

CARDIOLOGISTS' PERSPECTIVES ON PHARMACOGENOMICS: UTILIZATION,
BARRIERS, AND THE ROLE OF GENETIC COUNSELORS

by

Erin Alexander

Copyright © Erin Alexander 2025

A Thesis Submitted to the Faculty of the

COLLEGE OF HEALTH SCIENCES

In Partial Fulfillment of the Requirements

For the Degree of

MASTER OF SCIENCE
GENETIC COUNSELING

In the Graduate College

THE UNIVERSITY OF ARIZONA

THE UNIVERSITY OF ARIZONA
GRADUATE COLLEGE

As members of the Master's Committee, we certify that we have read the thesis prepared by Erin Alexander, titled *Cardiologists' Perspectives on Pharmacogenomics: Utilization, Barriers, and the Role of Genetic Counselors* and recommend that it be accepted as fulfilling the thesis requirement for the Master's Degree in Genetic Counseling.




Valerie Schatbley, PhD

Date: 4/4/25



Will Heise, MD

Date: 4/15/2025



Sonia Sabrowsky, MS, CGC

Date: 4/18/2025




Chris Stallman, MLS, MS, CGC

Date: 4/11/25

Final approval and acceptance of this thesis is contingent upon the candidate's submission of the final copies of the thesis to the Graduate College.

I hereby certify that I have read this thesis prepared under my direction and recommend that it be accepted as fulfilling the Master's requirement.



Valerie Schaibley, PhD
Master's Thesis Committee Chair
University of Arizona Genetic Counseling Graduate Program

Date: 4/18/25

ACKNOWLEDGEMENTS

I would like to thank the following people, without whom I would not have been able to complete this research, and without whom I would not have made it through this degree:

My committee chair, Dr. Valerie M. Schaibley, PhD for her consistent guidance, encouragement, patience, and support, especially when I was discouraged or overwhelmed.

My committee advisors, Dr. Will Heise, MD, Sonia Sabrowsky, MS, CGC, and Chris Stallman, MLS, MS, CGC, for their enthusiasm for this project, wealth of experience and knowledge, and their mentorship throughout this project and beyond.

The PGx Education Team at Mayo Clinic, for their continued support and efforts to improve PGx education in the healthcare system, and for believing in my project from the beginning.

My cohort, Maddie Gorman, Catherine Jirikowic, Chloe DeGiorgio, and Hope Wollen for their constant encouragement, emotional support, and lifelong friendship.

My loved ones, for all their support throughout these past two years.

For my mother, who has fully and whole-heartedly supported my educational endeavors over the last several years, in all the forms that they took.

Table of Contents

LIST OF FIGURES AND TABLES6

ABSTRACT8

INTRODUCTION9

METHODS13

SURVEY DESIGN AND INSTRUMENTATION.....13

PARTICIPANT RECRUITMENT13

DATA COLLECTION14

ETHICAL CONSIDERATIONS.....14

DATA ANALYSIS.....15

RESULTS15

RESPONDENT DEMOGRAPHICS.....15

PROVIDER KNOWLEDGE AND UTILIZATION OF PHARMACOGENOMIC TESTING.....18

AWARENESS OF GENE-DRUG INTERACTIONS IN CARDIOLOGY.....19

CONFIDENCE WITH INTERPRETATION AND COMMUNICATION OF PG_x TEST RESULTS.....21

BARRIERS TO PG_x IMPLEMENTATION	23
FAMILIARITY WITH GENETIC COUNSELING AND REFERRAL PATTERNS	24
<u>QUALITATIVE ANALYSIS OF OPEN-ENDED RESPONSES</u>	26
PERCEIVED ROLE OF GENETIC COUNSELORS IN PG_x TESTING	26
EXPECTED FUTURE IMPACT OF PG_x IN CARDIOVASCULAR MEDICINE	27
<u>DISCUSSION</u>	27
<u>STUDY LIMITATIONS</u>	31
<u>CONCLUSIONS AND FUTURE DIRECTIONS</u>	31
<u>APPENDIX A - SUPPLEMENTAL MATERIALS</u>	33
<u>REFERENCES</u>	43

