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Review Article

Redefining Drug Discovery: A Review of Drug Repurposing –Approaches, Benefits and Breakthroughs

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Abstract *- The pharmaceutical industry uses drug repurposing or drug repositioning as an innovative method to find new medical uses for existing medications that are already on the market. The method has gained widespread acceptance because it provides a speedier and more budget-friendly solution to traditional drug development, which often takes years and costs substantial amounts. The process of drug repurposing uses existing safety information and pharmacokinetic data to decrease development risks while making treatments available more quickly, especially during public health crises. This review examines the historical development of drug repurposing, its benefits, and current experimental and computational methods for drug repurposing. This review explains how regulatory and intellectual property barriers restrict the widespread adoption of this technology. This review also considers some case studies about Sildenafil, Thalidomide, and Remdesivir to demonstrate how successful drug repositioning can be achieved. The growing importance of drug repurposing becomes evident through its applications in pandemic situations, neglected diseases, and worldwide health challenges. The scientific field of drug repurposing has transformed from accidental discovery to a structured discipline that will revolutionize disease treatment methods through advances in artificial intelligence, multi-omics, and international partnerships.*

Keywords *- Computational Approaches, Drug Repositioning, Drug Repurposing, Pharmaceutical Innovation, Therapeutic Development.*

1. Introduction

The medical practice of discovering fresh therapeutic applications for existing approved medications is called drug repurposing or drug repositioning. The drug development method has gained significant interest because it enables the creation of new medicines at reduced costs and shorter development times. The drug development process through repurposing offers multiple advantages compared to traditional methods, which need 10 to 15 years and $2 billion to bring new compounds to market. [1]

The existing safety and pharmacokinetic information of approved drugs enables repurposing to minimize new compound development risks and costs while speeding up the delivery of innovative treatments to patients. [2, 3]. The practice of drug repurposing exists as an established concept. The clinical and commercial success of drug repurposing becomes evident through historical examples such as thalidomide treatment of multiple myeloma and sildenafil's transition from angina medication to pulmonary hypertension and erectile dysfunction therapy.[4]

The practice of drug repurposing has gained increased importance during recent years because it helps treat neurological illnesses, rare diseases, and cancer. Drugs like Remdesivir and Hydroxychloroquine, which were quickly repurposed during COVID-19, demonstrated the urgent need for fast-acting quinolones.[5]

The advancement of technology has accelerated the process of drug repurposing. The combination of computational biology, bioinformatics, and artificial intelligence allows scientists to perform in-silico screening of extensive compound libraries and biological datasets to discover drug-disease relationships through gene expression profiles, protein targets, and pathway analysis.

[6] The Drug Repurposing Hub and Connectivity Map platforms enable researchers to develop and validate new drug candidates for potential repurposing through simplified hypothesis testing. The new methods have transformed our ability to detect concealed drug-disease relationships, especially when we lack sufficient mechanistic data.[7]

Drug repurposing has drawbacks despite its potential. Commercial growth can be hampered by legal restrictions, financial limitations, and intellectual property concerns, particularly when pharmaceuticals are no longer covered by patents.

Furthermore, to guarantee efficacy in novel indications, extensive research employing randomized controlled trials is still necessary for clinical validation of repurposed medications. Although regulatory bodies like the FDA and EMA have set up procedures for authorizing repurposed medications, following these routes is still difficult and differs depending on the region and disease indication.[2]

This method decreases the possibility of clinical trial failure while accelerating research timelines.[1] Drug repurposing is becoming a more significant tactic in the pharmaceutical industry due to the growing expense of developing new drugs and the pressing need for short-term remedies, particularly during pandemics.

2. Historical Background

Previously, drug repurposing depended significantly on clinical observation and serendipity. However, with the availability of systematic screening, molecular biology, and bioinformatics tools, the approach has evolved over time to provide more rational approaches to discovering repurposable drugs. [8]

The possibility of repositioning already-existing compounds has increased significantly as scientific knowledge of disease pathways and molecular targets has grown. Many popular medications have been successfully repurposed in the past.

Originally prescribed to treat pain, aspirin is now frequently used to protect the cardiovascular system after it was discovered to have antiplatelet effects. Similar to this, thalidomide, which was first sold as a sedative, has found new use in the treatment of leprosy complications and multiple myeloma.

