Crimson Publishers
Wings to the Research

Mini Review

Recent Advances of Polypyrrole for Biomedical Applications – A Mini-Review

ISSN: 2576-8840

Sai Prasad Nayak*, Bhavana Rikhari*

Department of Chemistry, Dayananda Sagar University, India

***Corresponding author:** Sai Prasad Nayak and Bhavana Rikhari, Department of Chemistry, Dayananda Sagar University, Kudlu gate, Hosur main road, Bengaluru 560068, India

Submission: July 20, 2023
Published: August 07, 2023

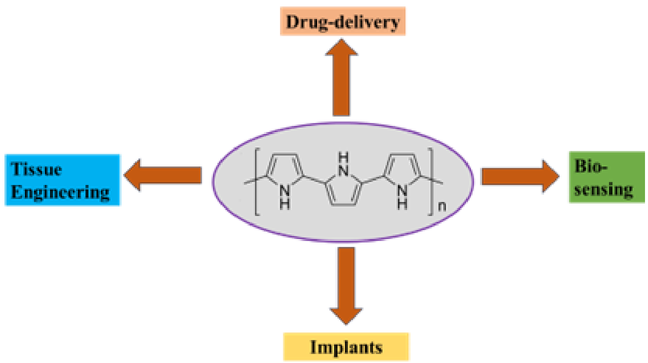
Volume 19 - Issue 2

How to cite this article: Sai Prasad Nayak*, Bhavana Rikhari*. Recent Advances of Polypyrrole for Biomedical Applications – A Mini-Review. Res Dev Material Sci. 19(2). RDMS. 000958. 2023.
DOI: 10.31031/RDMS.2023.19.000958

Abstract

The conducting polymers are conjugated carbon chains with alternating single and double bonds with highly delocalized, polarized, and electron-dense π bonds that are responsible for their electrical behaviour. Amongst various conducting polymers, polypyrrole (PPy) is a heterocyclic oxidized pyrrole which is one of the most demanding conducting polymers that has gained significant attention in the field of biomedical applications due to their unique electrical and physicochemical properties. This mini-review provides an overview of the synthesis and recent applications of PPy for various biomedical applications such as tissue engineering, bio-sensing, drug delivery, and implants.

Keywords: Conducting polymer; Polypyrrole; Bio-medical applications



Graphical abstract

Introduction

Background

Polypyrrole (PPy) is an inherent conducting polymer widely employed as a biomaterial due to its remarkable attributes, including electrical conductivity, stability, and outstanding biocompatibility [1]. PPy's electrical conductivity and biocompatibility makes it an ideal material for developing more advanced neural interfaces and implants. Biocompatibility is the property of a biomaterial without adverse effect on the human body. PPy is non-toxic and does not induce significant inflammation or immune response when implanted *in-vivo*. PPy-based drug delivery systems have shown tolerance in preclinical studies. However, it is important to note that the biocompatibility of PPy can be influenced by synthesis method. The special properties of PPy makes it a promising material which has resulted an extensive research and application of PPy in various domains, like biomedical, electronics, and energy storage.

This mini-review provides a comprehensive overview of the synthesis and recent advances in the utilization of PPy for biomedical applications.

Synthesis of PPy

Synthesis of PPy is majorly carried out from its monomer pyrrole (Py) by following a) chemical oxidation and b) electro polymerisation methods. The structure of Py monomer and polypyrrole is shown in Fig. 1. The chemical oxidation is carried out by using Py monomer, along with oxidizing agents such as $FeCl_3$, other salts of iron (III) and copper (II) in an appropriate solvent such as water, alcohols, benzene, tetrahydrofuran, chloroform, acetone, acetonitrile, dimethylformamide for a particular duration at an optimum temperature [2]. Electro polymerisation is an alternative method where various potential forms such as potentiostatic (constant potential), potentiodynamic (cyclic voltammetry), galvanostatic (constant current), and the pulsed techniques are applied on a solution containing Py monomer in both aqueous and non-aqueous media to obtain PPy [2]. The electro polymerisation of PPy films can occur in acidic, neutral and basic aqueous solutions [3] and non-aqueous mediums such as acetonitrile, dichloromethane, and propylene carbonate [2]. Combination of aqueous and non-aqueous media is preferred for higher yield [4]. Electrochemical polymerization provides various advantages over chemical oxidation such as a) tuning the thickness of PPy on electrode surface and b) higher yield of PPy (Figure 1).