List of Tables

Table 1. Demographics of Survey Respondents17

Table 2. Cardiologists’ Familiarity with Genetic Counseling and Clinical Impact of a Genetic Counselor on PGx Practices.25

List of Figures

Figure 1. Cardiologist Knowledge of Genetic Testing and Frequency of Test Ordering19

 A. Cardiologists’ Knowledge of Genetic Testing19

 B. Annual Frequency of PGx Testing Ordered by Provider19

Figure 2. Cardiologists’ Ability to Recall Cardiac-related Drugs with PGx Implications20

 A. Provider Ability to Recall Cardiac-Related Medications with PGx Implications.....20

 B. Medications Recalled by Providers.....20

Figure 3. Figure 3. Cardiologist Self-Reported Confidence in Communication and Interpretation of PGx Test Results22

Figure 4. Reported barriers to PGx implementation in clinical practice23

Supplemental Materials

Figure 1. Map of United States Representing Geographical Spread of Respondents33

Figure 2. Cardiologists’ Self-Reported Familiarity with CPIC Guidelines.....33

Survey: Cardiologists' Perceptions and Use of Pharmacogenomic Testing Survey34

Abstract

Pharmacogenomics (PGx) has the potential to personalize cardiovascular treatment by optimizing drug efficacy and minimizing adverse drug reactions. Despite well-established guidelines for PGx-informed prescribing, its integration into cardiology remains limited. In this study, we conducted a nationwide survey to assess cardiologists' knowledge, utilization, and perceptions of PGx testing, as well as their views on the role of genetic counselors in this space. The survey was distributed via email, flyers, and social media, utilizing a snowball sampling method. A total of 63 responses were included in the analysis. The majority of respondents were white, male, and practicing adult general cardiology. Most (58%) reported having no or only limited knowledge of PGx, and 55% had never ordered PGx testing in their practice. We found statistically significant positive correlations between provider degree of PGx knowledge and the frequency of test ordering ($p = 1.226e-09$), provider confidence in result interpretation, ($p < 2.349e-16$) and confidence with communicating test results ($p = 6.968e-13$). Additionally, many cardiologists expressed some interest in the integration of genetic counselors into PGx workflows, highlighting an opportunity for increased interdisciplinary collaboration. Notably, there was a statistically significant positive correlation between cardiologists' perceived impact of genetic counselors involved in PGx and their likelihood to refer patients to them for PGx testing ($p = 3.004 \times 10^{-6}$). PGx is an emerging field with the potential to improve patient outcomes and reduce healthcare costs, yet gaps in provider knowledge and confidence hinder its clinical use. Expanding provider education and incorporating genetic counselors into cardiology and PGx workflows may facilitate broader adoption of PGx testing and enhance personalized treatment strategies in cardiovascular care.

Introduction

Pharmacogenomics (PGx) offers the potential to personalize medicine by using genetic variations to understand an individual's drug metabolism, efficacy, and safety. By tailoring treatments to a patient's unique genetic profile, PGx can help optimize drug efficacy, minimize adverse drug reactions, and reduce the trial-and-error approach that often characterizes medication prescribing today. This personalized approach to healthcare represents a transformative advancement, particularly in the management of complex, chronic diseases like cardiovascular disease (CVD), where medications are central to long-term care and the risks of side effects and non-adherence are significant.

