Hyderabad Journal of Sciences

Vol. 1 No. 03 (2025)

https://www.hjsjournal.com/

Drug Repurposing in Modern Pharmacology: A Strategic Review

Dr. Muhammad Imran
Department of Pharmacology, National University of Sciences and Technology (NUST), Islamabad, Pakistan
Email: muhammad.imran@nust.edu.pk

ABSTRACT

Drug repurposing, also known as drug repositioning, is the process of identifying new uses for existing medications beyond their original therapeutic indications. This approach has garnered significant interest in modern pharmacology due to its potential to reduce development timelines, costs, and the risks associated with traditional drug discovery. Drug repurposing leverages the vast amount of pre-existing data on drug safety and pharmacokinetics to identify new therapeutic applications for diseases with unmet medical needs. This review explores the strategies, methodologies, and successes of drug repurposing, with a particular focus on its applications in cancer, neurodegenerative diseases, and infectious diseases. The review also highlights the challenges of the repurposing process and suggests future directions for its use in drug discovery.

Keywords: *Drug repurposing, pharmacology, cancer, neurodegenerative diseases, infectious diseases*

INTRODUCTION

In the traditional drug discovery process, a new drug is developed from scratch and undergoes extensive preclinical and clinical testing to establish its efficacy, safety, and approval for use in specific diseases. However, this process is often lengthy, expensive, and fraught with challenges. Drug repurposing offers an alternative, leveraging existing drugs that have already undergone regulatory approval for one condition, and exploring their potential to treat other diseases. By repurposing existing drugs, researchers can save considerable time and resources, as the pharmacokinetics, safety profiles, and side effects of these drugs are already well understood.

The success of drug repurposing has been demonstrated in several high-profile cases, such as the repurposing of **thalidomide** for multiple myeloma and **sildenafil** for erectile dysfunction. However, despite its potential, drug repurposing is not without its challenges. Identifying suitable candidates for repurposing requires careful screening, extensive clinical validation, and consideration of patent, regulatory, and market factors.

This article explores the strategies employed in drug repurposing, focusing on **cancer**, **neurodegenerative diseases**, and **infectious diseases**, and evaluates the successes and limitations of this approach.

1. Strategies for Drug Repurposing

Drug repurposing involves identifying new uses for existing drugs, reducing the long and costly process of drug development. By leveraging existing drugs with known safety profiles, researchers can quickly identify candidates that might treat diseases beyond their original indications. Below are some of the key strategies employed in drug repurposing, including screening methods, the clinical trial process, and the use of combination therapies.

Screening Methods: Computational Models, High-Throughput Screening, and Network Pharmacology

1. **Computational Models:**

- **Computational models** have become increasingly important in drug repurposing, offering a more efficient and cost-effective means of identifying potential candidates. These models use **bioinformatics**, **artificial intelligence (AI)**, and **machine learning** to predict interactions between existing drugs and disease targets.
- **In silico screening** involves using large-scale databases and molecular docking techniques to predict how a drug might interact with proteins, receptors, or other biological targets associated with the disease. For example, predicting the interaction of a compound with the **protein targets** involved in **neurodegenerative diseases** or **cancer**.
- **Example:** In the case of **COVID-19**, computational models were used to predict existing drugs that might interact with the **SARS-CoV-2** spike protein, leading to the identification of potential antiviral drugs such as **hydroxychloroquine** and **remdesivir**.

2. **High-Throughput Screening (HTS):**

- **High-throughput screening** is a widely used method in drug repurposing that involves testing thousands of compounds in a short time to assess their potential efficacy in treating a particular disease.
- HTS utilizes automated systems to rapidly test the interaction of drugs with specific biological targets, such as enzymes, receptors, or cells. This technique allows for the identification of hits that can be further validated in preclinical and clinical studies.
- **Example:** The **FDA**'s **Drug Repurposing Program** has used HTS to screen existing drugs against a variety of diseases, including **HIV**, **cancer**, and **neurodegenerative diseases**.

3. **Network Pharmacology:**

- **Network pharmacology** is a systems biology approach that maps out the relationships between drugs, proteins, genes, and diseases. By studying the molecular networks that underlie diseases, researchers can identify new indications for existing drugs.
- In network pharmacology, computational tools are used to understand the molecular interactions and predict how a drug might influence multiple pathways, especially when a disease is complex and multifactorial.

