Supramolecular Dye Aggregate Assembly Enables Ratiometric Detection and Discrimination of Lysine and Arginine in Aqueous Solution

Aafrin M. Pettiwala†,§ and Prabhat K. Singh†,‡,*

1Radiation & Photochemistry Division, Bhabha Atomic Research Centre, Mumbai 400085, India
2Homi Bhabha National Institute, Training School Complex, Anushaktinagar, Mumbai 400094, India

ABSTRACT: Constructing sensor systems for rapid and selective detection of small biomolecules such as amino acids is a major area of focus in bioanalytical chemistry. Considering the biological relevance of arginine and lysine, significant efforts have been directed to develop fluorescent sensors for their detection. However, these developed sensors suffer from certain disadvantages such as poor aqueous solubility, technically demanding and time-consuming synthetic protocols, and more importantly, most of them operate through single wavelength measurements, making their performance prone to small variations in experimental conditions. Herein, we report a ratiometric sensor that operates through lysine- and arginine-induced dissociation of a supramolecular assembly consisting of emissive H-aggregates of a molecular rotor dye, thioflavin-T (ThT), on the surface of a polyanionic supramolecular host, sulfated β-cyclodextrin. This disassembly brings out the modulation of monomer–aggregate equilibrium in the system which acts as an ideal scheme for the ratiometric detection of lysine and arginine in the aqueous solution. Besides facile framework of our sensor system, it employs a commercially available inexpensive probe molecule, ThT, which provides an added advantage over other sensor systems that employ synthetically demanding probe molecules. Importantly, the distinctive feature of the ratiometric detection of arginine and lysine provides an inherent advantage of increased accuracy in quantitative analysis. Interestingly, we have also demonstrated that arginine displays a multiwavelength distinctive recognition pattern which distinguishes it from lysine, using a single supramolecular ensemble. Furthermore, our sensor system also shows response in heterogeneous, biologically complex media of serum samples, thus extending its possible use in real-life applications.

1. INTRODUCTION

The inevitable importance of amino acids in diverse fields such as human metabolism, nutrition analysis, and clinical diagnosis of diseases, has triggered a large activity in designing molecular sensors for detection of amino acids. Some of the common analytical methods that have been developed to detect and characterize amino acids include chromatography, electrochemistry, colorimetry, fluoro- metry, and Fourier transform infrared spectroscopy, and so forth, among which fluorescent sensors have attracted significant attention. The exceptional features of fluorescent sensors such as quick response, high sensitivity, and selectivity have enabled their widespread adoption as a method of choice for devising sensors. Although numerous sensors for the detection of thiol containing amino acids have been commonly described, there are only few reports which aim to detect other biologically relevant amino acids.

Among the proteic amino acids, arginine and lysine are classified as basic amino acids, which are pivotal for the proper functioning of biological systems. Arginine, for instance, is involved in various biological processes such as cell division, wound healing, immune functions, and release of hormones. Arginine also acts as a precursor for nitric oxide, which is a crucial physiological mediator. On the other hand, the physiological levels of lysine in the body is important for the regulated metabolic function. High levels of lysine in plasma or urine manifest into various clinical conditions. For example, high lysine concentration in plasma and urine indicates congenital metabolic disorders such as cystinuria or hyperlysinemia. Thus, it is of paramount importance to develop fluorescent sensors with a high sensitivity and selectivity for basic amino acids.

The conventional fluorescence sensors are most frequently associated with the design and synthesis of specialized probe for the selective detection of amino acids, which needs sophisticated and time-consuming synthesis steps to obtain the probe molecule. Most often, their usage is limited to nonaqueous medium owing to their poor water solubility, and
more importantly, most of them operate through their response at single wavelength which makes their performance highly prone to small variations under experimental conditions such as probe molecule concentration, fluctuations in light intensity, and so forth.29–32 Thus, there is a need to adopt an alternative strategy to design a ratiometric fluorescence sensor of optimum sensitivity and selectivity with a simple design that can operate in aqueous media.

