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The role of pharmacogenomics in personalized nursing care: Laboratory techniques and clinical applications

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***Abstract*---Background:** Pharmacogenomics (PGx), the study of genetic variations affecting drug response, is a cornerstone of personalized medicine. It holds immense potential in nursing care by enabling tailored treatment strategies, enhancing therapeutic efficacy, and minimizing adverse drug reactions (ADRs). Despite its promise, PGx integration into clinical nursing practice faces challenges such as high costs, limited access to testing, and a knowledge gap among healthcare professionals. **Aim:** This paper aims to examine the role of pharmacogenomics in advancing personalized nursing care. It focuses on identifying key genetic markers influencing drug response, exploring laboratory techniques employed in PGx testing, and highlighting clinical applications that inform nursing practice. **Methods:** The study undertakes a systematic literature review from databases like PubMed and Google Scholar, emphasizing pharmacogenetic markers, laboratory methodologies, and nursing applications. Laboratory techniques such as next-generation sequencing (NGS) and genotyping are analyzed, alongside clinical case studies to demonstrate the real-world impact of PGx on nursing interventions. **Results:** Pharmacogenomics significantly improves nursing care by guiding drug selection and dosages through genetic

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insights. Laboratory techniques identify key markers such as CYP450 polymorphisms, optimizing medication safety and efficacy. Clinical applications show reduced ADRs, improved adherence, and better patient outcomes. Nurses, with their patient-centered focus, play a vital role in implementing PGx strategies but require enhanced training and resources. **Conclusion:** Pharmacogenomics revolutionizes personalized nursing care, offering improved therapeutic outcomes and reduced healthcare costs. Addressing barriers like cost, ethical concerns, and education is essential for widespread adoption. Nurses are central to integrating PGx into routine care, bridging genetic insights with practical interventions.

***Keywords*---**pharmacogenomics, personalized nursing, genetic testing, clinical applications, precision medicine, adverse drug reactions.

Introduction

Pharmacogenomics (PGx), the examination of how genetic variations affect individual drug responses, has become a revolutionary paradigm in personalized medicine. Pharmacogenomics enhances therapeutic efficacy, minimizes adverse drug reactions (ADRs), and reduces healthcare costs by customizing pharmacological treatments according to patients' genetic profiles. The implementation of pharmacogenomics is especially important in nursing care, where personalized therapies are essential for attaining optimal health outcomes. Nurses, as primary healthcare practitioners, are ideally equipped to incorporate pharmacogenomics into their practice, acting as a conduit between genetic science and patient-centered treatment.

Pharmacogenomics is crucial in nursing care as it tackles the ongoing issue of diversity in individual drug reactions. Conventional pharmacotherapy methods frequently depend on population-level data concerning efficacy and safety, overlooking the substantial genetic variations that can influence drug metabolism, transport, and receptor interactions. Pharmacogenomics offers an exact resolution by clarifying the genetic factors contributing to this variability, therefore improving the customization of treatments [1, 2]. Theoretical frameworks like precision medicine advocate for the integration of genomic data into healthcare to enhance treatment options, in accordance with the concepts of pharmacogenomics. Furthermore, the incorporation of pharmacogenomics into nursing practice corresponds with fundamental nursing abilities, such as patient education, medication management, and advocacy, highlighting the pivotal role of nurses in executing genomic-informed healthcare.

Recent breakthroughs in pharmacogenomics have highlighted its increasing significance in clinical practice. Technologies like next-generation sequencing (NGS) and high-throughput genotyping have markedly expedited the identification of genetic variants associated with medication metabolism and efficacy [4, 5]. Polymorphisms in genes like CYP2D6, CYP2C19, and SLCO1B1 are frequently examined to inform medication selection and dose. The expansion of pharmacogenetic databases, including those curated by the Clinical

Pharmacogenetics Implementation Consortium (CPIC), has enabled the evidence-based utilization of pharmacogenomics across many clinical environments. These databases offer defined protocols for incorporating pharmacogenomic data into decision-making, guaranteeing that genetic insights are efficiently converted into enhanced patient outcomes. Collaborative interdisciplinary approaches among geneticists, doctors, pharmacists, and nurses are essential for the effective integration of pharmacogenomics into healthcare [7].

The capacity of pharmacogenomics to transform nursing practice is significant. Pharmacogenomics enables nurses to utilize genomic knowledge and technologies to customize therapies according to specific patient profiles, thereby improving therapeutic outcomes and reducing risks. The effective incorporation of pharmacogenomics into nursing care necessitates overcoming various hurdles, such as the requirement for specialized training, ethical issues with genetic data, and inequities in access to genomic testing. Nurses must comprehend the basic concepts of pharmacogenomics and acquire the abilities to convey intricate genetic information to patients while advocating for equal access to genomic resources.

