INTERNATIONAL JOURNAL OF PHARMACEUTICAL SCIENCES
[ISSN: 0975-4725; CODEN(USA): IJPS00]
Journal Homepage: https://www.ijpsjournal.com

OPEN ACCESS

Review Article

Innovations And Future Prospects in COPD Management: Advancing Treatment and Care

Nancy Srivastava, Dr. Umesh Pratap Singh, Priyanka Pal, Purnendra Gupta, Sandeep Singh, Alok Dixit

Rameshwaram Institute of Technology and Management, Lucknow, India.

ARTICLE INFO

Published: 28 June 2025
Keywords:
Global Health, Biologic Therapies, AI and Digital Health, Advanced Drug Delivery, Current challenges, COPD Treatment Innovations.
DOI:
10.5281/zenodo.15757931

ABSTRACT

Chronic Obstructive Pulmonary Disease (COPD) remains a major cause of disease, death, and economic burden globally, particularly in low- and middle-income countries where access to new therapies remains limited. New strategies are being formulated to revolutionize the management of COPD as the global health landscape evolves. Treatment strategies are evolving due to advances in precision medicine, biologic therapies, and AI-based healthcare solutions. By targeting inflammation at the molecular level, biologic drugs such as Dupixent are creating new opportunities for individualized treatment. AI-based diagnostic devices and intelligent inhalers are some of the digital health technology that are improving patient compliance, disease monitoring, and early diagnosis. In addition, treatment efficacy and patient outcomes are being enhanced by regenerative medicine and next-generation drug delivery technologies such as sustained-release inhalers and nano-formulations. The future of COPD management will be defined by innovation, access, and targeted interventions as the world progresses toward a more technology-driven and globalized health environment. The paper discusses the most recent progress and looks to a future where managing COPD becomes more effective, equitable, and sustainable across the globe.

INTRODUCTION

Chronic obstructive pulmonary disease (COPD) is the fourth leading cause of death worldwide, responsible for 3.5 million deaths in 2021. It disproportionately affects low- and middle-income countries, where most deaths occur before age 70. Beyond mortality, COPD is a major cause of poor health globally. While smoking is the primary risk factor in high-income countries, household air pollution plays a significant role in lower-income regions. Reducing risk factors and improving early diagnosis are key to addressing its growing burden. [1]

***Corresponding Author:** Nancy Srivastava
Address: *Rameshwaram Institute of Technology and Management, Lucknow, India*
Email : nancysrivas70@gmail.com

Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

COPD is a major global health challenge, affecting millions of people and placing a heavy burden on healthcare systems. It's a progressive lung disease that makes breathing increasingly difficult, often due to long-term exposure to harmful pollutants like cigarette smoke, air pollution, and workplace irritants. Despite being preventable in many cases, COPD remains one of the leading causes of death worldwide, yet it is frequently underdiagnosed and undertreated. [2, 3]

Over the last 30 years, the number of people living with COPD has continued to rise, largely due to aging populations and persistent exposure to risk factors. Research shows that different regions experience varying levels of disease burden, influenced by lifestyle, environmental conditions, and access to healthcare. [4]

COPD management is complicated by its slow progression and the presence of other health conditions like heart disease, diabetes, and osteoporosis, which can make treatment more difficult. [5]

Early diagnosis remains a major challenge, as many people don't recognize symptoms until the disease has significantly progressed, leading to delayed treatment. [6] Additionally, COPD care is evolving beyond symptom management to focus on preventing disease progression and inflammation. As new treatments emerge, healthcare systems must adapt to provide more personalized and effective care. [7]

The role of pharmaceutical innovation in COPD care:

Advances in drug delivery and precision medicine are transforming COPD treatment, making it more targeted and effective. [8] Personalized approaches now focus on providing the right treatment at the right time based on individual needs. [9] Emerging therapies using biomarkers and innovative drug formulations offer hope for better disease control and improved quality of life. [10] As research progresses, pharmaceutical innovation will continue to shape the future of COPD care.

2. Emerging Innovations in COPD Treatment

Biologic Therapies: Biologic therapies, particularly monoclonal antibodies, are revolutionizing COPD treatment by targeting specific inflammatory pathways. The approval of Dupixent (dupilumab) by the FDA marks a breakthrough for patients with eosinophilic COPD, significantly reducing exacerbations and improving lung function. With Phase 3 trials confirming its effectiveness, Dupixent has become the most prescribed biologic by pulmonologists, signaling a shift toward precision-based COPD care. Ongoing research into new biologic targets is expanding treatment options, offering hope for select patient populations [11, 12].

