

A fluorescent probe with a thiophene tail for monitoring polarity in water and powder injections

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ABSTRACT: In this work, a fluorescent probe with a thiophene tail named TBT-Po was developed for monitoring the polarity in water and powder injections. It had the planar thiophene subunit as a rotatable tail instead of the previously reported multiple chains. In the EtOH-in-water solution system, the fluorescence intensity at 551 nm increased along with the EtOH proportion (lower polarity) under excitation at 446 nm, while the absorbance varied simultaneously. TBT-Po showed rapid and stable performance in polarity detection, while the monitoring system was sensitive to pH conditions. The fluorescence response with TBT-Po was not obviously affected by the solutes. Most significantly, using dexmedetomidine as a representative, the recovery of the established approach with TBT-Po in both the water and powder injections was stable. The findings of this work are useful for developing further strategies for the production, storage, and utilization of the injections.

KEYWORDS: fluorescent probe, systemic polarity, thiophene tail, medicine injection, anesthesia schedule

INTRODUCTION

In both emergency treatment and outpatient services, injections are essential and require strict preparation processes and storage conditions [1,2]. Commonly prepared in water- or powder-based forms, the injections are drug formulations in which the drugs are refined, dissolved in a sterile solution, and then loaded into a container for intravenous, intramuscular, and other injection uses [3,4]. Oral medications are affected by digestion with their efficacy reduced, while injections directly enter human tissues and quickly produce an effect [5,6]. Typically, the quality control of the injections focuses on the accurate content of drug ingredients [7]. It is closely associated with patient safety and health. The key factors include dust particles, microorganisms, pressure differences, humidity, and so on [8]. In particular, the water content (or humidity, polarity) affects the systemic status of the injections [9]. For example, in the ethanol-water system, the increase of the water content meant the increase of the polarity; while in the air-water system, the increase of the water content meant the increase of the humidity. In chemical and biological investigations, polarity is more suitable for the description. In addition to water (H₂O), other solvent species in the injections included ethanol (EtOH), propylene glycol, polyethylene glycol, glycerol, benzyl benzoate, and dimethylacetamide [10]. Thus, with the above-mentioned organic solvents as components of the solvent system, the polarity increases accordingly as the water content increases. EtOH is a typical represen-

tative solvent used in combination with water, and the EtOH proportion in the injections is important [11,12]. Furthermore, during clinical utilization, the sophisticated procedures involving the drug prescribing and pharmaceutical dispensing may introduce extra risks in addition to those associated with production and storage [13,14]. During this period, the absolute content of the drug and packaging raw materials no longer changes remarkably. Correspondingly, the polarity affects the relative drug content. As a special subdivision in clinical affairs, anesthesia places higher requirements on injections than conventional anti-infective and anti-inflammatory treatments [15]. The injections are mainly used for intravenous anesthesia, while the commercially available drugs include dexmedetomidine, propofol, remifentanyl, ketamine, and so on [16,17]. When water is the basic solvent in injection systems used for anesthesia, polarity is crucial for both efficacy and safety. If any organic solvent is added, it should be annotated. Therefore, monitoring polarity is of significance in the production, storage, and utilization of the injections.

The current methods for monitoring polarity include electrochemical detection, high-performance liquid chromatography (HPLC), infrared spectroscopy, and so on [18,19]. They have been optimized to improve the convenience of signal reporting, whereas the accuracy and sample preparation remain limitations. The fluorescence analysis is a non-invasive, well-operative, and highly sensitive approach for real-time and *in situ* tracking of the biological and physiological processes [20,21]. Several investigations

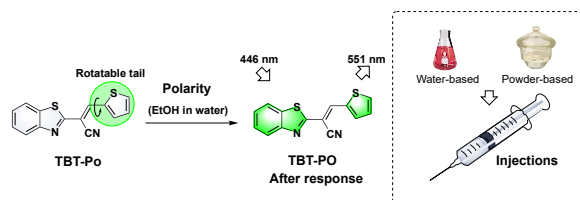


Fig. 1 The design of the fluorescent probe TBT-Po for monitoring polarity in water and powder injections.

on the fluorescent probes for monitoring the polarity have been conducted [22–24], while some other reports demonstrated the cooperation with interpolymer complexes [25, 26]. As a possible index, the polarity can be considered together with other molecular indicators such as hydrogen sulfide (H_2S), peroxydinitrite ($ONOO^-$), and nitroreductase [27–29]. In the specific field of the injections, it can also be the calibration index of the drug content. After the construction of the various monitoring approaches, the analysis in drug management, specific medicinal therapies, physiological dynamics, and nursing matters may be combined in a comprehensive system.

In this work, a fluorescent probe with a thiophene tail was developed for monitoring the polarity in the injections, both water- and powder-based ones (Fig. 1). The prepared probe was named TBT-Po from the structural subunits of thiophene and benzothiazole as well as the the abbreviation for polarity. The previous fluorescent probes for the polarity detection indicated the typical pattern consisting of a highly conjugated head and a rotatable tail. The most commonly reported rotatable tails contain multiple chains, while in this work the planar thiophene subunit acted as the tail to introduce a challenging trial. The tails of chains terminated themselves, while the rotor of thiophene might connect to another thiophene [30, 31] and limit the internal twisting angles of the probe. Stacking thiophene did not increase the oxidative stress and showed the potential of introducing the red-shift of the emission wavelength. It was also beneficial for reducing the effect of viscosity. The benzothiazole moiety was frequently used as the highly conjugated subunit in developing the fluorescent probes [32]. The fluorescent responses were analyzed together with the absorption signal. The effects of various solvents and viscosity were checked. Then, the water and powder injection samples were tested to evaluate the performance of TBT-Po. It was expected that the probe might enable polarity monitoring in this specific context.

MATERIALS AND METHODS

General information

The chemicals and solvents were purchased from Sigma-Aldrich (Shanghai) Trading Co., Ltd. (China). The nuclear magnetic resonance (NMR) data were

recorded on a Bruker DRX-600 spectrometer (Germany) and analyzed with MestReNova software (Spain). The high-resolution mass spectrum (HRMS) was obtained using an AB SCIEX Triple-TOF 4600 (USA). The absorption spectra were recorded on Shimadzu UV2450 spectrometer (Japan). The fluorescence properties were conducted using a Hitachi F-7000 fluorescence spectrophotometer (Japan). The pH was measured using a Shanghai Leici PHS-25 pH meter (China). The pure water for preparing the injections was produced using a Merck Milli-Q System (Germany). The calibration of the polarity (water content) was performed using directly readable values from a Bruker Alpha II Fourier transform-infrared (FT-IR) spectrometer. The test paper patch photos were taken with a Redmi K40 smartphone (China).

