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Comprehensive Review of Pharmacogenomics and the Expanding Scope of Pharmacy Practice in Precision Medicine

Gassim hassan Mohammed almoyed[1], Hamzah Khaled M Alsharif[2], Ahamed Mohammed Alshareef[3], Saeed Ali Hussain Alofair[4], Mansour Mohammed Al yaseen[5], Hamad Mahdi Faris Yaseen[6], Ahmad Samran Ali Aldosari[7], Ali Mohammed Hussein Al shareef[8], Moslah Hussain Moslah Alaglah[9], Ibrahim Saleh Hamad Alhashel[10]

Abstract

This review aims to examine the relevance of understanding pharmacogenomics to develop precision medicine and the broadening role of pharmacy in this field. Pharmacogenomics, the study of genetic factors affecting drug action, has emerged as an essential component in clinical practice, thus providing individualized therapy. The paper aims to provide a background of pharmacogenomics, identify its current use in healthcare, and discuss the possibility of pharmacies incorporating and enhancing drug therapy. It considers such issues as pharmacogenomics/pharmacy bottlenecks, potential benefits, and consequences for patients, and the costs and responsibilities of the pharmacists and pharmaceutical organizations for pharmacogenomic-based treatments. The review's author provides suggestions for merging pharmacogenomics even more into clinical practice and pharmacy education.

Keywords: *Pharmacogenomics, Precision Medicine, Pharmacy Practice, Personalized Medicine, Genetic Variability, Drug Therapy Optimization, Pharmacogenetic Testing.*

Introduction

Pharmacogenomics, a new area under the broader umbrella of personalized medicine, fundamentally alters patient care by establishing a correlation between genetic differences and drug sensitivity. The research on how hereditary differences impact medication response in individuals allows prescribing medicine according to each patient's hereditary makeup. Through such principles, pharmacogenomics gives the possibility of maximizing drug effectiveness, minimizing side effects, and enhancing general therapy results. This approach completely differs from the prevalent "cookie-cutter" approach to healthcare, wherein treatment plans are based on population averages rather than the patient's profile.

Pharmacogenomics and Its Importance

Pharmacogenomics is the application of biotechnology that deals with genetic differences in drug response. Pharmacogenomics comprises the determination of genetic characteristics that may influence the pharmacokinetics of the active drug substance and its therapeutic outcomes. For instance, genetic polymorphisms associated with the CYP450 family of enzymes determine how drugs such as warfarin, clopidogrel, and statins are metabolized in the body, as well as the risk of side effects of these drugs. According to pharmacogenomic testing, choosing suitable drugs and their dosage depending on a patient's characteristics is possible, which contrasts the standard practice of testing one drug result.

[1] Ministry of Health, Saudi Arabia; galmoyed@moh.gov.sa
[2] Ministry of Health, Saudi Arabia; h888h1999@hotmail.com
[3] Ministry of Health, Saudi Arabia; amalshreef@moh.gov.sa
[4] Ministry of Health, Saudi Arabia; saaeedxx@hotmail.com
[5] Ministry of Health, Saudi Arabia; Mbalyaseen@gmail.com
[6] Ministry of Health, Saudi Arabia; hmfy1010@hotmai.com
[7] Ministry of Health, Saudi Arabia; Ahmed25123@hotmail.com
[8] Ministry of Health, Saudi Arabia; ali2005mohammed@icloud.com
[9] Ministry of Health, Saudi Arabia; maglah@moh.gov.sa
[10] Ministry of Health, Saudi Arabia; ialhashel@moh.gov.sa