Precision Medicine: Advances in genetic and biomarker-driven approaches are allowing for more tailored COPD treatments, ensuring that patients receive medications best suited to their specific disease subtype. Biomarkers help identify COPD variations, guiding targeted therapies and improving treatment precision [13], [14]. However, fully integrating precision medicine into routine care remains a challenge, requiring further research and healthcare adaptation to make personalized treatments widely accessible [15].

AI and Digital Health: Technology is making COPD care more personalized and proactive. Smart inhalers, equipped with sensors, track medication use, improve inhaler technique, and provide real-time feedback, helping patients manage their condition more effectively [16], [17]. AI is also accelerating drug discovery by identifying new treatment possibilities, while

remote monitoring tools and mobile apps, enable doctors to track symptoms, detect exacerbations early, and reduce hospitalizations [18]. While these innovations offer exciting advancements, challenges like data privacy, accessibility, and healthcare integration must be addressed to maximize their impact.

Regenerative Medicine: Stem cell-based therapies are emerging as a potential game-changer in COPD treatment, aiming to repair lung damage, reduce inflammation, and restore lung function [19]. Early studies suggest these treatments may slow disease progression and promote lung tissue regeneration. However, variability in patient response, lack of standardized protocols, and long-term safety concerns remain key hurdles. While still in the experimental stage, regenerative medicine holds immense promise for the future of COPD care, requiring further clinical validation and research before widespread adoption.

With ongoing advancements in biologics, precision medicine, AI-driven care, and regenerative treatments, COPD management is entering a new era of innovation, offering hope for better disease control, improved quality of life, and long-term treatment breakthroughs.

3. Future Prospects in COPD Care

Advancements in COPD treatment are focusing on next-generation drug development, innovative therapeutic delivery systems, and biomarker-driven approaches. Novel bronchodilators and anti-inflammatory agents are being developed to enhance symptom control and slow disease progression [20]. Advanced drug delivery systems, including nanotechnology and inhalable biologics, aim to improve treatment precision and efficacy by targeting airway remodeling and inflammation more effectively [21]. Biomarker research is playing a crucial role in predicting disease progression, personalizing treatment, and improving early diagnosis [22]. Additionally, integrating clinical and molecular data could lead to more tailored interventions and better patient outcomes [23].

AI-driven predictive analytics are transforming COPD management by forecasting disease progression and optimizing treatment strategies. Wearable devices and mobile health applications enable real-time monitoring, reducing hospitalizations and improving patient outcomes [24]. Innovations in nano-formulations, long-acting inhalers, and inhaled RNA therapeutics are enhancing drug efficacy and patient adherence, while wearable respiratory devices ensure continuous bronchodilator delivery, addressing limitations of traditional inhalers [25]. AI-assisted imaging techniques and biomarker-based detection are facilitating early and accurate COPD diagnosis, shifting the focus of COPD management toward proactive interventions [26].

While these technological and therapeutic advancements offer promising possibilities, further research, clinical validation, and strategic implementation are needed to ensure widespread adoption and improve long-term COPD outcomes.

4. Case Studies and Real-World Applications

Table I:

S.No.	Category	Key Findings	Source
Innovative COPD Treatments in Clinical Trials and Healthcare Settings			
1.	Machine Learning for Readmission Prediction	AI models analyzing patient data improved readmission risk prediction (AUC 0.60 →	[27]