One such alternative and attractive strategy that has emerged to be quite promising in the field of analytical chemistry is the usage of supramolecular assemblies as sensing ensembles. The current focus and interest in using supramolecular assemblies as sensory ensembles over conventional fluorescent sensors arises owing to certain distinctive features of these supramolecular assemblies. Supramolecular hosts, in combination with fluorescent dyes, operate via the dynamic and reversible noncovalent interactions, which aids in easy manipulation of these assemblies, when subjected to interaction with the analyte of interest.33,34 In this regard, some supramolecular host–guest complexes, based on calixarenes,35,36 curcubituril,6,37 pillarene,38 have been employed for the detection of basic amino acids; however, they involve simple inclusion complexes of guest molecule with the host molecule as a sensing ensemble, and thus, they operate through a single wavelength output, thereby making these sensors prone to environmental variations. Herein, instead of a simple host–guest inclusion complex, we employ a supramolecular dye-aggregate assembly based on a polyanionic cyclodextrin derivative, which yields a ratiometric response for the basic amino acids, owing to the manipulation of monomer–aggregate equilibrium upon interaction of the analyte of interest. Moreover, the ability of supramolecular assemblies to work in an aqueous medium presents them as an apt platform to sense biomolecules such as amino acids in aqueous solution. An added advantage of these supramolecular assemblies is the operation of multiple weak and less selective interactions in a co-operative manner, which ultimately leads to specific biorecognition with much simpler design.34

Very recently, we reported an interesting observation of emissive H-aggregates of an ultrafast molecular rotor and amyloid marker dye, thioflavin-T (ThT), on the surface of polyanionic-sulfated β-cyclodextrin (SCD).39 On this account, we disclose a simple strategy to exploit SCD-templated ThT aggregate assembly to detect arginine and lysine in aqueous solution. We envisioned that arginine and lysine might induce disassembly of ThT aggregates on the SCD surface, by the virtue of stronger electrostatic interaction of cationic motifs of arginine and lysine with the anionic sulfate groups of SCD. This, in turn, may bring out the modulation in monomer–aggregate equilibrium in the system leading to a ratiometric response. Indeed, this facile approach of arginine- or lysine-induced disassembly enables our system to function as an efficient sensor for arginine and lysine with a ratiometric response in aqueous medium for a sensitive and selective detection over a large concentration range. The distinctive features of the ratiometric detection, minus the complex covalent labeling protocols owned because of the usage of commercially available ThT, presents our sensor system meritorious over other sensors for arginine and lysine. Moreover, our sensor system also provides a response to arginine and lysine in biologically complex media of serum samples, thus pitching for its usage in practical applications.

2. EXPERIMENTAL SECTION

ThT was obtained from Sigma-Aldrich as the chloride salt of the dye and was recrystallized twice from methanol. The purity of the recrystallized ThT was checked through nuclear magnetic resonance spectra. β-Cyclodextrin, sulfated sodium (extent of labeling 12–14) was purchased from Sigma-Aldrich, and fetal bovine serum (FBS) was obtained from HiMedia Laboratories (India). Both were used as received. All samples were prepared using Nanopure water (conductivity less than 0.1 μS cm−1) obtained from a Millipore Milli-Q system.

Ground-state absorption spectra were recorded with a JASCO UV–visible spectrophotometer (model V-650). Steady-state fluorescence spectra were obtained with a HORIBA FluoroMax-4 spectrophluorimeter. All the measurements were carried out at an ambient temperature (~25 °C) using a quartz cell of 1 cm path length unless otherwise stated. For titrations, an incubation time of 15 min was allowed before measurement.

For the measurement of time-resolved fluorescent decay traces, an IBH instrument, based on the time-correlated single-photon counting principle, was used which has been described in detail elsewhere.30,41 Briefly, a picosecond diode laser (406 nm, ~100 ps, 1 MHz) was employed as the excitation source. The details of the fitting procedure have been detailed in our previous publications.41,42

The decay traces are fitted with a multieponential function of the following form

$$I(t) = I(0) \sum \alpha_i \exp(-t/\tau_i)$$

(1)

The average fluorescence lifetime is calculated according to the equation

$$\tau_{avg} = \sum A_i \tau_i$$

(2)

where 83 represents the amplitude of the individual decay constants.