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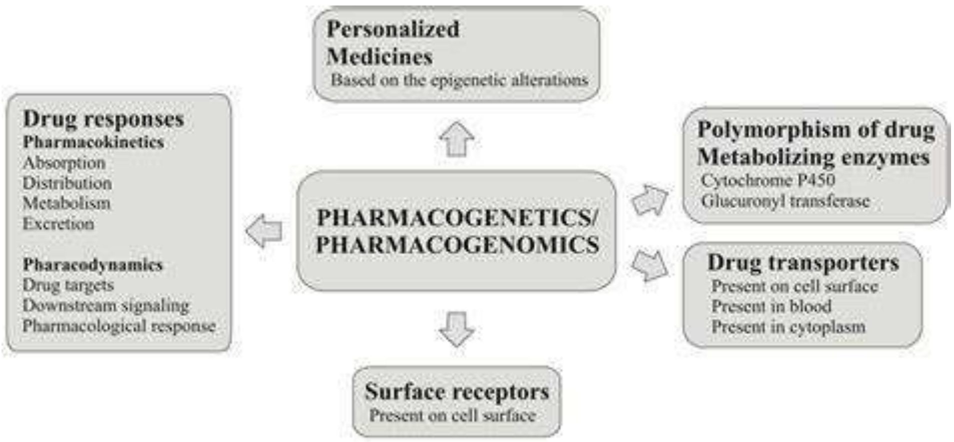
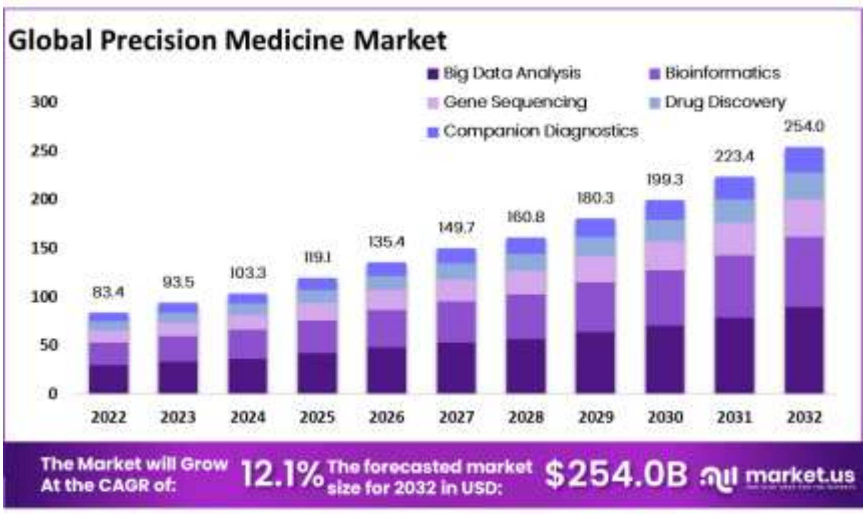
This tailor-made approach to treating patients helps to enhance patient outcomes and reduce ADRs, which are known to contribute to hospitalization and mortality worldwide. Pharmacogenomics can also determine how best to use limited healthcare resources in treatment by distinguishing between patients who will not reap any benefits from a certain drug, thereby avoiding unnecessary prescriptions and expensive trials where certain treatment methods may harm a patient.



The Growth of Precision Medicine

Precision medicine, a newer approach to delivering new treatments, targets care based on genetics, the environment, and the patients' lifestyles. As opposed to conventional medicine, which develops treatment protocols based on standardized data, precision medicine seeks to allow for precise treatment of a particular patient. Pharmacogenomics also forms the core of precision medicine in that it ensures that any drug prescribed includes appropriate genetic characteristics that ensure that the treatment being administered to the patient can target the disease effectively and has little chance of causing a reaction in the patient's body.

The use of precision medicine in health care delivery has gained momentum recently, especially in areas such as oncology, cardiology, and psychiatry. For instance, pharmacogenomics directs which chemotherapy drugs are more responsive to genetic mutations within a patient's tumor in cancer treatment. In the same way, precision medicine helps in the efficient control of diseases that are long-term diseases, such as diabetes, hypertension, and mental disorders.



The Role of Pharmacists in Pharmacogenomics

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Clinical pharmacists, who have the professional mandate for dispensing drugs, are gradually becoming vital in applying pharmacogenomics in clinical settings. Because of their pharmacology and medication therapy management knowledge, pharmacists implement genetic testing for pharmacogenomics and manage patient medication therapy effectively. Currently, pharmacists are strategic players in the healthcare teams working hand in hand with doctors to choose the right treatment course according to the patient's genetics.

The implementation of pharmacogenomics in pharmacy practice demands that pharmacists review current literature, technologies, and genetic testing platforms. In addition, pharmacists must inform patients of the advantages and disadvantages of pharmacogenomic testing and embrace genetic data in their marketing plans.

Objective of the Review

This review aims to pursue the evolution of pharmacogenomics in pharmacy practice with a topical emphasis on precision medicine. The aspects discussed during the review include the current relevant research and development of pharmacogenomics, mainly in oncology, cardiovascular diseases, and psychiatry fields. It will also explore the shifting function of pharmacists to analyze these results and respond by modifying a patient's medication regimen. Furthermore, this review will also look at difficulties that may surround the implementation of pharmacogenomic work in the clinical setting, which include cost factors, availability of services, and standardization. Last, the review will briefly discuss trends/anticipated developments in pharmacogenomics and/or pharmacy practice while noting that many standpoint areas will require further education and/or collaboration in the evolving healthcare sectors.

