



MJ MULTISCIA
JOURNALS PUBLISHERS

FRONTIERS IN PHARMACEUTICAL ANALYSIS

ISSN: (3065- 1352)

[https://multisciajournals.com/
journals/index.php/fpa](https://multisciajournals.com/journals/index.php/fpa)

editor.fpa1@gmail.com



Therapeutic Potential of Iron and Vanadium Complexes: Antimicrobial, Antioxidant, and Biomedical Perspectives

Dr.R.Jeevi Esther Rathnakumari

*Associate Professor of Chemistry,
Nazareth Margoschis College at Pillaiyanmanai,
Nazareth 628617, Tamil Nadu,
Affiliated to Manonmaniam Sundaranar University,
Tirunelveli, Tamil Nadu, India – 627 012.*

Article Info

Received: 11-03-2026 Revised:23-03-2026 Accepted:15-04-2026 Published:23-05-2026

Abstract

Transition metal complexes have attracted remarkable scientific attention due to their diverse coordination chemistry and broad range of biomedical applications. Among various transition metals, iron and vanadium complexes have emerged as highly promising compounds because of their unique redox properties, multiple oxidation states, structural versatility, and significant biological activities. The present review focuses on the coordination chemistry, antimicrobial potential, antioxidant behavior, and biomedical applications of iron and vanadium complexes, with particular emphasis on Schiff base ligand systems. Iron complexes are widely recognized for their excellent biocompatibility, enzyme-mimetic properties, antioxidant activity, and lower toxicity, whereas vanadium complexes exhibit strong antimicrobial, anticancer, insulin-mimetic, and catalytic properties. Coordination of ligands with iron and vanadium ions significantly enhances the stability, lipophilicity, and therapeutic efficiency of the resulting complexes. Recent studies reveal that these complexes exhibit considerable inhibitory activity against Gram-positive and Gram-negative bacterial strains, fungal pathogens, and multidrug-resistant microorganisms. Their biological activity is strongly influenced by factors such as oxidation state, ligand geometry, donor atoms, and substituent groups. Furthermore, iron and vanadium complexes interact effectively with DNA, proteins, and microbial enzymes, contributing to their pharmacological and

antimicrobial mechanisms. Advances in nanotechnology and bioinorganic chemistry have further expanded their applications in targeted drug delivery, biosensors, and therapeutic formulations. Comparative investigations suggest that vanadium complexes generally demonstrate superior antimicrobial and anticancer properties, while iron complexes show enhanced antioxidant activity and better biological compatibility. Despite significant advancements, challenges related to toxicity, stability, and clinical applicability still remain. This review summarizes recent developments in the coordination chemistry and therapeutic applications of iron and vanadium complexes and discusses future research perspectives for developing novel metal-based therapeutic agents.

Keywords: Coordination Chemistry, Iron Complexes ,Vanadium Complexes , Antimicrobial Activity, Antioxidant Activity.

1. Introduction

Coordination chemistry is an important branch of inorganic chemistry that deals with the interaction between metal ions and ligands to form coordination complexes. Transition metal complexes have attracted significant interest because of their versatile structures, electronic configurations, catalytic behavior, and biological applications. Among various transition metals, iron and vanadium occupy a unique position due to their biological relevance, variable oxidation states, and therapeutic potential. Their complexes have been extensively investigated for antimicrobial, antioxidant, anticancer, catalytic, and pharmaceutical applications.

Iron is an essential trace element involved in several biological processes including oxygen transport, enzymatic catalysis, electron transfer, and DNA synthesis. Iron-containing proteins such as hemoglobin, cytochromes, and iron-sulfur enzymes are fundamental to normal physiological functions. Iron complexes possess excellent redox properties and are capable of participating in electron transfer reactions, making them valuable in medicinal and biochemical applications. Iron coordination compounds exhibit remarkable antioxidant activity and have shown promising antimicrobial and anticancer properties. Furthermore, iron complexes generally possess lower toxicity and greater biological compatibility compared with many other transition metal complexes, increasing their suitability for therapeutic applications.