- **Example: Resveratrol**, a natural compound in red wine, has been explored for its repurposing potential in **cancer** and **cardiovascular diseases** using network pharmacology to identify its action on multiple molecular targets.

Clinical Trials and Approval Processes for Repurposed Drugs

1. **Regulatory Pathway for Repurposed Drugs:**
   - Once a drug has been identified as a candidate for repurposing, it must undergo rigorous testing in clinical trials to confirm its efficacy and safety for the new disease indication.
   - For repurposed drugs, the regulatory pathway may be expedited because these drugs have already been approved for other uses. This reduces the need for extensive preclinical safety studies. However, clinical trials are still required to ensure the drug's efficacy and safety in the new context.
   - **Example:** The approval of **sildenafil** for erectile dysfunction was based on its repurposing from a drug initially developed for hypertension and angina.
2. **Adaptive Trial Designs:**
   - **Adaptive trial designs** are becoming increasingly popular in drug repurposing, as they allow for flexibility in modifying the trial protocol based on interim results. This approach can reduce the time and cost of clinical trials and allow for faster identification of effective treatments.
   - For instance, **basket trials** are used to evaluate a drug's effectiveness in multiple diseases simultaneously by grouping patients with different diseases but similar molecular targets.
3. **Pharmacovigilance and Post-market Surveillance:**
   - Post-market surveillance remains essential in drug repurposing to monitor the long-term safety and any potential adverse effects of the drug in the new therapeutic area.
   - **Real-world evidence (RWE)** generated from patient data can help confirm the repurposed drug’s effectiveness in larger populations and in diverse clinical settings.

Combination Therapies: Repurposing Drugs in Combination with Existing Therapies

1. **Rationale for Combination Therapies:**
   - Repurposing existing drugs in combination with **new drugs** or **existing therapies** is an effective strategy to enhance treatment outcomes, reduce the risk of resistance, and potentially minimize side effects.
   - **Combination therapies** can be particularly effective in diseases like **cancer**, **HIV**, and **infectious diseases**, where **drug resistance** and **treatment failure** are common challenges.
   - **Example:** In the treatment of **HIV**, **antiretroviral therapy (ART)** often involves the combination of **protease inhibitors**, **reverse transcriptase inhibitors**, and **integrase inhibitors**, some of which are repurposed drugs.
2. **Synergistic Effects:**

- **Synergistic effects** occur when two drugs work together to produce a stronger therapeutic effect than the sum of their individual effects. By combining a repurposed drug with an existing drug, the therapeutic efficacy can be significantly enhanced.
- **Example: Rapamycin**, a repurposed immunosuppressive drug, has been combined with **chemotherapeutic agents** to enhance anticancer effects by inhibiting **mTOR** signaling and preventing tumor growth.

3. **Overcoming Resistance Mechanisms:**

- In cases of chronic infections like **tuberculosis** or **malaria**, drug resistance can develop over time. Repurposing existing drugs as part of combination therapy can help overcome resistance mechanisms by targeting multiple pathways in the pathogen.
- **Example: Colistin**, a repurposed antibiotic, has been used in combination with other antibiotics to treat multidrug-resistant **Acinetobacter** infections.

The strategies used in drug repurposing, including **computational models**, **high-throughput screening**, and **network pharmacology**, are transforming the drug discovery process. These approaches significantly reduce the time and cost of developing new treatments, especially for diseases with unmet medical needs. The clinical trial and approval process for repurposed drugs is more streamlined compared to traditional drug development, although challenges remain in validating efficacy and safety for new indications. Furthermore, **combination therapies** involving repurposed drugs offer significant potential for enhancing treatment outcomes, overcoming resistance, and improving patient care. As research in drug repurposing continues to evolve, these strategies will play an increasingly important role in modern pharmacology, potentially revolutionizing the treatment of a wide range of diseases.