This paper aims to outline the present state of pharmacogenomics and its contribution to precision medicine so that the audience will be informed about how pharmacogenomics is reforming medication prescription and management and patient status.

Literature Review

Overview of Pharmacogenomics

Pharmacogenomics, the study of how genetic differences in individuals result in differences in drug response, has expanded as one of the key aspects of precision medicine. It aims to comprehend genetic disparities in drug metabolism, thus enabling the determination of patients' reactions to certain drugs, promoting increased drug effectiveness and fewer side effects.

1. The Genetic Basis of Drug Response

Common genetic variations will significantly impact drug metabolism, distribution, and effect. For instance, the CYP450 enzymes are involved in the metabolic process, and genetic variations determine the rate of drug metabolism. Patients who have certain genetic variations in the CYP2D6 gene can rapidly or slowly metabolize a range of medications, including antidepressants, beta-blockers, and antipsychotics, to such an extent that they may be insufficient in their pharmacological activity or cause toxicityOther genes, such as *VKORC1* and *CYP2C9*, impact the metabolism of anticoagulants like warfarin. The sensitivity to the anticoagulant effect of warfarin depends on these genetic factors; as a result, dosing should be personalized. Also, differences in expressions and activities of UGT1A1 have been known to affect the response to chemotherapy, such as that involving irinotecan. Understanding how pharmacogenomic testing can be applied to building the best medication plan and understanding how genetic differences may impact drug metabolism is important.

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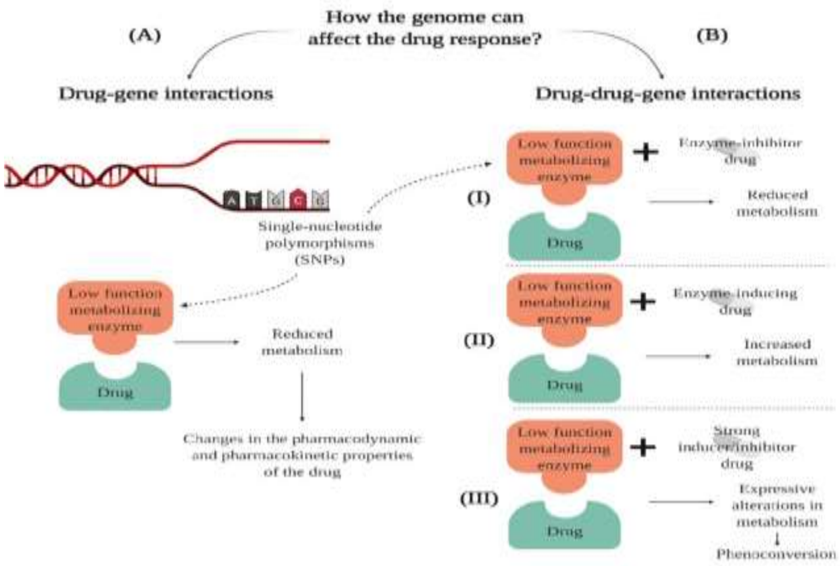

(Dunnenberger et al., 2016).

2. Clinical Applications of Pharmacogenomics

Oncology

Pharmacogenomics has been defined as one of the main strategies in the management of cancer and, more specifically, using targeted therapy. For instance, HER2 testing is very relevant in breast cancer care due to its ability to guide doctors toward identifying patients who will benefit from drugs such as trastuzumab. In lung cancer, these biomarkers can predict or orient if the patient will have positive outcomes to EGFR inhibitors, including gefitinib and erlotinib. Through such mutations, oncologists can prescribe treatment that will ensure they get the right treatment for cancer through a molecular analysis of the body.

Cardiovascular Diseases

In the cardiovascular framework, pharmacogenomic testing is important in anticipating reactions to medications such as warfarin and statins. One of the most prescribed anticoagulants is warfarin, which has a relatively small toxic-nontoxic range and for which dose depends on specific genotypes involving VKORC1 and CYP2C9 genes. Genotyping for these polymorphisms guides the appropriate warfarin dosing and thus decreases the chance of side effects such as bleeding. Likewise, polymorphism of the SLCO1B1 gene incurs statin metabolic consequences and susceptibility to side effects, including muscle toxicity. Such risks include personalized doses that greatly minimize these effects and enhance cardiovascular status.