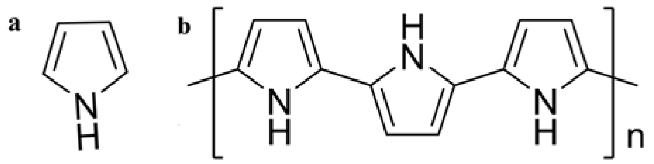


Figure 1: Structure of a) Py monomer b) PPy.

Biomedical applications of PPy

The electroconductive multi-functional PPy has various biomedical applications, which are mentioned below:

Tissue Engineering: PPy can be integrated into three-dimensional scaffolds used in tissue engineering to provide structural support for cell growth and tissue formation. Its unique electrical conductivity enables the application of electrical stimulation directly to the cells residing within the scaffold [5]. Research has demonstrated that electrical stimulation can influence cellular behavior, including enhancing cell adhesion, proliferation, and differentiation. By incorporating PPy into scaffolds, it becomes possible to promote cell attachment and tissue regeneration by using electrical stimulation.

Drug delivery systems: PPy can be utilized as a carrier material in drug delivery systems to encapsulate and release therapeutic agents [6]. The drug molecules can be loaded into the PPy matrix either through physical encapsulation or chemical conjugation. PPy-based drug delivery systems offer several advantages, such as targeted and controlled drug release, protection of the drug from degradation, and the ability to incorporate multiple drugs within the same system.

Bio-sensing: PPy, exhibits good electrical conductivity, enhanced surface area and low charge transfer resistance which is essential for their application in bio-sensing [7]. PPy-based nanocomposites possess potential to provide better diffusion paths for smaller ions, organic, inorganic and biomolecules. These properties allow for better signal transduction and enhanced sensitivity in PPy-based biosensors [7]. PPy-based biosensors have been employed for detection of neural signals or monitoring neurotransmitter release [8]. The biocompatibility and electrical properties of PPy makes it an ideal material for interfacing with neural tissues. PPy is inherently electroactive, which means it can undergo reversible redox reactions when stimulated by electrical signals. It can facilitate direct communication with biological systems and provide real-time monitoring with control capabilities.

Implant: PPy coated on titanium (Ti) metal behaves as a promising implant for orthopaedic applications [9]. PPy-coated Ti implants has shown promising potential as an orthopaedic implant material. Titanium is renowned for its exceptional biocompatibility, osseo-integration, and corrosion resistance properties. The formation of PPy layer also enhances the biocompatibility of the Ti implant by reducing the release of metal ions from its surface, thereby promoting long-term stability, and minimizing adverse reactions. Moreover, the PPy coating facilitates improved osseo-integration, creating a favourable surface for bone cells to attach and grow, resulting in a stronger bond between the implant and the surrounding bone. Additionally, PPy coatings enhance the corrosion resistance of the Ti implants, safeguarding them from degradation and prolonging their lifespan within the body.

Conclusion and Future Perspectives

In this mini-review, we have presented that the electro polymerization of PPy is preferred due to a higher yield of desired thickness. PPy's outstanding properties have positioned it as a highly favored material in the biomedical field, extensive research, and development for a diverse array of medical applications and devices due to high surface area, flexibility, and ease of using.

PPy holds a great scope in biomedical applications. The future research can focus on improving biocompatibility, stability, and advanced fabrication techniques. The clinical translation of PPy can be explored for long-term monitoring and therapeutics in future. Advanced research in these domains can impel the field of conducting polymers and leads to transformation in healthcare industry.

References

1. Singh N (2022) Polypyrrole-based emerging and futuristic hybrid nanocomposites. Polymer Bulletin 79: 6929-7007.
2. Vernitskaya TV, Efimov ON (1997) Advances in Chemistry 66: 502-505.
3. Asavapiriyanont S, Chandler GK, Gunawardena GA, Pletcher D (1984) Journal of Electroanalytical Chemistry 177: 229-244.
4. Zotti G, Cattarin S, Comisso N (1987) Journal of Electroanalytical Chemistry 235: 259-273.
5. Huang ZB, Yin GF, Liao XM, Gu JW (2014) Frontiers of Materials Science 8: 39-45.
6. Geetha S, Rao CRK, Vijayan M, Trivedi DC (2006) Analytica Chimica Acta 568: 119-125.

7. Jain R, Jadon N, Pawaiya A (2017) TrAC - Trends in Analytical Chemistry 97: 363-373.

8. Alahmadi N, El-Said WA (2023) Biosensors 13: 578.

9. Mathai S, Shaji PS (2023) Bioactive conductive polymeric nanocomposite coating for titanium implants. Materials Today: Proceedings.