Cardiovascular diseases remain one of the leading causes of morbidity and mortality worldwide, with many patients requiring lifelong pharmacologic treatment to manage conditions such as hypertension, hyperlipidemia, and thromboembolic disorders. Despite the availability of effective drugs, such as statins, warfarin, and clopidogrel, the clinical outcomes for patients are often unpredictable due to genetic variability in drug responses. For example, variations in the *SLCO1B1* gene can impact how statins are metabolized, and patients with certain genetic variants may experience muscle toxicity (statin-associated muscle symptoms, or SAMS) because of higher levels of the drug circulating outside the liver (Link, Parish et al. 2008). Similarly, variants in *CYP2C9* and *VKORC1* influence the response to warfarin, affecting the appropriate dosage and increasing the risk of either bleeding or thrombotic events when not managed with genetic guidance (Johnson, Caudle et al. 2017). Furthermore, genetic differences in the *CYP2C19* gene can determine how patients respond to clopidogrel, with loss-of-function alleles leading to reduced effectiveness of the drug and potentially increasing the risk of adverse cardiac events (Mega, Close et al. 2009). In such cases, pharmacogenomic testing offers an opportunity

to identify individuals at risk of poor drug response or adverse effects, allowing clinicians to adjust dosages or select alternative therapies for more personalized care.

Despite the growing body of evidence supporting the benefits of PGx testing for drugs commonly prescribed in cardiology, widespread adoption of PGx into routine clinical practice remains slow. This underutilization can be attributed to a range of barriers, including limited provider knowledge, logistical challenges, and a lack of standardized workflows for integrating genetic information into clinical decision-making (Al-Mahayri, Khasawneh et al. 2022, Russell, Campion et al. 2024). Many cardiologists report feeling inadequately prepared to incorporate PGx into their prescribing practices. A lack of familiarity with the principles of pharmacogenomics, combined with uncertainty over how to interpret genetic test results and apply them in a real-world clinical context, also contributes to hesitancy in adopting PGx (Kim, Kim et al. 2020, Russell, Campion et al. 2024). Studies indicate that many cardiologists remain unaware of the pharmacogenomic clinical protocols that significantly impact the efficacy and safety of cardiovascular medications, despite the presence of well-established guidelines for drugs like warfarin, statins, and clopidogrel (Russell, Campion et al. 2024).

Provider education is a key factor influencing the integration of PGx into clinical cardiology. Many healthcare providers have not received formal training in pharmacogenomics, either during medical school or in continuing education programs. As a result, there is a gap in the knowledge required to confidently order, interpret, and apply genetic testing to drug therapy (Haga, Burke et al. 2012, Russell, Campion et al. 2024). Even though pharmacogenomic testing has been shown to improve clinical outcomes in certain patient populations, providers are often unaware of the clinical guidelines that support its use, or they may be unsure of how to translate genetic information into actionable treatment decisions. A survey of primary care providers,

cardiologists, and psychiatrists revealed that while some specialists are aware of pharmacogenomics, only a small percentage feel confident in their ability to use PGx results to guide clinical decisions (Johansen Taber and Dickinson 2014). This knowledge gap is a significant barrier to the implementation of PGx testing, underscoring the need for educational interventions that can improve understanding and increase provider confidence in using genetic data to inform prescribing practices.

In addition to education, logistical barriers also hinder the adoption of PGx in cardiology. Healthcare systems often lack streamlined processes for ordering pharmacogenomic tests and integrating the results into electronic health records (EHRs), making it difficult for clinicians to access and use genetic information at the point of care (Kabbani, Akika et al. 2023). Moreover, PGx testing can be costly, and reimbursement for these tests is inconsistent, leaving many providers unsure about whether insurance will cover the expense of testing for their patients (Phillips, Veenstra et al. 2001). These financial and logistical concerns, coupled with the fast-paced nature of cardiology, where time constraints are a major factor, make it difficult for many cardiologists to prioritize PGx testing in their practice. These challenges may be particularly pronounced in community-based settings or among providers who do not have easy access to genetic counseling services, which can support the interpretation and application of PGx test results.

