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Integrating pharmacogenetic testing into primary care

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Abstract

Introduction—Pharmacogenetic (PGx) testing has greatly expanded due to enhanced understanding of the role of genes in drug response and advances in DNA-based testing technology development. As many primary care visits result in a prescription, the use of PGx testing may be particularly beneficial in this setting. However, integration of PGx testing may be limited as no uniform approach to delivery of tests has been established and providers are ill-prepared to integrate PGx testing into routine care.

Areas covered—In this paper, the readiness of primary care practitioners are reviewed as well as strategies to address these barriers based on published research and ongoing activities on education and implementation of PGx testing.

Expert Commentary—Widespread integration of PGx testing will warrant continued education and point-of-care decisional support. Primary care providers may also benefit from consultation services or team-based care with laboratory medicine specialists, pharmacists, and genetic counselors.

Keywords

Primary care; pharmacogenetics; education; clinical decision support

1. Introduction

Use of prescription medications continues to increase, with 59% of patients in the US taking at least one prescribed medication.[1] For the majority of office visits to a general practitioner, a medication is prescribed [2]. Thus, general practitioners and their patients may benefit from the use of genetic tests that predict drug response. Known as pharmacogenetic (PGx) tests, the results can identify patients at increased risk of experiencing an adverse response or no response to a given medication due to variations in genes involved in drug metabolism, transport or therapeutic targets. Based on the test results, dosing may be adjusted or an alternative medication selected to improve therapeutic outcomes. The body of PGx literature has grown tremendously in the last few decades,

Declaration of Interest

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increasing understanding of genetic contributions to drug response, leading to development of several commercially available clinical tests. Although several U.S. medical centers have begun to implement PGx programs [3–6], uptake of PGx testing in routine clinical practice has been slower than anticipated due to several factors including general practitioner preparedness, reimbursement and availability of clinical decision support patients.[7,8] This paper aims to provide an overview of current practice, barriers to uptake, and strategies to assist general practitioners' knowledge, skill, and experience with PGx testing, from a U.S. rather than a global perspective.

2. Overview of PGx Testing

Understanding of the genetic contribution to drug response has been known for several decades[9], but has exploded following the sequence of the human genome and new analytical tools. Some key genes encoding proteins involved in drug metabolism are highly polymorphic, meaning that genetic variants may be commonly present. These variations can impact protein function, thereby altering the rate of drug metabolism. One retrospective study reported that about a third of adverse responses may be due to drug-gene or drug-drug-gene interactions.[10] Early single gene PGx tests were developed for rare conditions such as malignant hyperthermia, but many of today's tests include multiple polymorphic genes whereby most of the population will carry at least one medically actionable PGx variant.[11] While single gene testing is still available, many gene panels have been developed for certain drug classes, particularly in oncology[12], pain management [13–15], and psychiatry. [16–18]

Although most tests for the genes mentioned above analyze germ-line PGx variants from blood or buccal swab samples, testing for somatic variation can greatly inform drug selection for cancer. For example, identification of key genetic aberrations within drug targets in various cancers has led to the co-development of tests with new drugs to identify genetically-defined sub-populations (known as companion diagnostics). Unlike testing of genes involved in drug metabolism, for instance, that provides more probabilistic information about treatment risks, testing of somatic mutations in genes targeted by medications informs efficacy resulting in a more straightforward, yes/no decision regarding medication use. Another difference between germline and somatic PGx testing is the latter is typically performed on tumor tissue, however, great progress has been made with liquid biopsies, or analysis of circulating tumor cells or cell-free DNA from blood.[19–22] In some cases, cancer patients may undergo both germline and somatic PGx testing to inform cancer treatment as well as treatment for associated conditions.

The type and extent of clinical evidence for PGx tests is highly variable.[23] For example, the evidence for the HLA-B*57:01 test, predictive of hypersensitivity to the HIV medication abacavir is quite robust.[24–26] These studies quickly led to the development of a clinical test, practice guidelines, and mandatory testing.[27,28] In contrast, the clinical utility of other PGx tests has been mired in debate due to equivocal results from clinical trials. The case of warfarin and testing for the CYP2C19/VKORC1 genes illustrates the complexity of the role of genetics in drug response.[29–31] While it is clear that genetic variants in these two genes contribute to the range of clinical response observed with warfarin treatment (in

addition to many other factors),[32] it is unclear whether knowledge of a patient's genotype for these two genes will reduce the time to achieve an effective dose and patient outcome.

