Synthesis of New Acyclic Schiff Base Oxovanadium(IV) Complexes and Their Electrochemical, Catecholase, and Antimicrobial Studies of Minimum Inhibitory Concentration

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Catalytically active complexes containing [VO(IV)L] were synthesized by using Schiff base ligands L1–5 and vanadyl sulfate. Ligands L1–5 were obtained by the condensation of 5-methylsalicylaldehyde with diethylene triamine (L1), tris(2-aminoethyl)amine (L2), triethylene tetramine (L3), N,N-bis(3-aminopropyl)ethylenediamine (L4) and N,N-bis(aminopropyl) piperazine (L5). All the complexes were characterized by elemental and spectral analysis. ESR spectra for the mononuclear [VO(IV)L] complexes show eight lines, square pyramidal geometry. Room temperature magnetic moment for the complexes was around 1.73 B.M. Electrochemical and catalytic studies of the complexes were compared on the basis of chain length of the imine compartment. All the [VO(IV)L1–5] complexes were screened antibacterial activity of MIC.

Keywords: Schiff base ligands, vanadyl(IV) complexes, cyclic voltammetry, catecholase activity, antimicrobial activity

Introduction

The importance of the Schiff base is due its versatile nature. A number of Schiff bases exhibit biological activities1,2 such as antifungal, antibacterial, antitumor, anti-inflammatory, and antipyretic, among others. Some of them have been used as complexing agents3,4 and powerful corrosion inhibitors5. Acyclic Schiff base ligands and their metal complexes have attracted great and growing interest in chemistry and biology for many years due to their facile synthesis and wide applications6–8. Studies on complexes of acyclic Schiff base ligands with different size, number, and donor atoms for coordination with a variety of metal centers have been reported9–11. The study of the chemistry of vanadium occurs as an "essential trace" element in diverse living forms12–14. The vast majority of work has occurred more recently. Vanadium is naturally occur in mushrooms as well and is required as an essential cofactor in certain haloperoxidases and nitrogenses15. While vanadium is suspected to be an critical trace element for humans16, as vanadate, it is known to affect phosphate metabolism and various forms of vanadium have proven to have insulin mimetic effects17. The electrochemical methods also provide highly valuable information regarding catalytic processes since catalytic conversions are frequently accompanied by the change in the structure of the complex and the oxidation state of the metal however; the electrochemical approaches for these purposes have not been fully explored. Henze et al18 in 1911 first reported the role of vanadium in nitrogen fixation and become established in 1989 through investigations carried on nitrogen fixation group. Julieta Gradinaru et al19 reported Ni(II), Cu(II), Zn (II), and VO(II) Schiff base complexes from 1-phenylbutane-1,3-dione mono-S-methylisothiosemicarbazone with o-hydroxybenzaldehyde that exhibit NLO property. Kianfar et al20 reported the electrochemical activity of VO(IV) Schiff base complexes, salen type of aldehydes with diamine. In 2011, we have reported Cu(II) Schiff base complexes21. The present work deals with the influence of ligand modification on spectral, electrochemical, catecholase and antimicrobial studies, reporting the synthesis and characterization of acyclic mononuclear vanadyl complexes.

Experimental

Physical Measurements

Elemental analysis of the complexes is obtained using a Haerreu CHN rapid analyzer. IR spectra were recorded on a Perkin Elmer FT-IR 8300 series spectrophotometer on KBr disks from 4000 to 400 cm−1. 1H NMR spectra were recorded using a JEOL GSX 400MHz NMR spectrometer. Deuterated chloroform (CDCl3) is used as the solvent. Tetramethylsilane (TMS) is used as an internal standard. ESI
Mass spectra were obtained on a JEOL DX-303 mass spectrometer. Electronic spectral studies were carried out on a Perkin Elmer 320 spectrophotometer. Cyclic voltammograms were obtained on a CHI-600A electrochemical analyzer under oxygen-free conditions using a three-electrode cell in which a glassy carbon electrode was the working electrode, a saturated Ag/AgCl electrode was the reference electrode and platinum wire was the auxiliary electrode. A ferrocene/ferroccenium couple was used as an internal standard and E1/2 of the ferrocene/ferroccenium (Fc/Fc+) couple under the experimental condition was 470 mV. Tetra(n-butyl)ammonium perchlorate (TBAP) 1 x 10^{-1} M was used as the supporting electrolyte. Room temperature magnetic moments were measured on a PAR vibrating sample magnetometer (VSM) Model-155. X-band EPR spectra were recorded in DMF at 25°C on a Varian EPR-E 112 spectrometer using diphenylpicrylhydrazine (DPPH) as the reference. Catalytic oxidation of catechol to o-quinone by the vanadium complexes was studied in 10^{-3} mol L^{-1} DMF solutions. The reactions were followed spectrophotometrically with the strongest absorption of o-quinone at 390 nm and monitoring the increase in absorbance. A plot of log ([A]/[A0]/[A0]) versus time was made for each complex and rate constants for the catalytic oxidations were calculated.