Minoxidil is another noteworthy example. Originally created as an antihypertensive medication, it was later used to treat androgenic alopecia because of its ability to stimulate hair growth.[9] The first FDA-approved treatment for HIV/AIDS was zidovudine (AZT), which was initially studied for the treatment of cancer. [10,11] These illustrations show how off-target observations or unexpected therapeutic effects can result in the identification of novel indications.

3. Benefits of Repurposing Drugs

3.1. Low Development Cost and Time

Conventional drug development can cost more than $2 billion and take 10 to 15 years. By utilizing preclinical and clinical data that already exists, repurposing drastically cuts down on this time and expense.[4]

3.2. Established Safety Profiles

Repurposed drugs are less likely to cause negative outcomes in subsequent clinical trials since they have already undergone tests for toxicity, pharmacokinetics, and side effects.[1]

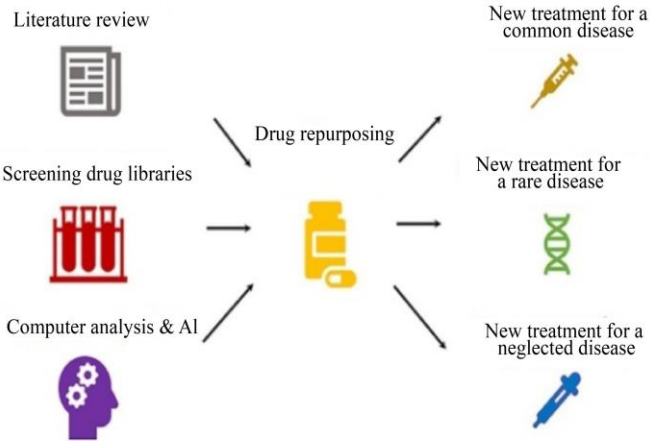

Fig. 1 Approaches and outcomes of drug repurposing

3.3. Higher Clinical Success Rates

The success rate of drugs progressing through clinical trials is generally higher for repurposed candidates, since Phase I safety trials are often not needed.[2]

3.4. Rapid Response to Emerging Diseases

During outbreaks like COVID-19, drug repurposing allowed for faster identification of treatment options from existing medications.[13]

3.5. Access to Rare and Neglected Disease Treatments

Drug repurposing provides potential treatments for diseases that lack commercial interest, such as orphan diseases or tropical infections.[3]

3.6. Facilitates Drug Lifecycle Extension

By finding new indications, pharmaceutical companies can extend the commercial life of a drug beyond its original patent.[8]

4. Approaches to Drug Repurposing

4.1 Experimental Approaches

Experimental methods involve direct testing of known drugs on new disease models. High-throughput screening of drug libraries and phenotypic screening are commonly used. Observations from off-label use in clinical settings also provide valuable insights. Experimental approaches to drug repurposing involve direct testing of existing drugs in biological systems to evaluate their efficacy against new disease targets.

Unlike computational approaches that rely on in-silico predictions, experimental strategies focus on phenotypic outcomes and mechanism-of-action studies *in-vitro* and *in-vivo*. These methods are valuable because they often identify drugs with unanticipated effects that may not be predicted based on target-based screenings alone.[16]

4.1.1. High-Throughput Screening

High-Throughput Screening (HTS) involves testing large libraries of approved or investigational compounds against disease-relevant biological models. This method is particularly useful when the mechanism of disease is unclear or when searching for modulators of complex phenotypes.

HTS has been successfully used in cancer, infectious diseases, and neurological disorders. Example- Screening of the ReFRAME library, which includes over 12,000 compounds, has led to the identification of several candidates for diseases like tuberculosis and COVID-19.[17]

4.1.2. Phenotypic Screening

This approach assesses the observable changes in cellular or organism models after drug treatment without knowing the molecular target. It is especially valuable in diseases with poorly understood pathophysiology. Phenotypic screening was instrumental in discovering the antipsychotic effects of chlorpromazine and the anti-epileptic use of valproate.[18]

4.1.3. Target-Based Assays

In target-based repurposing, drugs are tested for their activity on a specific molecular target (e.g., a receptor, enzyme, or protein) implicated in a new disease. This requires knowledge of the drug's pharmacodynamics and the disease's molecular underpinnings. Ex. Kinase inhibitors originally developed for cancer have shown potential in autoimmune and inflammatory diseases.[9]

4.1.4. In-vivo Disease Models

Animal models are used to test the efficacy of existing drugs in mimicking human disease conditions. This can validate the therapeutic potential of a drug identified through HTS or phenotypic screening.