PGx testing can be ordered at different times during the spectrum of clinical care. PGx testing could be ordered in advance of treatment, or pre-emptively. Inevitably, all patients will require some type of pharmacological treatment, many of which will be impacted by PGx variants, particularly as we age.[10,11,33] Thus, performing testing when patients are healthy would allow for the results to be immediately available when treatment is needed in the future. Depending on the testing laboratory, PGx testing may take 7 to 10 days to complete (a more rapid turnaround time may be 1–3 days upon receipt of the sample), which may be an unacceptable length of time if testing is ordered at the time treatment is needed. Several groups in the US and Europe have begun pilot programs to implement preemptive PGx testing.[6,34,35] Analysis of the test results for five drug metabolism enzymes and a drug target, almost all patients (99%) were found to have at least one genetic variant known to be clinically significant.[36] In some cases, treatment could be initiated at a low dose or with close monitoring until testing is completed. More than likely, testing is performed when medication is needed; depending on the risk, treatment would be initiated without the test result and re-adjusted if indicated after testing is completed. In some cases, testing may only be ordered after an adverse response develops. Lastly, some point-of-care DNA-based tests (those that can be performed at the bedside or in the provider's office within a few hours) are currently available, but have not yet been developed for PGx testing. One rapid-based PGx test, the Spartan RX CYP2C19 System, has been approved by the Food and Drug Administration (FDA). With the rapid developments in testing technology, we anticipate development of POC PGx testing in the near future.

In many cases, testing ordered by one provider can inform treatment decisions by another provider, highlighting the importance of the portability of or sharing results with treating providers or potentially the pharmacist. With the increasing use of whole genome or exome sequencing, patients may also acquire 'incidental' PGx test results. While most likely unrelated to the clinical indication for sequencing, the test results may nonetheless inform treatment decisions.[37] Furthermore, direct-to-consumer testing may provide an opportunity for patients to order testing on their own [38] and share the test results with providers.

3. Barriers to Test Utilization

3.1. Provider Knowledge

In the past few decades, provider knowledge of genetics, and more recently, genomics and personalized medicine, has been assessed in multiple countries and medical disciplines. In general, the findings have been less than encouraging, with reports of limited knowledge about and experience with clinical applications in precision or personalized medicine, including PGx testing.[39–43] This knowledge deficit likely reflects a combination of factors including lack of exposure in medical school, with only a minority of medical schools including personalized or precision medicine into curricula.[44,45] In addition, providers have not likely had the opportunity to experience and observe the benefits of PGx testing in clinical training or practice. A range of focused continuing educational efforts

have been implemented at academic medical centers in the U.S. that have initiated PGx testing programs.[46] However, as the majority of primary care is delivered in community-based practices in the U.S., more efforts are required to more broadly educate general practitioners about PGx testing, particularly in settings with limited resources or access to PGx experts.

In contrast, other professions have recognized the need for PGx knowledge and have been active in developing new educational opportunities. Pharmacy schools have increased the curricular content and exposure to PGx material [47–49] and multiple educational opportunities have been developed.[50–54] Certificate and training programs for pharmacists on PGx have also been developed.[55] Nurses are also an important part of the delivery of PGx testing and thus, need to be familiar with PGx to educate patients, assist with test orders, and communicate results.[56,57]

In addition to enabling providers and students to become knowledgeable about PGx, training must also include a set of skills, including patient communication to collect informed consent and explain results, test interpretation and use in therapeutic decision-making, and collection of a DNA sample. As many testing laboratories have begun to accept a buccal or saliva sample, specimen collection is relatively simple and rapid and at least one study has demonstrated providers' ease in collecting patient samples for testing.[58] Likewise, many laboratories have developed lengthy lab reports that include explanatory information to assist providers interpret the results and the recommended actions for treatment based on those results.[59]

3.2. Test Evaluation

Unlike other routine clinical tests that are generally equivalent between testing laboratories regarding the biomarker(s) analyzed and the testing methodology or platforms used, there is a large diversity among PGx tests commercially available currently. For PGx testing, limited provider knowledge may substantially hinder the ability to evaluate and select an appropriate test for a given patient. In particular, PGx tests may differ with respect to which genes are analyzed, the type of testing platform used, the turnaround time, and type of biospecimen required. The genes analyzed and how they are analyzed can impact test specificity and sensitivity. Even tests of the same gene may analyze different variants and therefore, have different test sensitivity and specificity values.[60]