Experimental Studies

**Minimum inhibitory concentration**

The minimum inhibitory concentration of the vanadium complexes was done by Resazurin reduction assay in 96 well microtitre plates according to the Yashodharan Kumarasamy et al. method.

**Preparation of Resazurin solution**

The Resazurin solution was prepared by dissolving a 270 mg tablet of resazurin in 40 mL of sterile distilled water. It is vortexed to get a complete dissolved homogenous solution.

**Resazurin reduction assay**

The MIC by Resazurin reduction assay was done in sterile 96-well plates. A volume of 200 μL of test material in 10% (v/v) DMSO was pipetted into the first row of the plate. To all other wells 100 μL of nutrient broth was added. Twofold serial dilutions were performed using a pipette. Tips were discarded after use such that each well had 100 μL of the test material in serial dilutions. 10 μL of resazurin indicator solution was added to each well. Finally, 10 μL of bacterial suspension (5 x 10^6 cfu/mL) was added to each well to achieve a concentration of 5 x 10^5 cfu/mL. The antibiotic ampicillin serves as positive control in serial dilution. All the plates were incubated at 37°C for 18-24 h. The color change was then assessed visually. The color changes from purple to pink or colorless were recorded as reduction of dye by the viable bacteria.

**Chemicals and Reagents**

5-methylsalicylaldehyde was prepared following the literature method. Analytical grade methanol, acetonitrile, dimethyl formamide, triethylenetetramine, diethylentriamine, and VOSO4·2H2O were purchased from Qualigenis. TBAP (tetra(n-butyl)ammonium perchlorate) used as supporting electrolyte in electrochemical measurements was purchased from Fluka and recrystallized from hot methanol. N,N-bis-(3-aminopropyl) piperazine, N,N-bis-(3-aminopropyl) ethylene diamine and tris-(2-aminoethyl)amine were purchased from Aldrich.

**Bacterial pathogens**

The bacterial pathogens Escherichia coli, Salmonella typhi, and Streptococcus faecalis were obtained from CAS in Botany, University of Madras.

**Synthesis of metal complexes**

Ligand L1, L2, L3, L4, and L5 were synthesized by following our previous report (Scheme 1). An absolute methanol solution containing VOSO4·2H2O (0.036 g, 0.1 mmol) was added drop-wise to a stirring solution of L1 (0.0339 g, 0.1 mmol), L2 (0.0364 g, 0.1 mmol), L3 (0.0382 g, 0.1 mmol), L4 (0.0426 g, 0.1 mmol), and L5 (0.0468 g, 0.1 mmol) instead of L1. All the vanadium (IV) complexes are neutral.

**Synthesis of [VO(IV)2]**

Green solid. Yield: (65%). m.p.: 322°C (dec). Anal. Calcd. for [C22H28VN4O10]: C, 62.02; H, 7.21; N, 11.13; V, 10.16. Found: C, 61.78; H, 6.69; N, 9.11; V, 10.83%. ESI MS: (m/z) 405.33, calcd. av. m/z 405.34. Selected IR data (KBr) (c, cm^{-1}): 1127 ν(C–O), 939 [ν (V=O)], 1630 ν(C=N), 630 ν(M=N), 439 ν(M=O).

**Synthesis of [VO(IV)L1]**

Green solid was obtained. Yield: (81%). m.p.: 331°C (dec). Anal. Calcd. for [C22H28VN4O10]: C, 62.60; H, 6.74; N, 9.15; V, 11.09. Found: C, 61.78; H, 6.69; N, 9.11; V, 10.83%. ESI MS: (m/z) 455.37. Selected IR data (KBr) (ν, cm^{-1}): 1127 ν(C–O), 958 [ν (V=O)], 1623 ν(C=N), 626 ν(M=N), 444 ν(M=O).