In-vivo testing is critical for assessing bioavailability, metabolism, and toxicity in complex biological systems before human trials.[2]

4.1.5. Clinical Observations and Off-Label Use

Repurposing opportunities often arise from clinical experience, where unexpected beneficial effects are observed in patients using a drug for another indication. These anecdotal findings can lead to formal investigations and trials. Ex. The erectile dysfunction indication for sildenafil (Viagra) was discovered during trials for angina when patients reported improved erectile function.[19]

4.2. Computational Approaches

Computational (in-silico) approaches to drug repurposing have transformed the field by providing rapid, cost-effective methods for screening large datasets to uncover novel drug-disease relationships. These techniques rely on the integration of bioinformatics, cheminformatics, network biology, Machine Learning (ML), and Artificial Intelligence (AI) to predict the potential of existing drugs to treat new symptoms.

4.2.1. Molecular Docking and Virtual Screening

Molecular docking simulates the interaction between a drug and a biological target (usually a protein). By virtually screening approved drugs against disease-relevant targets, researchers can identify candidates with high binding affinity, indicating potential therapeutic effects.

For example, docking studies during the COVID-19 pandemic identified existing anti-virals and anti-inflammatory agents with theoretical activity against SARS-CoV-2 proteins.[20]

4.2.2. Gene Expression Signature Matching

This approach compares gene expression profiles of diseases with those altered by drug treatment. A drug that reverses disease-associated gene expression changes may have therapeutic potential. The Connectivity Map (CMap) is a key resource for such studies, allowing the identification of drugs that produce gene expression signatures opposite to those found in specific diseases.[21]

4.2.3. Network-Based Approaches

Network pharmacology maps the interactions among drugs, targets, and diseases in complex biological networks. These methods identify potential repositioning opportunities by analyzing shared pathways, target similarities, and disease-gene associations. Protein-Protein Interaction (PPI) networks and drug-target interaction (DTI) networks are often employed in these analyses.[22]

4.2.4. Machine Learning and Artificial Intelligence

To forecast novel drug-disease connections, machine learning models examine enormous datasets, such as chemical structures, genetic profiles, clinical outcomes, and electronic medical records. The ability of deep learning algorithms to identify nonlinear correlations in biomedical data has shown special promise. By anticipating its anti-inflammatory and anti-viral properties, artificial intelligence was utilized to repurpose the licensed medication for rheumatoid arthritis, baricitinib, as a treatment for COVID-19.[23]

4.2.5. Data Mining of Clinical and Real-World Data

Mining Electronic Health Records (EHRs), adverse event reports, and clinical trial databases can reveal unanticipated beneficial effects of drugs in off-label uses. These real-world evidence sources can serve as a foundation for repositioning hypotheses. For example, Statins were found to have potential anti-cancer properties based on retrospective analysis of patient data.[24]

The advantages and limitations of the main computational approaches are mentioned in Table 1.