The solution system for the polarity tests was constructed with various proportions (0–90%) of EtOH in water. Here, a higher EtOH proportion meant lower polarity. Because the water-soluble ions were tested to check their effects, the system retained at least 10% water. In the fluorescence tests, unless otherwise noted, the working conditions were set as follows: photomultiplier voltage, 600 V; excitation and emission slit widths, 5 nm × 5 nm; excitation wavelength, 446 nm; incubation time, 5 min; pH 7.4; and incubation temperature, 25 °C. Dexmedetomidine was selected as a representative anesthetic to prepare both the water and powder injections at a concentration of 100 µg/ml with various proportions of EtOH. In particular, dexmedetomidine is frequently used in the form of injections in anesthesiology, and dexmedetomidine injection is also a common clinical preparation [33].

Determination of fluorescence quantum yields

In consideration of both the absorption and fluorescence data, the reference method with rhodamine B in EtOH was used to determine the fluorescence quantum yield (FQY) values herein. Water was regarded as the solvent with a refractive index of 1.33, while the combination of EtOH and TBT-Po was regarded as the solute. Accordingly, the FQY values of TBT-Po in water and 90% EtOH were 0.12 and 0.69, respectively.

Computational method

The ground geometries and electronic transitions of the title compounds were investigated using the Gaussian 09 program. The ground state (S_0) geometries were fully optimized without constraints at the PBE1PBE/6-31G(d) level, and all the local minima were confirmed by vibrational frequency analysis. On the basis of the optimized structures of the S_0 states, the TDDFT calculation using the PBE1PBE/6-31+G(d) method was performed to compute the lowest unoccupied molecular orbital (LUMO) and highest occupied molecular orbital (HOMO) energies of the title compounds. All calculations were performed in the gas phase.

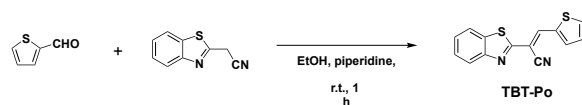


Fig. 2 The synthetic process of the probe TBT-Po with a thiophene tail.

Chemical synthesis protocol

The synthetic route of the probe TBT-Po was depicted in Fig. 2. The reaction conditions were modified from the previous report [34]. In a 50 ml round-bottom flask, 2-thiophenecarboxaldehyde (0.17 g, 1.5 mmol) and benzothiazole-2-acetonitrile (0.26 g, 1.5 mmol) were dissolved in 20 ml of anhydrous ethanol. Then, 0.5 ml of piperidine was added to the mixture dropwise, and the reaction was continued at room temperature for 1 h. Afterwards, thin-layer chromatography (TLC) was used to check the completion of the reaction. Then, the mixture was adjusted to the neutral conditions, and the precipitate was collected. After the recrystallization with anhydrous ethanol, the purified product was freeze-dried. The probe TBT-Po was obtained as a yellow solid (yield 68.4%). ^1H NMR (600 MHz, CDCl_3) δ 8.35 (s, 1H), 7.99 (d, J = 8.2 Hz, 1H), 7.83 (d, J = 8.0 Hz, 1H), 7.76 (d, J = 3.6 Hz, 1H), 7.66 (d, J = 4.9 Hz, 1H), 7.46 (t, J = 7.3 Hz, 1H), 7.36 (t, J = 7.3 Hz, 1H), 7.16 (t, J = 4.8 Hz, 1H). ^{13}C NMR (151 MHz, CDCl_3) δ 162.39, 153.60, 138.90, 136.89, 135.61, 134.96, 133.41, 128.54, 126.99, 125.86, 123.33, 121.72, 116.70, 102.03. HRMS (Q-TOF m/z): calculated for $[\text{C}_{14}\text{H}_9\text{N}_2\text{S}_2]^+$: 269.0207, found: 269.0208.

RESULTS AND DISCUSSION

Synthesis of the probe TBT-Po

The synthesis of the probe TBT-Po, modified from previous reports [30–32], was performed in one step, as shown in Fig. 2. It was a condensation reaction between the methylene and aldehyde groups. Accordingly, the benzothiazole and acetonitrile acted as the highly conjugated head, while the thiophene patch acted as the rotatable tail. The probe TBT-Po did not contain an oxygen atom and thus avoided the risk of introducing free oxygen. Meanwhile, when the chain terminal was replaced with the planar patch, the repeating structural subunits might be stacked continuously to provide further benefits for optical performance. In brief, the possible advantages of the structural modification included the avoidance of higher oxidative stress and the red-shift of emission wavelength. The structural features were verified by the NMR and HRMS data (Fig. S1–Fig. S3, Supporting Information). No isomerism was observed in the NMR data, and the signal suggested that the probe TBT-Po was in the *trans*-conformation.

Systematic tests on optical performance

The most significant capability in this work was the fluorescence response to polarity, while the absorption variation was also taken into consideration for the calibration. After the construction of the solution system with various EtOH-in-water proportions (0–90%), the fluorescence response of the probe TBT-Po to polarity was investigated. Then, the correlation between the fluorescence intensity and the polarity was investigated. As shown in Fig. 3a, under excitation at 446 nm, the probe TBT-Po was almost non-fluorescent in water, while the increase of the EtOH-in-water proportion (also lower polarity) caused the enhancement of the fluorescence intensity at 551 nm. In particular, as shown in Fig. 3b, the fluorescence intensity at 551 nm and the EtOH-in-water proportion showed a linear correlation ($Y = 14.14X + 30.26$), while the Pearson's r value was 0.9999. Thus, the polarity was successfully represented by the fluorescence intensity in the above system. On the other hand, regarding the absorption variation, as shown in Fig. 3c, the absorbance of TBT-Po itself was low, close to the baseline, while the increase in the EtOH-in-water proportion led to the corresponding increase of the absorbance. In Fig. 3d, it was found that the absorbance and the EtOH-in-water proportion showed a linear correlation ($Y = 0.00242X + 0.0262$), while the Pearson's r value was 0.9999. Accordingly, when the polarity varied, the fluorescence intensity at 551 nm and the absorbance showed simultaneous responses. The FQY values of TBT-Po in water and 90% EtOH were 0.12 and 0.69, respectively. Both fluorescence and absorbance showed turn-off responses to polarity. In brief, TBT-Po exhibited preliminary applicability for monitoring polarity. Compared with the absorbance, the fluorescence variation exhibited larger gradients and smaller standard errors. Therefore, the fluorescence was chosen as the reporting signal, and the absorbance was used for the calibration.

