimetallic catalytic centers were fabricated by forming coordinate bonds between Pt nanoparticles (Pt NPs) and $-NH_2$ on metal–organic frameworks (MOF). The catalytic activity of Pt/NH_2 -MIL-101 was increased by 1.5 times via enlarging the exposure of more active sites and improving the activity of the active sites through the strategy of forming bimetallic catalytic centers. In the presence of DA, competing with 3, 3', 5, 5'-tetramethylbenzidine (TMB) for the generated hydroxyl radicals (\bullet OH), the blue oxidation state TMB (Ox-TMB) is reduced to colorless TMB, showing dramatic color changes. The Pt/NH₂-MIL-101-based colorimetric assay enables the sensitive and robust detection of DA molecules with a detection limit of only 0.42 μ M and has an observable potential in clinical applications.

Keywords: peroxidase-like activity; Pt NPs; metal-organic framework; colorimetric; dopamine

1. Introduction

Dopamine (DA) is an intracerebral messenger that plays a necessary role in regulating neuronal behavior and cardiovascular and endocrine regulatory systems [1,2]. Abnormal DA content in the body can cause cognitive abnormalities. For example, a lack of DA can cause Parkinson's disease, manifestations including stiffness and tremors in the limbs, and can trigger restless legs syndrome [3]. However, excessive levels of DA will increase the probability of self-inability and schizophrenia [4]. Therefore, the accurate and sensitive detection and analysis of DA levels in humans are of great significance for the early detection of diseases such as Parkinson's and schizophrenia. Various analytical techniques, like liquid chromatography [5], electrochemistry [6], and fluorescence [7], have been employed to measure DA molecules. The challenge comes as how to rapidly and sensitively detect DA molecules in real samples, which generally requires time-consuming pretreatments and complex analytical procedures. With directly and conveniently detecting analytes by observing color changes, the colorimetric detection method based on the activity of nanozymes is expected to be an ideal technique for DA detection.

Metal–organic frameworks (MOFs) mimicking enzymes are important materials for colorimetric detection due to their large surface areas, well-defined pore structures, tunable chemical compositions, and multifunctional sites [8,9]. In addition, the unique physical



Citation: Li, J.; Xu, K.; Chen, Y.; Zhao, J.; Du, P.; Zhang, L.; Zhang, Z.; Lu, X. Pt Nanoparticles Anchored on NH₂-MIL-101 with Efficient Peroxidase-Like Activity for Colorimetric Detection of Dopamine. *Chemosensors* **2021**, *9*, 140. https:// doi.org/10.3390/chemosensors9060140

Academic Editor: Xiaobing Zhang

Received: 10 May 2021 Accepted: 8 June 2021 Published: 14 June 2021

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Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). and chemical properties of MOFs not only enable MOFs with various characteristics of nanozymes but also offer more possibilities for the engineering design of MOFs and expand the scope of their applications [10]. For example, MOFs (MIL-53, MIL-101, and Cu-MOF) were constructed by ligating metal ions/clusters (Fe, Co, and Cu) with organic ligands (terephthalic acid and 1, 3, 5-benzenetricarboxylic acid) to obtain modulated peroxidase-like catalytic activity [11–16]. However, it has low peroxidase-like activity due to its low metal ion content, chemical instability, and other shortcomings, which limits its development in the field of colorimetric detection. Therefore, strategies such as altering the size or morphology, constructing MOFs of bimetallic active centers, and transforming surface properties are usually adopted to heighten the mimicking enzyme activity of MOFs [17–19]. For example, the two-dimensional Zn-TCPP(Fe) prepared by Wei's group exhibits a lower diffusion barrier and a two-fold higher catalytic activity than the three-dimensional Zn-TCPP(Fe) [20]. Zhao's group prepared the Au/MOFs(Fe and Mn)/CNTs, which exhibit enhanced peroxidase-like activity due to the increase of active sites and electron transfer between the Fermi levels of the MOFs Au and CNTs; the synergistic effect between Fe and Mn promotes the material to exhibit enhanced peroxidase-like activity [21]. Therefore, from the perspective of the nanozyme catalytic process (substrate adsorption, diffusion, catalysis, and product desorption), the increase of catalytic active sites can enhance the peroxidaselike activity of MOFs. Furthermore, the unique structure of MOFs has important guiding value for the design of functional nanocomposites with high peroxidase activity.