This study examines the importance of pharmacogenomics in enhancing individualized nursing care. Subsequent to this introduction, the background section offers a comprehensive examination of the genetic and clinical principles underpinning pharmacogenomics. The next sections explore the laboratory approaches utilized in pharmacogenomic testing, encompassing techniques such as polymerase chain reaction (PCR) and next-generation sequencing. The clinical applications section analyzes the influence of pharmacogenomics on enhancing nursing interventions, emphasizing its effects on drug safety, efficacy, and adherence. The essay assesses the existing problems and prospective potential in this field, providing recommendations for improving the incorporation of pharmacogenomics into nursing practice. This analysis seeks to underscore the revolutionary potential of pharmacogenomics in enhancing healthcare delivery and patient outcomes.

Pharmacogenomics in Personalized Nursing Care

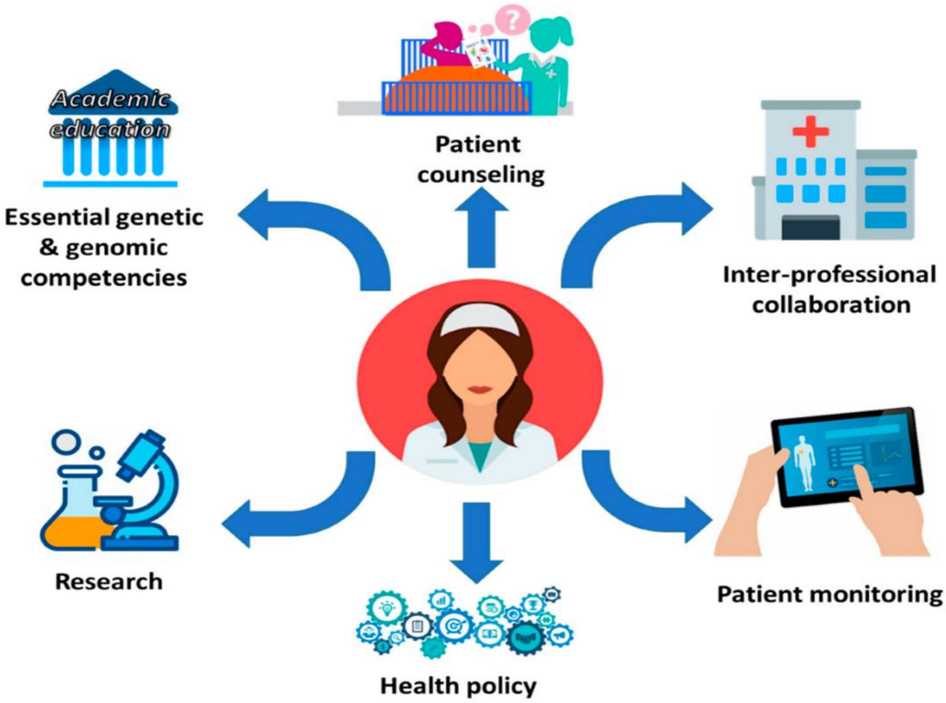
Pharmacogenomics (PGx) stands as a cornerstone of precision medicine, heralding a transformative era in healthcare by examining how genetic variations shape an individual's response to medications. By integrating genetic insights into clinical practice, PGx offers the potential to revolutionize patient care, particularly in the domain of personalized nursing. This innovative field enables a deeper understanding of the genetic underpinnings of drug metabolism, efficacy, and safety, thus providing a framework for tailoring pharmacological interventions to each patient's unique genetic profile. The implications of PGx are profound, as it empowers healthcare professionals to optimize therapeutic outcomes, reduce the incidence of adverse drug reactions (ADRs), and enhance patient safety.

In nursing practice, PGx plays a critical role by supporting individualized care plans that align with a patient's genetic predispositions. Through PGx, nurses can predict how a patient might metabolize a specific drug—whether they are likely to be a poor, intermediate, normal, or ultra-rapid metabolizer—and adjust dosages or drug choices accordingly. This capability is especially valuable in managing chronic diseases, polypharmacy, and conditions requiring long-term medication use, where traditional approaches often fail to account for interindividual variability.

The integration of PGx into nursing practice not only refines therapeutic strategies but also improves patient education and advocacy. Nurses can utilize genetic information to inform patients about potential drug responses, adherence strategies, and possible side effects, fostering a more collaborative and informed approach to care. Moreover, PGx enhances the precision of drug selection for vulnerable populations, such as pediatric, geriatric, and oncology patients, who are particularly susceptible to ADRs and suboptimal treatment outcomes.