Genetic counselors (GCs) play a crucial role in addressing these barriers by helping providers navigate the complexities of pharmacogenomic testing. In the context of cardiology, GCs can assist cardiologists in understanding how genetic variants may influence drug response and help integrate this information into personalized treatment plans (Zierhut, Campbell et al. 2017). By collaborating with genetic counselors, cardiology teams can improve the interpretation

of genetic test results, offer more precise recommendations for drug therapy, and ensure that patients fully understand the risks and benefits associated with PGx-guided treatment. The involvement of GCs can also foster better communication between providers and patients, enhancing patient trust and adherence to treatment recommendations (Mills and and Haga 2013). As the use of PGx testing continues to grow, GCs into cardiology workflows will be essential for optimizing care and improving patient outcomes.

Although the evidence supporting the clinical benefits of PGx in cardiology is robust, the practical application of pharmacogenomics remains inconsistent. Studies have shown that while certain specialists, including cardiologists, are more likely to recognize the value of PGx testing for specific medications, their overall adoption of these practices is still limited (Russell, Campion et al. 2024). Barriers such as insufficient education, unclear reimbursement policies, and lack of integration into existing clinical workflows must be addressed to improve the uptake of PGx testing. Furthermore, the introduction of PGx testing into routine cardiology practice may help reduce healthcare disparities, as patients from underserved communities often face greater obstacles in accessing genetic services (Shaaban and Ji 2023). Understanding these barriers is crucial to bridging the gap between pharmacogenomic research and its clinical application.

This study aims to explore cardiologists' perceptions and utilization of pharmacogenomic testing in clinical practice. Specifically, it seeks to identify knowledge gaps, barriers to implementation, and potential facilitators of PGx adoption in cardiology. Additionally, we investigate the role of GCs in the integration of PGx testing and improving the overall quality of care. This study offers a broad assessment of the current state of PGx integration in cardiovascular care throughout the country by studying perspectives of cardiologists nationwide without limiting recruitment to specific geographic regions. By understanding cardiologists'

attitudes toward PGx testing and studying the challenges they face, this study provides valuable insights that can inform future educational initiatives, policy decisions, and resource allocation efforts aimed at enhancing the clinical adoption of pharmacogenomics in cardiovascular medicine.

Methods

Survey Design and Instrumentation

We developed a survey to investigate cardiologists' perceptions and usage of pharmacogenomic testing in the clinical cardiology setting, as well as their knowledge and opinions on implementation of GCs in this space. The survey was created using Qualtrics (Qualtrics, Provo, UT), an online survey platform, which allowed for the collection of both quantitative and qualitative data. The survey was structured with a combination of multiple-choice, Likert scale, and open-ended questions to ensure a comprehensive understanding of the respondents' experiences, perspectives, and practices. The survey included five sections covering demographics, genetic testing in cardiovascular medicine, pharmacogenomics, genetic counseling, and follow-up questions. The full survey can be found in the supplemental materials.

Participant Recruitment

The target population for this survey consisted of cardiologists currently practicing in the United States. Participants were recruited using a multi-faceted approach, including email invitations, social media posts, flyers, and a snowball sampling technique. Email invitations were sent to a list of cardiologists obtained from publicly available internet sources, and social media posts were distributed through platforms such as LinkedIn and X (formerly known as Twitter).

Flyers were also distributed in relevant academic and professional settings, such as cardiology conferences. To increase response rates, participants were encouraged to share the survey with colleagues through the snowball sampling method. The survey remained open for 12 weeks and participants were informed that participation was voluntary and anonymous. As an incentive, those who completed the survey had the option to provide their email address to be entered into a drawing to receive a scholarship for a Mayo Clinic pharmacogenomics continuing medical education (CME) course.

Data Collection

Data was collected using Qualtrics, which allowed for automated responses and ensured the confidentiality of the survey participants. The survey link was distributed electronically, and participants could access the survey at their convenience. All responses were stored securely within the Qualtrics platform and subsequently transferred to Box for further analysis. A total of 66 responses were collected during the study period. Three responses were less than 75% complete and were removed from analysis, leaving 63 responses for analysis.