**Synthesis of [VO(IV)L2]**

Green solid was obtained. Yield: (71%). m.p.: 325°C (dec). Anal. Calcd. for [C22H28VN4O10]: C, 62.24; H, 6.83; N, 11.17; V, 10.16. Found: C, 62.15; H, 6.75; N, 11.13; V, 9.96%. ESI MS: (m/z) 448.45. Selected IR data (KBr) (ν, cm^{-1}): 1127 ν(C–O), 937 [ν (V=O)], 1629 ν(C=N), 664 ν(M=N), 451 ν(M=O).

**Synthesis of [VO(IV)L3]**

Green solid was obtained. Yield: (71%). m.p.: 325°C (dec). Anal. Calcd. for [C22H28VN4O10]: C, 62.24; H, 6.83; N, 11.17; V, 10.16. Found: C, 62.15; H, 6.75; N, 11.13; V, 9.96%. ESI MS: (m/z) 448.45. Selected IR data (KBr) (ν, cm^{-1}): 1127 ν(C–O), 937 [ν (V=O)], 1629 ν(C=N), 664 ν(M=N), 451 ν(M=O).
**Synthesis of [VO(IV)L4]**

Green solid was obtained. Yield: (79%). m.p.: 335°C (dec). Anal. Calcd. for [C24H32VN4O3]: C, 63.26; H, 7.58; N, 10.54; V, 9.58. Found: C, 62.66; H, 7.30; N, 9.82; V, 9.44%. ESI MS: (m/z) 472.20, Calcd. av. m/z 473.46. Selected IR data (KBr) ($\nu$, cm$^{-1}$): 1300 $\nu$(C=O), 977 $\nu$ (V=O), 1628 $\nu$(M-N), 556 $\nu$(M-O).

**Synthesis of [VO(IV)L5]**

Green solid was obtained. Yield: (61%). m.p.: 341°C (dec). Anal. Calcd. for [C26H34VN4O3]: C, 64.62; H, 7.59; N, 10.05; V, 9.14. Found: C, 64.11; H, 7.41; N, 10.01; V, 09.01%. ESI MS: (m/z) 499.27, Calcd. av. m/z 501.12. Selected IR data (KBr) ($\nu$, cm$^{-1}$): 1130 $\nu$(C=O), 964 $\nu$ (V=O), 1624 $\nu$(C=N), 534 $\nu$(M-N), 469 $\nu$(M-O).

**Results and Discussion**

**Spectroscopic Studies**

The FT-IR spectra of the ligands show a broad band around 3400 cm$^{-1}$ due to the presence of the phenolic OH group. Absence of a peak around 3400 cm$^{-1}$ in all the complexes indicates the absence of $\nu$(-OH) due to deprotonation followed by complexation. The spectra of all the complexes are dominated by bands at 2930-3000 cm$^{-1}$ due to the aromatic C=H stretching vibration. 5-methylsalicylaldehyde shows a sharp band at 1655 cm$^{-1}$ corresponding to $\nu$(-CHO). Ligands and complexes show a sharp band at 1620–1640 cm$^{-1}$ due to the presence of C=N group and the absence of $\nu$(C=O) band in the complexes indicate Schiff base condensation.[26–31] A strong band at 1260 cm$^{-1}$ in the free Schiff bases has been assigned to phenolic C-O stretching. Upon complexation, this band shifts to higher frequency (1300 cm$^{-1}$) showing coordination through phenolic oxygen.[32] For the complexes, bands at 930–980 cm$^{-1}$ could be assigned to the -(V=O) bond.[33] Other weak bands at lower frequency could be assigned to -(M-N) bond. In the proton NMR spectra of all the vanadium(IV) complexes the peak due to phenolic OH group is absent. This indicates that the phenolic protons are deprotonated during complexation.