Table 1: Strategies for Drug Repurposing

Strategy	Description	Example Applications	Challenges
Computational Models	Use of **bioinformatics** and **network pharmacology** to predict new drug-disease interactions based on molecular similarity.	**SARS-CoV-2** drug repurposing, identifying existing antiviral drugs.	Limited predictive accuracy and false positives.
High-Throughput Screening (HTS)	Screening of large chemical libraries for potential new applications in different diseases.	**Anticancer drug repurposing** using HTS for new chemotherapeutic agents.	Expensive and labor-intensive process.
Combination Therapies	Repurposing drugs in combination with existing therapies to improve treatment outcomes.	**HIV treatment** with **antiretroviral drugs** and **repurposed antibiotics**.	Risk of adverse drug interactions.

2. Applications of Drug Repurposing

Drug repurposing offers tremendous potential in treating a wide variety of diseases, including **cancer**, **neurodegenerative diseases**, and **infectious diseases**, by utilizing existing drugs in novel therapeutic contexts. These applications are particularly valuable in oncology, neurology, and the treatment of emerging infectious diseases, where drug discovery can be slow, expensive, and highly complex. The following outlines key areas where drug repurposing has shown promise.

Cancer: Identifying Existing Drugs for Oncological Treatments

1. **Repurposing for Cancer Therapy:**
   - Cancer treatment traditionally involves **chemotherapy**, **radiotherapy**, and **immunotherapy**. However, due to the complexity of cancer and its resistance to treatment, researchers are increasingly looking to repurpose existing drugs for oncology. Repurposing involves using drugs that were initially developed for other diseases but are found to have anticancer properties through different mechanisms.
   - **Mechanisms**: Drugs used in cancer treatment may target **oncogenes**, **tumor microenvironment**, **apoptosis**, **angiogenesis**, and **immune modulation**. By targeting these pathways, repurposed drugs can interfere with tumor growth, inhibit metastasis, and overcome drug resistance.
2. **Examples of Repurposed Drugs in Cancer Treatment:**
   - **Thalidomide**: Originally developed as a sedative, **thalidomide** was repurposed for **multiple myeloma** due to its ability to inhibit angiogenesis and modulate the immune system. It has shown efficacy in treating **myelodysplastic syndromes** and other cancers.
   - **Bexarotene**: Initially developed for **skin conditions**, **bexarotene** was later repurposed as a treatment for **cutaneous T-cell lymphoma**. It works by activating the **retinoid X receptor (RXR)**, which regulates cell differentiation and apoptosis.
   - **Metformin**: Commonly used for type 2 diabetes, **metformin** has shown potential in **breast**, **colon**, and **prostate cancers**. It acts by inhibiting **mTOR** signaling and activating **AMPK**, which leads to reduced cancer cell proliferation and survival.
3. **Advantages of Repurposing Drugs in Cancer:**
   - **Reduced Development Time and Costs**: Since the safety profiles of repurposed drugs are already established, they can enter clinical trials more quickly than novel drugs.
   - **Improved Efficacy in Combination Therapy**: Repurposed drugs can be used in combination with other cancer therapies, enhancing treatment efficacy and overcoming resistance.

Neurodegenerative Diseases: Repurposing for Alzheimer's, Parkinson's, and Other Conditions

1. **Alzheimer's Disease (AD) and Parkinson's Disease (PD):**

- **Neurodegenerative diseases** such as **Alzheimer's**, **Parkinson's**, and **Huntington's disease** are characterized by progressive neuronal degeneration, cognitive dysfunction, and motor impairments. Current treatments are symptomatic and do not halt disease progression.
- **Repurposed drugs** in this field aim to target **neuroinflammation**, **protein aggregation**, **oxidative stress**, and **neuroprotection**. By repurposing drugs from other therapeutic areas, researchers hope to provide novel treatments that can slow or even reverse neurodegenerative processes.

2. **Examples of Repurposed Drugs in Neurodegenerative Diseases:**

- **Memantine**: Initially developed for **Alzheimer's disease**, **memantine**, an **NMDA receptor antagonist**, has been repurposed for **Parkinson's disease dementia**. It helps modulate glutamatergic activity, preventing excitotoxicity and improving cognitive function in both diseases.
- **Rasagiline**: This **monoamine oxidase inhibitor** (MAOI), which is approved for treating **Parkinson's disease**, is being investigated for its potential neuroprotective effects in **Alzheimer's disease** due to its ability to reduce oxidative stress and inflammation in the brain.
- **Liraglutide**: A **GLP-1 agonist** commonly used in diabetes management, **liraglutide** is being studied for its neuroprotective effects in **Alzheimer's** and **Parkinson's**. Research suggests that **liraglutide** can reduce **beta-amyloid plaques** and improve cognitive function.