Ethical Considerations

Ethical approval for this study was obtained from the University of Arizona Institutional Review Board (STUDY00004937). Participants were informed of the study's purpose, the voluntary nature of participation, and the confidentiality of their responses through an informed consent statement displayed at the beginning of the survey. Respondents were assured that their data would be anonymized and used solely for the purposes of this research. No personal

identifying information was collected, and all data were stored securely in compliance with institutional and federal privacy regulations.

Data Analysis

Data were exported from Qualtrics and stored in Box for secure access and analysis. Quantitative data were analyzed using Microsoft Excel and R Studio (version 2023.12.1+402) using descriptive statistics. To examine associations between variables, Pearson's product-moment correlation coefficients (Pearson's r) were calculated to assess the strength and direction of relationships between variables. Qualitative responses were analyzed thematically using Microsoft Excel to identify recurring themes and patterns in the open-ended data. EA performed initial coding of open-ended survey responses and VS reviewed the coding. Any discrepancies between the coding were discussed and agreed upon by both authors. The results of the quantitative and qualitative analyses were then integrated to provide a comprehensive understanding of the survey findings.

Results

Respondent Demographics

A total of 66 cardiologists took the survey, 63 of which completed at least 75% of the survey and are included in this analysis. The majority of respondents identified as male (83%), and most self-identified as White/Caucasian, followed by Asian, Black/African American, and Middle Eastern or North African (Table 1). Respondents were evenly distributed across years in practice, with 33% having practiced for 5–10 years, 25% for more than 20 years, and the remaining spread across less than 5 years (21%) and 11–20 years (21%) in practice (Table 1).

Most participants specialized in general cardiology (41%), with additional representation from interventional cardiology (14%), heart failure/transplant (13%), congenital cardiology (9%), and electrophysiology (8%). Other subspecialties included preventive cardiology, critical care, lipid disorders, vasculopathies, pulmonary hypertension, and cardio-oncology (Table 1). The majority worked with adult populations (90%) and practiced in urban (75%) or suburban (21%) settings (Table 1). Most respondents reported working in teaching hospitals (78%), with others working in combined hospital/outpatient roles (17%), non-teaching hospitals (3%), or outpatient clinics (2%) (Table 1). Respondents represented a broad geographic distribution across the United States, with completed surveys coming from 27 states (Supplemental Figure 1).

Table 1. Demographic characteristics of survey respondents.