Psychiatric Disorders

Pharmacogenomics equally has a central role in the management of psychiatric diseases. Drugs used in illnesses such as depression, anxiety, and schizophrenia are known to have a genetic influence on drug metabolism. For instance, the genetic variation that involves the CYP2D6 gene influences the metabolism of various antidepressants, for example, SSRIs and tricyclic antidepressants. Thus, relevant polymorphisms in the CYP2D6 gene plan dose adjustment of certain drugs to prevent side effects or increase therapeutic efficacy in patients. Likewise, pharmacogenomic testing can help determine appropriate antipsychotics to prescribe to any patient so that a patient will only get the best antipsychotic matched to his or her genetics.

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Pain Management:

Scholars have used pharmacogenomics to try to individualize opioid prescriptions—especially under the current conditions of an opioid epidemic. Opioid metabolism can be identified through genetic tests, and therefore, doctors get directions on the right opioids to use with special gene-related factors for the patient. For example, patients with genetic differences in the CYP2D6 gene can suffer from toxic reactions to codeine because bodies with the mutated gene process the drug into toxic substances faster. Knowledge of these genetic

3. Pharmacogenomics in Polypharmacy and Elderly Populations

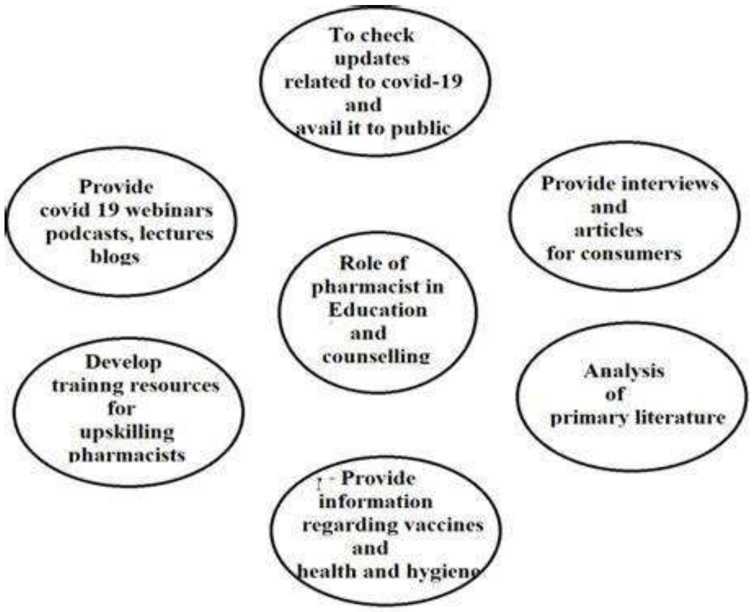
Pharmacogenomic tests will greatly benefit the elderly patient group, who regularly take multiple medications. Metabolic alterations due to aging, along with genetic factors, predispose older patients to develop adverse drug reactions. Pharmacogenomics used in clinical practice will enable clinicians to manage polypharmacy in elderly patients by decreasing drug-drug interactions, toxicity, and hospitalization. For instance, the CYP450 enzymes act on many drugs taken by elderly patients, and genetic tests enable physicians to establish suitable drugs and the right proportions that are safe and effective.

Pharmacogenomics and the Current Role of Pharmacists

Therefore, pharmacists have a central role to play in the implementation of pharmacogenomics in practice. Since pharmacists deal with drugs and patient care, they should take full responsibility for genetic testing, drug/route choice, and educating patients.

1. **Pharmacists as Educators and Advocates**

Pharmacists have the role of patient and provider educators as the public and healthcare professionals about pharmacogenomic testing and its use. Self-administering patients to the fact that pharmacogenomics is about the likelihood of introducing more suitable drugs for their genetic disposition. Pharmacists also prescribe genetic tests as an important part of the patient care plan, trying to help the patient understand what is happening at the genetic level and how these factors may affect the patient's description and management.



(Katara & Yadav 2019).