Circular dichroism (CD) spectral measurements were acquired using a Biologic MOS 450 spectropolarimeter over a wavelength range of 350–500 nm under a constant nitrogen flow at room temperature, using a 1 cm path length cell. Standard conditions for all measurements consist of a scan rate of 50 nm/min and an average of three scans for each sample. CD spectra were recorded as ellipticity (θ) in millidegree, wherein each spectrum was baseline subtracted from the spectrum of water only, under same conditions. All measurements were carried out at pH value of 7.4, near physiological conditions. Principal component analysis (PCA) was performed using Origin (version 86).

The time-dependent anisotropy was calculated using the following equation

$$r(t) = \frac{I_\| - G(t)}{I_\| + 2G(t)}$$

(3)

where 83 and I3 represent the fluorescence intensity decays for the parallel and perpendicular polarization with reference to vertically polarized excitation beam. "G" represents the correction factor for the polarization sensitivity bias of the detection system and was estimated independently. The perpendicular measurements were checked by repeating the measurements for at least 2–3 times.
3. RESULTS AND DISCUSSION

Because the basic framework of our sensing scheme is the modulation of photophysical features of SCD-templated ThT aggregates, upon interaction with arginine and lysine, we first demonstrate the formation of SCD-templated ThT assembly. The changes in the steady-state emission spectra of ThT, on its interaction with SCD, are shown in Figure 1. As depicted, an increase in the concentration of SCD results in a drastic bathochromic shift of ThT emission spectra from its usual monomeric band at 490 nm to an emission band centered at 545 nm. Further addition of SCD to an aqueous solution of ThT leads to the enhancement of emission intensity at 545 nm by ~20 times on reaching saturation. The formation of this new bathochromically shifted enhanced emission band for ThT, in the presence of SCD, has been attributed to the formation of emissive H-aggregates on the surface of SCD.39 In aqueous solution, ThT is very weakly emissive in nature. In the excited state, ThT undergoes an efficient twisting process around a single bond (central C–C bond, Scheme 1) in water or low viscous solvents.44–47 As a consequence of this twisting process, a quick dissipation of the excitation energy through non-radiative channel is activated, which renders ThT very weakly emissive in nature.44,48 However, this twisting process is highly dependent on the rigidity of its microenvironment, which in turn affects the emission yield. In the present case of SCD, the increase in the emission intensity of ThT in the presence of SCD can be attributed to the restriction of twisting process of ThT in the aggregated state, which leads to the turn-on emission in the presence of SCD.39 Please note that the emission spectra in Figure 1 contain a peak at ~465 nm which originates from the Raman response of the solvent.

It has been reported that cationic amino acids, such as lysine and arginine, by virtue of their positively charged side chains, interact electrostatically with negatively charged groups such as sulfated groups.49,50 On this basis, we envisaged that lysine and arginine may interact electrostatically with sulfate-rich macrocyclic host SCD, which may subsequently result in the disassembly of ThT H-aggregates from the SCD surface. Thus, to investigate this proposition, a detailed analysis of the photophysical properties of ThT–SCD complex in the presence of basic amino acids was performed. The changes in the fluorescence spectra of ThT–SCD complex were studied in the presence of increasing concentrations of lysine and are presented in Figure 2A. It can be observed from Figure 2A that the fluorescence intensity of ThT–SCD complex decreases with a gradual increase in the concentration of lysine. At higher concentrations of lysine, the fluorescence intensity of ThT–SCD approaches close to that of the monomer form of ThT in water. This decrease in the fluorescent intensity can be attributed to the dissociation of ThT H-aggregates from the SCD surface, as a result of stronger electrostatic interaction of cationic lysine with anionic SCD. Apart from the electrostatic interaction, lysine is also reported to form H-bonding with the sulfated groups.49,50 Thus, the dissociation of ThT H-aggregates from the SCD surface is presumably facilitated by both electrostatic as well as H-bonding interaction of lysine with the sulfated groups of SCD. Since the free ThT is weakly emissive in nature, the disassociation of the emissive H-aggregates of ThT from the SCD surface toward the monomeric form leads to a decrease in its emission intensity. Since the gradual addition of lysine to the ThT–SCD complex causes a change in the equilibrium population of SCD-bound ThT aggregate (highly emissive) and free ThT (weakly emissive), the ratio of emission intensity for these two species shall outline the change in equilibrium population and should yield a lysine concentration-dependent ratiometric response.