Pt nanoparticles (Pt NPs) are one of the most effective catalysts, because they have more active sites and can be served as the mimic enzymes of peroxidase, oxidase, catalase, and superoxide dismutase [22–24]. However, they tend to aggregate in catalytic reactions, resulting in reduced catalytic activity. At present, the hybrid nanomaterials formed by growing Pt NPs on substrates such as graphene oxide, MoS_2 nanosheets, MoO_3 nanosheets, and Pd nanosheets are an effective method to solving this problem [25–28]. More importantly, the synergistic effect between the bimetallic active centers in these hybrid nanomaterials can effectively improve their catalytic activity. Inspired by these, Pt/MOF hybrid nanozymes may be synthesized to achieve enhanced catalytic activity.

In this work, NH₂-MIL-101 with a uniform and dispersed octahedral structure was synthesized by the hydrothermal method, and then, Pt/NH₂-MIL-101 with a bimetallic catalytic center was prepared by a covalent bond with Pt NPs (Scheme 1a). The peroxidase-like activity of Pt/NH₂-MIL-101 was increased by 1.5 times. On the one hand, the number of catalytic centers can be increased by the larger specific surface area of NH₂-MIL-101 (2668 m²/g) and the construction of bimetallic centers. Additionally, the catalytic performance is enhanced by the existence of a potential difference between Fe with Pt that is sufficient to facilitate an electron transfer [29,30]. Moreover, Pt/NH₂-MIL-101, which has outstanding peroxidase activity, can quickly catalyze H₂O₂ breakdowns to form hydroxyl radicals (\bullet OH), thus changing the color of TMB. By using the competitive consumption effect of DA on \bullet OH to inhibit the catalytic reaction of TMB, a convenient, sensitive, and reproducible colorimetric method for the determination of the content of DA in human serum was constructed (Scheme 1b). This is of vital meaning for the clinical diagnosis of various diseases caused by DA.



Scheme 1. Illustration of the synthesis of Pt/NH₂-MIL-101 (a) and the detection of DA (b).

2. Methods

2.1. Preparation of Pt/NH₂-MIL-101

NH₂-MIL-101 (24 mg) was ultrasonically dispersed in 12 mL DMF, then added to a previously treated Pt NPs (2.0 mL) solution and stirred at room temperature at 750 rpm/min for 10 h. The Pt/NH₂-MIL-101 hybrid nanozyme was obtained by centrifugation and ethanol washing 3 times. Finally, the precipitate after centrifugal washing was dried under vacuum to obtain Pt/NH₂-MIL-101.

2.2. Peroxidase-Like Activity of Pt/NH₂-MIL-101

First of all, 3, 3', 5, 5'-tetramethylbenzidine (TMB), 1, 2-diaminobenzene (OPD) and 2, 2'-azino-bis(3-ethylbenzothia-zoline-6-sulfonic acid) (ABTS) were selected as chromogenic substrates. We added 50 μ L of 800 μ g/mL Pt/NH₂-MIL-101 to 1850 μ L HAc-NaAc (0.1 M, pH = 4.0) buffer solution; then, the same volume and concentration of TMB (50 μ L, 10 mM), OPD, ABTS, and H₂O₂ were injected into the above solution, respectively. The mixture reacted for 10 min, and then the UV-vis absorption spectra of the reaction system was also recorded by a UV-vis absorption spectrometer.