Vanadium is another biologically important transition metal known for its multiple oxidation states and catalytic behavior. Vanadium complexes have attracted growing scientific interest because of their insulin-mimetic, antimicrobial, antioxidant, and anticancer properties. These complexes can interact strongly with proteins, nucleic acids, and enzymes, thereby influencing several biochemical pathways. The therapeutic importance of vanadium compounds has been widely explored in diabetes treatment, cancer therapy, and antimicrobial drug development. Schiff base vanadium complexes, in particular, exhibit enhanced biological activity because Schiff base ligands improve the stability and coordination efficiency of the metal ion.

The emergence of multidrug-resistant microbial strains has become a serious global health concern. Conventional antibiotics are gradually losing effectiveness due to microbial resistance mechanisms such as mutation, enzyme-mediated drug degradation, and biofilm formation. Consequently, there is an urgent need to develop novel antimicrobial agents with improved therapeutic efficiency. Transition metal complexes have emerged as promising alternatives because metal coordination can significantly enhance biological activity. Chelation reduces the polarity of the metal ion and increases lipophilicity, thereby facilitating penetration through microbial cell membranes.

Recent developments in coordination chemistry and nanotechnology have further expanded the biomedical applications of iron and vanadium complexes. Researchers have developed nanoparticle-supported metal complexes, hybrid materials, and polymer-based systems to improve drug delivery, selectivity, and pharmacological performance. Structural modification of ligands through electron-donating and electron-withdrawing substituents has also been investigated to optimize biological activity and stability.

This review aims to discuss the coordination chemistry, antimicrobial activity, antioxidant behavior, and biomedical significance of iron and vanadium complexes. Comparative evaluation of these metal systems is presented with emphasis on their structural characteristics, biological mechanisms, therapeutic applications, and future prospects in medicinal chemistry.

2. Methodology

2.1 Literature Collection

Scientific articles related to iron and vanadium complexes were collected from databases including [ScienceDirect](#), [PubMed](#), [SpringerLink](#), and [Google Scholar](#).

2.2 Inclusion Criteria

The review included:

- Experimental studies on iron and vanadium complexes
- Antimicrobial and antioxidant investigations
- Biomedical and therapeutic applications
- Peer-reviewed articles published between 2010–2026

2.3 Characterization Techniques

The reviewed studies commonly employed:

- FT-IR Spectroscopy
- UV–Visible Spectroscopy
- NMR Spectroscopy
- X-ray Diffraction
- Thermogravimetric Analysis
- Mass Spectrometry

3. Results and Discussion

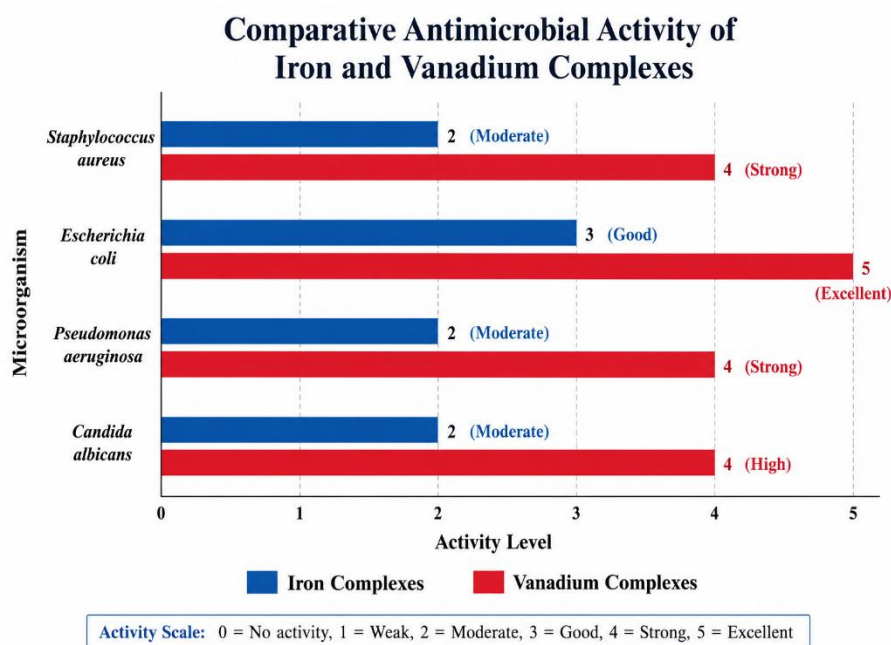
3.1 Antimicrobial Activity

Iron and vanadium complexes demonstrated significant antimicrobial activity against several pathogenic microorganisms.