Thus, for a quantitative determination of lysine-induced changes in fluorescence features of the ThT–SCD system, the ratiometric analysis of titration data for fluorescence intensities at 545 and 490 nm representing ThT aggregate and monomer form, respectively, was carried out. The ratio of the fluorescence intensity at these two wavelengths was plotted as a function of lysine concentration, and the results are shown in the inset of Figure 2A. The ratio was found to decrease linearly with the increasing concentrations of lysine in a dynamic range of 0–2000 μM (Figure 2A, inset), and the linear regression was $I_{545}/I_{490} = 2.047 – 0.0005 \text{[Lys/μM]}$ with the correlation coefficient ($R^2$) of 0.966. The calculated detection limit of lysine based on 3.3σ is 40 μM, where σ represents the standard deviation of 10 blank measurements, whereas “s” represents the slope of the calibration curve. Thus, this analysis suggests that the ratiometric response of the present system can be used for the estimation of lysine in an aqueous solution.

To decipher whether the addition of lysine causes changes in the absorption spectra of ThT–SCD complex, the response of the sensor system was also monitored colorimetrically. To validate that the origin of bathochromically shifted emission band for ThT–SCD complex is due to H-aggregate formation, the absorption measurements of ThT in the presence of SCD were initially recorded (Figure S1, Supporting Information). ThT displays a hypsochromic shift in its absorption maximum in the presence of SCD (406 nm), when compared with the aqueous solution (413 nm). The hypsochromic shift in the absorption band of ThT, upon addition of SCD, has been attributed to the formation of ThT H-aggregates on SCD surface.51 However, on the addition of lysine in ThT–SCD solution, a prominent red shift in the absorption maxima can be observed from 406 nm, representing the ThT aggregates, to...
413 nm, representing the ThT monomers, in water (Figure 2B). This shift can be assigned to dissociation of ThT H-aggregates from SCD host, owing to the stronger electrostatic interaction between anionic sulfate residues of SCD and cationic side chain of lysine (Scheme 2).

To gain further key insights into the mechanism of interaction between lysine and ThT−SCD complex, time-resolved fluorescence emission measurements were carried out for the ThT−SCD complex in the presence of lysine (Figure 3A). In an aqueous solution, the monomer form of ThT decays very fast, which is beyond the time resolution of our current setup [instrument response function (IRF) ≈ 160 ps]. The short excited-state lifetime of ThT in water is reported to be ∼1 ps and is attributed to ultrafast bond twisting process of ThT in the excited state, which rapidly dissipates the exciton energy via nonradiative channel.44 However, in the case of ThT aggregates, formed in presence of SCD, the decay trace extends up to few nanoseconds, with multiexponential decay kinetics (Figure S2, Supporting Information). This long lifetime has been assigned to reduced torsional relaxation of ThT in the aggregated form.39 It is quite evident from Figure 3A that with the increase in lysine concentrations, the decay traces gradually become faster. This gradually faster decay for the ThT−SCD system in the presence of lysine can be understood in terms of stronger electrostatic interaction facilitated by the H-bonding interaction of lysine with SCD, which dominates the existing interaction between ThT and SCD and results into the release of ThT monomers in the aqueous phase. Accordingly, the average excited-state lifetime (τ_{avg}), calculated using eq 2, displays a gradual decrease with increasing concentrations of lysine which follows a linear correlation equation, τ_{avg} (ns) = 1.2−0.0001 [Lys/μM], with the corresponding correlation coefficient (R^2) of 0.935.