2.3. Detection of Dopamine

First of all, we added gradient concentrations of 200 μ L of DA solution (0–200 μ M) to 1650 μ L HAc-NaAc buffer solution containing 50 μ L Pt/NH₂-MIL-101 (800 μ g/mL), H₂O₂ (10 mM), and TMB (10 mM). At 30 °C for 10 min, the absorption spectrum was measured by UV-vis spectrometer.

The obtained serum samples (the First Teaching Hospital of Tianjin University of Traditional Chinese Medicine, Tianjin) were pretreated through a high-speed refrigerated centrifuge at 8000 rpm, and the supernatant was separated and cryopreserved at 4 °C. Then, the serum sample was diluted and used to prepare different concentrations of DA; 50- μ L TMB (10 mM), 50 μ L Pt/NH₂-MIL-101 (800 μ g/mL), and 50 μ L H₂O₂ (10 mM) were added to the HAc-NaAc buffer solution. Subsequently, three concentrations of 50- μ L DA (20 μ M, 30 μ M, and 40 μ M) were injected into the above mixed solution. The values of absorbance were measured when the reaction was completed 10 min later. Each experiment was performed three times to minimize any errors.

3. Results

3.1. Material Characterization

Pt/NH₂-MIL-101 was synthesized in a two-step process. As illustrated by a scanning electron microscopy (SEM) image (Figure 1a), NH₂-MIL-101 with an average size of 450 nm synthesized by the hydrothermal method showed a uniform octahedral structure. The Powder X-ray diffraction (XRD) characteristic diffraction peak of NH₂-MIL-101 was consistent with that reported in the literature [31], which indicated that NH₂-MIL-101 with a good crystal structure was successfully prepared (Figure 1b). As illustrated in the Fourier-transform infrared (FTIR) spectra (Figure 1c), the characteristic peaks of NH₂-MIL-101 at the positions of 3448 and 3369 cm⁻¹ were attributed to the symmetric and asymmetric stretching vibrations of $-NH_2$, respectively. At the same time, the specific surface area and pore size distribution analyzer (BET) were used to obtain the nitrogen adsorption-desorption curve and adsorption values of the adsorption isotherm curve, and the specific surface area of NH₂-MIL-101 was calculated to be 2668 m²/g (Figure 1d). The FTIR and BET characterization results indicated that NH₂-MIL-101 contained a large number of NH₂ groups and a large specific surface area, which was conducive to the combination of Pt NPs in the next step [32].



Figure 1. (a) SEM image of NH₂-MIL-101 (Inset: particle size distribution of NH₂-MIL-101). (b) XRD pattern of NH₂-MIL-101 and Pt/NH₂-MIL-101. (c) The FTIR spectrum. (d) N₂ adsorption–desorption isotherm of NH₂-MIL-101. (e) TEM image of Pt/NH₂-MIL-101 (Inset: HRTEM image pattern of Pt NPs). (f) Elemental mapping image of the C, N, O, Fe, and Pt elements, respectively, in Pt/NH₂-MIL-101.

A hybrid nanozyme NH₂-MIL-101 was prepared by loading Pt NPs onto the surface of NH₂-MIL-101 through covalent bonding. Firstly, Pt NPs with an average size of 3.27 nm were synthesized (Figures S1 and S2). As shown in Figure 1e, the transmission electron microscope (TEM) image showed that Pt NPs were evenly distributed on the surface of NH₂-MIL-101, and Pt NP loading had no effect on the morphology and size of NH₂-MIL-101 (Figure S3). The lattice spacing was 0.23 nm, corresponding to the Pt (111) plane that was observed from high-resolution TEM (Figure 1e). The inductively coupled plasma mass spectrometry (ICP-MS) measured that the loading capacity of Pt was 4.59 wt% (Table S1). As shown in the XRD spectra (Figure 1b), the characteristic diffraction peaks of NH₂-MIL-101 and Pt/NH₂-MIL-101 did not change significantly, indicating that the loading of the Pt NPs had no remarkable effect on the crystal structure of NH₂-MIL-101. At the same time, both the elemental mapping image (Figure 1f) and X-ray photoelectron spectroscopy (XPS) (Figure S4) showed that the hybrid nanozymes had corresponding C, Fe, N, O, and Pt signals responses and characteristic peaks, which also indicated that Pt

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NPs had a successfully anchored set on the surface of NH₂-MIL-101, indicating that the Pt/NH₂-MIL-101 hybrid nanozymes were successfully synthesized.