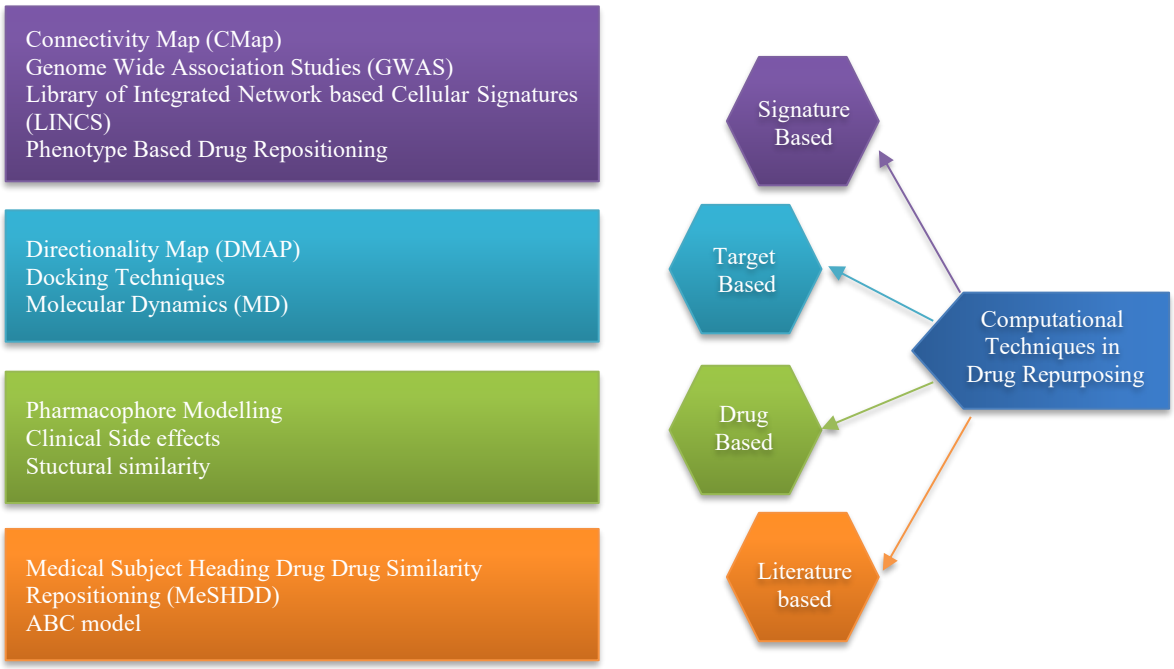

Fig. 2 Computational techniques in drug repurposing

5. Regulatory and Intellectual Property Issues

Drug repurposing has several benefits, including time and money savings, but it also poses special difficulties in terms of regulatory and Intellectual Property (IP) protection.

5.1. Regulatory Framework

In many countries, drug repurposing benefits from regulatory pathways that expedite approval. In the United States, the FDA's 505(b) (2) pathway allows for the submission of new drug applications that rely in part on existing safety and efficacy data. This pathway significantly reduces the burden of generating extensive preclinical and early-phase clinical data, making it ideal for repositioned drugs.[31]

Similarly, the European Medicines Agency (EMA) provides routes such as well-established use applications and hybrid applications under Directive 2001/83/EC, enabling drug repurposing based on literature and bridging studies.

Despite these facilitations, repurposed drugs still require evidence for the new indication, including dose justification, pharmacokinetics, and safety in the new patient population, often necessitating Phase II or III clinical trials.[32]

5.2. Intellectual Property Challenges

Intellectual property protection remains a significant hurdle for drug repurposing, especially for off-patent drugs. Since the original compound may no longer be under patent protection, pharmaceutical companies face limited incentives to invest in costly clinical trials without robust exclusivity rights.

While **"**use patents**"** (i.e., patents on new therapeutic uses of known compounds) can be filed, they are often weaker and more difficult to enforce compared to compound patents. In some jurisdictions, off-label use by physicians further undermines the exclusivity of use patents.[1] To address these concerns, regulatory exclusivity clauses such as data exclusivity or orphan drug designation, which can last from five to ten years depending on the location, can provide a short-term monopoly and encourage investment in repurposing, especially for rare or neglected diseases.

6. Challenges in Drug Repurposing

Drug repurposing has many advantages, but it also encounters significant challenges that could hinder its progress and impact its effectiveness in both the lab and the market.

6.1. Intellectual Property and Economic Barriers

One of the biggest obstacles to drug repurposing is the absence of intellectual property protection for new uses of previously approved drugs, especially for off-patent substances.

Pharmaceutical companies are therefore less financially motivated to invest in costly clinical trials. "Use patents" or "method-of-use" patents offer less protection and are often difficult to enforce, which deters private investment and promotes generic competition.[1]

Table 1. Table Summarizing Computational Approaches

Approach	Description	Tools/Databases	Advantages	Limitations
Molecular Docking	Predicts drug-target binding by simulating molecular interactions [25]	Auto Dock, DOCK	Fast and cost-effective for screening	Requires accurate structural data
Gene Expression Profiling	Compares disease vs. drug-induced gene expression patterns [20]	Connectivity Map (C Map), L1000	Identifies transcriptomic signatures	Data complexity and potential for noise
Network Pharmacology	Analyzes interactions between drugs, targets, and diseases [27, 28]	STRING, Cytoscape	Provides systems-level understanding	Dependent on quality and completeness of networks
Machine Learning & AI	Uses algorithms to predict drug-disease relationships [29, 30]	DeepChem, Chemprop	Efficient handling of large datasets	Requires extensive, high-quality training data