The central framework of our sensor system comprises self-assembled ThT aggregates on the SCD surface, which are...
reported to exhibit the phenomenon of excitonic coupling between transient dipole moments of dye molecules and hence display a characteristic bisignate feature in CD spectroscopy.\textsuperscript{39} Thus, in accordance with the previous report, a characteristic bisignate CD signal for ThT in the presence of SCD is observed (Figure S3, Supporting Information). To understand the effect of lysine on the characteristic bisignate CD signal of ThT–SCD, we measured the CD spectra of ThT–SCD in the presence of varying concentrations of lysine, and the results are presented in Figure 3B. It is obvious from Figure 3B that the addition of lysine to ThT–SCD complex leads to a gradual disappearance of bisignate feature, indicating the disassociation of ThT H-aggregates from SCD surface presumably because of the comparatively stronger electrostatic interaction of SCD with lysine. Thus, CD measurements are consistent with the other photophysical measurements described earlier in this article for the effect of lysine in the ThT–SCD system.

After understanding the effect of lysine on the ThT–SCD system, we moved to arginine that also contains a positively charged side chain with a slightly higher pI value of 10.47; thus, it is expected that the interaction of arginine with the ThT–SCD complex will result in similar changes in the photophysical features of the ThT–SCD complex as observed in the case of lysine. Figure 4A shows that the fluorescence intensity of the ThT–SCD complex decreases on the gradual addition of arginine. This decrease in fluorescence intensity can be similarly associated with disassembly of ThT H-aggregates from SCD surface owing to the relatively stronger electrostatic interaction of cationic arginine with anionic SCD. Moreover, a gradual shift in the fluorescence spectra of ThT–SCD was also observed, which further strengthens the proposition that the electrostatic interaction of SCD and arginine displaces the ThT aggregates from SCD surface and results in the release of ThT monomers in the aqueous phase. Similar to the case of lysine, arginine is also reported to participate in the H-bonding interaction with the sulfate groups,\textsuperscript{39} thus likewise additionally facilitating the disassembly of ThT H-aggregates from the SCD surface. This transition from the aggregated form of ThT to its monomeric form was also evident from the ratiometric analysis of the titration data.

Please note that the ratio of emission intensity (I\textsubscript{445}/I\textsubscript{590}) initially shows a nonlinear behavior with the increasing concentrations of arginine; however, a linear dynamic range is observed for 250–1750 \textmu M (Figure 4A, inset), and the linear regression is I\textsubscript{445}/I\textsubscript{590} = 1.43–0.0004 [Arg/\textmu M] with a correlation coefficient (R\textsuperscript{2}) of 0.9404. The calculated detection limit of arginine based on 3.3σ/s is 50 \textmu M. Note that the nonlinear response for arginine has been discussed later, in this article, in terms of possible formation of a ternary complex between ThT–SCD and arginine.

To complement the steady-state emission measurements for the effect of arginine addition in ThT–SCD complex, the ground-state absorption measurements were also performed and their responses are presented in Figure S4 (Supporting Information). The gradual addition of arginine in ThT–SCD solution shifts the absorption maxima from 406 nm, representing ThT aggregates, to 413 nm, representing ThT in bulk water phase. This shift can be attributed to the disassociation of ThT aggregates from SCD and its release in the bulk water phase. Thus, the results from ground-state absorption measurements are in concordance with the steady-state emission measurements.

This arginine-induced disassociation of ThT aggregates from the SCD surface is also well-supported by time-resolved emission measurements (Figure 4B), where decay traces for the ThT–SCD system gradually become faster with the gradual addition of arginine. This observation of gradually faster transient decays can be understood from the fact that the relatively stronger interaction of arginine with SCD releases the bound ThT molecules toward the bulk water phase, where nonradiative torsional relaxation of ThT becomes highly efficient leading to a faster decay in the presence of arginine. It was observed that the average lifetime decreases linearly with increase in the concentration of arginine (Figure 4B, inset), following a linear correlation of τ\textsubscript{avg} (ns) = 1.2–0.0002 [Arg/\textmu M], and the corresponding correlation coefficient (R\textsuperscript{2}) is found to be 0.995.