Many commercially available drugs are formulated in aqueous solvent systems, and the EtOH-water solvent system is one of the most common ones in clinical trials. To consider a wider range of pharmaceutical formulations and matrices, the solvatochromic analysis was conducted to check the fluorescence spectra (Fig. S4). Except for EtOH, the tested solvents included acetone, dichloromethane (DCM), *N,N*-dimethylformamide (DMF), dimethyl sulfoxide (DMSO), ethyl acetate (EA), acetonitrile (MeCN), tetrahydrofuran (THF), and toluene. In the solvents with relatively high polarity (DMSO, DMF, and MeCN), the fluorescence intensity was lower than that in EtOH. The intensity in acetone was close to that in EtOH. In the solvents with quite low polarity (EA, THF, DCM, and toluene), the fluorescence intensity was quite low, which agreed with the previous report [35].

The response mechanism was preliminarily stud-

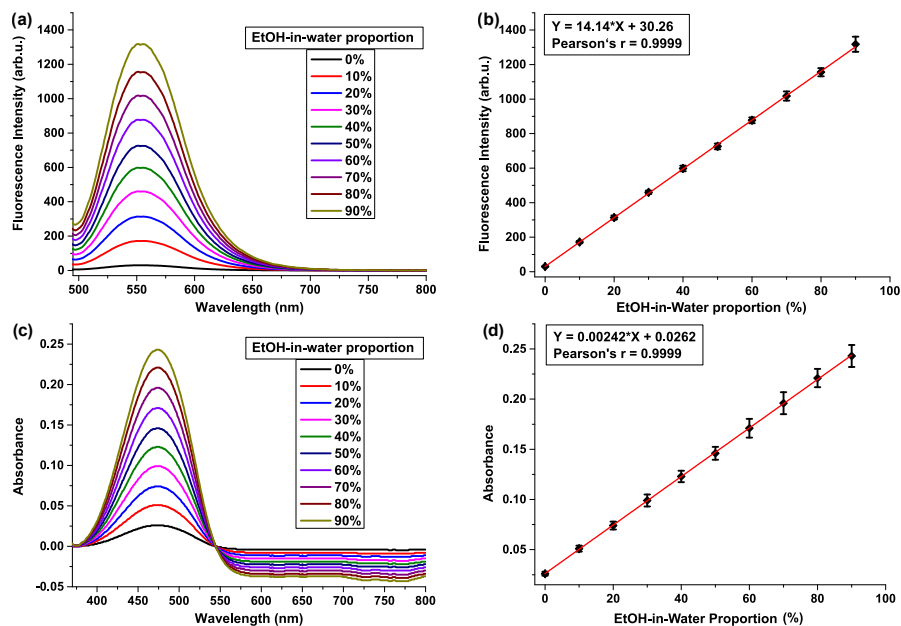


Fig. 3 (a) The fluorescence spectra of TBT-Po (10 μ M) with various proportions of EtOH in water (0–90%); (b) The correlation between the fluorescence intensity at 551 nm and the proportions of EtOH in water (0–90%); (c) The absorption spectra of TBT-Po (10 μ M) with various proportions of EtOH in water (0–90%); (d) The correlation between the absorbance and the proportions of EtOH in water (0–90%). Working conditions: photomultiplier voltage, 600 V; excitation and emission slit widths, 5 nm $\times$ 5 nm; excitation wavelength, 446 nm; incubation time, 5 min; pH 7.4; incubation temperature, 25 $^{\circ}$ C.

ied using density functional theory (DFT) simulations (Fig. S5). In comparison with the typical rotors of multiple chains or aryl-modified chains [36, 37], the modified structure in this work showed a feasible HOMO-LUMO gap (3.7043 eV). Accordingly, the response mechanism was based on intramolecular charge transfer (ICT) pattern. In combination with the rotatable tail, the probe exhibited a twisted intramolecular charge transfer (TICT) mechanism. When the polarity increased, TBT-Po adopted the ground-state conformation through the TICT mechanism. In contrast, when the polarity decreased, the rotation was limited and the TICT-blocking mechanism led to the fluorescence-emission conformation. Upon further observation of the electron density of the HOMO and LUMO, the pattern in this work was more homogeneous than that in the previous reports [36, 37]. This result was beneficial for limiting the rotation and reducing the effect of viscosity [38–40]. Thus, the glycerol-in-water solvent system was constructed (Fig. S6). As a result, TBT-Po was not sensitive to variations in viscosity. Therefore, viscosity might show negligible interference with polarity detection.

Tests on working conditions

Subsequently, the effects of the working conditions were studied. In this section, a test paper patch was sufficiently incubated with a TBT-Po (10 μ M) solution and dried. Then, the prepared test paper patch was floated on the surface of a 90% EtOH-in-water

solution. During the gradual infiltration, a notable fluorescence response was observed. As shown in Fig. 4a, the total process of infiltration and response took 14 s, which was quite a short period. For both full completion of the response and convenience, the common incubation time was set at 5 min. Unlike small molecular indicators, polarity was a micro-environmental index which might be seriously affected by the working conditions. In Fig. 4b, the fluorescence intensity at 551 nm increased as the pH value of the solution increased over the tested range from 3.0 to 12.0. Meanwhile, as shown in Fig. S7, the absorbance also increased along with the increase in the pH value. Thus, regarding the pH condition, the fluorescence response can also be calibrated with the absorbance. Furthermore, the temperature was tested over the range of 25–45 $^{\circ}$ C. As shown in Fig. 4c, the fluorescence intensity at 551 nm after the response was stable over the entire tested range, which indicated the weak impact of the temperature condition. For monitoring the polarity, TBT-Po showed rapid and stable performance, while the system was sensitive to the pH conditions.