		0.653). Early identification of high-risk patients allows for better intervention.	
2.	Triple Therapy (ICS/LABA/LAMA) Effectiveness	Trelegy Ellipta (fluticasone furoate, vilanterol, umeclidinium) showed better symptom control and lung function improvements compared to dual therapy.	[28]
3.	Secretion Clearance in Advanced COPD	Airway clearance therapy (The Vest™) led to significant improvement in mucus clearance, reduced hospitalizations, and better quality of life.	[29]
4.	Role of Vitamin C & Trace Minerals	Vitamin C deficiency linked to worsening COPD symptoms (wheezing, dyspnea). Dietary intake can help reduce oxidative stress and enhance lung function.	[30]
5.	Blood eosinophil count correlated with COPD treatment patterns in South Korea, influencing ICS prescription decisions.	Supports precision medicine approaches for COPD therapy.	[31]
6.	Focused on early COPD diagnosis and treatment, stressing spirometry and risk factor identification	Highlights the importance of early intervention to prevent disease progression	[32]
Success Stories of AI and Digital Health in COPD Management			
7.	AI-Based Risk Stratification	Machine learning algorithms enabled early COPD exacerbation prediction, reducing hospital admissions.	[27]
8.	Telemedicine and Digital Health Gaps	Real-world studies highlight underuse of remote monitoring and digital adherence tools, despite their potential in improving COPD outcomes.	[33]
9.	Patient-Centered Digital Interventions	A 73-year-old COPD patient benefited from AI-driven care pathways, integrating digital monitoring and predictive analytics.	[34]
10.	Investigated the **link between COPD and non-alcoholic fatty liver disease (NAFLD),** suggesting shared inflammatory pathways.	Highlights the need for multidisciplinary approaches in COPD patients with metabolic comorbidities.	[36]
11.	Reviewed **COPD treatment guidelines and comorbidities**, emphasizing **personalized care strategies**	Strengthens the case for integrated COPD management and comorbidity screening	[37]
Real-World Data on COPD Management Gaps			
12.	Delayed Diagnosis & Missed Opportunities	85% of COPD patients had missed diagnosis chances in the five years before confirmation. Many were not diagnosed until severe airflow limitation occurred.	[33]
13.	Medication Non-Adherence & Overuse	Overuse of inhaled corticosteroids (ICS) and underuse of bronchodilators led to suboptimal disease control.	[33]
14.	Preventable COPD Hospitalizations	21% of COPD patients are readmitted within 30 days. AI-driven interventions can help reduce exacerbation-related readmissions.	[27]
15.	COPD Exacerbation & Co-Morbid Conditions	A 67-year-old COPD patient with diabetes and osteoarthritis faced worsening dyspnea and	[35]

		reduced mobility. Early intervention could have prevented severe progression.	
16.	COPD and Chronic Bronchitis/Bronchiectasis	A 53-year-old COPD patient with chronic bronchitis and bronchiectasis improved significantly with airway clearance therapy. Quality of life and hospital-free survival increased.	[29]
17.	Explored **COPD prevention, diagnosis, and treatment strategies in low- and middle-income countries (LMICs)**	Underlines the role of primary care and cost-effective interventions.	[38]
18.	Found that **earlier diagnosis and treatment in primary care** lead to better outcomes in COPD.	Supports early intervention programs and primary care engagement.	[39]

5. Challenges for COPD Innovation

Despite significant advancements in COPD treatments and digital health technologies, several barriers continue to limit widespread adoption and slow the pace of innovation. Many patients struggle to obtain new inhalation therapies and biologics due to cost constraints and lack of insurance coverage [40]. Primary care providers often lack training in emerging COPD management strategies, leading to inconsistent treatment approaches [41]. Additionally, low awareness and poor inhaler technique reduce the effectiveness of advanced drug delivery systems, limiting treatment success rates [40]. Ethical concerns surrounding AI-driven risk prediction and remote monitoring focus on data privacy, algorithmic bias, and patient autonomy, while strict regulatory frameworks delay the approval of biologic treatments and precision medicine approaches. In low- and middle-income countries (LMICs), disparities in healthcare infrastructure and resource allocation further restrict access to cutting-edge COPD therapies [38]. Looking ahead, biomarker-based therapies and genetic profiling will help optimize individualized COPD treatment plans, ensuring more effective and targeted interventions [31]. AI-driven diagnostic tools, predictive analytics, and remote monitoring will enhance early detection, risk assessment, and personalized treatment adjustments [27]. Strengthening collaboration between academia, industry, and policymakers will accelerate the development of novel inhalation therapies, biologic treatments, and digital therapeutics, making COPD care more accessible and effective [40].