Testing methodology may use genotyping (limited to a selected number of variants) or sequencing (analyzing the entire gene). Laboratories may use microarray-based platforms to detect specific polymorphisms [61,62] or more comprehensive next-generation sequencing platforms to analyze more genes comprehensively and avoid the need to revise array-based platforms as new variants are discovered.[63] Compared to single gene analysis, for other clinical indications, some evidence suggests that the use of gene panels are more beneficial. [64] Use of PGx testing in primary care practices, particularly when ordered pre-emptively, would involve ordering a multi-gene panel. If ordering a test to inform a treatment decision, a panel may still be preferable as it would include gene(s) relevant to the current treatment indication and other commonly used medications that may be prescribed in the future.

Prevalence of PGx variations have been demonstrated to vary substantially between populations.[65] Depending on the testing platform used, rare variants may be missed [66], including those present in less studied populations, thereby limiting benefit of testing to some population groups due to the prevalence disparities between groups.[67] For minority patients, use of PGx gene panels may return more uncertain findings [68] and providers should disclose this to patients and be prepared for this possibility when discussing test results. As evidenced by early experiences with cancer susceptibility panels, providers are faced with challenges in implementation due to unanticipated issues.[69]

3.3. Regulatory Oversight

In the U.S., there are two major types of oversight for clinical laboratory tests – the oversight of the laboratory and test performance and the oversight of the evidence for the test’s analytical and clinical validity. In the U.S. the FDA is responsible for the oversight of clinical tests, but the agency has been selective in enforcing its authority, resulting in relatively limited oversight of laboratory-developed tests (LDTs). LDTs are not limited to genetic tests, and discussion about oversight of LDTs has been ongoing for the past few decades.[70] The 2014 effort to develop an oversight framework for LDTs [71], including for PGx testing, garnered divisive perspectives.[72,73] For companion diagnostics, the test is either co-approved along with the drug, or approved after the drug is approved (because the genetics information may not have been known at the time of drug development). For example, a test for the Her2-Neu (ERBB2) gene amplification was co-developed and approved with the targeted drug trastuzumab for breast cancer. Testing for the gene fusion (BCR-ABL or Philadelphia chromosome) was available prior to the approval of the targeted medication Gleevec® for patients with chronic myeloid leukemia who carry the BCR-ABL gene fusion. Other PGx tests may be developed independently of a drug and have not sought approval or clearance by regulatory agencies. More than 100 drug labels include information about drug-gene interactions.[74]

In the U.S., all clinical testing laboratories are also subject to regulations known as the Clinical Laboratory Improvement Amendments (CLIA) that includes a biannual inspection to review laboratory operations, personnel, quality assurance/control measures, and analytical validity of testing. CLIA oversight spans the test spectrum from the pre-test to post-test phase. However, in the current regulatory schema, a test’s clinical validity and clinical utility is not reviewed by federal authorities, although some state health departments require evidence (e.g., New York). In summary, the gap in current oversight and the tenuous, long-standing debate about the appropriate level of oversight moving forward has caused frustrations and uncertainty for the industry, academic laboratories, and patients and providers alike. However, given the numerous tests and new technologies that have become available over the past few years, the need to finalize the oversight structure will become more urgent and may adversely impact clinical utilization until resolved.[75]

3.4. Reimbursement/Coverage Decisions

In the U.S., insurance coverage decisions for precision medicine testing, including PGx testing, have been limited and inconsistent.[76] Decisions regarding choice of laboratory for routine clinical tests may be more driven by the patient’s insurance policies or contracts

between practice sites and laboratories. As a result, this presents a major barrier to uptake of PGx testing.[8] Several cost-effectiveness and cost-savings assessments have been performed for PGx testing. [77] Recent reviews of economic studies of PGx testing showed favorable findings, particularly if PGx results were gained through other clinical tests. [77,78] One example of a PGx test with wide support is the HLA-B*57 for patients to be prescribed the drug abacavir.[79] While evidence is accumulating regarding clinical benefit for several types of genomic applications, the paucity of studies is a major factor influencing coverage decisions.[80] The cost-effectiveness of PGx testing for some patients has not been demonstrated [81] or in some cases, testing may only be cost-effective in high-risk patient populations.[82,83] Federal regulatory oversight of PGx testing may also impact reimbursement decisions.