Tests on solute and injections

Subsequently, the effect of the solutes was investigated. The solutes included the commonly used components in the injection scenarios. As shown in Fig. 5a, most of the anions (F^{-} , Cl^{-} , Br^{-} , I^{-} , SO_4^{2-} , NO_2^{-} , NO_3^{-} , HCO_3^{-} , CO_3^{2-} , and PO_4^{3-}), cations (Na^{+} , K^{+} , Ca^{2+} , and Al^{3+}),

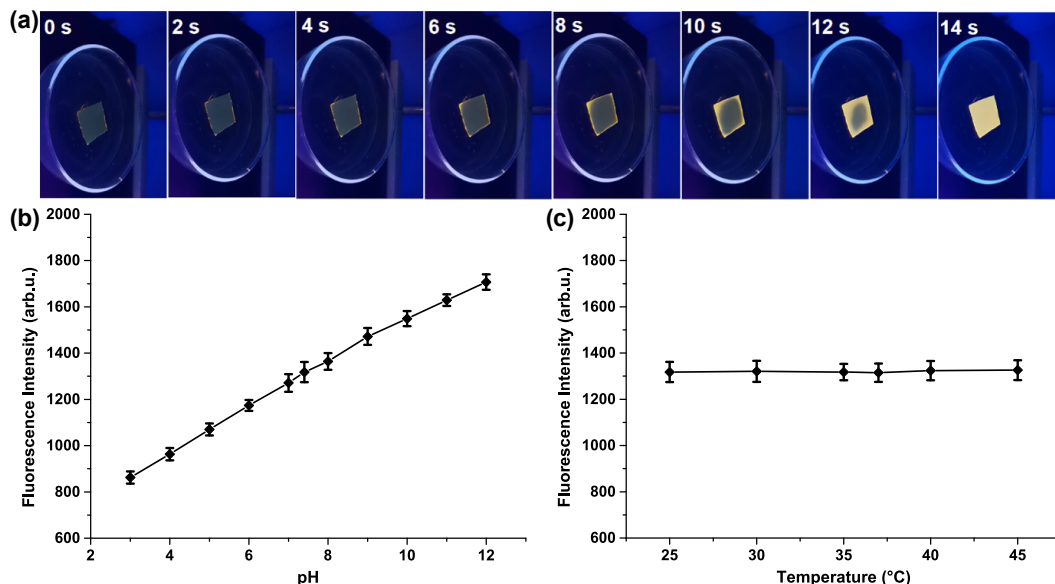


Fig. 4 (a) The photographs of the test paper patch during infiltration by 90% EtOH-in-water solution under 365 nm UV light at the time points of 0, 2, 4, 6, 8, 10, 12, and 14 s; (b) The fluorescence intensity at 551 nm of TBT-Po (10 μ M) with different pH conditions (3.0–12.0); (c) The fluorescence intensity at 551 nm of TBT-Po (10 μ M) with different temperature conditions (25–45 $^{\circ}$ C). Working conditions unless otherwise noted: photomultiplier voltage, 600 V; excitation and emission slit widths, 5 nm $\times$ 5 nm; excitation wavelength, 446 nm; incubation time, 5 min; pH 7.4; incubation temperature, 25 $^{\circ}$ C.

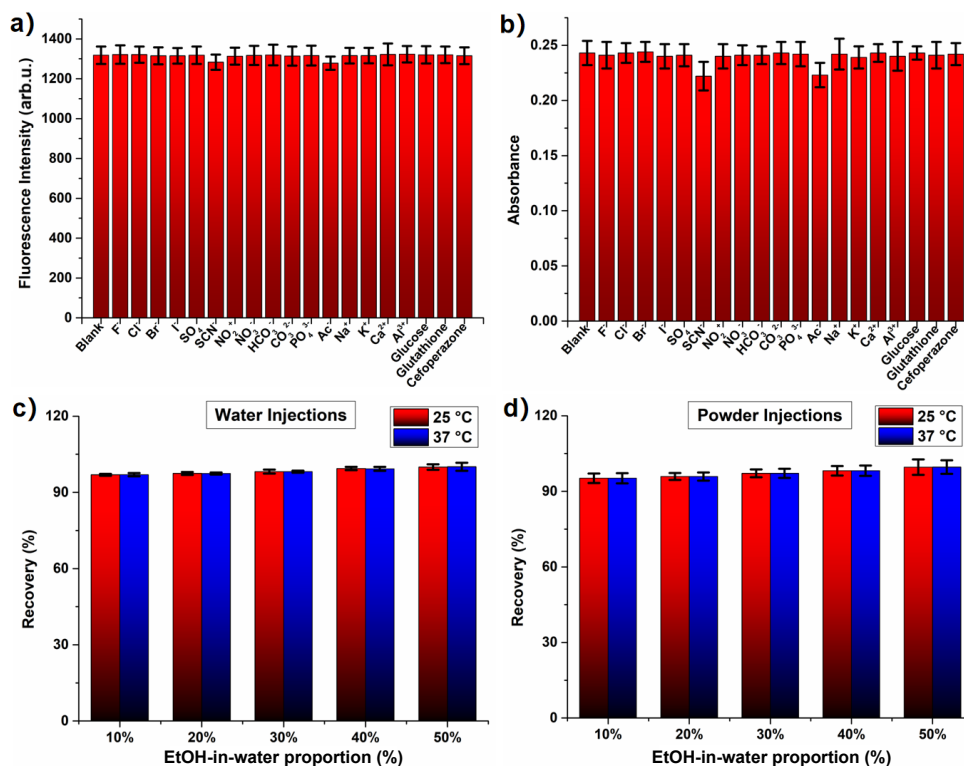


Fig. 5 (a) The fluorescence intensity at 551 nm of TBT-Po (10 μ M) with different analytes; (b) The absorbance of TBT-Po (10 μ M) with different analytes; (c) The recovery of dexmedetomidine (100 μ g/ml) water injections with different EtOH-in-water proportion (10–50%) at 25 $^{\circ}$ C and 37 $^{\circ}$ C; (d) The recovery of dexmedetomidine (100 μ g/ml) powder injections with different EtOH-in-water proportion (10–50%) at 25 $^{\circ}$ C and 37 $^{\circ}$ C. Concentration of the analytes: 100 μ M. Working conditions unless otherwise noted: photomultiplier voltage, 600 V; excitation and emission slit widths, 5 nm $\times$ 5 nm; excitation wavelength, 446 nm; incubation time, 5 min; pH 7.4; incubation temperature, 25 $^{\circ}$ C.

glucose, glutathione, and cefoperazone did not affect the fluorescence intensity at 551 nm from a 90% EtOH-in-water solution with TBT-Po (10 μ M), while SCN^- and Ac^- led to a slight decrease in intensity. Similarly, as shown in Fig. 5b, the effect of the above-mentioned solutes on the absorbance was similar to that on the fluorescence intensity. The two modes showed simultaneous responses.