CONCLUSION

COPD management has seen remarkable advancements, from triple therapy inhalers improving symptom control to AI-driven tools predicting exacerbations and reducing hospital readmissions [28], [27]. Digital health innovations, like smart inhalers and remote monitoring, are transforming care by enhancing adherence and real-time symptom tracking [33]. Personalized medicine, using biomarkers like blood eosinophil counts, is refining treatment

strategies; ensuring patients receive the most effective therapies [31]. Looking ahead, AI and digital health will continue to revolutionize early diagnosis and management, while new drug delivery systems and biologics promise more tailored and effective treatments. Healthcare improvements must prioritize early intervention, patient education, and equitable access to these innovations [42]. However, to truly advance COPD care, continued research into emerging therapies like gene therapy and regenerative medicine, stronger policy support for global treatment accessibility and greater collaboration between researchers, industry, and healthcare providers are essential. By embracing these opportunities, we can ensure that COPD patients receive better, more personalized, and more accessible care, ultimately improving their quality of life.

REFERENCES

1. World Health Organization. (n.d.). Chronic obstructive pulmonary disease (COPD). World Health Organization. Retrieved [6 November 2024], from https://www.who.int/news-room/fact-sheets/detail/chronic-obstructive-pulmonary-disease-(copd)
2. Quaderi SA, Hurst JR. The unmet global burden of COPD. Global Health, Epidemiology and Genomics. 2018;3:e4. doi:10.1017/gheg.2018.1)
3. López-Campos, J. L., Tan, W., & Soriano, J. B. (2015). Global burden of COPD. Respirology, 21(1), 14-23. doi:10.1111/resp.12660
4. Li, H-Y., Gao, T-Y., Fang, W., Xian-Yu, C-Y., Deng, N-J., Zhang, C., & Niu, Y-M. (2022). Global, regional, and national burden of chronic obstructive pulmonary disease over a 30-year period: Estimates from the 1990 to 2019 Global Burden of Disease Study. Respirology, 28(1), 29-36. doi:10.1111/resp.14349
5. Mariniello, D. F., D'Agnano, V., Cennamo, D., Conte, S., Quarcio, G., Notizia, L., Pagliaro, R., Schiattarella, A., Salvi, R., Bianco, A., & Perrotta, F. (2024). Comorbidities in COPD: Current and Future Treatment Challenges. Journal of Clinical Medicine, 13(3), 743. https://doi.org/10.3390/jcm13030743
6. Doña, E., Reinoso-Arija, R., Carrasco-Hernandez, L., Doménech, A., Dorado, A., & Lopez-Campos, J. L. (2023). Exploring Current Concepts and Challenges in the Identification and Management of Early-Stage COPD. Journal of Clinical Medicine, 12(16), 5293. https://doi.org/10.3390/jcm12165293
7. Agustí, A., Vogelmeier, C., & Faner, R. (2020). COPD 2020: changes and challenges. American Journal of Physiology-Lung Cellular and Molecular Physiology, 319(5), L879-L883.
8. Wang, J., Wang, P., Shao, Y., & He, D. (2023). Advancing Treatment Strategies: A Comprehensive Review of Drug Delivery Innovations for Chronic Inflammatory Respiratory Diseases. Pharmaceutics, 15(8), 2151. https://doi.org/10.3390/pharmaceutics15082151
9. Agusti, A., Ambrosino, N., Blackstock, F., Bourbeau, J., Casaburi, R., Celli, B., ... & ZuWallack, R. (2023). COPD: providing the right treatment for the right patient at the right time. Respiratory Medicine, 207, 107041.
10. Appleton, L. K., Hanania, N. A., & Adrish, M. (2024). Personalized COPD Care: The Future of Precision-Based Therapies. Journal of clinical medicine, 13(21), 6339. https://doi.org/10.3390/jcm13216339
11. (Sanofi. (2024, September 27). FDA approves Dupixent (dupilumab) as first biologic to treat

COPD with an eosinophilic phenotype. Sanofi. https://www.sanofi.com/en/media-room/press-releases/2024/2024-09-27-13-35-00-2954551)