By bridging the gap between genomics and pharmacology, PGx represents a vital tool in advancing nursing practice and achieving the goals of precision medicine. Through its integration into healthcare systems, PGx not only enhances the safety and efficacy of pharmacological treatments but also positions nurses at the forefront of personalized medicine, where they play a pivotal role in translating genetic insights into meaningful patient care.

Pharmacogenomics (PGx) represents a pivotal advancement in precision medicine, focusing on how genetic variations influence an individual's response to drugs. This emerging field has vast potential in personalized nursing care, where the tailoring of pharmacological interventions is critical to optimizing therapeutic outcomes, minimizing adverse drug reactions (ADRs), and enhancing overall patient safety. PGx enables nurses to provide more effective, individualized care by leveraging genetic insights to predict drug metabolism, efficacy, and safety. This section delves into the genetic basis of drug response, the importance of PGx for nursing practice, ethical considerations, and real-world examples of PGx-guided interventions.



Genetic Basis of Drug Response: The Role of CYP450 Enzymes in Metabolism

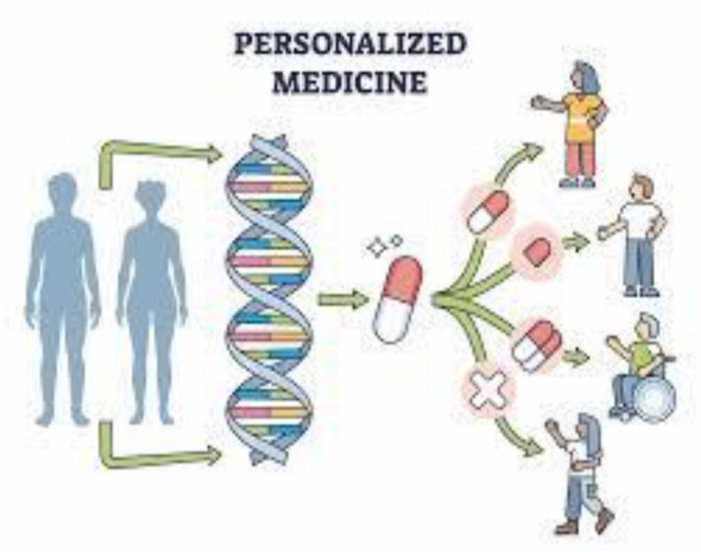
The genetic variability of drug-metabolizing enzymes is central to pharmacogenomics. Among these, the cytochrome P450 (CYP450) enzyme family plays a critical role in the metabolism of approximately 75% of clinically used drugs [8]. Genes encoding these enzymes, such as **CYP2D6, CYP2C9, and CYP3A4**, exhibit polymorphisms that can alter enzymatic activity. For instance, individuals with a poor metabolizer phenotype for CYP2D6 may experience elevated drug levels and increased risk of toxicity, while ultrarapid metabolizers may exhibit subtherapeutic effects due to accelerated drug clearance [9, 10].

These polymorphisms significantly impact the pharmacokinetics of various medications, including antidepressants, anticoagulants, and chemotherapeutic agents. For example, CYP2C19 polymorphisms affect the metabolism of clopidogrel, an antiplatelet drug, resulting in reduced efficacy in individuals with loss-of-function alleles. This variability underscores the necessity of incorporating PGx testing into routine clinical care, particularly in nursing, where medication management is a cornerstone of practice [11].

Importance for Nursing: Enhancing Efficacy and Minimizing Risks

Incorporating pharmacogenomics into nursing care offers numerous benefits. By identifying genetic variants that influence drug response, nurses can tailor interventions to individual patients, thereby optimizing therapeutic efficacy and minimizing the risk of ADRs. Adverse drug reactions account for significant morbidity and healthcare costs globally, with up to 30% of hospital admissions linked to preventable ADRs [12]. PGx-guided care allows for the early identification of at-risk individuals, enabling personalized drug selection and dosing adjustments.

Nurses are uniquely positioned to integrate PGx insights into clinical care due to their role in medication administration, patient education, and interdisciplinary communication. By interpreting pharmacogenomic test results and translating them into actionable clinical decisions, nurses can bridge the gap between genetic science and practical healthcare delivery. Furthermore, nursing interventions informed by PGx align with the broader goals of precision medicine, which emphasize individualized care plans tailored to patients' unique genetic, environmental, and lifestyle factors [13].