Moreover, dexmedetomidine, as a specific solute, was selected as a representative commercially available anesthetic to prepare both the water and powder injections for the recovery test. The concentration of dexmedetomidine was set at 100 $\mu\text{g/ml}$; the EtOH-in-water proportion was set at 10%, 20%, 30%, 40%, and 50% according to the commonly used conditions in the preparation of the injections; and the temperature conditions were set at 25 $^{\circ}\text{C}$ and 37 $^{\circ}\text{C}$ to cover the room temperature and physiological condition. The recovery was calculated by comparing the result obtained using the fluorescence approach with that obtained using the FT-IR method. As shown in Fig. 5c, the recovery in the water injections varied in the range of 96.93%–100.1%. The temperature conditions did not obviously interfere with the recovery. There were also no remarkable differences in the groups with different EtOH-in-water proportions. As shown in Fig. 5d, the recovery in the powder injections varied in the range of 95.21%–99.62%. It was also not obviously affected by the temperature conditions. When the EtOH-in-water proportion increased, the recovery exhibited a slight increase. Furthermore, when the water and powder injections were compared, the fluctuation of the recovery in the water injections was smaller. Therefore, TBT-Po was applicable to monitoring polarity in both water and powder injections.

CONCLUSION

To conclude, a fluorescent probe with a thiophene tail named TBT-Po was developed for monitoring polarity in water and powder injections. Unlike previous fluorescent probes with multiple chains as rotatable tails, this work selected the planar thiophene subunit. Structurally, TBT-Po avoided the risk of introducing free oxygen and retained the possibility of stacking repeating subunits such as thiophene. In particular, stacking the second thiophene was an ideal approach for introducing the possible red-shift of the emission wavelength. In the solution system with various EtOH-in-water proportions (0–90%), the fluorescence intensity at 551 nm increased along with the EtOH proportion under excitation at 446 nm, while the absorbance showed the simultaneous response. Both the fluorescence and absorbance correlations were linear, while the FQY values of TBT-Po in water and 90% EtOH were 0.12 and 0.69, respectively. On the basis of the DFT simulation, the fluorescence response mechanism was probably TICT. The response was not seriously affected by viscosity. TBT-Po showed rapid and stable per-

formance for polarity detection, while pH conditions affected the response to a certain extent. Most of the tested solutes did not obviously affect the fluorescence and absorbance responses. Most significantly, using dexmedetomidine as a representative, the recovery of the established approach with TBT-Po in both the water and powder injections was stable. These findings may facilitate the development of further strategies for the production, storage, and utilization of injections.

Appendix A. Supplementary data

Supplementary data associated with this article can be found at <https://dx.doi.org/10.2306/scienceasia1513-1874.2026.086>.

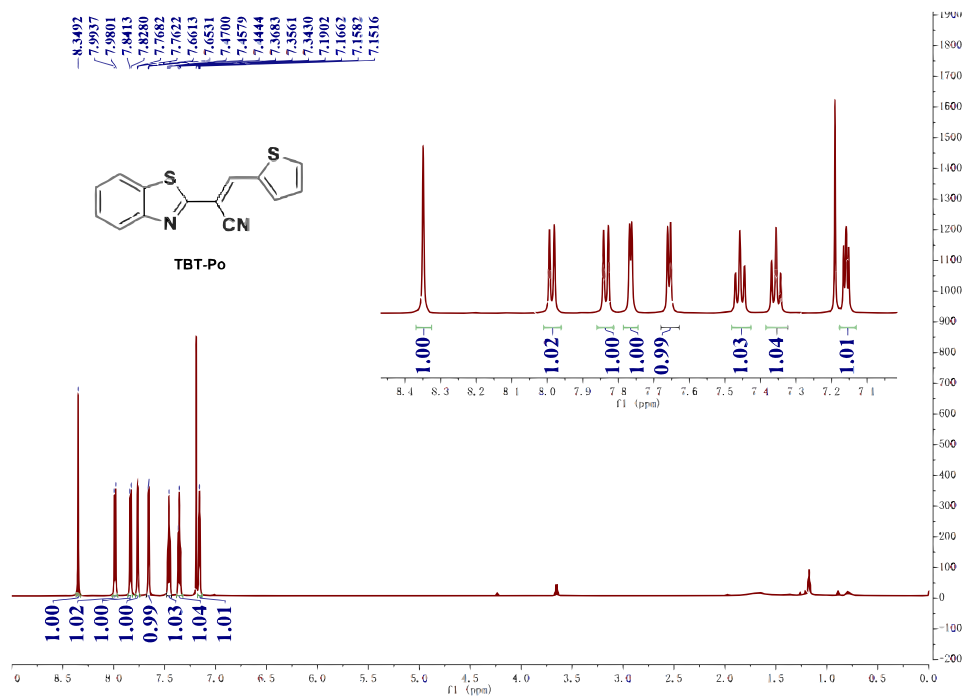
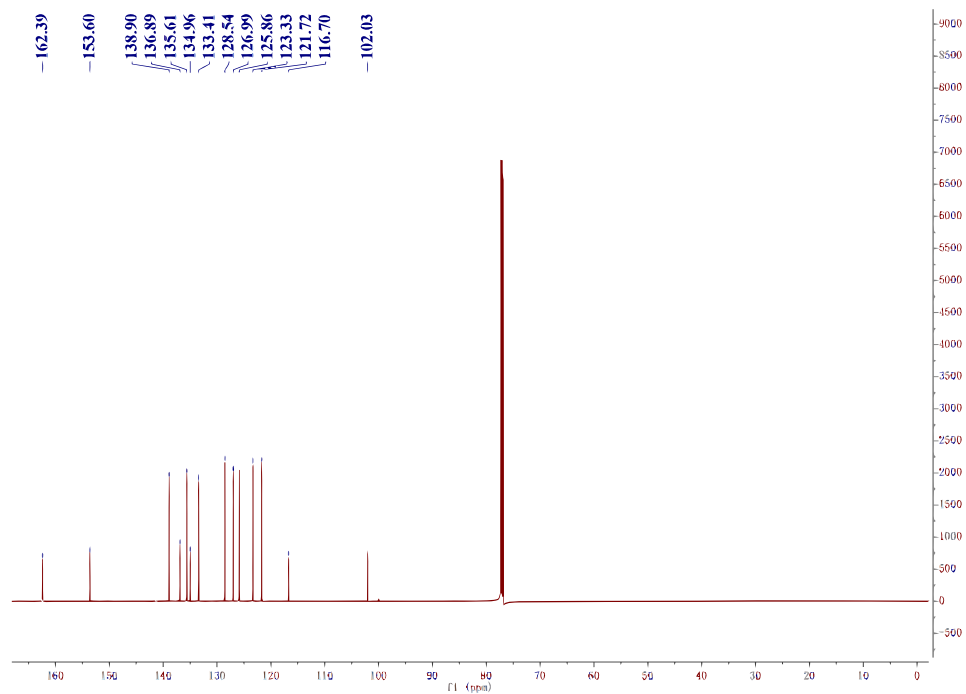
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REFERENCES