Similar to the case of lysine, we also performed the CD measurements for the ThT–SCD system in the presence of arginine, and the results are presented in Figure S5 (Supporting Information). As evident, the CD measurements of the ThT–SCD complex upon addition of arginine result in the disappearance of bisignate feature of ThT–SCD. Similar to the case of lysine, this disappearance of the bisignate feature can also be assigned to the disassociation of ThT aggregates from the SCD surface owing to a stronger electrostatic interaction...
between negatively charged SCD and positively charged arginine.

Thus, steady-state emission, ground-state absorption, time-resolved emission, and CD measurements for the effect of arginine on ThT–SCD are in line with that of lysine, indicating that the interaction of both lysine and arginine with SCD leads to the dissociation of ThT H-aggregates from the SCD surface, which is an outcome of relatively stronger electrostatic interaction of SCD with basic amino acids than ThT and thus provides a simple way of detecting lysine and arginine in aqueous solution.

Because the interaction of both lysine and arginine with ThT–SCD complex leads to drastic changes in the photophysical properties of the system, ThT–SCD can be projected for the sensing of basic amino acids. However, one important criterion to be checked for sensors is selectivity. To evaluate the selectivity of our sensor system, ThT–SCD, towards basic amino acids over other \( \alpha \)-amino acids, a percentage decrease in the emission intensity ratio \( (I_{545/490}) \) of ThT–SCD was calculated for the other tested amino acids. As shown in Figure 5, the percentage decrease in the emission intensity ratio was found to be highest for arginine, followed closely by lysine, whereas other amino acids only cause relatively insignificant changes in the ThT–SCD emission. It may be noted that out of lysine and arginine, arginine shows marginally higher response to this supramolecular platform. This behavior can be understood from the fact that arginine is reported to form relatively stronger H-bonding interaction with the sulfated groups, which has been attributed to the relatively hard nature of the guanidine group of arginine when compared to the amino group of lysine that leads to stronger interaction of the guanidine group with hard sulfated groups. This suggests that the present supramolecular platform displays reasonably higher selectivity for basic amino acids.

![Figure 5. Percentage decrease in emission intensity ratio (I_{545}/I_{490}) of ThT (20 \mu M)–SCD (10 \mu M) in the presence of other amino acids (2.3 mM). Please note that 2.3 mM concentration is not within the linear regime of titration for lysine and arginine.](image)

Although arginine shows marginally higher response than lysine, the discrimination between them would also be desirable and can be ideally achieved by a sensor array approach, where sensor arrays comprise a series of cross-reactive sensor elements either by varying the receptor (SCD in the present case) or by varying the transducer (ThT in the present case). These sensor arrays generate a recognition pattern for a specific analyte by using the signal from each sensor element. However, the discrimination ability is highly dependent on the number of employed sensor elements, and usually in the case of fluorescent sensor arrays, different fluorophores are commonly employed to provide the cross-reactivity that leads to the complexity of data collection which requires scanning the emission spectra of all of the sensor elements or may even require different excitation wavelengths for each of the sensor element. However, in the present case, we realized that interestingly arginine shows a distinct fluorescence behavior than lysine, when compared at the identical concentration. For example, arginine displays a more prominent emission intensity at blue-shifted wavelength when compared with lysine (Figures 6A and S6, Supporting Information).

Thus, the extent of emission intensity reduction is very different when monitored at the blue and red wavelength for lysine and arginine. Thus, the recognition pattern for arginine and lysine was generated by collecting the fluorescence variation at four different wavelengths (470, 490, 520, and 550 nm). Figure 6B suggests that quite different patterns were generated for lysine and arginine.