12. Kersul, A. L., & Cosio, B. G. (2024). Biologics in COPD. Open respiratory archives, 6(2), 100306. https://doi.org/10.1016/j.opresp.2024.100306
13. Shakshuki, A., Agu, R.U. Improving the Efficiency of Respiratory Drug Delivery: A Review of Current Treatment Trends and Future Strategies for Asthma and Chronic Obstructive Pulmonary Disease. Pulm Ther 3, 267–281 (2017). https://doi.org/10.1007/s41030-017-0046-2
14. Pantazopoulos, I., Magounaki, K., Kotsiou, O., Rouka, E., Perlikos, F., Kakavas, S., & Gourgoulianis, K. (2022). Incorporating Biomarkers in COPD Management: The Research Keeps Going. Journal of personalized medicine, 12(3), 379. https://doi.org/10.3390/jpm12030379
15. Franssen, F. M., Alter, P., Bar, N., Benedikter, B. J., Iurato, S., Maier, D., Maxheim, M., Roessler, F. K., Spruit, M. A., Vogelmeier, C. F., Wouters, E. F., & Schmeck, B. (2019). Personalized medicine for patients with COPD: where are we?. International journal of chronic obstructive pulmonary disease, 14, 1465–1484. https://doi.org/10.2147/COPD.S175706
16. Greene, G., & Costello, R. W. (2019). Personalizing medicine - could the smart inhaler revolutionize treatment for COPD and asthma patients? Expert Opinion on Drug Delivery, 16(7), 675–677. https://doi.org/10.1080/17425247.2019.1628017
17. Watson, A., & Wilkinson, T. M. A. (2022). Digital healthcare in COPD management: a narrative review on the advantages, pitfalls, and need for further research. Therapeutic advances in respiratory disease, 16, 17534666221075493. https://doi.org/10.1177/17534666221075493
18. Chan, A. H. Y., Pleasants, R. A., Dhand, R., Tilley, S. L., Schworer, S. A., Costello, R. W., & Merchant, R. (2021). Digital Inhalers for Asthma or Chronic Obstructive Pulmonary Disease: A Scientific Perspective. Pulmonary therapy, 7(2), 345–376. https://doi.org/10.1007/s41030-021-00167-4
19. Calzetta, L., Aiello, M., Frizzelli, A., Camardelli, F., Cazzola, M., Rogliani, P., & Chetta, A. (2022). Stem Cell-Based Regenerative Therapy and Derived Products in COPD: A Systematic Review and Meta-Analysis. Cells, 11(11), 1797. https://doi.org/10.3390/cells11111797
20. Gong, L., & Tawil, B. (2024). A Review of Chronic Obstructive Pulmonary Disease (COPD) and its Effects, Treatment Market, Products, and Upcoming Developments. Scholastic Medical Sciences, 2, 01-10.
21. Dhanjal, D. S., Sharma, P., Mehta, M., Tambuwala, M. M., Prasher, P., Paudel, K. R., ... & Satija, S. (2022). Concepts of advanced therapeutic delivery systems for the management of remodeling and inflammation in airway diseases. Future Medicinal Chemistry, 14(4), 271-288.
22. Li, C. L., & Liu, S. F. (2024). Exploring molecular mechanisms and biomarkers in COPD: an overview of current advancements and perspectives. International Journal of Molecular Sciences, 25(13), 7347
23. Gonçalves, I., Guimarães, M. J., van Zeller, M., Menezes, F., Moita, J., & Simão, P. (2018). Clinical and molecular markers in COPD. Pulmonology, 24(4), 250–259.
24. Long H, Li S, Chen Y. Digital health in chronic obstructive pulmonary disease. Chronic Dis Transl Med. 2023; 9: 90-103. doi:10.1002/cdt3.68