Table 1. Comparative Antimicrobial Activity of Iron and Vanadium Complexes

Microorganism	Iron Complexes	Vanadium Complexes
<i>Staphylococcus aureus</i>	Moderate	Strong
<i>Escherichia coli</i>	Good	Excellent
<i>Pseudomonas aeruginosa</i>	Moderate	Strong
<i>Candida albicans</i>	Moderate	High

Graph 1: Comparative antimicrobial activity of Iron and Vanadium complexes



Vanadium complexes generally exhibited stronger antimicrobial activity than iron complexes. This enhanced activity may be attributed to higher redox behavior and stronger interaction with microbial enzymes and DNA.

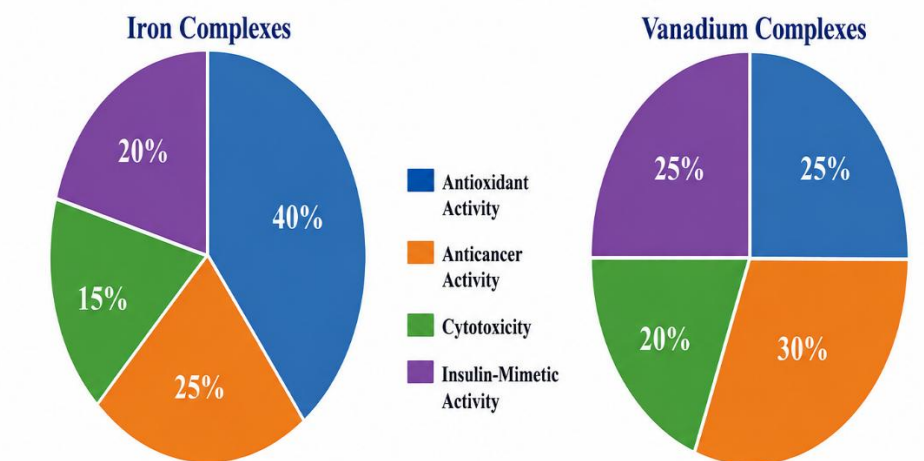
3.2 Antioxidant Activity

Iron complexes demonstrated excellent antioxidant properties due to their redox-active behavior and enzyme-mimetic activity.

Table 2. Antioxidant and Biomedical Properties

Property	Iron Complexes	Vanadium Complexes
Antioxidant Activity	Excellent	Good
Anticancer Activity	Moderate	High
Cytotoxicity	Low	Moderate
Insulin-Mimetic Activity	Low	Excellent

Graph 2. Distribution of Antioxidant and Biomedical Applications of Iron and Vanadium Complexes



Iron complexes showed superior antioxidant behavior because of their ability to scavenge reactive oxygen species. Vanadium complexes exhibited stronger anticancer and insulin-mimetic activity.