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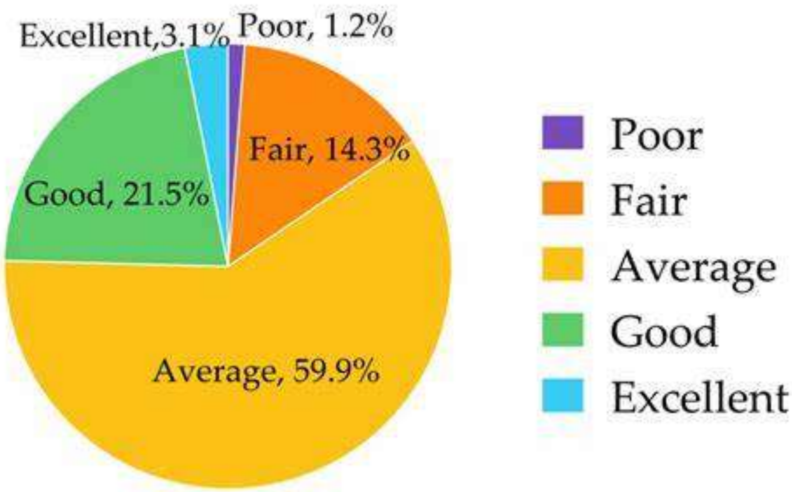
2. Pharmacogenomic Testing in Pharmacy Practice

In real-life pharmacy practice, pharmacists explain the results of pharmacogenomic tests and try to change drug treatments based on them. Through analyzing genetic information, pharmacists can identify substitutions of drugs and changes in dosage and be allowed to consult with physicians on the best course of action concerning the patient's genetic profile. Pharmacists also perform the role of detecting and referring patients for pharmacogenomic tests, supporting the implementation of pharmacogenomic tests into patient care, and, most importantly, bridging the gap between genetic information and clinical practice.



(Klein et al., 2017).

3. Integration of Pharmacogenomics in Pharmacy Curriculum

The most critical aspect of pharmacy education is introducing genetic testing and interpreting the results as part of the pharmacogenomic curriculum. It seems that pharmacy students are being educated to comprehend the foundation associated with genetic influences on medication metabolism and efficacy and how pharmacogenomic tests and results can be used in patient care. This shift also guarantees that future pharmacists are well-equipped with the tools to help advance individualized medicine and improve patient outcomes.

Barriers to Widespread Adoption of Pharmacogenomics

Despite the clear benefits, several barriers hinder the widespread adoption of pharmacogenomics in clinical practice.

1. Cost and Accessibility

Pharmacogenomic testing is still expensive compared to standard genotyping, especially in some developing countries. However the cost of performing genetic tests has continued to reduce over the years, but it may still be expensive to price for most patients or healthcare facilities, mostly in the developing world. Also, insurance reimbursement for pharmacogenomic testing is still contested, which makes it a challenge for patients to get PCR to diagnose pharmacogenomic testing. Increasing menu offerings of genetic testing solutions is important for making more patients part of pharmacogenomic-guided treatment.

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1. Policies and Standards

Ethical and regulatory questions related to pharmacogenomics include patient autonomy and their ability to decide whether or not to take pharmacogenomic tests and how genetic information is used. Pharmacogenomic testing involves a patient's genetic makeup, so the patient should fully understand the ramifications of the pharmacogenomic tests (Ji et al., 2018).. They also include such issues as genetic fundamentalism, that is, the ability of genetics to produce biased results and genetic discrimination coupled with the proper handling of genetic data.

1. Lack of Standardization

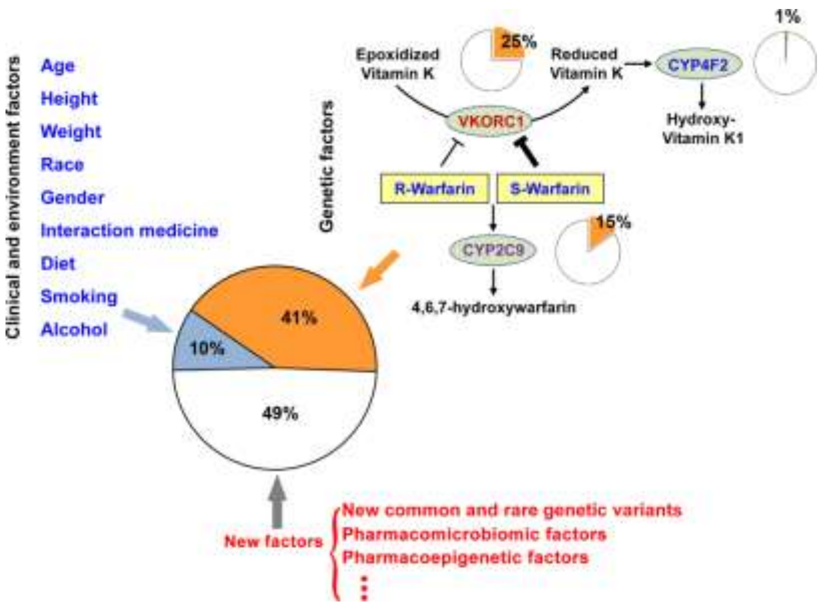
The final problem is the absence of ideal best practices for introducing pharmacogenomic testing to healthcare facilities. As the technologies used in genetic tests are emerging, there is a systematic, evidence-based approach to supporting healthcare providers in adopting pharmacogenomics in practice. Promoting standardization of testing procedures and the evaluation of the outcomes will assist in the safe promotion of the use of pharmacogenomics in different healthcare facilities.