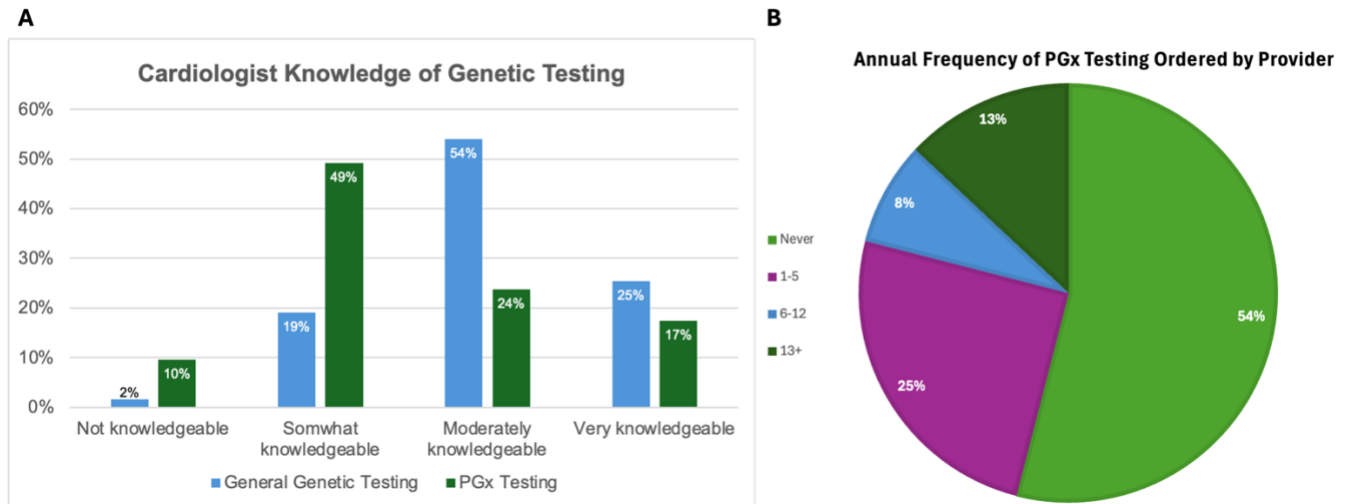
Demographic	N (%)
Gender	
Male	52 (83%)
Female	11 (17%)
Race and Ethnicity	
White/Caucasian	43 (65%)
Asian	15 (23%)
Black/African American	5 (8%)
Middle Eastern or North African	1 (2%)
Other	2 (3%)
Years in Practice	
< 5 years	13 (21%)
5-10 years	21 (33%)
11-20 years	13 (21%)
> 20 years	16 (25%)
Cardiology Subspecialty	
General Cardiology	26 (41%)
Interventional Cardiology	9 (14%)
Heart Failure/Transplant	8 (13%)
Congenital Cardiology	6 (9%)
Electrophysiology	5 (8%)
Preventive	3 (5%)
Critical Care	2 (3%)
Lipid Disorders	2 (3%)
Vasculopathies	1 (2%)
Pulmonary Hypertension	1 (2%)
Cardiooncology	1 (2%)
Population	
Adult	57 (90%)
Pediatric	6 (10%)
Location	
Urban	50 (75%)
Suburban	14 (21%)
Rural	3 (4%)
Practice Setting	
Hospital, Teaching	49 (78%)
Combination of Hospital and Outpatient	11 (17%)
Hospital, Non-Teaching	2 (3%)
Outpatient Clinic	1 (2%)

Provider Knowledge and Utilization of Pharmacogenomic Testing

When asked to assess their knowledge of general genetic testing in cardiology, 25% of cardiologists reported being very knowledgeable, 54% were moderately knowledgeable, 19% were somewhat knowledgeable, and 2% indicated they were not knowledgeable at all (Figure 1). However, when prompted to assess their own knowledge of PGx, only 17% of cardiologists reported being very knowledgeable and 24% said they were moderately knowledgeable. The majority, however, indicated limited understanding as 49% described themselves as somewhat knowledgeable and 10% reported not being knowledgeable at all (Figure 1A). When asked about how often they order PGx testing, more than half of the surveyed cardiologists (54%) reported that they had never ordered PGx testing, while 25% had ordered PGx testing 1–5 times per year, 8% had ordered 6–12 tests annually, and 13% had ordered PGx testing more than 13 times per year. These findings indicate that even among cardiologists familiar with PGx, routine utilization remains low (Figure 1B).

Statistical analysis revealed a strong positive correlation between provider knowledge of PGx and the frequency of PGx test ordering ($p < 1.226 \times 10^{-09}$). This suggests that greater self-reported knowledge of PGx is associated with increased likelihood of test utilization. Additionally, a significant positive correlation was identified between provider knowledge of general genetic testing in cardiology and their knowledge of PGx ($p = 1.744 \times 10^{-07}$).