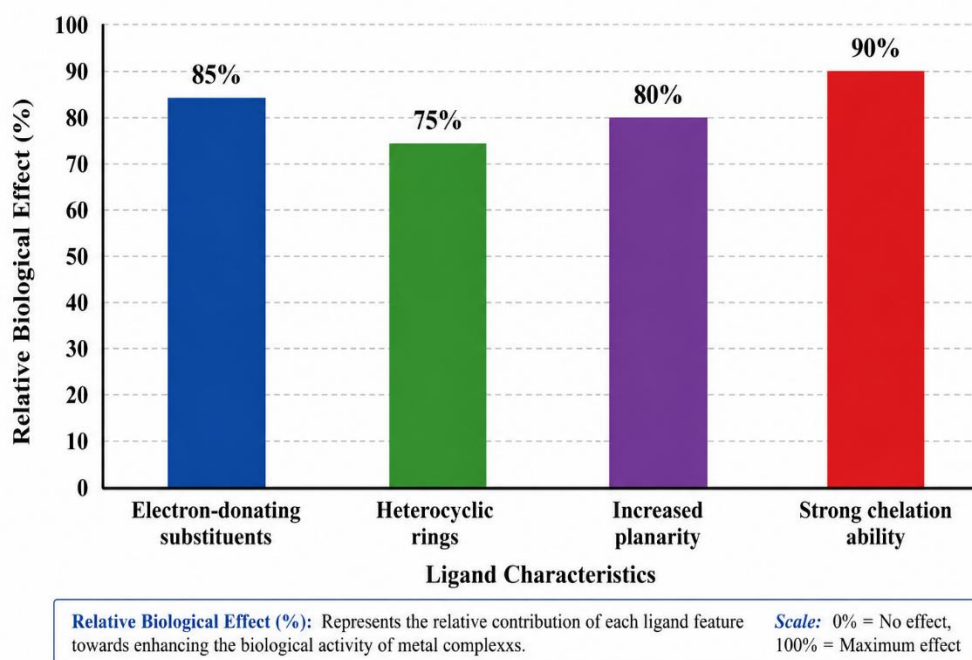
3.3 Influence of Ligand Structure

The biological activity of coordination complexes is significantly influenced by ligand structure and donor atom characteristics.

Table 3. Influence of Ligand Characteristics on Biological Activity

Ligand Feature	Biological Effect
Electron-donating groups	Increased antimicrobial activity
Heterocyclic rings	Enhanced DNA interaction
Increased planarity	Better membrane penetration
Strong chelation ability	Improved stability

Graph 3. Influence of Ligand Characteristics on Biological Activity



Ligands containing nitrogen and oxygen donor atoms improved biological activity through enhanced coordination stability and membrane permeability.

3.4 Biomedical Applications

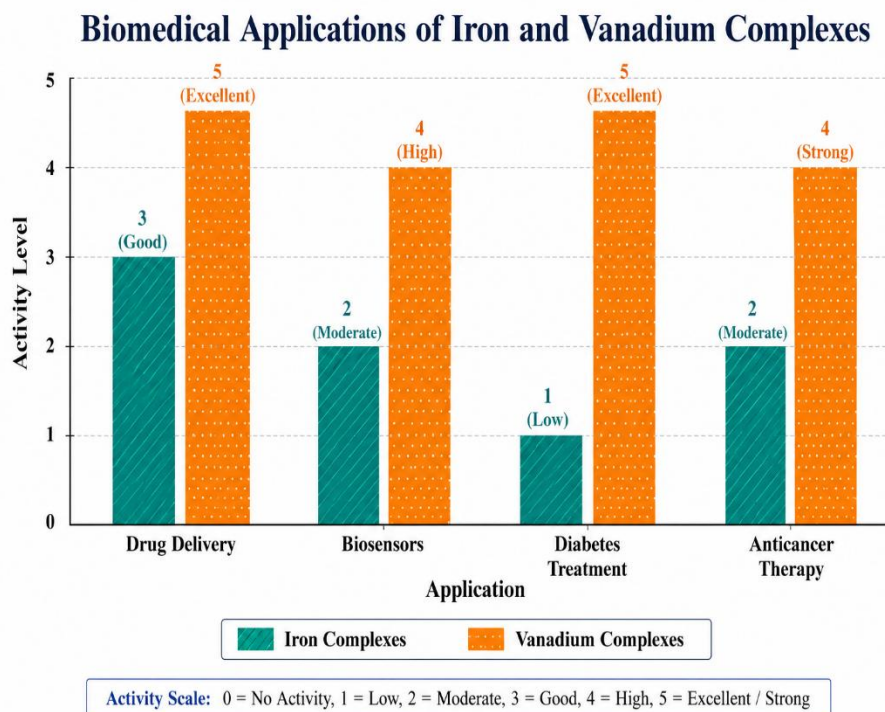
Iron and vanadium complexes have shown significant biomedical applications in:

- Anticancer therapy
- Antidiabetic treatment
- Drug delivery systems
- Biosensor development
- Antioxidant therapy

Table 4. Biomedical Applications of Iron and Vanadium Complexes

Application	Iron Complexes	Vanadium Complexes
Drug Delivery	Good	Excellent
Biosensors	Moderate	High
Diabetes Treatment	Low	Excellent
Anticancer Therapy	Moderate	Strong

Figure 4: Biomedical applications of Iron and Vanadium complexes



Vanadium complexes displayed greater therapeutic versatility, particularly in diabetes treatment and anticancer applications, whereas iron complexes showed greater biological compatibility and antioxidant efficiency.

4. Summary and Conclusion

Iron and vanadium coordination complexes represent highly promising compounds in medicinal and bioinorganic chemistry. Their biological activity is strongly influenced by coordination geometry, oxidation state, and ligand structure. Iron complexes exhibit excellent antioxidant activity, lower toxicity, and superior biocompatibility, while vanadium complexes demonstrate stronger antimicrobial, insulin-mimetic, and anticancer properties.

Comparative evaluation suggests that vanadium complexes possess enhanced pharmacological activity because of their multiple oxidation states and stronger redox behavior. However, iron complexes remain more biologically compatible and safer for therapeutic use. Advances in

nanotechnology and ligand engineering may further improve the stability, selectivity, and biomedical applications of these complexes.

Future investigations should focus on toxicity reduction, targeted drug delivery, and clinical evaluation of iron and vanadium complexes for developing next-generation therapeutic agents.

References

1. Hugo Schiff, "Condensation Products of Amines and Aldehydes," *Annalen der Chemie*, 1864.
2. Cotton, F.A., and Wilkinson, G., *Advanced Inorganic Chemistry*, Wiley Publications.
3. Rehder, D., *Vanadium: Its Role in Life*, Springer Publications, 2008.
4. Thompson, K.H., and Orvig, C., "Vanadium compounds in medicinal chemistry," *Journal of Inorganic Biochemistry*, 2006.
5. Crans, D.C., "Chemistry and insulin-like properties of vanadium compounds," *Journal of Biological Inorganic Chemistry*, 2000.
6. Gupta, K.C., and Sutar, A.K., "Catalytic activities of Schiff base complexes," *Coordination Chemistry Reviews*, 2008.
7. Chohan, Z.H., et al., "Metal-based antibacterial agents," *Bioinorganic Chemistry and Applications*, 2006.
8. Raman, N., et al., "Antimicrobial studies of Schiff base complexes," *Journal of Chemical Sciences*, 2010.
9. Dhar, D.N., and Taploo, C.L., "Schiff bases and applications," *Journal of Scientific and Industrial Research*, 1982.
10. Joseph, J., and Nagashri, K., "Biological activities of transition metal complexes," *Journal of Chemical Sciences*, 2008.
11. Kostova, I., "Metal complexes as antimicrobial agents," *Current Medicinal Chemistry*, 2006.

12. Ali, M.A., et al., "Biological applications of Schiff base complexes," *Transition Metal Chemistry*, 2012.
13. Sakurai, H., "Pharmacological aspects of vanadium complexes," *Chemical Record*, 2002.
14. Abdel-Rahman, L.H., "Spectral and antimicrobial studies of metal complexes," *Spectrochimica Acta Part A*, 2013.
15. Butler, A., and Clague, M.J., "Vanadium compounds in biological systems," *Coordination Chemistry Reviews*, 1999.
16. Mishra, A.P., and Pandey, L.R., "Synthesis and antimicrobial activities of metal complexes," *Indian Journal of Chemistry*, 2005.
17. Cozzi, P.G., "Metal-Salen Schiff base complexes," *Chemical Society Reviews*, 2004.
18. Ispir, E., "Transition metal Schiff base complexes," *Dyes and Pigments*, 2009.
19. Parekh, H.M., and Patel, M.N., "Biological activity of Schiff base complexes," *Russian Journal of Coordination Chemistry*, 2006.
20. Belaid, S., et al., "Vanadium Schiff base complexes and biological applications," *Polyhedron*, 2008.