Ethical Considerations: Privacy, Informed Consent, and Access

While pharmacogenomics offers transformative potential, it also raises significant ethical concerns. Key issues include genetic privacy, informed consent, and equitable access to PGx testing. Genetic data is inherently sensitive, and its misuse can lead to discrimination in employment or insurance, underscoring the importance of robust data protection measures [14]. Nurses must ensure that patients fully understand the implications of PGx testing, including potential risks related to genetic data security.

Informed consent is another critical consideration. Patients must be adequately educated about the purpose, benefits, and limitations of PGx testing to make informed decisions. This requires clear communication, particularly for populations with limited health literacy. Additionally, disparities in access to PGx testing, often driven by socioeconomic factors, may exacerbate health inequities. Nurses, as patient advocates, play a vital role in promoting equitable access to PGx services and addressing systemic barriers that limit availability in underserved populations [15].

Case Study Examples: Reducing ADRs Through PGx-Guided Interventions

Real-world applications of pharmacogenomics demonstrate its potential to reduce ADRs and improve clinical outcomes. For instance, the implementation of CYP2C19 genotyping in patients prescribed clopidogrel has significantly reduced the incidence of thrombotic events in individuals with loss-of-function alleles [16]. Similarly, the use of PGx testing in oncology has improved dosing precision for chemotherapeutic agents like 5-fluorouracil, reducing toxicity and enhancing treatment efficacy [17].

In nursing practice, case studies highlight the integration of PGx into care plans. A prominent example is the management of warfarin therapy, where CYP2C9 and VKORC1 genotyping has enabled personalized dosing, reducing the risk of bleeding complications. Nurses, by monitoring patient responses and adjusting therapy based on genetic insights, have demonstrated the ability to improve patient outcomes and reduce healthcare costs. These examples underscore the critical role of nurses in operationalizing PGx findings within clinical settings.

Laboratory Techniques in Pharmacogenomics

Laboratory techniques form the cornerstone of pharmacogenomics (PGx), enabling the identification of genetic variations that influence drug response. The precision and reliability of these techniques are critical for integrating PGx into clinical practice. Methods such as genotyping, sequencing, and biomarker identification facilitate the detection of genetic markers linked to drug metabolism, efficacy, and safety. However, challenges related to cost and accessibility hinder the widespread implementation of these technologies. This section provides an overview of genotyping and sequencing methods, highlights the role of biomarkers in predicting drug responses, and examines the implications of cost and accessibility challenges for large-scale application.

Genotyping and Sequencing

Genotyping and sequencing are fundamental techniques in pharmacogenomics, providing insights into genetic variations associated with drug metabolism. **Polymerase chain reaction (PCR)** is one of the most widely used methods for genotyping. It allows the amplification of specific DNA sequences, making it possible to identify single nucleotide polymorphisms (SNPs) in genes such as **CYP2D6** and **CYP2C19**, which are critical for drug metabolism [18]. Variations in these genes can lead to significant differences in drug response, ranging from adverse drug reactions (ADRs) to therapeutic failure.

Microarray technology represents another key advancement, enabling the simultaneous analysis of thousands of genetic variants. This high-throughput method is particularly useful for identifying pharmacogenetic markers across large patient populations. **Next-generation sequencing (NGS)**, however, offers a more comprehensive approach by analyzing entire genomes or exomes. NGS provides detailed insights into genetic variations, including rare mutations, with applications in identifying polymorphisms that affect drug-metabolizing enzymes, transporters, and receptors [19]. For example, NGS has been used to identify variants in the **SLCO1B1** gene, which impacts statin metabolism and the risk of myopathy [20].

Biomarker Identification

Biomarkers play a pivotal role in predicting patient responses to specific drugs and guiding the selection of appropriate therapies, making them a cornerstone of personalized medicine. By identifying biological indicators that correlate with disease states or therapeutic responses, biomarkers enable healthcare providers to tailor treatments to the individual needs of patients. This approach is particularly transformative in oncology, where biomarkers are extensively utilized to optimize targeted therapies. For instance, HER2 is a well-established biomarker used to identify breast cancer patients who are likely to benefit from trastuzumab therapy. HER2 overexpression, which can be detected through advanced diagnostic techniques such as immunohistochemistry (IHC) or fluorescence in situ hybridization (FISH), exemplifies the clinical utility of biomarkers in pharmacogenomics. The accurate detection of HER2 not only guides the selection of trastuzumab but also contributes to improved patient outcomes by ensuring that treatments are specifically tailored to those who are most likely to respond [21].