1. Lu MQ, Lu Z, Zhang T, Wang W, Xue Y, Cao ZQ (2020) Efficacy and safety of Chinese patent medicine injection for COVID-19: A protocol for systematic review and meta-analysis. *Medicine* **99**, e20706.
2. Bliddal H, Bays H, Czernichow S, Hemmingsson JU, Hjelmestaeth J, Morville TH, Koroleva A, Neergaard JS, et al (2024) Once-weekly semaglutide in persons with obesity and knee osteoarthritis. *New Engl J Med* **391**, 1573–1583.
3. Zhao YF, Zhang LM, Han R, Si YH, Zhao ZG (2019) Intravenous injection of post-hemorrhagic shock mesenteric lymph induces multiple organ injury in rats. *Exp Ther Med* **17**, 1449–1455.
4. McCartan AJS, Mrsny RJ (2024) *In vitro* modelling of intramuscular injection site events. *Expert Opin Drug Del* **21**, 1155–1173.
5. Jiang LX, Sun Y, Lu A, Wang XY, Shi YJ (2022) Ionic liquids: promising approach for oral drug delivery. *Pharm Res* **39**, 2353–2365.
6. Lubecka K, Checinska K, Blizniak F, Checinski M, Turosz N, Rapalska I, Michcik A, Chlubek D, et al (2024) Update on evidence and directions in temporomandibular joint injection techniques: A rapid review of primary research. *J Clin Med* **13**, 4022.
7. Chong XM, Wang LX, Hu CQ, He LC (2023) Quality control and consistency evaluation of ceftriaxone sodium for injection. *J Chemotherapy* **35**, 477–490.
8. Feng WW, Zhang Y, Tang JF, Zhang CE, Dong Q, Li RY, Xiao XH, Peng C, et al (2018) Combination of chemical fingerprinting with bioassay, a preferable approach for quality control of Safflower Injection. *Anal Chim Acta* **1003**, 56–63.
9. Buajarern S, Kajhonjaratkul M, Youngvises N, Sereenonchai K (2026) Quantification of salt content in commercial fish sauces through reagent-free flow-injection method. *Talanta* **297**, 128751.
10. Shen YC, Wang DM, Yang XT, Wang ZF, Wen MZ, Han YF, Zheng LZ, Di RY, et al (2024) Novel radiopaque ethanol injection: physicochemical properties, animal experiments, and clinical application in vascular malformations. *Military Med Res* **11**, 39.