Methods

Although this paper is a work review, one may refer to various available literature regarding pharmacogenomics, its clinical implications, and the growing role of pharmacists. Data sources such as research articles, clinical trials, and reviews published in scientific peer-reviewed journals and reports from medical professional associations and organizations, including ASHP, FDA, and NIH, were considered. Primary data from clinical trials of pharmacogenomic medicine in oncology, cardiovascular diseases, and cancer pain were reviewed.

Further, views regarding the application of pharmacogenomics in routine clinical settings were also evaluated using surveys and interviews with healthcare providers and community pharmacists.

Figure 1: Pharmacogenomic application for detecting ideal warfarin dose regarding VKORC1 and CYP2C9 gene variations.



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Results and Findings

Impact on Patient Outcomes

Recent advances in pharmacogenomics have provided significant evidence that genetic variations can significantly enhance patient treatment results relative to drug-based treatment protocols. This is perhaps one of the main advantages of pharmacogenomic-based therapies, if not the most significant, since the chances of enhancing drug efficacy will be greatly enhanced. Pharmacogenomics enables doctors to choose the right medicines depending on the nature of different genes and how they affect the patient's response to the drug. For instance, oncogenomics tests performed on tissue samples, like the HER2 assay test for breast cancer, will help identify patients who benefit from trastuzumab(Kisor et al., 2019). Such an individualized treatment concept has been proven to increase survival rates and, at the same time, minimize the patient's time in the hospital receiving less effective treatment. Likewise, genetic typing for EGFR in lung cancer patients allows for identifying patients who should be administered EGFR inhibitors, yielding much better outcomes for the patients in question.

Apart from optimizing drug efficacy, pharmacogenomics has the major task of minimizing ADRs, a major issue in clinical practice. Pharmacogenomic testing is also useful to identify an individual with a higher likelihood of having poor metabolism or toxic effects of the drugs and thus reduces adverse drug effects. One important application of this is in the determination of patients with abnormalities in the CYP450 enzymes that govern the rate of drug metabolism. For example, individuals with particular genotypes of the CYP2C9 gene are likely to metabolize warfarin—an anticoagulant—slowly and are, therefore, at a higher risk of bleeding if they are administered a normal dose. Since various genetic variations affect the metabolism of warfarin, through these tests, the clinician can determine the right dose to administer to a particular patient to minimize adverse effects. It is also applied to other therapies, such as depressants, schizophrenia, and analogous pains, where it has lowered the occurrence of ADRs in other classifications as well.

The Use of Pharmacogenomic Information in Clinical Practice

The introduction of pharmacogenomics in clinical management has greatly advanced the provision of personalized treatment, mostly in cancer and cardiovascular diseases.

Oncology

In oncology, pharmacogenomic testing has changed how cancer treatments are chosen. The most illustrative example is HER2 testing for breast cancer, in which molecular testing is performed to find out if patients have an overexpression of HER2 protein as a symbol of the aggressive cancer type. HER2-positive breast cancer patients are more favorably responsive to targeted therapies like trastuzumab, which directly affects the HER2-positive protein and enhances therapeutic effectiveness and survival odds(Weitzel et al., 2016).. In colorectal cancer, the pharmacogenomic test for mutation is useful in directing the usage of anti-EGFR monoclonal antibodies. KRAS testing is important because patients with KRAS mutations do not benefit from these therapies, so testing avoids giving these patients treatments that will be ineffective and potentially trigger side effects. Some of such tailored treatment strategies that involve therapies based on the genetic analysis of a cancer patient's tumors are revolutionizing cancer treatment by allowing doctors to fashion a treatment plan that is unique to each patient's disease.