In addition to HER2, other genetic biomarkers such as EGFR and ALK have revolutionized the treatment of non-small cell lung cancer (NSCLC). Genetic variants in these markers enable clinicians to determine the suitability of targeted therapies, thereby enhancing treatment efficacy and reducing unnecessary exposure to non-beneficial medications. For example, EGFR mutations guide the use of tyrosine kinase inhibitors (TKIs), while ALK rearrangements support the application of ALK inhibitors. These biomarker-driven approaches in NSCLC highlight the significant advancements in treatment personalization, offering improved survival rates and quality of life for patients [22].

The impact of biomarkers is not confined to oncology; they are equally valuable in other therapeutic domains. In cardiovascular medicine, for instance, the pharmacogenomic profiling of VKORC1 and CYP2C9 genotypes is employed to optimize warfarin dosing. Warfarin, a commonly used anticoagulant, has a narrow therapeutic index, and improper dosing can lead to severe complications such as bleeding or thrombosis. By identifying genetic variations in VKORC1, which affects warfarin sensitivity, and CYP2C9, which influences drug metabolism, clinicians can personalize warfarin therapy to mitigate risks and enhance patient safety. This example underscores the broader applicability of pharmacogenomics in improving drug safety and efficacy across diverse medical disciplines [23].

Overall, biomarkers are central to the paradigm shift towards precision medicine. Their ability to provide actionable insights into disease mechanisms and therapeutic responses underscores their transformative potential in healthcare. From oncology to cardiovascular medicine, the integration of biomarker-driven approaches into clinical practice is paving the way for more effective, individualized, and safer treatments. As the field of pharmacogenomics continues to evolve, the identification and validation of new biomarkers are expected to expand the scope of personalized medicine, further revolutionizing patient care.

Cost and Accessibility Challenges

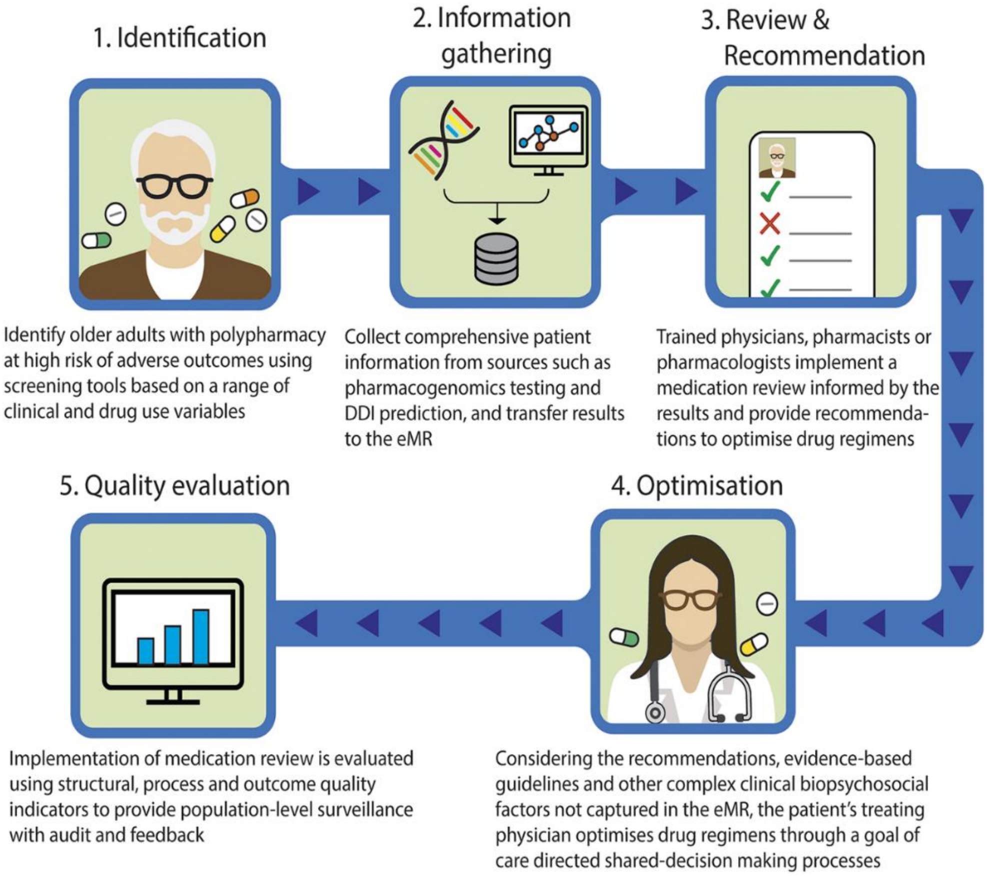
Despite the promise of pharmacogenomics, the high cost of genotyping and sequencing technologies poses significant barriers to large-scale implementation. Advanced methods like NGS, while offering unparalleled accuracy and comprehensiveness, remain prohibitively expensive for routine clinical use. The cost of reagents, equipment, and bioinformatics analysis further compounds the challenge, limiting access in resource-constrained settings [24].