6.2. Regulatory Uncertainty

Even though regulatory agencies offer streamlined methods, there is still a lack of consistency and clarity regarding the clearance requirements for repurposed medications. The need for additional data in multiple regulatory frameworks across different regions may make global growth strategies more complicated. For new indications, companies still have to conduct costly and time-consuming Phase II and III trials.[32]

6.3. Scientific Limitations

Therapeutic repurposing requires a deep understanding of drug mechanisms and disease biology. The precise mechanism of action of older medications or the molecular pathways underlying diseases are frequently poorly understood. This makes it challenging to confidently match medications to novel therapeutic targets, particularly for complex or multifactorial diseases.[2]

6.4. Data Integration and Accessibility

Drug repurposing often requires the integration of diverse datasets**,** such as clinical data, genomic information, drug-target interactions, and adverse event reports. However, these data are frequently incomplete or inaccessible due to proprietary restrictions. A lack of standardized data formats also hinders computational analyses.[33]

6.5. Clinical and Safety Considerations

Even though repurposed drugs have known safety profiles, their use in a new patient population or at different dosages can lead to unexpected side effects or efficacy issues**.** This necessitates rigorous clinical evaluation to confirm that the benefit-to-risk ratio is acceptable for the new indication.[34]

7. Case Studies

A number of treatments that are currently widely utilized in clinical practice were successfully developed as a result of drug repurposing. These case studies highlight how this approach, which is frequently predicated on coincidental observations or focused screening, has the ability to find novel uses for already-approved drugs.

7.1. Sildenafil (Viagra®)

Originally developed by Pfizer as an anti-anginal agent for the treatment of hypertension and ischemic heart disease, sildenafil was observed during clinical trials to have a significant side effect—induction of penile erection. This led to its repurposing and FDA approval in 1998 as Viagra® for erectile dysfunction. Later, sildenafil was also approved for pulmonary arterial hypertension under the brand name Revatio®**.**[35]

7.2. Thalidomide

Due to its teratogenic consequences, Thalidomide was withdrawn from use after being first prescribed in the 1950s as a sedative and antiemetic for morning sickness in pregnant women. After being discovered to possess strong anti-angiogenic and immunomodulatory qualities decades later, it was repurposed to treat erythema nodosum leprosum and multiple myeloma.[36]

7.3. Metformin

Initially introduced in the 1950s for type 2 diabetes**,** metformin has gained attention in recent years for its potential anti-cancer, anti-aging, and cardiovascular protective effects**.** Ongoing research suggests that metformin may exert antitumor activity by modulating metabolic and cellular growth pathways such as AMPK/mTOR signaling.

7.4. Minoxidil

Minoxidil was first authorized as an oral hypertension medication in the 1970s. However, topical minoxidil, which is currently often used to treat androgenetic alopecia, was developed as a result of its unanticipated side effect of encouraging hair growth.**[**37]

Table 2. Drug repurposing case studies

Drug Name	Original Indication	New Indication(s)	Mechanism of Repurposing
Aspirin	Pain relief	Cardiovascular disease prevention	Antiplatelet effect [2]
Thalidomide	Sedative	Multiple myeloma, leprosy	Immunomodulatory effects [9]
Sildenafil	Angina	Erectile dysfunction, pulmonary hypertension	PDE5 inhibition [4]
Remdesivir	Ebola virus	COVID-19	RNA polymerase inhibitor [36]

7.5. Remdesivir

Remdesivir, which was first created by Gilead Sciences to treat Ebola virus infections, was quickly repurposed in 2020 during the COVID-19 pandemic. Blocking RNA-dependent RNA polymerase demonstrated broad-spectrum anti-viral action. Its usage in hospitalized COVID-19 patients was authorized by the FDA for Emergency use and subsequently given full approval.[38]

8. Role in Pandemics and Global Health

During international health emergencies, drug repurposing has proven to be an essential tool, especially during pandemics when it is crucial to discover and implement efficient treatments quickly. The COVID-19 pandemic made this strategy even more urgent as researchers and medical systems around the globe looked for quick fixes with licensed medications.