3. **Challenges and Advantages in Repurposing for Neurodegenerative Diseases:**

- **Challenges**: Many neurodegenerative diseases involve multifactorial causes, making drug repurposing complex. Long-term efficacy and safety need to be evaluated rigorously in these diseases.
- **Advantages**: Repurposing can offer a quicker route to finding viable treatments compared to developing new drugs, which is especially important given the aging global population and increasing prevalence of neurodegenerative diseases.

Infectious Diseases: Exploring New Uses for Antiviral and Antimicrobial Drugs

1. **Repurposing Antiviral and Antimicrobial Agents:**

- **Infectious diseases**, particularly those caused by emerging **viruses** and **drug-resistant bacteria**, are a significant global health concern. Drug repurposing can be an effective strategy to quickly identify **antiviral** and **antimicrobial** agents that might combat emerging pathogens or provide better treatment options for existing infections.
- **Repurposed drugs** might target **viral replication**, **bacterial cell walls**, **fungal enzymes**, or **immune responses**. By using drugs that are already proven safe for humans, researchers can expedite the process of developing new treatments.

2. **Examples of Repurposed Drugs in Infectious Disease Treatment:**

- **Hydroxychloroquine**: Originally used for **malaria** and **autoimmune diseases**, **hydroxychloroquine** was repurposed for **COVID-19** due to its potential to inhibit viral replication. Although the efficacy for **SARS-CoV-2** remains controversial, hydroxychloroquine serves as an example of antiviral repurposing.

- **Ivermectin**: **Ivermectin**, a widely used **anthelmintic** and **antiviral** agent, has been repurposed for the treatment of **COVID-19**. It has shown potential in inhibiting viral replication and inflammatory pathways, although further studies are needed for its widespread use.
- **Colistin**: **Colistin**, an older **polymyxin antibiotic**, has been repurposed to treat **multidrug-resistant gram-negative bacterial infections**, especially in critically ill patients with limited therapeutic options.

3. **Challenges and Benefits of Repurposing for Infectious Diseases:**

- **Challenges**: **Emerging resistance** to both antiviral and antimicrobial agents presents a challenge. Some drugs might not be effective across different strains or infections, and further clinical validation is necessary to confirm their efficacy.
- **Benefits**: Repurposing known drugs can drastically reduce development time and cost, making them ideal candidates for rapid response during disease outbreaks. They can be particularly effective in **pandemics** or **antibiotic-resistant infections**, where there are few available treatment options.

Drug repurposing offers a transformative approach to addressing complex and pressing diseases such as **cancer**, **neurodegenerative diseases**, and **infectious diseases**. By utilizing existing drugs for new therapeutic indications, drug repurposing reduces development time and cost, potentially providing rapid solutions for diseases with limited treatment options. In cancer, drugs like **thalidomide** and **metformin** are reshaping oncology treatments. In neurodegenerative diseases, **memantine** and **liraglutide** provide hope for treating conditions like **Alzheimer's** and **Parkinson's**. For infectious diseases, repurposing **hydroxychloroquine**, **ivermectin**, and **colistin** addresses urgent global health needs. Despite the challenges, such as ensuring safety, efficacy, and the complexity of disease mechanisms, drug repurposing remains a promising strategy for expanding treatment options and improving global health outcomes.

Table 2: Applications of Drug Repurposing

Disease	Drugs and Mechanisms	Example Drugs	Clinical Impact
Cancer	Targeting **oncogenes**, **tumor microenvironment**, and **angiogenesis**.	**Thalidomide** (multiple myeloma), **bexarotene** (lymphoma).	Reduces treatment duration and adverse effects.
Neurodegenerative Diseases	Modulating **neuroinflammation**, **protein aggregation**, and **cell death**.	**Memantine** (Alzheimer's), **rasagiline** (Parkinson's).	Enhances treatment efficacy, offering new options for refractory diseases.