3.2. Feasibility Analysis of the Peroxidase-Like Activity of Pt/NH₂-MIL-101

To evaluate the feasibility of the peroxidase-like activity of Pt/NH_2 -MIL-101, three typical chromogenic substrates TMB, ABTS, and OPD were tested with H₂O₂. As illustrated in Figure 2a, Pt/NH₂-MIL-101 can oxidize colorless TMB, ABTS, and OPD solutions into blue, green, and yellow, respectively, and presents characteristic peaks in the corresponding positions (652, 420, and 452 nm) of the UV-vis spectrum. In addition, the catalytic performance of Pt/NH₂-MIL-101 was evaluated by the mechanism of TMB color-changing. As illustrated in Figure 2b, the TMB solution in the presence of $H_2O_2 + NH_2$ -MIL-101 had only a weak color change and absorption value, indicating that NH₂-MIL-101 had low peroxidase-like activity. In contrast, Pt/NH2-MIL-101 showed a significantly enhanced peroxidase activity and color change. Moreover, as shown in Figure 2c, the catalytic speed of Pt/NH₂-MIL-101 was obviously higher than that of NH₂-MIL-101. These results indicated that Pt/NH₂-MIL-101 had significant peroxidase-like activity, and the catalytic performance of Pt/NH₂-MIL-101 was much better than that of NH₂-MIL-101. For quantitative comparison, the absorbance value of Pt/NH_2 -MIL-101 was used as a reference (100%), and the values of NH₂-MIL-101 and Pt NPs were calculated to be 31.0% and 9.3%, respectively (Figure 2d). The results confirmed that the catalytic activity of Pt/NH_2 -MIL-101 was 2.5 times that of the sum of NH₂-MIL-101 and Pt NPs. The construction of the bimetallic catalytic center formed a synergistic effect and significantly improved the catalytic performance of Pt/NH₂-MIL-101.



Figure 2. (a) UV-vis spectra of TMB, ABTS, and OPD catalyzed by Pt/NH_2 -MIL-101. (b) UV-vis spectra of four groups of samples (1: TMB, 2: TMB + H_2O_2 , 3: TMB + H_2O_2 + NH_2 -MIL-101, and 4: TMB + H_2O_2 + Pt/NH_2 -MIL-101) in the HAc-NaAc (0.1 M, pH = 4.0) buffer solution. (c) Time absorption curves of Pt NP_S, NH₂-MIL-101, and Pt/NH₂-MIL-101. (d) The relative activity histogram of Pt NPs, NH₂-MIL-101, and Pt/NH₂-MIL-101 catalyzed TMB oxidation in the presence of H₂O₂.

Actually, pH and temperature had an obvious influence on the enzyme-like activity [33–35]. As shown in Figure S5a,b, the peroxidase-like activity of the Pt/NH₂-MIL-101 hybrid nanozyme reached the highest value at pH = 4.0 and showed the best catalytic performance at 35 °C. Furthermore, the catalytic activity of Pt/NH₂-MIL-101 could maintain over 80% in the temperature range of 25–45 °C, which also indicated that the material has good thermal stability. Meanwhile, the catalytic performance of Pt/NH₂-MIL-101 also increased with the increase of the material concentrations (Figure S5c). The results of the repeated cyclic catalytic activity measurements in Figure S5d indicated that the peroxidase-like activity of Pt/NH₂-MIL-101 has excellent stability. Therefore, after comprehensive consideration, we chose pH = 4.0, the temperature of 35 °C, and a concentration of 800 μ g/mL as the optimal reaction conditions for the subsequent experiments.