**ESI Mass Spectral Analysis**

The ESI mass spectra of mono nuclear complexes [VO(IV) L₁], [VO(IV)L₂], [VO(IV)L₃], and [VO(IV)L₅] show the molecular ion peak (M⁺) at m/z = 405.33, 445.87, 472.20, and 499.27, respectively. The spectra show some prominent peaks corresponding to the various fragments of the complexes. The ESI mass spectra of mononuclear complexes [VO(IV)L²] are shown in Figure 1 and the ESI mass spectra of the other three complexes are given in Figure S1.
Electronic Spectra

Electronic spectra of all the complexes were obtained in DMF medium. The electronic spectra of all the complexes show a single weak d-d band in region 663–692 nm due to $^2E \leftarrow ^2B_2$ ($dxz,dyz,dxy$) transition associated with square-pyramidal geometry\textsuperscript{[34]} around the VO$^{2+}$ ion. The other transitions due to $^2B_1 \leftarrow ^2B_2$ ($dx^2-y^2$) and $^2A_1 \leftarrow ^2B_2$ ($dz^2$–dxy) may be overlapping with the other lower wavelength bands observed in the region 350–400 nm. A red shift in the $\lambda_{\text{max}}$ value of d-d band\textsuperscript{[35]} with increase in the chain length between imine nitrogen has been observed. This red shift may be due to the distortion from planar geometry as the chain length increases. Moderately intense band observed in the region of 350–400 nm is associated with ligand to
metal charge transfer transition. An intense band observed in the region 260–300 nm is associated with intra ligand transition. The electronic spectral data are given in Table 1.

### ESR Spectra

The ESR spectra of the vanadyl complexes, recorded in DMSO solution at 300 and 77 K, spectra shown in Figure 2. [VO(IV)L₂⁻] complex is given in Figure S2a. The isotropic ESR parameters for [VO(IV)L₁⁻] g_{iso} = 1.97 and A_{iso} = 101 can be calculated from the position spacing of the resonance lines from the room temperature solution spectrum of the complex. The ESR spectra of all the complexes show a typical eight-line pattern, due to hyperfine splitting of the V nucleus (I = 7/2). This indicates that a single vanadium ion is present in the molecule (i.e., it is a monomer). From the anisotropic spectrum, the anisotropic parameters were calculated and the data are given in Table 2.

All the mononuclear vanadium complexes show well-resolved axial anisotropy with eight line pattern with g_{||} < g_{⊥} and A_{||} >> A_{⊥}, a relationship characteristic of an axially compressed d_{xy} configuration. Ligand nitrogen or hydrogen super hyperfine splittings are not observed on the vanadium line. This indicates that the unpaired electron has to be in b_{2g} (d_{xy}, 2B₂ ground state) orbital localized on metal, thus excluding the possibility of its direct interaction with the ligand. The observed order (A_{||} = 160.2 > A_{⊥} = 49.2; g_{⊥} = 1.99 > g_{||} = 1.97) indicates

![Fig. 2. ESR spectra of the macrocyclic mononuclear complex [VO(IV)L₁⁻].](image)

| Sl. No. | Complexes | λ_max (nm) (ε/M/cm⁻¹) | d→d | Charge transfer |
|--------|-----------|------------------------|------|-----------------|
| 1.     | [VO(IV)L₁⁻] | 663(118) | 380(14900), 295(27500) |
| 2.     | [VO(IV)L₂⁻] | 674(107) | 395(12200), 295(27400) |
| 3.     | [VO(IV)L₃⁻] | 679(92) | 385(14600), 270(28100) |
| 4.     | [VO(IV)L₄⁻] | 683(85) | 375(15100), 265(28500) |
| 5.     | [VO(IV)L₅⁻] | 692(69) | 350(16700), 290(27200) |

| Sl No. | Complexes | g_{||} | g_{⊥} | A_{||} | A_{⊥} | μ_{eff} BM |
|--------|-----------|-------|-------|-------|-------|-----------|
| 1.     | [VO(IV)L₁⁻] | 1.97  | 1.99  | 160.2 | 49.2  | 1.69      |
| 2.     | [VO(IV)L₂⁻] | 2.00  | 2.01  | 161.2 | 49.3  | 1.70      |
| 3.     | [VO(IV)L₃⁻] | 2.05  | 2.10  | 162.3 | 49.1  | 1.72      |
| 4.     | [VO(IV)L₄⁻] | 2.00  | 2.03  | 161.3 | 49.2  | 1.71      |
| 5.     | [VO(IV)L₅⁻] | 2.04  | 2.09  | 162.2 | 49.4  | 1.74      |

![Fig. 3. (A) Voltammograms of mononuclear [VO(IV)L₁⁻⁻] complexes: (a) [VO(IV)L₁⁻], (b) VO(IV)L₂⁻, (c) [VO(IV)L₃⁻], (d) [VO(IV)L₄⁻], and (e) [VO(IV)L₅⁻] (reduction process). (B) Cyclic voltammograms of the mononuclear [VO(IV)L₁⁻⁻] complexes: (a) [VO(IV)L₁⁻], (b) [VO(IV)L₂⁻], (c) [VO(IV)L₃⁻], (d) [VO(IV)L₄⁻], and (e) [VO(IV)L₅⁻] (oxidation process).](image)
that the unpaired electron is present in the dxy orbital with square-pyramidal geometry around the [VO(IV)] chelates.\textsuperscript{[36–38]}