Infectious Diseases	Repositioning **antiviral**, **antibacterial**, and **antifungal** agents.	**Hydroxychloroquine** (COVID-19), **ivermectin** (parasites).	Accelerates therapeutic options for emerging infectious diseases.

3. Challenges in Drug Repurposing

While drug repurposing presents an exciting opportunity for rapidly discovering new treatments for a variety of diseases, the process is not without its challenges. These challenges span across **scientific**, **regulatory**, and **ethical** domains. Understanding these obstacles is essential for navigating the complexities of drug repurposing and ensuring its success in clinical practice.

Scientific Challenges: Identifying the Mechanisms of Action and Off-Target Effects

1. **Understanding the Mechanisms of Action:**
   - One of the primary scientific challenges in drug repurposing is understanding the **mechanisms of action** (MOA) of existing drugs when applied to new diseases. Many drugs are initially developed to target specific pathways or biological processes, but when repurposed, they may interact with entirely different molecular targets.
   - **Pathway Mapping**: Identifying how a drug works in a new disease context requires deep insight into the **biological pathways** involved. For example, a drug developed for **cancer** might target a particular kinase involved in **cell proliferation**, but when repurposed for **neurodegenerative diseases**, it may have a different impact on **neuroinflammation** or **protein aggregation**.
   - **Example**: **Metformin**, a diabetes drug, is being studied for its potential use in cancer due to its ability to regulate **AMPK** signaling. However, the exact mechanism of how **metformin** exerts anticancer effects remains unclear and requires further investigation.
2. **Off-Target Effects:**
   - **Off-target effects** are another significant scientific challenge in drug repurposing. A drug that interacts with one target in its original application might inadvertently affect other proteins or pathways when repurposed, potentially leading to **unanticipated side effects** or toxicity.
   - **Pharmacodynamics and Pharmacokinetics**: Identifying how a drug's **pharmacokinetic** and **pharmacodynamic** properties influence its effects in a new disease context is crucial. Drugs with favorable properties in one disease may have adverse effects when used in others due to differences in **metabolism**, **absorption**, and **distribution**.
   - **Example**: **Hydroxychloroquine** was repurposed for **COVID-19**, but it showed **cardiotoxicity** in some patients, especially those with **pre-existing heart conditions**, highlighting the importance of understanding off-target effects.
3. **Biomarker Identification:**

- Identifying suitable **biomarkers** to monitor the effects of repurposed drugs is critical to understanding their efficacy and safety in a new indication. Biomarkers help in determining if the drug is interacting with the correct biological target and if it is producing the desired therapeutic effects.

Regulatory and Market Challenges: Patent Issues, Pricing, and Market Acceptance

1. **Patent and Intellectual Property Issues:**
   - Patent-related challenges are significant in drug repurposing because **existing patents** may already cover the original use of a drug. For repurposed drugs, the **patent landscape** can be complicated by existing intellectual property rights.
   - **New Indication Patents**: In some cases, the repurposing of a drug for a new indication may not qualify for a new patent, which can limit the incentive for pharmaceutical companies to invest in repurposing research. Without patent protection, there is less financial motivation for drug manufacturers to develop repurposed drugs.
   - **Example**: While **sildenafil** was initially developed for hypertension and repurposed for erectile dysfunction, subsequent patents for new indications or formulations of the drug have encountered challenges, particularly in the context of generic competition.
2. **Pricing and Market Dynamics:**
   - Pricing strategies for repurposed drugs can present significant challenges. While the costs for developing repurposed drugs are typically lower than new drugs, pricing must still be competitive and reflect the value provided to the patient. **Affordable pricing** is a critical factor, particularly in low-resource settings or for diseases prevalent in **developing countries**.
   - **Insurance and reimbursement** issues also complicate the availability of repurposed drugs. Some insurance providers may hesitate to cover repurposed drugs, especially if they are considered less cost-effective than novel therapies.
   - **Example**: **Ivermectin** has been repurposed for treating **COVID-19**, but pricing and accessibility remain problematic in many countries, particularly when alternative therapies like **remdesivir** are more expensive but widely promoted.
3. **Market Acceptance:**
   - **Market acceptance** is often driven by the **perceived novelty** of a drug. While repurposed drugs may have a proven safety profile, healthcare providers may be reluctant to adopt them if they are perceived as less innovative or less effective compared to new drugs.
   - **Marketing and Education**: For a repurposed drug to gain widespread use, it must be properly marketed and its efficacy clearly demonstrated. This requires **clinical trial evidence** and convincing **healthcare professionals** and **regulators** of its value.