3.3. Steady-State Dynamic Analysis

The enzyme kinetics parameters of Pt/NH₂-MIL-101 were evaluated by the Michaelis– Menten curve of Pt/NH₂-MIL-101. As illustrated in Figure 3a–d, v_{max} and K_m were obtained according to the Lineweaver–Burk equation. Among them, K_m represented the affinity between the enzyme and the substrate, and the smaller the K_m value, the stronger the affinity between the enzyme and the substrate. Compared with the reports in recent years, the K_m value of Pt/NH₂-MIL-101 was much smaller than other nanozyme catalysts, even lower than that of horseradish peroxidase (HRP) (Table S2). v_{max} , which represented the reaction rate, was also higher than most nanozyme catalysts. In short, the Pt/NH₂-MIL-101 prepared in this work had a larger v_{max} , and a smaller K_m , which proved that it can indeed be used to mimic natural enzymes.



Figure 3. (a) Michaelis–Menten curve of the H_2O_2 concentration change when the TMB concentration was 1 mM, (b) the Lineweaver–Burk plots of the double reciprocal of H_2O_2 as a substrate, (c) Michaelis–Menten curve of the TMB concentration change when the H_2O_2 concentration was 1 mM, and (d) the Lineweaver–Burk plots of the double reciprocal of TMB as a substrate.

3.4. The Mechanism of Pt/NH₂-MIL-101 as a Peroxidase Mimetics and Detecting Dopamine

The peroxidase-like activity of Fe-based compounds has been studied extensively [36–39]. The typical peroxidase-like reactions involved were carried out by the following equations:

$$Fe^{3+} + H_2O_2 \rightarrow Fe^{3+} - H_2O_2 \text{ (complex)}$$
 (1)

$$\operatorname{Fe}^{3+}-\operatorname{H}_2\operatorname{O}_2(\operatorname{complex}) \rightarrow \operatorname{Fe}^{2+} + \bullet\operatorname{O}_2\operatorname{H} + \operatorname{H}^+$$
 (2)

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + \bullet OH + OH^-$$
(3)

 H_2O_2 and Fe³⁺ formed a surface complex on the Pt/Fe-MOF surface during the heterogeneous Fenton reaction. Then, H_2O_2 and Fe³⁺ underwent electron transfer on the surface of the complex to form $\bullet O_2H$ and Fe²⁺. Subsequently, Fe²⁺ reacted with H_2O_2 to form $\bullet OH$. Among them, the rate constant (9.1 $\times 10^{-7}$ M⁻¹ s⁻¹) of Equation (2) was lower, which was the rate-limiting step [40]. Therefore, the catalytic performance is often inhibited by the rate-limiting step in most Fe-based peroxidase catalysts [41,42].

To prove the above, the synergistic effect of Pt/NH_2 -MIL-101 was studied through XPS. As shown in Figure 4a, the Fe 2p characteristic peaks appeared at 724.8 and 711.4 eV, which were attributed to Fe $2p_{1/2}$ and Fe $2p_{3/2}$, respectively. The XPS peak splitting results indicated that Fe in Pt/NH_2 -MIL-101 behaved as Fe^{3+} in the absence of H_2O_2 . On the contrary, when H_2O_2 was present, the peak position shifted in the direction of a lower binding energy, indicating that Fe mainly behaved as Fe^{2+} . At the same time, as illustrated in Figure 4b, the peak splitting results of Pt indicated that the peak position of Pt 4f moved in the direction of a high binding energy, and the valence state of Pt changed from Pt⁰ to Pt²⁺. Combined with Figure 4a, when Pt/NH₂-MIL-101 reacted with H_2O_2 , an electron transfer occurred between the two metal active centers of Pt and Fe atom, in which part of the electrons in the Pt atom were transferred to the Fe atom to accelerate the Fe³⁺/Fe²⁺ redox cycle and, thus, accelerated the process of the Fenton reaction. Furthermore, the overall efficiency of Pt/NH₂-MIL-101 as a peroxidase-like catalytic reaction was further improved [43,44].