11. Ben Said T, Chaieb F, Ghorbel F (2019) Computer-assisted planning for percutaneous ethanol injection of hepatocellular carcinoma. *Imaging Sci J* **67**, 407–416.
12. Gouda A, Sakr OS, Nasr M, Sammour O (2021) Ethanol injection technique for liposomes formulation: an insight into development, influencing factors, challenges and applications. *J Drug Deliv Sci Tec* **61**, 102174.
13. Di Lorenzo L, Forte F, Forte AM (2023) Targeted injection can improve Groin Pain management in Osteitis Pubis: A narrative review. *MLTJ Muscle Ligament* **13**, 408–414.
14. Bowen EC, Benedict KC, Sullivan JM, Baker KE, Schock ME, Walker ME (2024) Surgical management of iatrogenic mercury poisoning from subcutaneous injection into the arm. *Ann Plas Surg* **93**, 205–207.
15. Abou Chedid JC, Salameh M, El Hindy C, Kaloustian MK, El Hachem C (2023) Comparative study of two different computer-controlled local anesthesia injection systems in children: A randomized clinical trial. *Eur Arch Paediatr De* **24**, 417–423.
16. Lee SH, Lee SE, Chung S, Lee HJ, Jeong S (2016) Impact of time interval between remifentanyl and propofol on propofol injection pain. *J Clin Anesth* **34**, 510–515.
17. Leff PJ, Dinner BA, Chuang KY, Leff DB (2024) Characteristics that increase the risk for pain on propofol injection. *BMC Anesthesiol* **24**, 190.
18. Ragusa E, Cambria E, Zunino R, Gastaldo P (2019) A survey on deep learning in image polarity detection: balancing generalization performances and computational costs. *Electronics* **8**, 783.
19. Polignano M, Basile V, Basile P, Gabrieli G, Vassallo M, Bosco C (2022) A hybrid lexicon-based and neural approach for explainable polarity detection. *Inform Process Manag* **59**, 103058.
20. Zheng DJ, Yang YS, Zhu HL (2019) Recent progress in the development of small-molecule fluorescent probes for the detection of hydrogen peroxide. *TrAC-Trend Anal Chem* **118**, 625–651.
21. Zhang XY, Yang YS, Wang W, Jiao QC, Zhu HL (2020) Fluorescent sensors for the detection of hydrazine in environmental and biological systems: Recent advances and future prospects. *Coord Chem Rev* **417**, 213367.
22. Tang YH, Song SR, Peng JJ, Zhan Q, Lin WY (2022) An ultrasensitive lipid droplet-targeted NIR emission fluorescent probe for polarity detection and its application in liver disease diagnosis. *J Mater Chem B* **10**, 6974–6982.
23. Chen ZH, Yue LZ, Guo YX, Huang HW, Lin WY (2024) A fluorescence probe for imaging lipid droplet and visualization of diabetes-related polarity variations. *Anal Chim Acta* **1312**, 342748.
24. Zhang HM, Liu JJ, Li MY, Ma SD, Zhou XC, Meng AX, Han WN, Zhou J (2024) Imaging polarity changes in pneumonia and lung cancer using a lipid droplet-targeted near-infrared fluorescent probe. *Chin Chem Lett* **35**, 110020.
25. Chen Y, Liu Y, Li JH, Zhao CL, Yang YG, He L, Wu M, Wang Q, et al (2024) Reversible hydrochromic CsPbBr₃/Cs₄PbBr₆@MCM-41 to enable organic solvent polarity detection. *Chem Eng J* **481**, 148600.
26. Leelasree T, Sidhartha PN, Tathacharya M, Chappanda KN, Aggarwal H (2024) A low-cost, swift response, highly sensitive MOF-based dual sensing device enables detection of ultralow humidity levels and solvent polarity changes. *J Mater Chem C* **12**, 7295–7305.
27. Qin WJ, Xu CC, Zhao YF, Yu CM, Shen S, Li L, Huang W (2018) Recent progress in small molecule fluorescent probes for nitroreductase. *Chin Chem Lett* **29**, 1451–1455.
28. Li HN, Fang YX, Yan JJ, Ren XY, Zheng C, Wu B, Wang SY, Li ZL, et al (2021) Small-molecule fluorescent probes for H₂S detection: Advances and perspectives. *TrAC-Trend Anal Chem* **134**, 116117.
29. Cui WL, Wang MH, Yang YH, Wang JY, Zhu XZ, Zhang HT, Ji XX (2023) Recent advances and perspectives in reaction-based fluorescent probes for imaging peroxynitrite in biological systems. *Coord Chem Rev* **474**, 214848.
30. Yang CY, Zhang SQ, Hou JH (2022) Low-cost and efficient organic solar cells based on polythiophene- and poly(thiophene vinylene)-related donors. *Aggregate* **3**, e111.
31. Tan YH, Sun Y, Huang WG, Zhu DX, Yan DY, Wang D, Tang BZ (2024) Thiophene π -bridge-based second near-infrared luminogens with aggregation-induced emission for biomedical applications. *Luminescence* **39**, e4606.
32. Mou Y, Zhang YF, Chen MY, Lin XR, Zhang JH, Han JN, Luo XY (2024) Dual-mode aptasensor based on a coumarin-benzothiazole fluorescent and colorimetric probe for label-free and visual detection of ochratoxin A. *Sensor Actuat B Chem* **408**, 135529.
33. Feng Y, Chen XB (2023) Comparison of intravenous and perineural dexmedetomidine in prolongation of analgesia for peripheral nerve block: A meta-analysis and systematic review. *Eur Rev Med Pharmacol* **27**, 4116–4134.
34. Arjunan V, Govindaraja ST, Jose SP, Mohan S (2014) DFT simulation, quantum chemical electronic structure, spectroscopic and structure-activity investigations of 2-benzothiazole acetonitrile. *Spectrochim Acta A* **128**, 22–36.
35. Deng B, Guo F, Duan N, Yang SX, Tian HY, Sun BG (2022) A solvatochromic fluorescent probe for solvent polarity detection using a smartphone. *Chemistryselect* **7**, e202200766.
36. Wang WB, Chai L, Chen X, Li ZY, Feng LY, Hu W, Li HB, Yang GF (2023) Imaging changes in the polarity of lipid droplets during NAFLD-Induced ferroptosis via a red-emitting fluorescent probe with a large Stokes shift. *Biosens Bioelectron* **231**, 115289.
37. Hang ZJ, Jiang SM, Wu ZT, Gong J, Zhang LZ (2024) A novel near-infrared tricyanofuran-based fluorophore probe for polarity detection and LD imaging. *Molecules* **29**, 5069.
38. He Y, Li LK, Wang MH, Tian JR, Chen GY, Wang JY (2024) A novel fluorescent probe for viscosity and polarity detection in real tobacco root cells and biological imaging. *Photoch Photobio Sci* **23**, 1883–1891.
39. Li YY, Hu JL, Wu JR, Wang YR, Zhang AH, Tan YW, Shang YJ, Liang T, et al (2024) Multifunctional fluorescence probe for simultaneous detection of viscosity, polarity, and ONOO⁻ and its bioimaging *in vitro* and *in vivo*. *Biosens Bioelectron* **254**, 116233.
40. Tian X, Wu D, Wei WH, Dai GF, Li ZX, Wang BH, Yu MM (2024) A lipid droplets-targetable fluorescent probe for polarity detection in cells of iron death, inflammation and fatty liver tissue. *Chin Chem Lett* **35**, 108912.

Appendix A. Supplementary data

Fig. S1 ¹H NMR of the probe TBT-Po (600 MHz in CDCl₃).Fig. S2 ¹³C NMR of the probe TBT-Po (151 MHz in CDCl₃).

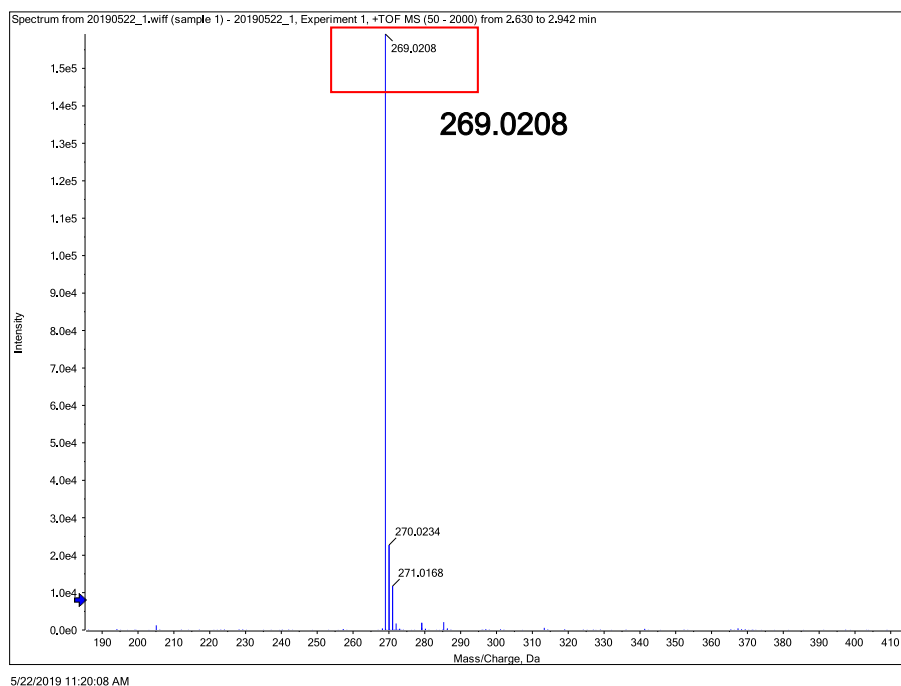


Fig. S3 HRMS spectrum of the probe TBT-Po in methanol.