25. Xu, Y., Thakur, A., Zhang, Y., & Foged, C. (2021). Inhaled RNA therapeutics for obstructive airway diseases: recent advances and future prospects. Pharmaceutics, 13(2), 177.
26. Baker, K. E., Bonvini, S. J., Donovan, C., Foong, R. E., Han, B., Jha, A., ... & Moir, L. M. (2014). Novel drug targets for asthma and COPD: lessons learned from in vitro and in vivo models. Pulmonary pharmacology & therapeutics, 29(2), 181-198.
27. Xu, M., Yu, B., & Wang, F. (2019). Predictive Modeling of the Hospital Readmission Risk from Patients' Claims Data Using Machine Learning: A Case Study on COPD. Scientific Reports, 9, 2362. [DOI: 10.1038/s41598-019-39071-y]
28. Englis, R. (2018). COPD Case Study. Nursing Capstones, University of North Dakota, 78. [Available at: https://commons.und.edu/nurs-capstones/78]
29. Conyers, K. (1998). COPD with Chronic Bronchitis and Bronchiectasis: A Case Study. Hill-Rom Publications
30. Rahm, C. (2024). Case Study: Chronic Obstructive Pulmonary Disease (COPD). PriMera Scientific Surgical Research and Practice, 4(3), 40-46. [DOI: 10.56831/PSSRP-04-129]
31. Rhee, C. K., Ho, Y. F., Shantakumar, S., Holbrook, T., Nam, Y., & Yoo, K. H. (2025). Blood eosinophil count and treatment patterns of chronic obstructive pulmonary disease patients in South Korea using real-world data. The Korean journal of internal medicine, 40(1), 78–91. https://doi.org/10.3904/kjim.2024.034 (kjim)
32. Choi, J. Y., & Rhee, C. K. (2020). Diagnosis and Treatment of Early Chronic Obstructive Lung Disease (COPD). Journal of Clinical Medicine, 9(11), 3426. https://doi.org/10.3390/jcm9113426 (jcm)
33. Halpin, D. M. G. (2023). Clinical Management of COPD in the Real World: Can Studies Reveal Errors in Management and Pathways to Improve Patient Care? Pragmatic and Observational Research, 14, 51–61. [DOI: 10.2147/POR.S396830]
34. Thomas, S. (2024). A Case Study on COPD Associated with Seizures in a Tertiary Care Hospital. Clinical Case Reports International, 8, 1665. [Available at: http://clinicalcasereportsint.com/]
35. Al-Farra, S. (2011). COPD Case Presentation: 67-Year-Old Male with Progressive Dyspnea. University of North Texas Health Science Center
36. Nikleski, Z., Avramovska, M., Avramovski, P., Todorovska, L., Sikloska, V., Zdraveski, D., ... & Stefanovska, S. (2025). Where We Now Stand: Unraveling the Link between COPD and NAFLD. EC Pulmonology and Respiratory Medicine, 14(1), 1-8.
37. Kahnert, K., Jörres, R. A., Behr, J., & Welte, T. (2023). The Diagnosis and Treatment of COPD and Its Comorbidities. Deutsches Arzteblatt international, 120(25), 434–444. https://doi.org/10.3238/arztebl.m2023.027 (treatment and comorbidity)
38. Rossaki, F. M., Hurst, J. R., van Gemert, F., Kirenga, B. J., Williams, S., Khoo, E. M., … van Boven, J. F. (2021). Strategies for the prevention, diagnosis and treatment of COPD in low- and middle- income countries: the importance of primary care. Expert Review of Respiratory Medicine, 15(12), 1563–1577. https://doi.org/10.1080/17476348.2021.1985762
39. Price, D., Freeman, D., Cleland, J. et al. Earlier diagnosis and earlier treatment of COPD in primary care. Prim Care Respir J 20, 15–22 (2011). https://doi.org/10.4104/pcrj.2010.00060 (PCRJ)

40. Izquierdo-Condoy, J. S., Salazar-Santoliva, C., Salazar-Duque, D., Palacio-Dávila, Y.-D.-C., Hernández-Londoño, J. M., Orozco-Gonzalez, R., Rodríguez-Sánchez, M.-S., Marín-Bedoya, V., & Loaiza-Guevara, V. (2024). Challenges and Opportunities in COPD Management in Latin America: A Review of Inhalation Therapies and Advanced Drug Delivery Systems. Pharmaceutics, 16(10), 1318. https://doi.org/10.3390/pharmaceutics16101318 (challenge)
41. Vachon, B., Giasson, G., Gaboury, I., Gaid, D., Noël De Tilly, V., Houle, L., Bourbeau, J., & Pomey, M. P. (2022). Challenges and Strategies for Improving COPD Primary Care Services in Quebec: Results of the Experience of the COMPAS+ Quality Improvement Collaborative. International journal of chronic obstructive pulmonary disease, 17, 259–272. https://doi.org/10.2147/COPD.S341905.

HOW TO CITE: Nancy Srivastava, Dr. Umesh Pratap Singh, Priyanka Pal, Purnendra Gupta, Sandeep Singh, Alok Dixit, Innovations And Future Prospects in Copd Management: Advancing Treatment and Care, Int. J. of Pharm. Sci., 2025, Vol 3, Issue 6, 5398-5406. https://doi.org/10.5281/zenodo.15757931