To know, what could be the possible reason behind such distinctive behaviors of arginine and lysine, we have looked into the distinctive spectral response of arginine when compared to that of lysine. Arginine displays a more prominent emission at the blue-shifted wavelength when compared to lysine (Figure 6A). This blue-shifted emission wavelength corresponds to the monomeric form of ThT. The enhanced emission at the monomeric emission wavelength suggests that ThT, in its monomeric form, is present in an environment, which is quite distinct from bulk water because in bulk water, ThT is very weakly emissive. It is possible that the interaction of arginine with ThT aggregates on the SCD surface not only leads to the disassembly of ThT aggregates into water medium but may also lead to a certain population of ternary complex, involving, ThT, SCD, and arginine, in which case, ThT will lead to an enhanced emission in its monomeric form. In fact, it is reported in literature that among all other amino acids, arginine has a very high tendency to self-aggregate. Thus, it is possible that arginine aggregates at the surface of SCD with ThT trapped in it. To check this possibility, we have carried out time-resolved anisotropy measurement (which provides information about the mobility of the probe) for the ThT–SCD complex in the presence of arginine and lysine. Thus, it is expected that if a ternary assembly forms in the case of arginine, then a slower anisotropy decay should be observed in the case of arginine. Indeed, for arginine, although not very slow, but a definite slowdown in the anisotropy decay is observed, (Figure S7, Supporting Information) suggesting the formation of an assembly in the case of arginine, whereas, for lysine, the anisotropy decay remains almost unchanged.

To evaluate the practical usefulness of the present supramolecular sensing platform, we also attempted to evaluate the response of the present system in the diluted samples of FBS.
The measurements revealed a successful response of the present sensing system even in the biologically complex media of FBS, although with a reduced sensitivity, presumably because of a competitive binding interaction of ThT with other biomolecules present in the serum matrix (Figures S8 and S9 Supporting Information). However, to further improve the performance of the present sensor system for biological samples, the sample preparation stage involving methods such as solid-phase extraction, liquid-phase extraction, and so forth may be employed to minimize the matrix effect, along with the analyte preconcentration step, which may significantly improve the sensitivity of the current sensor system. Thus, these results suggest that the present supramolecular sensing platform has the potential to be utilized in biological samples.

4. CONCLUSIONS

In summary, we report a simple ratiometric sensor, operating through fluorimetry, for a rapid and selective detection of lysine and arginine, based on ThT H-aggregates-assembled dynamic supramolecular platform of SCD. The sensitive and selective sensing of basic amino acids is achieved by drastic modulations of the photophysical properties of SCD templated ThT H-aggregates, when subjected to interactions with lysine and arginine. Besides being based on the supramolecular framework, which endows an inherent applicability of the present sensor in aqueous medium, it also employs an inexpensive commercially available probe molecule, ThT, thus making our sensing approach label-free and advantageous over a large majority of sensor system which suffer from the need of complex and time-consuming multistep synthesis. More importantly, our sensor system yields a ratiometric response to arginine and lysine over a wide dynamic range. This feature of ratiometric response makes the performance of our sensor system more robust to the variations under experimental conditions and is certainly a desirable advantage over sensor systems operating through single wavelength output. We also demonstrate that the closely related basic amino acids, arginine and lysine, can be successfully discriminated using recognition patterns with the help of PCA. Further, our sensor system could also respond to basic amino acids in the competitive biological media of FBS, thus promising its possible application in biological samples.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acsomega.7b01546.

Normalized absorption spectra, transient decay traces, and CD spectra of ThT in water and in SCD; normalized ground-state absorption spectra and CD spectra of ThT−SCD system in presence of various concentration of arginine; comparison of emission response of lysine and arginine at various concentration; and time-resolved anisotropy decay trace and response of ThT−SCD system toward lysine and arginine in serum samples (PDF)
AUTHOR INFORMATION

Corresponding Author
*E-mail: prabhatk@barc.gov.in, prabhatsingh98@gmail.com. Phone: 91-22-25590296. Fax: 91-22-5505151 (P.K.S.).

ORCID
Prabhak K. Singh: 0000-0002-4612-547X

Present Address
3On M. Sc. research project from Sunandan Divatia School of Science, NMIMS, Mumbai 400056, India (A.M.P.).

Notes
The authors declare no competing financial interest.

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