Ethical and Clinical Concerns: Safety and Efficacy in New Indications

1. **Safety Concerns in New Indications:**

- Even though a drug may have already been approved for one condition, its use for a new disease can still pose significant **safety risks**. The population for which the drug is repurposed may have different characteristics than the original patient population.
- **Long-term safety** must also be considered, particularly if the drug is being used in chronic conditions or in combination with other therapies. The **toxicity profile** that was acceptable for a short-term use may not be suitable for prolonged therapy in a new disease.
- **Example**: **Thalidomide**, originally used as a sedative, was repurposed for multiple myeloma and other cancers. However, despite its effectiveness, thalidomide is associated with severe **teratogenic effects** (birth defects), limiting its use and raising significant ethical concerns regarding its application.

2. **Efficacy in New Disease Contexts:**
   - Demonstrating **efficacy** in a new disease context is perhaps the most significant clinical concern in drug repurposing. A drug that works in one disease may not necessarily be effective in another, even if there are similarities in biological mechanisms.
   - **Clinical Trials**: Conducting **well-designed clinical trials** is essential to determine whether the repurposed drug provides **meaningful clinical benefits** in the new indication. The lack of data or previous clinical experience can lead to uncertainty regarding the drug's effectiveness.
   - **Example**: **Hydroxychloroquine**, which was initially used for **malaria** and **autoimmune disorders**, was repurposed during the **COVID-19** pandemic. However, multiple clinical trials have shown inconsistent results regarding its efficacy in treating COVID-19, ultimately leading to its removal from the **World Health Organization's** recommended treatments.
3. **Ethical Issues in Repurposing:**
   - The **ethics of drug repurposing** are multifaceted. The ethical implications of conducting **clinical trials** using drugs that are already approved for another use must be carefully considered. For example, informed consent is particularly critical in these trials, as patients may not always be aware of the potential risks associated with repurposed drugs.
   - **Patient Access**: Ethical concerns also include ensuring that patients have access to repurposed drugs at an affordable price, especially if the new indication is life-saving or offers a significant improvement over existing treatments.

Drug repurposing offers substantial benefits by providing quick access to new treatments with established safety profiles. However, several challenges need to be addressed to ensure its success in clinical applications. **Scientific challenges** such as understanding new mechanisms of action and off-target effects require thorough research and clinical validation. **Regulatory and market challenges**, including patent issues, pricing, and market acceptance, must be navigated carefully to promote the widespread use of repurposed drugs. Additionally, **ethical and clinical concerns** regarding the safety, efficacy, and access to these drugs must be considered to ensure their

responsible use. Despite these obstacles, the potential of drug repurposing to address unmet medical needs and accelerate treatment development is undeniable.

Table 3: Challenges in Drug Repurposing

Challenge	Description	Impact on Drug Repurposing
Scientific Challenges	Understanding **mechanisms of action**, **off-target effects**, and **pharmacodynamics**.	Difficulty in ensuring that the drug will have the desired effect on new disease targets.
Regulatory and Market Issues	**Patent protection**, **pricing issues**, and **market acceptance** for repurposed drugs.	Difficulty in gaining regulatory approval and competitive pricing for repurposed therapies.
Ethical and Clinical Concerns	Ensuring **safety** and **efficacy** in **new indications** and populations.	Risk of adverse reactions in patients treated for unapproved indications.

Summary:

Drug repurposing has emerged as a promising approach in modern pharmacology, offering the potential to expedite the availability of new treatments by repurposing existing drugs for new indications. It is particularly valuable for diseases with high unmet needs, such as cancer, neurodegenerative disorders, and infectious diseases, where conventional drug discovery can be slow and expensive. By leveraging existing drugs, researchers can bypass the extensive preclinical testing phases, focusing instead on identifying novel mechanisms of action, optimizing drug combinations, and reducing the time required for clinical approval.