Accessibility challenges are particularly pronounced in low- and middle-income countries, where healthcare infrastructure may lack the capacity to support sophisticated genetic testing. Even in high-income countries, disparities in access to pharmacogenomics services persist due to socioeconomic factors. These limitations not only hinder equitable access to personalized medicine but also restrict the broader adoption of pharmacogenomics in healthcare systems [25].

Efforts to address these challenges include the development of cost-effective technologies and the integration of pharmacogenomics into existing healthcare workflows. For instance, portable genotyping devices and cloud-based bioinformatics platforms are emerging as potential solutions to reduce costs and enhance accessibility. Additionally, policy initiatives aimed at subsidizing genetic testing and expanding insurance coverage for pharmacogenomics could play a crucial role in overcoming these barriers [26].

Clinical Applications of Pharmacogenomics in Nursing

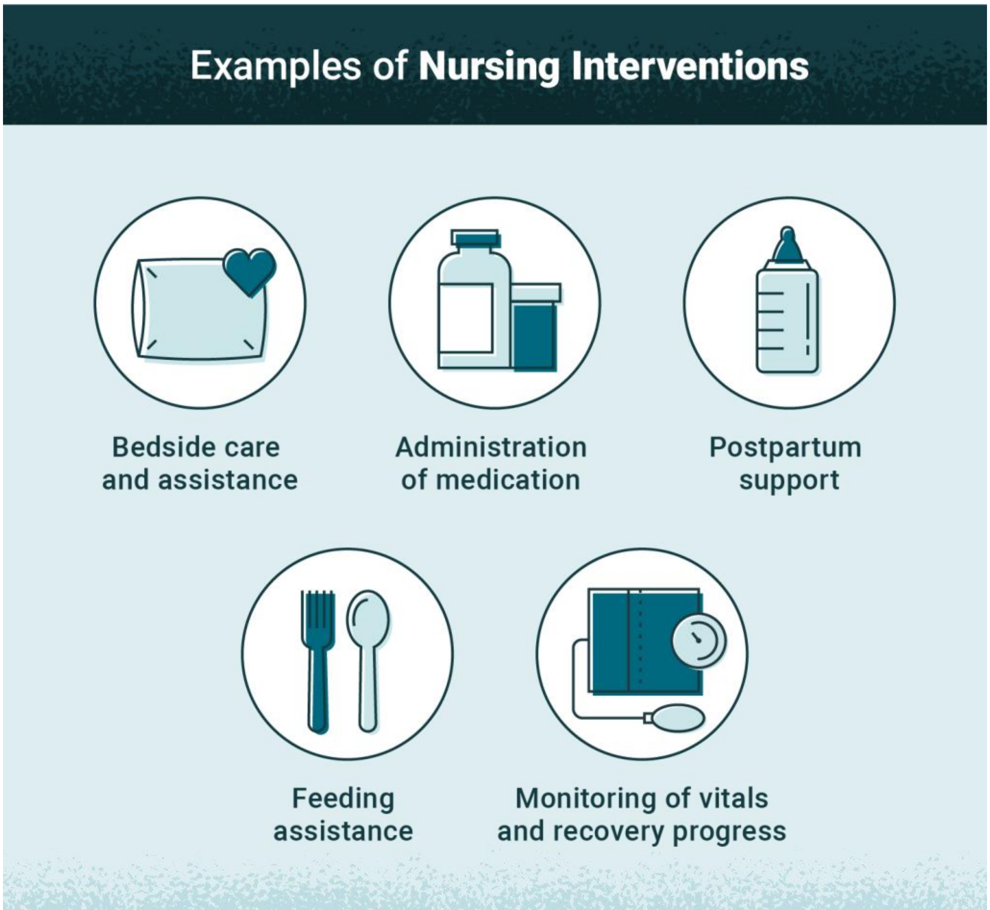
The clinical applications of pharmacogenomics (PGx) have gained significant attention for their potential to enhance drug safety, efficacy, and patient outcomes. Pharmacogenomics is increasingly recognized as a cornerstone of precision medicine, enabling healthcare providers to tailor therapies to individual genetic profiles. For nurses, the integration of PGx into clinical practice represents an opportunity to advance patient care through personalized interventions. This section explores the impact of PGx on drug safety and efficacy, the critical role of nurses in its implementation, and the importance of training and competency in integrating PGx into nursing practice.