Figure 4. (a) Fe 2p and Pt 4f (b) XPS spectra of Pt/NH₂-MIL-101 before and after the reaction with H_2O_2 . (c) Fluorescence spectra of TA as a probe in different reaction systems. (d) ESR spectra of the •OH radical captured by DMPO in different reaction systems.

Meanwhile, electron spin resonance (ESR) and terephthalic (TA) probes were used to investigate whether •OH was generated in the catalytic reaction of Pt/NH₂-MIL-101 [45,46]. As shown in Figure 4c, compared with the other three groups, the fluorescence intensity of Pt/NH₂-MIL-101 + TA + H₂O₂ increased obviously at 450 nm, indicating that •OH was indeed produced during the catalytic reaction. For NH₂-MIL-101 and NH₂-MIL-101 + TA, faint peaks also appeared at 450 nm, because NH₂-MIL-101 itself also had fluorescence at the 315-nm excitation wavelength. As shown in Figure 4d, compared with the other four groups, when trace amounts of H₂O₂ were added to Pt/NH₂-MIL-101 + DMPO, a

characteristic peak of 5, 5-dimethyl-1-pyrroline N-oxide (DMPO)-captured •OH of 1:2:2:1 was observed. The results indicated that Pt/NH₂-MIL-101 can catalyze H₂O₂ to generate •OH. It was worth noting that, after adding the corresponding amount of DA to Pt/NH₂-MIL-101 + DMPO + H₂O₂, the characteristic signal peak intensity of •OH was significantly reduced, indicating that DA can indeed be combined with TMB, competing with •OH, so Pt/NH₂-MIL-101 can be used to construct a system to detect DA.

3.5. Detection of Dopamine

The Pt/NH₂-MIL-101 system conducts DA detection through the principle of DA and TMB competing with •OH. DA was protonated in the pH < 8.0 aqueous solution, and the protonated DA (DA⁺) competed with TMB for •OH [47]. Ultimately, the higher reactivity of DA⁺ resulted in a lower absorbance [48]. As shown in Figure 5a, with the increase of DA concentration, the absorbance of the system at 652 nm decreased gradually. The fitting results indicated that Pt/NH₂-MIL-101 had a good linear relationship in the range of 1–60 μ M (R² = 0.993), and the detection limit was 0.42 μ M (Figure 5b,c). Compared with the previous reports [49,50], the detection limit of Pt/NH₂-MIL-101 was sufficiently low, and the linear range was wider (Table S3). Therefore, this provided a method for the detection of DA. However, when it comes to the amount of DA measured in the actual blood, the composition of the target solution is often very complex. Therefore, some cations and amino acids commonly found in the human body were used to evaluate the selectivity of the Pt/NH₂-MIL-101 system had almost no response to other interfering substances, indicating that Pt/NH₂-MIL-101 has good selectivity.



Figure 5. (a) The fitting curves of absorbance at various concentrations of DA (from 0 to 200 μ M) at 652 nm. (b) UV-Vis absorption spectra of the DA concentration range 0–60 μ M. (c) Linear curves of absorbance of different concentrations of DA. (d) The selectivity of DA was detected by Pt/NH₂-MIL-101 + TMB + H₂O₂.