Cardiovascular Applications

Another area whereby pharmacogenomics has also brought considerable improvements to cardiovascular diseases is in the dosing of warfarin, an anticoagulation drug. Warfarin is a drug with a small margin of safety, and certain inherited traits, such as polymorphism of the VKORC1 and CYP2C9 genes, impact the patient's ability to metabolize the product. It has been established that there are patients with genetic factors that will need a smaller or greater amount of warfarin to reach the desired anticoagulation level without causing bleeding. Clinical application of pharmacogenomic testing in these cases has demonstrated better

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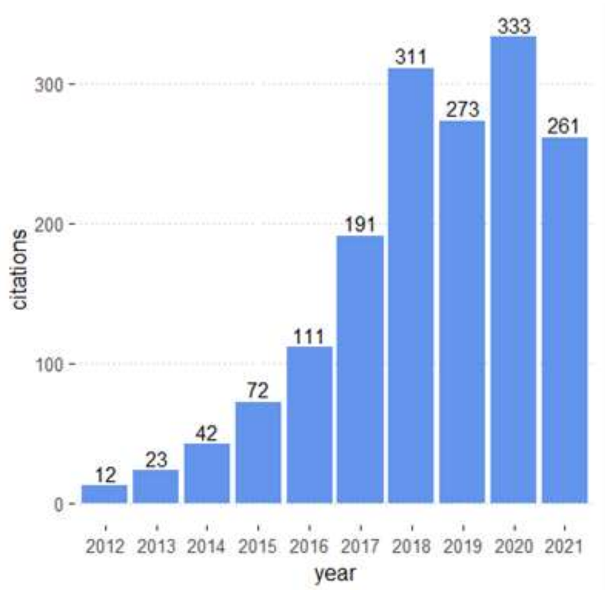
identification of accurate warfarin dosing, decreased life-threatening side effects, and overall greater patient safety. More specifically, pharmacogenomic testing has been utilized for statin therapy, which shows that genetic changes in the SLCO1B1 can predict the risk of side effects such as muscle pain or myopathy. Individualized statin therapy has been proven to decrease these side effects while ensuring that the drug reduces cholesterol(van der Lee et al., 2020)..

In addition, pharmacogenomics is playing a growing role in hypertension, most especially in choosing the correct antihypertensive drug. Certain mutations to the AGT gene may determine the patient's receptiveness to ACE inhibitors or angiotensin receptor blockers (ARBs) and can allow for a more targeted treatment plan. This personalized method has benefited clinicians by enhancing blood pressure control, decreasing side effects, and improving overall cardiovascular prognosis.

Pharmaceutical Care: A Conceptual Framework.

Pharmacogenomics in clinical pharmacy relies mainly on pharmacists' input as practitioners in its implementation. They are perfect candidates for translating genetic information and working with other healthcare providers to enhance pharmaceutical management.

Graph 1: Pharmacogenomic testing trends over the last decade in clinical practice



(Alessandrini et al., 2016).

Patient Engagement

Apart from translating genetic information, pharmacists play a crucial role in sharing the pros and cons of pharmacogenomic testing with patients. A purveyor of drugs can discuss with a patient the genetic testing implications of the approach to treatment, adverse drug reactions, possible risks, and strict compliance with prescribed therapy regimens. Pharmacists often acted as educators who assisted clients in making correct perceptions about their health conditions and proactively increased their roles in their disease management systems. It is crucially important to educate such patients because, as pharmacogenomic tests are increasingly implemented and incorporated as adjunct diagnostic tests, an expanding number of patients will be affected. The pharmacists also explain the implications of the genetic test results and how the results will influence the patient's total and medication management.

Other roles include pharmacists, who can also foster the practice of pharmacogenomics in the healthcare setting as members of the multi-healthcare team. Pharmacists can join physicians, genetic counselors, and

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other healthcare providers in ensuring that pharmacogenomic testing is fully integrated into clinical practice and that individualized drug therapy is provided optimally. This presentation identifies how they support interprofessional practice to enhance patients' well-being and advance their best outcomes.

Discussion

Pharmacogenomics has progressed in providing safer alternatives in drug administration based on an individual's genomics. It has gained value and interest in pharmacy practice and thus enhanced patients' well-being, although it is yet to realize its full potential. This section discusses prospects, future issues and advancements, and increased perspectives of pharmacists in pharmacogenomics.