Impact on Drug Safety and Efficacy

Adverse drug reactions (ADRs) are a significant concern in clinical practice, contributing to substantial morbidity, mortality, and healthcare costs. Pharmacogenomics addresses this challenge by identifying genetic variants that influence drug metabolism, transport, and receptor activity, thereby enabling the optimization of drug selection and dosing. For instance, PGx testing for **warfarin** therapy has demonstrated the potential to reduce bleeding risks by incorporating genetic insights into dosing algorithms. Polymorphisms in **CYP2C9** and **VKORC1** genes are key determinants of warfarin metabolism and sensitivity, highlighting the importance of PGx in minimizing ADRs and improving therapeutic outcomes [27]. Similarly, genetic testing for **CYP2C19** variants has improved the efficacy of **clopidogrel**, an antiplatelet medication, by identifying individuals who are poor metabolizers and thus at risk for suboptimal therapy [28].

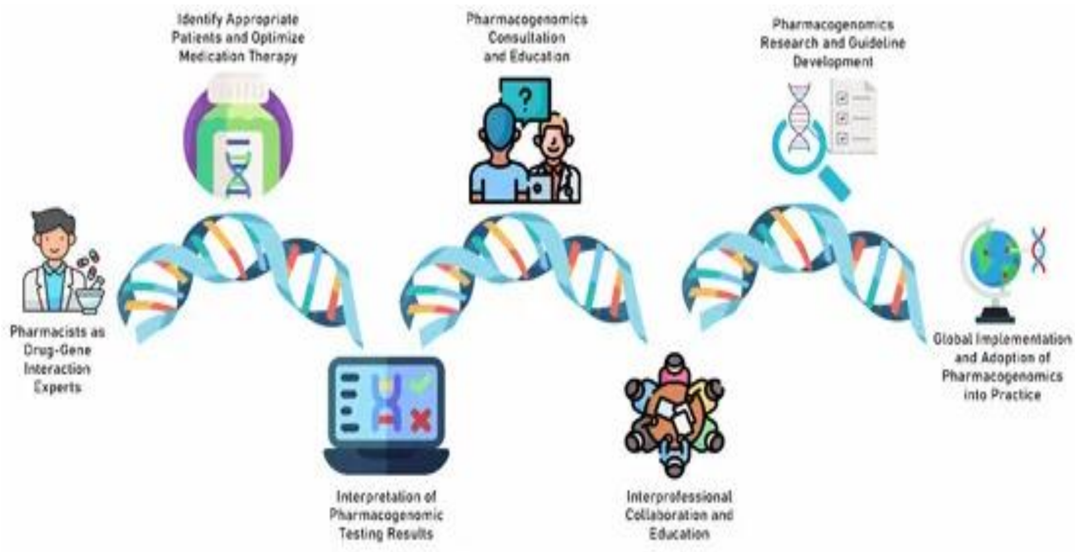
In oncology, pharmacogenomics has facilitated more precise interventions. For example, PGx testing for **tamoxifen**, a selective estrogen receptor modulator used in breast cancer treatment, has improved outcomes by identifying variations in **CYP2D6** that affect its activation to endoxifen, the active metabolite. Such insights have enabled the personalization of treatment regimens, reducing the likelihood of treatment failure and adverse effects [29]. These examples underscore the transformative potential of PGx in enhancing drug safety, efficacy, and adherence.



Nurses' Role in Implementation

Nurses play a pivotal role in the clinical implementation of pharmacogenomics, bridging the gap between genetic science and patient care. A critical aspect of their role involves educating patients about the purpose and implications of PGx testing. Patients must understand how genetic insights inform medication decisions, the potential benefits of testing, and the limitations of current knowledge. For example, nurses can explain how PGx testing for warfarin or clopidogrel might prevent complications and improve therapeutic outcomes, fostering patient trust and adherence to recommended interventions [30].

Another essential responsibility is the monitoring and adjustment of therapies based on genetic data. Nurses collaborate with interdisciplinary teams to ensure that PGx results are integrated into clinical decision-making. This includes tracking patient responses to therapy, identifying potential ADRs, and recommending adjustments in drug selection or dosing when necessary. For instance, if a patient is identified as a poor metabolizer for clopidogrel, nurses can advocate for alternative therapies, ensuring safe and effective care [31].



Training and Competency

The integration of pharmacogenomics into nursing practice necessitates specialized training to equip nurses with the knowledge and skills required to apply genetic insights in clinical care. Current nursing education often lacks comprehensive coverage of pharmacogenomics, creating a gap in competency that must be addressed to enable effective implementation. Training programs should focus on the principles of PGx, interpretation of test results, patient communication, and the ethical implications of genetic testing [32].