In order to assess the feasibility of the Pt/NH_2 -MIL-101-TMB- H_2O_2 system in a real serum environment, a standard addition method was used to detect the DA content in a complex blood sample environment. As shown in Table 1, the DA content measured by the system was close to the standard addition value, and the recovery rate was between

96.5% and 100.1%, indicating that the colorimetric detection system had high accuracy and sensitivity. At the same time, to evaluate the repeatability of DA detection by the system, the system was used to measure the DA content of each group three times in a row. The calculation results showed that the relative standard deviation (RSD) of DA was between 1.00%–1.86%, indicating that the colorimetric detection system had excellent reproducibility. Finally, Pt/NH₂-MIL-101 was stored for different days and then used to detect DA with good accuracy (Figure S6). According to the above results, it is indicated that the Pt/NH₂-MIL-101-TMB-H₂O₂ has important medical value in the determination of the DA content in blood samples.

Samples	Add (µM)	Found (µM)	Recovery (%)	RSD (%, $n = 3$)
1	20	19.30	96.5	1.86
2	30	30.03	100.1	1.23
3	40	39.83	99.58	1.06

Table 1. The detection of DA in serum samples with Pt/NH₂-MIL-101.

4. Conclusions

In summary, we developed a smart colorimetric method for the ultrasensitive and robust detection of DA by supporting Pt NPs on NH₂-MIL-101. The larger surface area of NH₂-MIL-101 enlarged the exposure of Fe species to exposing more active sites for H₂O₂ activation. The incorporated Pt NPs increased the active sites, affording rich Pt sites for electron transfer from the Pt atoms to the Fe atoms, improving the activity of the active sites in the MOFs. The experimental results showed that the Pt/NH₂-MIL-101 catalyst showed a 1.5-times enhanced peroxidase-like catalytic rate in comparison with NH₂-MIL-101 and Pt NPs. Using the peroxidase-like activity of Pt/NH₂-MIL-101, DA molecules can be sensitively and specifically colorimetrically recognized with a limit of detection of 0.42 μ M, which has great potential for the early diagnosis of some neurological diseases and Parkinson's disease.

Supplementary Materials: The following are available online at: https://www.mdpi.com/article/ 10.3390/chemosensors9060140/s1: Experimental Section. Figure S1: TEM image of Pt NPs, Figure S2: Particle size distribution of Pt NPs, Figure S3: The particle size distribution of Pt/NH₂-MIL-101, Figure S4: XPS spectrum of Pt/NH₂-MIL-101, Figure S5: (a) pH. (b) Temperature. (c) The concentration of Pt/NH₂-MIL-101. (d) The effect of cycles on the peroxidase-like activity of Pt/NH₂-MIL-101, Figure S6: The stability of the Pt/NH₂-MIL-101, Table S1: Elements content of Fe and Pt in Pt/NH₂-MIL-101, Table S2: Compare the K_m and ν_{max} between Pt/NH₂-MIL-101 and other nanozymes, Table S3: Comparison analytical performance of the Pt/NH₂-MIL-101 with that of other reported nanomaterials for dopamine detection.

Author Contributions: Conceptualization, synthesis, characterization, catalytic activity assay, and original draft preparation, J.L.; methodology, writing the manuscript, and data curation K.X.; Y.C. and J.Z. helped in the analysis, paper drafting, and reviewed the paper; supervision, P.D.; supervision, writing—review and editing, Z.Z., L.Z., and X.L.; and funding acquisition, Z.Z. and X.L. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the National Natural Science Foundation of China (No. 21705117, No. 21575115, No. 21904095, and No. 22004089); the Program of Tianjin Science and Technology Major Project and Engineering (19ZXYXSY00090); the Program for Chang Jiang Scholars and Innovative Research Team, Ministry of Education, China (IRT-16R61); and the Special Fund Project for the Central Government to Guide Local Science and Technology Development (2020).

Institutional Review Board Statement: Ethical approval by an institutional board was not necessary, because this study did not include any patients.

Informed Consent Statement: This study did not involve any patients.

Data Availability Statement: All relevant data is contained within the article and supplementary materials.

Conflicts of Interest: The authors declare no conflict of interest.

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