In the absence of insurance coverage of tests, patients may be willing to pay out-of-pocket. Studies have also investigated patients' willingness to pay and cost-sharing.[84] Contingent valuation (CV) analyses for diagnostic testing in general have been performed to determine what factors patients consider and the perceived weight of these factors in their final decision.[85] Patient factors such as age, level of education and income as well as perceived benefit(s) of testing have been associated with willingness. With respect to genetic testing, similar patient features (older age and higher income) are associated with willingness to pay, but willingness decreased with disclosure of more specific details about testing (the scope of purported benefits or information revealed) and increasing cost. [86] Both clinical and personal utility benefits factor into patients' willingness to pay. [87]

3.5. Need for Patient Education Resources

Patient interest and willingness to pay may be based on an incomplete knowledge of testing, suggesting a need to promote patient understanding for informed decision-making. As with any new clinical application, patient education will be critical to enabling informed consent and patient engagement. Given the repeated benefits to be gained from PGx test results due to shared metabolic pathways among commonly prescribed drugs, it becomes even more critical for patients to understand about testing and to share this information with other prescribers. However, two major barriers to promoting patient understanding about testing are providers' limited time during an office visit and the limited availability of resources for patients. The use of patient educational materials (PEMs) could address the constraint of limited patient time and give patients an opportunity to review the materials on their own time and pace and share/discuss with family members if desired. Given that many patients will likely seek additional information, most often online, a web-based search may yield a plethora of hits, but the information may be difficult for patients to understand, incomplete, or not up to date.

While more patient-provider communication has garnered more attention to empower patient and increase patient engagement, relatively less has been written about communicating information about genetic testing and test results, especially for general practitioners.[88] This may be due to lack of distinction between genetics and other types of medical information or due to the limited number of non-geneticist providers ordering testing. One non-geneticist professional opinion about communication for genetic testing

was published by the American College of Obstetricians and Gynecologists, stating that “As with any medical test, expectations regarding the performance of a genetic test should be discussed with the **patient** before the test is ordered.”[89]

4. Strategies to Overcome Barriers

Provider attitudes and interests regarding PGx testing have generally been positive [90,91] and the particular benefit (and challenges) to using PGx testing in general care settings has been recognized.[92] In addition to the benefits of informing treatment decisions, potential secondary benefits include increased adherence and patient interest in treatment.[93–95] However, insuring the appropriate delivery of PGx testing, including test utilization, interpretation, application of test results, and patient-provider communication will warrant efforts on multiple fronts. These barriers are not unique to PGx testing, and have been recognized for other novel genomic applications.[96,97]

4.1. Clinical Decision Support

Limited provider knowledge may impact several steps in the delivery of PGx testing including patient-provider communication about testing and test results, appropriate test utilization, and results interpretation and treatment decision-making. In a few studies, limited provider knowledge may have attributed to the lack of impact of PGx test results on prescribing behaviors with respect to clopidogrel and CYP2C19.[98,99] With the rapidly changing evidence basis and multiple PGx test results generated for a given patient, broad implementation of PGx testing will benefit from the development of clinical decision support systems.[100,101] Provider information-seeking about PGx can waste valuable time given the incomplete and dispersed online resources.[102] Several PGx CDSs have already been developed (or are under development) [103] and have been viewed favorably by providers.[104–106] In some systems, prescription of a new medication impacted by a genetic variant may trigger an alert about PGx testing or may link to a result if the patient has already had testing. For example, at the Cleveland Clinic, a total of 63 alerts were developed for three gene/drug pairs (TPMT/thiopurines, HLA-B*57:01/abacavir, and HLA-B*15:02/anticonvulsants).[107] A clinical research team in Vancouver, British Columbia developed a condition-based CDS (in contrast to medication-based systems used by other groups) of the top 10 conditions managed by primary care providers.[58] This CDS provided options for individualized therapy and linked to a panel of PGx test results and was used repeatedly by providers and pharmacists, particularly for hyperlipidemia and hypertension.