In addition to education, the development of clinical guidelines is crucial for standardizing PGx integration into nursing practice. These guidelines should outline the processes for interpreting PGx results, applying findings to patient care, and addressing potential challenges such as cost, accessibility, and patient consent. Interdisciplinary collaboration among geneticists, pharmacists, and nurses is essential for creating practical, evidence-based protocols that facilitate the seamless incorporation of PGx into clinical workflows [33].

Conclusion

Pharmacogenomics (PGx) is revolutionizing personalized medicine by providing a framework for tailoring pharmacological interventions to individual genetic profiles. Its integration into healthcare enables the optimization of drug safety, efficacy, and adherence, addressing long-standing challenges such as adverse drug reactions (ADRs) and suboptimal therapeutic outcomes. For nursing, PGx aligns with core principles of patient-centered care, safety, and advocacy, empowering nurses to deliver more precise and individualized interventions.

PGx applications have demonstrated significant clinical impact across various domains. Genetic markers such as **CYP2C9**, **VKORC1**, and **CYP2D6** are instrumental in informing medication selection and dosing for drugs like warfarin, clopidogrel, and tamoxifen. These insights reduce ADRs, enhance therapeutic efficacy, and improve patient adherence. Additionally, PGx-guided therapies in oncology exemplify its potential in disease-specific precision medicine, offering more effective treatment regimens.

Nurses play a critical role in operationalizing PGx by educating patients about testing, interpreting results, and collaborating with interdisciplinary teams to ensure evidence-based interventions. However, this requires enhanced training and the development of clinical guidelines to standardize practice. Addressing barriers such as cost, limited access to testing, and ethical concerns surrounding genetic data privacy is essential for widespread PGx adoption.

Emerging technologies like next-generation sequencing (NGS) and portable genotyping platforms promise to improve accessibility and affordability. As nurses remain central to patient care, their leadership in implementing PGx will be vital in realizing its potential to improve outcomes. By addressing current challenges and fostering competency, PGx can become a transformative tool in personalized nursing care.

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دور علم الصيدلة الجيني في التمريض الشخصي: التقنيات المختبرية والتطبيقات السريرية

الملخص
:الخلفية
هو أحد ركائز الطب الشخصي، حيث يدرس تأثير التباينات الجينية على (Pharmacogenomics) علم الصيدلة الجيني (ADRs) استجابة الأدوية، مما يعزز تخصيص العلاجات وتحسين النتائج العلاجية. يتيح هذا العلم تقليل التفاعلات الدوائية السلبية وتحسين سلامة المرضى. في التمريض، يوفر علم الصيدلة الجيني فرصة لتطوير الرعاية من خلال تكييف الأدوية حسب البصمة الجينية لكل مريض، لكنه يواجه تحديات تشمل التكاليف العالية، محدودية الوصول إلى الاختبارات، والحاجة إلى تدريب .متخصص
:الهدف
يهدف هذا البحث إلى استكشاف دور علم الصيدلة الجيني في الرعاية التمريضية الشخصية من خلال تحليل التقنيات المختبرية، .دراسة التطبيقات السريرية، وتحديد أهمية دمج هذه المعرفة في الممارسات التمريضية
:الطرق
(PCR) تم إجراء مراجعة منهجية للأدبيات الحديثة (2018-2019) حول دور التقنيات مثل تفاعل البوليميراز المتسلسل ، إلى جانب استعراض أمثلة سريرية تبين دور الممرضين في تحسين العلاج باستخدام علم (NGS) والتسلسل الجيني المتقدم .الصيدلة الجيني
:النتائج
تبين أن علم الصيدلة الجيني يقلل من التفاعلات السلبية ويحسن الالتزام العلاجي. تشمل الأمثلة جرعات الوارفارين المخصصة، تقليل الجلطات باستخدام كلوبيدوجريل، وتحسين العلاج الهرموني باستخدام تاموكسيفين. يلعب الممرضون دورًا محوريًا في تثقيف .المرضى، مراقبة الاستجابة، وتعديل العلاجات وفقًا للنتائج الجينية
:الخلاصة
علم الصيدلة الجيني يعزز الرعاية التمريضية الشخصية من خلال تحسين العلاجات وتقليل المخاطر. دمج هذا النهج يتطلب تدريبًا .متخصصًا وإرشادات عملية، مع تقدم التكنولوجيا وخفض التكاليف لضمان وصول أوسع وتحسين جودة حياة المرضى
:الكلمات المفتاحية
.علم الصيدلة الجيني، الرعاية التمريضية، التفاعلات الدوائية السلبية، التطبيقات السريرية، تقنيات مختبرية، الطب الشخصي