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Pharmacogenomics at the Bedside: Moving from Genetic Testing to Truly Individualized Drug Therapy

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Perspective
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Abstract

Pharmacogenomics is changing the way clinicians understand variability in drug response by providing information about how genetic differences can influence drug efficacy, metabolism, and toxicity. Although numerous gene–drug associations have been established, the greatest challenge is no longer generating genetic information but translating that information into practical decisions at the bedside. A pharmacogenomic test has limited clinical value if its result remains isolated in a laboratory report or is difficult for clinicians to interpret. Truly individualized drug therapy requires integration of genetic results with clinical characteristics, medication history, comorbidities, and patient preferences. Evidence-based resources such as the Clinical Pharmacogenetics Implementation Consortium (CPIC) have helped establish standardized approaches for translating genotype into prescribing recommendations. However, implementation still faces barriers involving clinician education, electronic health record integration, cost, reimbursement, test accessibility, and equitable representation of diverse populations. The future of pharmacogenomics should therefore focus less on increasing the volume of genetic testing and more on ensuring that clinically relevant genetic information reaches the right clinician at the right time and results in an appropriate therapeutic action. Moving from genetic testing to individualized treatment will require pharmacogenomics to become part of routine clinical decision-making rather than remaining a specialized genomic service.

Keywords: Pharmacogenomics; Precision Medicine; Personalized Therapy; Drug Response; Clinical Decision Support; Genetic Testing

From Genetic Results to Clinical Decisions

For decades, prescribing has largely followed a population-based approach. Patients with the same diagnosis are often offered similar medications and doses, even though their responses can differ substantially. Some patients obtain the expected therapeutic benefit, some respond poorly, and others experience adverse reactions despite receiving a standard dose. Pharmacogenomics provides one explanation for this variability by examining how inherited genetic differences influence the way individuals respond to medicines [1].

However, the real promise of pharmacogenomics does not lie in identifying genetic variants alone. Its value begins when the genetic result changes a treatment decision.

This distinction is important because genetic testing and individualized therapy are not synonymous. A patient may have a detailed pharmacogenomic report containing multiple genetic variants, but if the clinician does not know which findings are clinically important, the report may contribute little to patient care. The essential pathway is therefore not simply testing → result. It is testing → interpretation →

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recommendation → clinical action [2].

CPIC has played an important role in developing evidence-based guidelines that help clinicians translate available genetic results into prescribing decisions. Its guidelines use standardized approaches to connect genotype with predicted phenotype and therapeutic recommendations.

This approach illustrates an important principle: pharmacogenomics should support clinical judgment rather than attempt to replace it. Genetic information is one component of a patient's therapeutic profile. Age, organ function, drug interactions, disease severity, adherence, and environmental factors can also influence treatment response [3].

The most useful pharmacogenomic result is therefore not necessarily the most detailed one. It is the one that answers a clinical question.

If a genetic result indicates that a patient is likely to have substantially altered exposure to a medication, the clinician may need to select another drug, modify the dose, or increase monitoring. In such circumstances, the genetic result becomes actionable information rather than simply another laboratory finding.

Recent clinical guidelines continue to demonstrate the expanding range of actionable gene–drug relationships. For example, updated CPIC guidance for thiopurines incorporates TPMT and NUDT15 genotypes into dosing decisions because reduced activity of these enzymes can increase the risk of serious toxicity at standard doses.

The direction of travel is therefore clear: pharmacogenomics is moving from the laboratory toward the prescribing decision.

Making Pharmacogenomics Work at the Bedside

The next challenge is implementation. A clinician working in a busy hospital does not have the time to search through multiple genomic databases every time a pharmacogenomic result becomes available. Genetic information must be incorporated into clinical workflows in a way that is simple, timely, and understandable.

Electronic health records could become particularly important in this transition. A pharmacogenomic result can remain relevant for many years and may influence several medications over a patient's lifetime. Once a clinically validated result is stored in the electronic record, it can potentially be used whenever a relevant medication is prescribed [4].

This creates an opportunity for pre-emptive pharmacogenomic testing. Instead of waiting until a patient requires a particular medication and then ordering a genetic test, relevant genetic information can be obtained in advance and retained for future prescribing decisions. When a medication is subsequently ordered, clinical decision-support software can identify whether the patient's genetic profile has therapeutic implications.