The substantial decrease in the time and expense needed to get a chemical into clinical usage is one of the main benefits of medication repurposing in a pandemic situation. Repurposed medications can avoid early-phase studies and be assessed directly for efficacy in novel applications because they have previously undergone comprehensive safety and pharmacokinetic testing.[1]

A number of currently available medications were examined for anti-viral properties during the COVID-19 pandemic. Originally created to treat the Ebola virus, Remdesivir was swiftly repositioned and given FDA Emergency Use Authorization to treat COVID-19 after demonstrating promise in shortening recovery time. [39] Similar to this, dexamethasone, a corticosteroid used to treat inflammatory diseases, was repurposed and showed a notable decrease in mortality in patients with severe COVID-19 who needed ventilation or oxygen. [13]

Drugs like hydroxychloroquine and lopinavir/ritonavir were also considered due to their previous use in malaria and HIV treatment, respectively. While these drugs ultimately did not show sufficient efficacy, the efforts highlight how drug repurposing enables a rapid, adaptive response to evolving scientific evidence and clinical needs[40]. Beyond pandemics, drug repurposing has also been vital in addressing neglected tropical diseases and rare diseases, areas typically underserved by traditional pharmaceutical pipelines due to limited commercial incentives. Repurposing allows for cost-effective development of treatments where there is a significant unmet medical need.[12]

In the context of global health in low- and middle-income countries (LMICs), where access to and affordability of innovative treatments continue to be barriers, the repurposing strategy is particularly advantageous. Using medications with established safety profiles and prior approval speeds up regulatory approvals and increases accessibility.

9. Future Perspectives

The future of drug repurposing is expected to be even more significant thanks to the application of cutting-edge technologies and collaborative international initiatives. With the increasing convergence of pharmaceutical innovation and computational science, several exciting opportunities are emerging. Artificial Intelligence (AI) and Machine Learning (ML) are revolutionizing the way researchers find repurposable drugs. These tools may look at massive datasets, such as genetic profiles and electronic medical records, to uncover hidden relationships between drugs, targets, and diseases. Clinical trial data and biological literature are also being searched for new insights using algorithms like deep learning and Natural Language Processing (NLP)[14].

Combining multi-omics techniques, such as transcriptomics, proteomics, metabolomics, and genomics, increases the accuracy and effectiveness of repurposing efforts by providing a systems-level understanding of pharmacological action and disease pathways. Network pharmacology, pathway analysis, and omics data can be used to more precisely identify drug-disease connections.[15]

Personalized therapy could also be revolutionized by drug repurposing. Treatments can be made as effective as possible with the fewest possible side effects by customizing drug repurposing processes based on each patient's genetic profile,

age, and co-morbidities. This is particularly important for complicated illnesses like cancer, where treatment response is greatly influenced by heterogeneity. The success of drug repurposing will also depend on international cooperation and open-access platforms. Initiatives like the Drug Repurposing Hub and the Open Targets Platform facilitate data sharing between academic institutions, regulatory bodies, and corporate players, speeding up discovery and eliminating effort duplication.[26]

10. Conclusion

One practical tactic for quickening the creation of novel treatments is drug repurposing. It applies current pharmacological knowledge to unmet clinical needs, particularly in rare diseases and during global health emergencies. To reach its full potential, enabling regulatory frameworks and ongoing innovation are needed. In contemporary drug discovery, drug repurposing has become a potent tactic that provides a safer, faster, and less expensive substitute for conventional drug development. Researchers can hasten the release of novel treatments for both common and uncommon disorders by utilizing the established pharmacological and safety characteristics of currently available medications. The strategy has shown great promise in tackling pressing public health emergencies like the COVID-19 pandemic and has already yielded several clinical successes.

Technological developments in multi-omics, artificial intelligence, and computational biology are turning the field from a random process to a methodical and predictive one. Intellectual property issues, regulatory restrictions, and financial incentives are just a few of the major obstacles that still need to be overcome. The future of drug repurposing rests on interdisciplinary cooperation, continuous innovation, and supportive legislative frameworks. Through the integration of technological capabilities, clinical knowledge, and international collaboration, drug repurposing can significantly contribute to addressing unmet medical needs and enhancing global health outcomes.