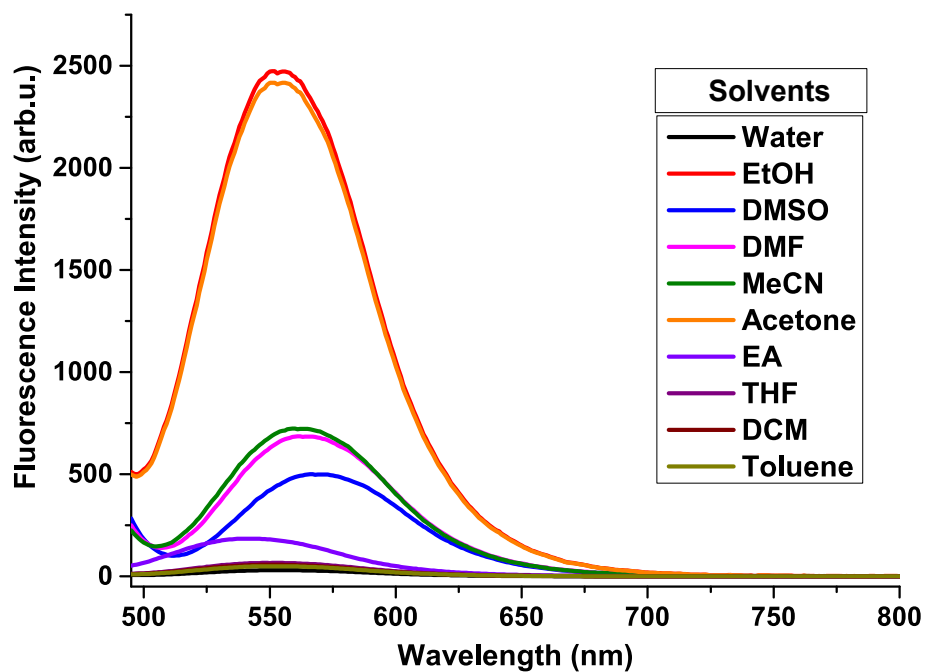


Fig. S4 The fluorescence spectra of the probe TBT-Po in various solvents. Conditions: photomultiplier voltage, 600 V; excitation and emission slit widths, 5 nm × 5 nm; excitation wavelength, 446 nm; incubation time, 5 min; incubation temperature, 25 °C.

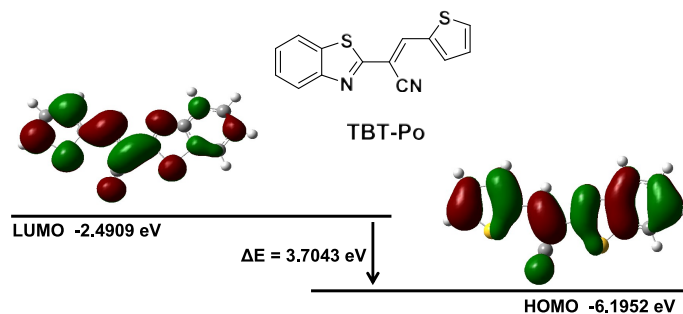


Fig. S5 The HOMO and LUMO of TBT-Po calculated with DFT at the PBE1PBE/6-31G(d) level using the Gaussian 09 program.

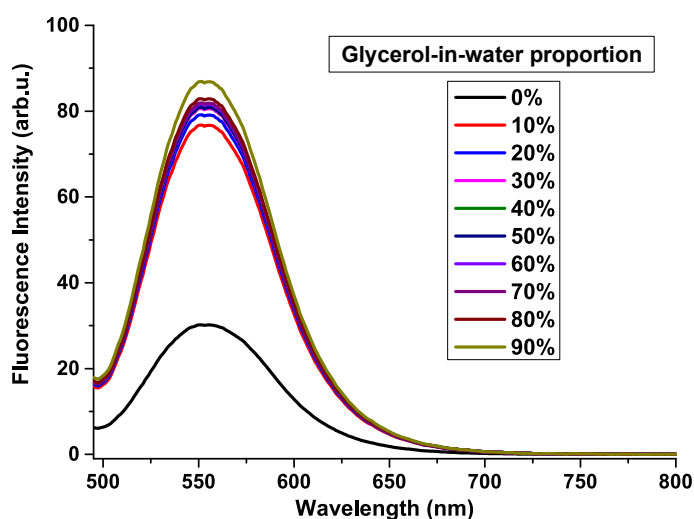


Fig. S6 The fluorescence spectra of TBT-Po (10 μM) with various proportions of glycerol in water (0–90%). Conditions: photomultiplier voltage, 600 V; excitation and emission slit widths, 5 nm $\times$ 5 nm; excitation wavelength, 446 nm; incubation time, 5 min; pH 7.4; incubation temperature, 25 $^{\circ}\text{C}$.

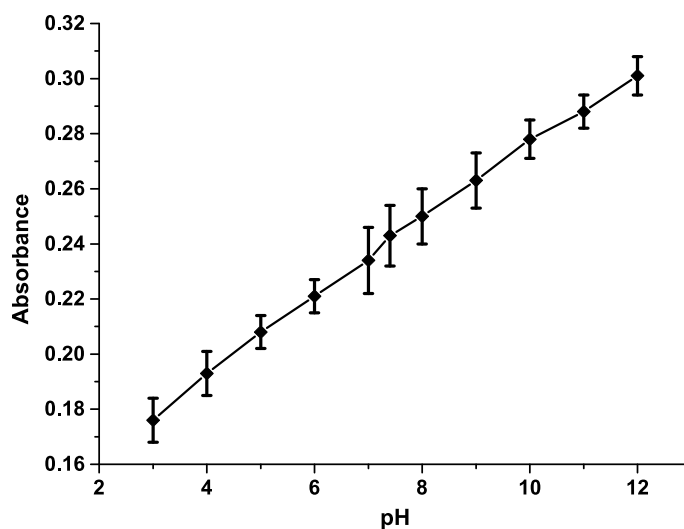


Fig. S7 The absorbance variation of TBT-Po (10 μM) with different pH conditions (3.0–12.0). Working conditions: incubation time, 5 min; incubation temperature, 25 $^{\circ}\text{C}$.