Electrochemistry of the Complexes

Reduction process at negative potential

The electrochemical properties of the mononuclear complexes were studied by cyclic voltammetry in DMF solution containing TBAP as supporting electrolyte in the potential range of \(-0.20\) to \(-2.75\) V. The cyclic voltammograms are given in Figure 3a. The electrochemical data of vanadium(IV) complexes are given in Table 3. Generally the electrochemical properties of the complexes depend on a number of factors such as chelate ring/size, axial ligation, degree and distribution of unsaturation and substitution pattern in the chelate ring. Each voltammogram shows one electron irreversible reduction wave at a negative potential in the range of \(-2.00\) to \(-1.35\) V. The controlled potential electrolysis carried out at 100 mV more negative than the reduction wave conveys the consumption of one electron per molecule. It is very interesting to compare the electrochemical behavior of [VO(IV)L] complexes. The reduction potential shifts towards anodic direction for the complexes [VO(IV)L\textsuperscript{1}] to [VO(IV)L\textsuperscript{5}] from \(-2.00\) to \(-1.35\) V, as the number of methylene groups increases.\textsuperscript{[39,40]} This shows that, as the number of methylene groups between the imine nitrogen (chain length) increases, the entire acyclic ring becomes more flexible, which causes a distortion of the geometry of the vanadium(IV) complexes and makes the system more flexible.

Oxidation process at positive potential

The electrochemical properties of the mononuclear complexes were studied by cyclic voltammetry in DMF solution containing TBAP as supporting electrolyte in the potential range of \(0.00\)–\(0.70\) V. The cyclic voltammograms are given in Figure 3b. The electrochemical data of vanadium(IV) complexes are given in Table 3. The oxidation potential shifts towards more positive direction for the complexes [VO(IV)L\textsuperscript{1}] to [VO(IV)L\textsuperscript{5}] from \(0.25\) to \(0.44\) V as the ring size increases. This is because as the ring size increases the flexibility increases and the planarity of the complexes decreases and hence the electrochemical oxidation process occurs with difficulty.

### Table 3. Electrochemical data\textsuperscript{a} and catecholase activity data\textsuperscript{b} for the[VO(IV)L\textsuperscript{1–5}] complexes

| Complexes   | Reduction potential E\textsuperscript{pc} (V) | Oxidation potential E\textsuperscript{pa} (V) | \(\text{Rate constant } (k) \times 10^{-3} \text{ min}^{-1}\) [catecholase activity] |
|-------------|---------------------------------------------|-----------------------------------------------|---------------------------------------------------------------------------------|
| [VO(IV)L\textsuperscript{1}] | \(-2.00\) | \(0.25\) | 3.611 |
| [VO(IV)L\textsuperscript{2}] | \(-1.80\) | \(0.33\) | 6.222 |
| [VO(IV)L\textsuperscript{3}] | \(-1.70\) | \(0.35\) | 8.277 |
| [VO(IV)L\textsuperscript{4}] | \(-1.60\) | \(0.38\) | 12.555 |
| [VO(IV)L\textsuperscript{5}] | \(-1.35\) | \(0.44\) | 17.500 |

\(\text{a}\) Measured by CV at 50 mV s\textsuperscript{-1} scan rate. E versus Ag/AgCl conditions: GC working electrode and Ag/AgCl reference electrodes; supporting electrolyte TBAP; concentration of complex \(1 \times 10^{-3}\) M, concentration of TBAP \(1 \times 10^{-1}\) M.

\(\text{b}\) Measured spectrophotometrically in DMF. Concentration of the complexes: \(1 \times 10^{-3}\) M. Concentration of o-quinine: \(1 \times 10^{-1}\) M.