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References

[1] Sudeep Pushpakom et al., "Drug Repurposing: Progress, Challenges and Recommendations," *Nature Reviews Drug Discovery*, vol. 18, no. 1, pp. 41-58, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[2] Nicola Nosengo, "Can you Teach Old Drugs New Tricks?," *Nature*, vol. 534, pp. 314-316, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[3] T.I. Oprea, and J. Mestres, "Drug Repurposing: Far Beyond New Targets for Old Drugs," *The AAPS Journal*, vol. 14, no. 4, pp. 759-763, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[4] Ted T. Ashburn, and Karl B. Thor, "Drug Repositioning: Identifying and Developing New Uses for Existing Drugs," *Nature Reviews Drug Discovery*, vol. 3, no. 8, pp. 673-683, 2004. [CrossRef] [Google Scholar] [Publisher Link]

[5] Yadi Zhou et al., "Network-Based Drug Repurposing for Novel Coronavirus 2019-nCoV/SARS-CoV-2," *Cell Discovery*, vol. 6, pp. 1-18, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[6] Maryam Lotfi Shahreza et al., "A Review of Network-Based Approaches to Drug Repositioning," *Briefings in Bioinformatics*, vol. 19, no. 5, pp. 878-892, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[7] Steven M Corsello et al., "The Drug Repurposing Hub: A Next-Generation Drug Library and Information Resource," *Nature Medicine*, vol. 23, no. 4, pp. 405-408, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[8] Joris Langedijk et al., "Drug Repositioning and Repurposing: Terminology and Definitions in Literature," *Drug Discovery Today*, vol. 20, no. 8, pp. 1027-1034, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[9] Curtis R. Chong, and David J. Sullivan Jr, "New Uses for Old Drugs," *Nature*, vol. 448, pp. 645-646, 2007. [CrossRef] [Google Scholar] [Publisher Link]

[10] Erik De Clercq, "Anti-Viral Drugs in Current Clinical Use," *Journal of Clinical Virology*, vol. 30, no. 2, pp. 115-133, 2004. [CrossRef] [Google Scholar] [Publisher Link]

[11] Álvaro Mourenza et al., "Drug Repurposing: A Quick and Easy Way of Finding New Medicines," *Frontiers for Young Minds*, vol. 9, pp. 1-7, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[12] Yadi Zhou et al., "Artificial Intelligence in COVID-19 Drug Repurposing," *The Lancet Digital Health*, vol. 2, no. 12, pp. e667-e676, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[13] R. Kiplin Guy et al., "Rapid Repurposing of Drugs for COVID-19," *Science*, vol. 368, no. 6493, pp. 829-830, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[14] Aravind Subramanian et al., "A Next Generation Connectivity Map: L1000 Platform and the First 1,000,000 Profiles," *Cell*, vol. 171, no. 6, pp. 1437-1452, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[15] Wei Jiang et al., "Network-Based Multi-Omics Integrative Analysis Methods in Drug Discovery: A Systematic Review," *BioData Mining*, vol. 18, no. 1, pp. 1-29, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[16] Jeff Janes et al., "The ReFRAME Library as a Comprehensive Drug Repurposing Library and Its Application to the Treatment of Cryptosporidiosis," *Proceedings of the National Academy of Sciences*, vol. 115, no. 42, pp. 10750-10755, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[17] David C. Swinney, and Jason Anthony, "How Were New Medicines Discovered?," *Nature Reviews Drug Discovery*, vol. 10, no. 7, pp. 507-519, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[18] Joong Sup Shim, and Jun O. Liu, "Recent Advances in Drug Repositioning for the Discovery of New Anticancer Drugs," *International Journal of Biological Sciences*, vol. 10, no. 7, pp. 654, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[19] Hossein A. Ghofrani, Ian H. Osterloh, and Friedrich Grimminger, "Sildenafil: From Angina to Erectile Dysfunction to Pulmonary Hypertension and Beyond," *Nature Reviews Drug Discovery*, vol. 5, no. 8, pp. 689-702, 2006. [CrossRef] [Google Scholar] [Publisher Link]

[20] Justin Lamb et al., "The Connectivity Map: Using Gene-Expression Signatures to Connect Small Molecules, Genes, and Disease," *Science*, vol. 313, no. 5795, pp. 1929-1935, 2006. [CrossRef] [Google Scholar] [Publisher Link]