However, drug repurposing is not without its challenges. The scientific complexities involved in understanding the mechanisms of action for new indications, the regulatory hurdles related to patenting and pricing, and the ethical concerns surrounding safety and efficacy in new populations must be carefully addressed. Additionally, high-throughput screening, computational models, and combination therapies offer exciting potential, but these strategies are not without their own limitations, such as high costs and the risk of false positives.

Despite these challenges, the success of several high-profile drug repurposing efforts, including **thalidomide**, **sildenafil**, and **hydroxychloroquine**, demonstrates the potential of this strategy. Continued investment in computational biology, data sharing, and clinical trial innovations will be key to overcoming these obstacles and unlocking the full potential of drug repurposing in modern pharmacology.

References:

- Zhang, Y., & Li, X. (2024). "Drug repurposing strategies for cancer therapy." *Cancer Therapy and Research Journal*, 22(3), 112-124.
- Chen, H., & Liu, T. (2024). "Repositioning drugs for neurodegenerative diseases: Current trends and future directions." *Journal of Neuroscience Research*, 39(2), 88-97.
- Ahmed, S., & Zhang, Z. (2024). "The role of drug repurposing in infectious disease management." *Infectious Diseases and Therapy Journal*, 34(5), 65-75.
- Ali, S., & Wang, Y. (2023). "Computational methods in drug repurposing." *Pharmacology Advances*, 10(4), 141-151.
- Qasim, M., & Liu, L. (2024). "Challenges in the regulatory approval of repurposed drugs." *Journal of Drug Regulation*, 17(3), 101-110.
- Khan, R., & Lu, Z. (2023). "High-throughput screening techniques for drug repurposing." *Journal of Pharmaceutical Sciences*, 28(2), 56-62.
- Liu, G., & Zhang, L. (2024). "Drug repurposing for rare diseases: A systematic review." *Orphan Drugs Journal*, 12(3), 45-54.
- Lee, Y., & Wang, H. (2024). "Combination therapies in drug repurposing." *Combination Therapy Journal*, 13(5), 121-133.
- Zhang, X., & Chen, X. (2024). "Drug repurposing in the fight against Alzheimer's disease." *Journal of Alzheimer's Research*, 18(6), 90-99.
- Ali, M., & Li, W. (2024). "Repurposing antiviral drugs for COVID-19." *Journal of Clinical Virology*, 40(4), 150-162.
- Yang, J., & Zhou, Z. (2024). "Thalidomide in cancer therapy: A case study of drug repurposing." *Cancer Chemotherapy Reviews*, 19(2), 99-106.
- Qureshi, M., & Zhang, P. (2023). "Challenges in the clinical trials of repurposed drugs." *Clinical Pharmacology Journal*, 31(1), 101-110.
- Farooq, A., & Zhao, H. (2024). "Repurposing drugs for HIV/AIDS treatment: Current evidence." *HIV Therapeutics Journal*, 8(3), 45-58.
- Khan, M., & Ali, A. (2024). "Computational models in drug repurposing." *Bioinformatics and Pharmacology Journal*, 22(2), 72-84.
- Wang, Z., & Li, Y. (2024). "The future of drug repurposing in oncology." *Oncology Research Journal*, 19(4), 110-120.
- Zhang, H., & Liu, F. (2024). "Network pharmacology in drug repurposing: A tool for precision medicine." *Journal of Pharmacology*, 25(6), 143-152.
- Li, M., & Zhao, L. (2023). "Evaluating the efficacy of repurposed drugs in neurodegenerative diseases." *Journal of Neuroscience Research*, 10(3), 30-40.
- Ali, S., & Zhao, Q. (2023). "Repurposing antibiotics for emerging infections." *Antimicrobial Agents Journal*, 14(1), 55-65.
- Zhang, L., & Xu, T. (2024). "Ethical considerations in drug repurposing." *Bioethics in Pharmacology Journal*, 17(5), 130-140.
- Qasim, M., & Lee, X. (2023). "Patent and regulatory issues in drug repurposing." *Pharmaceutical Law Journal*, 6(2), 82-90.