In a community clinical setting, however, access to these CDS systems may be limited. In addition to CDS for PGx, some groups have also established consultative services.[108] For example, the Cleveland Clinic established a ‘pharmacogenomics ambulatory clinic’ staffed by a pharmacist and a physician-geneticist.[107] Alternatively, a web-based CDS may be useful to provider practices that do not have an EMR or the informatics support or the means available to implement a CDS linked to the EMR.[109] Some other applications exist to assist with interpreting and integrating PGx results into therapeutic decision-making (e.g., warfarindosing.org)

4.2. Provider Resources

Both the U.S. Food and Drug Administration (FDA) and European Medicines Agency (EMA) have revised several drug labels to include PGx information as evidence becomes available and includes it in new drug labels.[110,111] The FDA has established a table of medications that include PGx information (<https://www.fda.gov/Drugs/ScienceResearch/ResearchAreas/Pharmacogenetics/ucm083378.htm>). However, providers have reported being unaware of the presence of PGx information in FDA-approved drug labels[112] and furthermore, many of the labels are not instructive regarding the need for testing.[113] Furthermore, labels may not necessarily reflect current evidence of clinical utility given the time required to obtain regulatory approval of changes.

Other groups have also established resources to help health providers utilize PGx test results. [114] In particular, the Clinical Pharmacogenomics Implementation Consortium (CPIC) is a group of pharmacogenetic experts that have developed several resources regarding the interpretation (clinical significance) of PGx variants and evidence for genotype-guided treatment. [115] Evidence-based guidelines have also been developed by the Canadian Pharmacogenomics Network for Drug Safety.[116,117] A useful table of all of the guidelines published by each group thus far, including the gene(s) and corresponding drug/drug class is included on their web-site.[118] Other web-based resources also are available but may not be easily found or utilized by less-experienced providers and are not comprehensive.[119]

Regarding provider training, the US National Human Genome Research Institute has established a repository of genomics educational materials known as G2C2 (<http://www.genomicseducation.net/>) and supported the development of several provider core competencies. Similarly, the NHS Health Education England's Genomics Education Programme (<https://www.genomicseducation.hee.nhs.uk/>) provides a variety of educational opportunities and resources to help clinicians integrate genomic applications into practice. In 2016, the UK group published a strategic vision to engage generalists in genomic medicine (https://www.genomicseducation.hee.nhs.uk/images/pdf/Engaging%20Primary%20Care_June%202016.pdf).

4.3. Patient Resources & Patient-Provider Communication

The limited time of an office visit can significantly limit the amount of information that can be exchanged. One study reported that about 30 seconds was devoted to discussing medications in a 16-minute office visit.[120] In addition to having appropriate resources to inform provider utilization, interpretation, and application of PGx testing, patient educational resources are needed to facilitate patient engagement, shared decision-making, and comprehension of results. Particularly in a busy general practice setting, PEMs about PGx testing can promote understanding and supplement a likely all-to-brief discussion about testing. Patients may notice media reports about PGx testing, however, these tend to be skewed towards presenting the benefits of testing.[121] In addition to print materials, videos can also serve to quickly educate patients about PGx testing and used in an office setting as well.[122]

If providers are not aware that testing has been performed (if ordered by another provider outside of a network), the value of PGx testing may not be fully realized. Thus, patients need to be proactive in informing providers that they have had testing performed previously. Since a test may include multiple genes, it is not likely that patients will be able to recall their results, however, they may request a copy of the results to share with other providers. Some laboratories provide patients with a copy of the results on a wallet-sized card.[123] In the near future, a digital gene ‘passport’ may be developed to facilitate portability and sharing of results, containing not only results of PGx testing, but likely the patient’s entire genome sequence. A similar idea has been proposed for athletes (Athlete Biological Passport).[124]

4.4. Team-based care

Given current limitations of general practitioners, delivery of PGx testing in these settings will likely benefit from consultations and coordination with other providers. Given pharmacy schools’ active incorporation of curricular content on PGx and their expertise in drug interactions and management, pharmacists are a logical group to consult regarding treatment decisions based on a PGx result.[125] Indeed, pharmacists have played a key role at several institutions that have or are working to implement PGx testing, as a champion/leader [126], as a liaison between the laboratory and ordering provider to assist with test interpretation, and as a part of the clinical team.[127] Pharmacists may integrate PGx testing into existing services such as medication therapy management [128] or serve as the lead provider of a PGx program offered in a clinic-based setting.[129]

Genetic counselors may also serve as valuable team members in the delivery of PGx testing, but their role may be limited to educating patients and providers about testing and translation of test results since they do not have training about medications. [91,130] The multi-disciplinary PGx clinic established at NorthShore University Health System in Evanston, IL (USA) includes not only a pharmacist and genetic counselors, but a nurse practitioner and medical geneticist.[131] Similarly, the Indiana Genomics Implementation (INGENIOUS) trial includes a pharmacogenomics consultation service provided by clinical pharmacy fellows and research investigators.[132]

Yet another group that may provide useful information are the testing laboratories and laboratory medicine specialists. These specialists can help clarify when testing should be ordered or assist in reviewing test reports.[133] Also, several specialty PGx labs have pharmacists on staff to respond to inquiries about test results.