[21] Albert-László Barabási, Natali Gulbahce, and Joseph Loscalzo, "Network Medicine: A Network-Based Approach to Human Disease," *Nature Reviews Genetics*, vol. 12, no. 1, pp. 56-68, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[22] Peter Richardson et al., "Baricitinib as Potential Treatment for 2019-nCoV Acute Respiratory Disease," *The Lancet*, vol. 395, pp. e30-e31, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[23] Pan Pantziarka et al., "Repurposing Drugs in Oncology (Redo)—Cimetidine as an Anti-Cancer Agent," *Cancer Medical Science*, vol. 8, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[24] Hema Sree GNS et al., "An Update on Drug Repurposing: Re-Written Saga of the Drug's Fate," *Biomedicine & Pharmacotherapy*, vol. 110, pp. 700-716, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[25] Garrett M. Morris et al., "AutoDock4 and AutoDockTools4: Automated Docking with Selective Receptor Flexibility," *Journal of Computational Chemistry*, vol. 30, no. 16, pp. 2785-2791, 2009. [CrossRef] [Google Scholar] [Publisher Link]

[26] William J. Allen et al., "DOCK 6: Impact of New Features and Current Docking Performance," *Journal of Computational Chemistry*, vol. 36, no. 15, pp. 1132-1156, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[27] Damian Szklarczyk et al., "STRING v11: Protein–Protein Association Networks with Increased Coverage, Supporting Functional Discovery in Genome-Wide Experimental Datasets," *Nucleic Acids Research*, vol. 47, no. D1, pp. D607-D613, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[28] Paul Shannon et al., "Cytoscape: A Software Environment for Integrated Models of Biomolecular Interaction Networks," *Genome Research*, vol. 13, no. 11, pp. 2498-2504, 2003. [CrossRef] [Google Scholar] [Publisher Link]

[29] Bharath Ramsundar et al., "Is Multitask Deep Learning Practical for Pharma?," *Journal of Chemical Information and Modeling*, vol. 57, no. 8, pp. 2068-2076, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[30] Jonathan M. Stokes et al., "A Deep Learning Approach to Antibiotic Discovery," *Cell*, vol. 180, no. 4, pp. 688-702, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[31] William F. Salminen, Marc E. Wiles, and Ruth E. Stevens, "Streamlining Nonclinical Drug Development Using the FDA 505(b)(2) New Drug Application Regulatory Pathway," *Drug Discovery Today*, vol. 24, no. 1, pp. 46-56, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[32] Guangxu Jin, and Stephen T.C. Wong, "Toward Better Drug Repositioning: Prioritizing and Integrating Existing Methods into Efficient Pipelines," *Drug Discovery Today*, vol. 19, no. 5, pp. 637-644, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[33] Jean-Pierre Jourdan et al., "Drug Repositioning: A Brief Overview," *Journal of Pharmacy and Pharmacology*, vol. 72, no. 9, pp. 1145-1151, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[34] Nicholas K. Terrett et al., "Sildenafil (VIAGRA™), A Potent and Selective Inhibitor of Type 5 cGMP Phosphodiesterase with Utility for the Treatment of Male Erectile Dysfunction," *Bioorganic & Medicinal Chemistry Letters*, vol. 6, no. 15, pp. 1819-1824, 1996. [CrossRef] [Google Scholar] [Publisher Link]

[35] Seema Singhal et al., "Antitumor Activity of Thalidomide in Refractory Multiple Myeloma," *New England Journal of Medicine*, vol. 341, no. 21, pp. 1565-1571, 1999. [CrossRef] [Google Scholar] [Publisher Link]

[36] Benoit Viollet et al., "Cellular and Molecular Mechanisms of Metformin: An Overview," *Clinical Science*, vol. 122, no. 6, pp. 253-270, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[37] John H. Beigel et al., "Remdesivir for the Treatment of Covid-19—Final Report," *New England Journal of Medicine*, vol. 383, no. 19, pp. 1813-1826, 2020. [CrossRef] [Publisher Link]

[38] Elise A. Olsen, "The Midline Part: An Important Physical Clue to the Clinical Diagnosis of Androgenetic Alopecia in Women," *Journal of the American Academy of Dermatology*, vol. 40, no. 1, pp. 106-109, 1999. [Google Scholar] [Publisher Link]

[39] RECOVERY Collaborative Group, "Dexamethasone in Hospitalized Patients with Covid-19," *New England Journal of Medicine*, vol. 384, no. 8, pp. 693-704, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[40] Kathleen L. Strong et al., "Patterns and Trends in Causes of Child and Adolescent Mortality 2000–2016: Setting the Scene for Child Health Redesign," *BMJ Global Health*, vol. 6, no. 3, pp. 1-13, 2021. [CrossRef] [Google Scholar] [Publisher Link]