Pharmacogenomics has a bright future, especially when augmented with artificial intelligence (AI) and machine learning (ML) technologies. AI and ML systems can find patterns in a large amount of data on genotype and drug effects and estimate the patient's reaction to a specific drug. These technologies might also enhance drug therapy decision-making paths in real-time if the algorithms improved further to become data-driven. For instance, AI can see multidimensional relationships between genetic factors and drug effects and use those insights to treat complicated diseases like tumors or heart diseases. Also, as the concepts of AI and machine learning algorithms become cheaper and more accessible, they may make the large-scale pharmacogenomic testing and availability of personalized medicine more widespread, especially where it is needed most.

Also, as genomic research unfolds and pharmacogenomic data expands, the establishment of vast drug repositories will assist in integrating pharmacogenomic testing into clinical practice. These will facilitate an understanding of which patients would gain the most from the defined pharmacogenomic therapy and enhance the overall system of drug delivery in different therapeutic fields.

Challenges in Implementation

However, several issues remain perplexing and slow down the expansion of pharmacogenomics in pharmacy. Among the challenges likely to inhibit such development is that genetic tests are expensive. Though genetic tests have decreased over the years, they are still very expensive for most patients and many healthcare facilities, especially in the developing world(Weinshilboum & Wang 2017, November).. The services of genetic counselors are also not easily accessible, meaning that even those patients with the test results may not easily comprehend their significance.

Pharmacogenomic testing and implementation are another moderate concern because they are not consistently applied in healthcare organizations. Different testing methodologies and protocols, test regulations, or variations in results mean variations inpatient treatment. There is also no coherent understanding of incorporating pharmacogenomics in clinical practice since there are no standard guidelines.

Expanding the Role of Pharmacists

Pharmacists have already been involved in integrating pharmacogenomics into practice but have even more potential for future development. Pharmacogenomic testing and the specific utilities that it enables require those who manage pharmacogenomic testing and its applications to have constant updates on genetic testing, bioinformatics, and genetic data interpretation. The following professional development programs should be initiated to arm pharmacists with adequate information and knowledge to use the pharmacogenomics system in the systemized practice. RC:

In addition, there will be more cross-referrals between pharmacists, genetic counselors, and physicians to develop accurate interpreters for pharmacogenomic data and enhance individualized drug therapy(Walko et al., 2016).. With time, pharmacists will require adequate knowledge of emerging genetic findings, changes in drug interactions, and the ever-changing methods of pharmacogenomic testing to adequately attend to their clients.

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Overall, pharmacogenomics offers massive potential for enhancing patient care and making individualized treatments a reality, but current obstacles remain pronounced and must be resolved. Given modern technology, enhanced and appropriate education, and intimate interdisciplinary cooperation, the future of pharmacogenomics is expected to be revolutionary for the practice of pharmacy and healthcare delivery.

(Ta et al., 2019).

Critical analysis determined whether Krishnan-Schroeder's (2007) strategic concept means that Maghribi firms can create ambivalently effective relations with European partners full of entrepreneurial opportunities for both while avoiding the disciplinary impending mechanisms of the Western market-oriented international business system.

Thus, pharmacogenomics is one of the most promising tools for advancing medicine at the individual level. It provides effective treatments aimed separately at the therapeutic targets with maximum effectiveness and minimum side effects according to the patient's genetic background. Pharmacogenomic testing is expected to become standard in managing patients' treatment, and as the work of pharmacists broadens, these specialists will also be involved in executing such tests, analyzing the results, and enhancing the patient's outcomes. However, obstacles like high testing costs, limited access, and less rigidity must be resolved before the tool becomes popular. Moreover, continuing education for pharmacists enhances their skills and knowledge in practice regarding new developments. As technology takes a further shift, genetic testing, the growth of facilities, education, and the practice of pharmacogenomics are likely to revolutionize the health of many.

Recommendations

1. Expansion of Pharmacogenomics Education: Enhance the existing PG training in PC educational curricula with more comprehensive student preparations to meet forthcoming responsibilities in precision medicine.

2. Collaboration with Healthcare Providers: Promote better relations between pharmacists and the rest of the caregivers to improve the implementation of pharmacogenomic tests in patients' care.

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3. Government and Institutional Support: Call for specific health policy reforms in prescribing costs for pharmacogenomic testing, especially for needy groups.

Ongoing Research and Standardization: Reauthorization for continued support of active investigations to confirm the effectiveness of pharmacogenomic-based therapies and the establishment of recognized protocols for testing and measurement.

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