4.5. Non-physician-Initiated PGx testing

In some cases, PGx testing may be initiated by other health providers and the results are shared with primary care providers. One example of this may be the use of PGx testing by pharmacy benefit managers.[134,135] Another example would be the initiation of PGx testing by the community pharmacist.[136–139] Alternatively, PGx results may be obtained from a whole genome or whole exome ordered for another clinical indication or as part of a health risk assessment. In these cases, PCPs may be even less prepared to integrate the PGx results into patient care and thus, the availability of provider resources is critical.

In addition, direct access or direct-to-consumer (DTC) testing may become another possible approach for PGx testing. In this scenario, patients would be able to order testing without a provider's authorization or involvement. Since testing is increasingly performed on buccal swabs or saliva samples, patients can easily order a test kit online and mail back the sample. Patients can access the report online and download a copy to share with their provider. In the early 2000's, some companies offered DTC PGx testing and efforts to sell the test kits in drug stores was attempted. FDA began to send out notifications to several companies offering DTC testing, followed by warning letters, essentially halting the industry by requiring approval of testing services.[140] At least one company has obtained approval to offer DTC testing now, though DTC PGx testing is not approved at this time in the U.S. (though is available in the UK [38]).

5. Conclusion

Utilization of PGx testing by general practitioners may provide patients with substantial benefit quite possibly on multiple occasions, but several factors will need to be addressed to insure appropriate use of PGx testing in this setting. As more and more patient data including PGx results will be available to inform treatment options, clinical support tools will be essential to promote appropriate utilization and improve therapeutic decision-making. Providers should begin to take initiative to learn about PGx testing and educators, clinical testing laboratories, health systems, and professional organizations alike must work to reduce the knowledge gap. In particular, efforts are needed to develop resources that are accessible to all providers, regardless of practice setting.

6. Expert Commentary

As research and technology development continue, some groups have begun to implement PGx testing in limited clinical settings or more broadly through pre-emptive programs. However, more efforts will be needed to prepare community practitioners, with potentially more limited resources than available at academic medical centers, to integrate PGx testing into practice for their patients. In some cases, general practitioners may be the recipients of test results ordered by other providers, and may be even less prepared to understand how to utilize results in treatment decisions. Increased content in curricula and training programs, continuing educational programs, and point of care clinical decisional support will all be needed to prepare providers to appropriately utilize testing into clinical practice.

7. Five-year view

The availability of many commercial PGx tests today will continue to expand with the rapid development of new technologies and biomarkers. Eventually, DNA-based PGx testing may be superseded or combined with gene expression and/or pharmaco-metabolomic data to provide a more accurate prediction of treatment response. Currently, PGx tests are performed by specialty, hospital, or reference laboratories, but as new technologies enable more rapid and automated testing, point-of-care PGx testing may shift to the provider's office. Thus, turnaround time will no longer be a concern, and laboratory results will be immediately linked to the patient's medical record. It is likely that single gene tests will be

replaced by more comprehensive panels and reduce the need to order tests each time a new medication is prescribed. Furthermore, with more routine use of the PGx testing, we can anticipate a larger role for pharmacists in collecting, storing and utilizing test results to reduce adverse events or non-response, particularly for polypharmacy patients.

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* Of interest

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Key issues

- The growth of PGx testing services is based on recent advances in research and DNA-based testing technology development.
- Primary care or general practitioners prescribe medications in the majority of office visits and therefore, their patients may benefit in particular from PGx testing. Panel-based PGx tests would likely yield greater benefit, given the anticipated need for treatment for multiple clinical indications over their lifetime.
- Despite the purported benefit for primary care patients, providers are ill-prepared to integrate PGx testing into routine care and warrant continued and point-of-care educational and decisional support.
- Primary care providers may benefit from a combination of support and training, including continuing education, clinical decision support, and consultation services provided by laboratory medicine specialists, pharmacists, and genetic counselors.