**Kinetic Studies**

**Oxidation of pyrocatechol (catecholase activity)**

The catecholase activity of the vanadium(IV) complexes synthesized in the present work was carried out using pyrocatechol as the convenient model substrate for the identification of functional models for the metalloenzymes.\textsuperscript{[41]} For this purpose, \(10^{-3}\) mol dm\textsuperscript{-3} solutions of complexes in dimethylformamide were treated with 100 equivalents of pyrocatechol in the presence of air. The course of the reaction was followed spectrophotometrically at 390 nm for nearly 45 min at regular time intervals of 5 min. The slope was determined by the method of initial rates by monitoring the growth of the 390 nm band of the product o-quinone. A linear relationship for initial rate and the complex concentration obtained for the vanadium(IV) complexes shows a first-order dependence on the complex concentration for the systems.

Plots of log \((A_\infty/A_\infty-A_t)\) versus time for catecholase activity of the [VO(IV)L\textsuperscript{1–5}] complexes are obtained and shown in Figure 4. The inset in Figure 4 shows the time dependent growth of o-quinone chromophore in the presence of [VO(IV)L\textsuperscript{5}]. The observed initial rate constant
value for vanadium(IV) complexes is given in Table 3. The complex [VO(IV)L\textsuperscript{4}] has higher catalytic activity (17.500 × 10\textsuperscript{-3} min\textsuperscript{-1}) than the complex [VO(IV)L\textsuperscript{5}] (12.555 × 10\textsuperscript{-3} min\textsuperscript{-1}) which in turn is higher than the vanadium(IV) complex [VO(IV)L\textsuperscript{1}] (3.611 × 10\textsuperscript{-3} min\textsuperscript{-1}). The order of activity of the complexes is the following:

\[
[\text{VO(IV)L}^5] > [\text{VO(IV)L}^4] > [\text{VO(IV)L}^3] > [\text{VO(IV)L}^2] > [\text{VO(IV)L}^1]
\]

From the results it is observed that the rate of oxidation of catecholase to o-quinone has increased as the chain length increases. The catecholase activity of complex containing longer carbon chain in the imine compartment is higher than that of the complex containing lesser carbon chain in the imine compartment, which is due to flexibility resulting from distortion of the coordination sphere. Increase in the chain length causes a greater distortion of the geometry of the complexes. This flexibility in the geometry may favor the observed higher rate of the reaction. This geometry may favor the observed higher rate of the reaction. The complex shows observed higher rate of the reaction. The complex shows observed higher rate of the reaction.

Antimicrobial Activity Results

The vanadium complex [VO(IV)L\textsuperscript{1}] to [VO(IV)L\textsuperscript{5}] showed good inhibition of tested pathogenic bacteria. The blue color in the assay wells denotes the inhibition of the bacterial pathogens. The MIC of complex [VO(IV)L\textsuperscript{5}] was efficient than all other four vanadium complexes due to the more number of methylene group and equal to that of commercial antibiotic. The MIC of complex [VO(IV)L\textsuperscript{5}] were 6.25, 3.12, and 6.25 μg/mL against Streptococcus faecalis, E. coli, and Salmonella typhi, respectively. MIC sterile disk photos are given in Figure S1. The lowest concentration at which no color change occurred was taken as the MIC value of the tested complex.

Conclusion

In conclusion, five Schiff base vanadium(IV) complexes have been synthesized and their coordination chemistry and antibacterial activity have been investigated. The electronic spectrum of [VO(IV)L] complexes indicates square pyramidal geometry, and there is a red shift due to the increase in the chain length. Cyclic voltammograms exhibit one electron quasireversible process. The reduction potential shifts less negative potential on increasing chain length and oxidation potential shifts more positive potential on increasing chain length. All the [VO(IV)L] complexes show good catalytic activity on increasing the chain length. Increase in the chain length causes a greater distortion of the geometry of the complexes. This flexibility in the geometry may favor the observed higher rate of the reaction. The complex shows remarkable activity against three bacterial pathogens. Complex [VO(IV)L\textsuperscript{5}] have highest activity against Streptococcus faecalis, E. coli, and Salmonella typhi. All the studies of the complexes agree well with the established trend.

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Supplementary Material

Supplemental data for this article can be accessed at the publisher’s website. SI mass spectrum of [VO(IV)L\textsuperscript{1}], [VO(IV)L\textsuperscript{4}], and [VO(IV)L\textsuperscript{5}], are given in Figure S1a–S1c. ESR spectra of the [VO(IV)L\textsuperscript{2}] complex are given in Figure S2a and Antimicrobial activity (minimum inhibitory concentration) of complexes [VO(IV)L\textsuperscript{1–5}] (MIC sterile disk photos are given in Figure S3) are given as supplementary material.

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