Such integration could make pharmacogenomics almost invisible to the clinician. Rather than requiring physicians to interpret complex genetic reports, the electronic system could provide a concise message explaining the relevant phenotype and recommended action.

However, decision support must be carefully designed. Excessive alerts can lead to alert fatigue, while poorly interpreted results can create confusion. The objective should not be to expose clinicians to every available genetic detail. Instead, systems should highlight findings that are sufficiently well supported and clinically actionable.

A practical implementation model should connect the laboratory, pharmacy, clinical team, and information technology infrastructure. Reviews of clinical implementation have emphasized the importance of selecting actionable drug–gene pairs, deciding between reactive and pre-emptive testing, establishing appropriate interpretation strategies, and integrating results into electronic health records and clinical decision-support systems [5].

The economics of implementation also deserve attention. Pharmacogenomic testing introduces an upfront cost, but the potential value may come from preventing adverse drug reactions, reducing ineffective treatment, and avoiding repeated medication changes. A systematic review of pharmacogenomic testing associated with CPIC guidelines found that a substantial proportion of evaluated strategies were reported as cost-effective or cost-saving, although results varied by drug and healthcare setting.

Thus, the question should not simply be whether a pharmacogenomic test costs money. The more relevant question is whether using that information improves the overall value of treatment.

Toward Truly Individualized Therapy

The future of pharmacogenomics will depend on recognizing both its strengths and its limitations. Genetics can provide powerful information, but it cannot explain every difference in drug response. Two patients with the

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same genotype may still respond differently because of age, comorbidities, concurrent medications, lifestyle, disease progression, or other biological factors.

Pharmacogenomics should therefore be viewed as one layer of precision medicine rather than its entire foundation.

This perspective is particularly important when considering equity. Genomic research has not always represented the full diversity of global populations. Differences in allele frequencies across populations can affect the interpretation and clinical utility of some pharmacogenomic findings. Expanding pharmacogenomic implementation without addressing diversity in research and access could unintentionally widen existing healthcare inequalities.

Cost, reimbursement, availability of validated testing, and clinician education remain important barriers. Recent assessments of implementation indicate that although several historical obstacles have weakened, challenges involving equity, evidence, reimbursement, electronic health records, test quality, and education continue to affect broader adoption.

For this reason, the next stage of pharmacogenomics should not be defined simply by how many people undergo genetic testing. The more meaningful measure will be whether testing leads to better treatment decisions and improved patient outcomes. The bedside is where this distinction becomes most visible.

A genetic test that does not influence prescribing is information. A genetic test that helps a clinician avoid an inappropriate medication, select a safer alternative, or determine a more suitable dose becomes part of individualized care.

This shift also changes the role of healthcare professionals. Physicians, pharmacists, laboratory specialists, geneticists, and informaticians will increasingly need to work together to interpret and apply pharmacogenomic information. Patient communication will be equally important. Patients should understand that pharmacogenomics can improve the probability of choosing an appropriate therapy but cannot guarantee a particular outcome.

The future should therefore move away from the idea of a single "perfect" medication determined entirely by the genome. Truly individualized therapy is more likely to emerge from the combination of genomic information with clinical and environmental data. Pharmacogenomics can provide an important missing piece of this picture.

Conclusion

Pharmacogenomics has reached a point where the major question is no longer whether genes influence drug response. The more important question is how effectively genetic information can be converted into better clinical decisions.

The transition from genetic testing to individualized therapy requires actionable evidence, clear guidelines, electronic integration, clinician education, appropriate patient communication, and equitable access. When these elements work together, pharmacogenomic information can become part of routine prescribing rather than remaining a specialized laboratory result.

The true promise of pharmacogenomics is therefore not simply to know more about a patient's genome. It is to use the information at the moment when it can make treatment safer, more effective, and more appropriate for that individual.

In this sense, the future of pharmacogenomics is not merely genomic. It is clinical. The success of the field will ultimately be measured not by the number of genetic variants identified, but by the number of better therapeutic decisions made because those variants were understood and used.

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