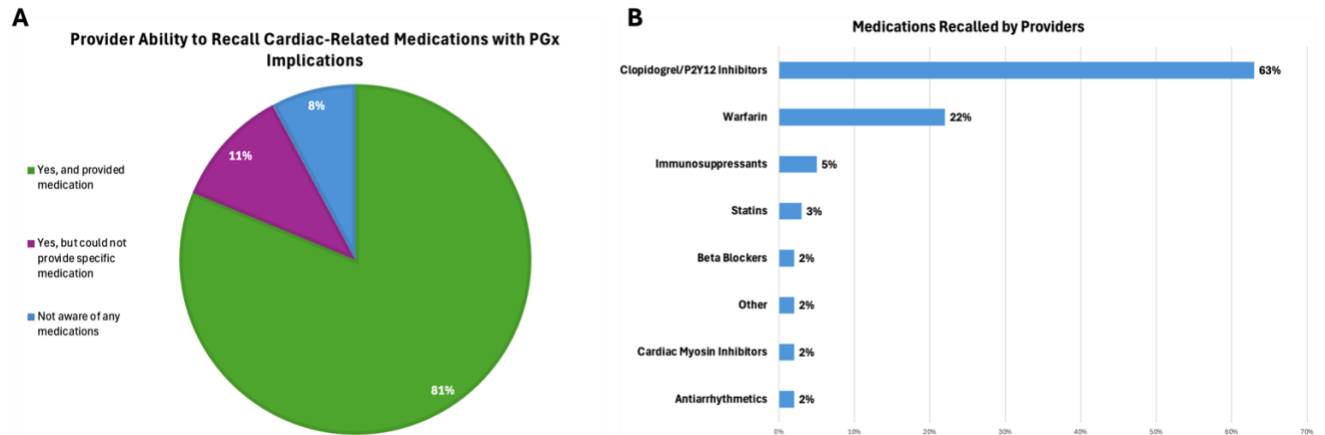
Figure 1: Cardiologist Knowledge of Genetic Testing and Frequency of Test Ordering. (A) Self-reported provider knowledge of both general genetic testing and pharmacogenomic testing. (B) Annual frequency of PGx test ordering among cardiologists.



Awareness of Gene-Drug Interactions in Cardiology

When asked about their awareness of cardiology-related medications that may have variable responses based on genetic information, 81% of respondents (n = 51) were able to name at least one relevant gene-drug interaction, while 19% (n = 12) did not identify any (Figure 2A). These findings suggest that the majority of cardiologists have at least some familiarity with pharmacogenomic (PGx) considerations in cardiovascular medicine.

Figure 2: Cardiologists' Ability to Recall Cardiac-related Drugs with PGx Implications. (A) Among respondents, 81% were able to recall at least one specific drug, 11% acknowledged knowing there were relevant drugs but could not recall specific names, and 8% reported not being aware of any cardiac-related PGx drugs. (B) Among participants who could recall drugs, the most frequently mentioned included clopidogrel (63%) and warfarin (22%), followed by immunosuppressants (5%) and statins (3%).



In addition to assessing overall awareness of pharmacogenomic (PGx) testing, the survey asked cardiologists to identify specific medications known to exhibit gene-drug interactions. The vast majority of respondents who could name at least one relevant medication identified clopidogrel or other P2Y12 inhibitors (63%). Warfarin was the second most frequently named drug, reported by 22% of respondents, reflecting its well-documented variability due to *CYP2C9* and *VKORC1* genetic influences (Johnson, Caudle et al. 2017).

Far fewer cardiologists (3%) identified pharmacogenomic relevance for statins, despite the established association between *SLCO1B1* genetic variants and statin-induced myopathy (Cooper-DeHoff, Niemi et al. 2022). Similarly, beta blockers, antiarrhythmic agents, and cardiac myosin inhibitors were rarely recognized as PGx-associated therapies, with only 2% of participants identifying each of these medications. Immunosuppressants were named by a small subset of providers (5%), possibly reflecting awareness of drug-gene interactions relevant to

transplant cardiology. A small percentage of respondents (2%) cited "other" medications, though specific drugs were not consistently specified.

To further explore differences in knowledge levels and ability to recall PGx-related drugs, respondents were stratified into high PGx knowledge and low PGx knowledge groups. The low knowledge group consisted of those who self-reported as "not knowledgeable at all" or "somewhat knowledgeable" (n = 37, 59%), while the high knowledge group consisted of those who reported being "moderately" or "very knowledgeable" about PGx (n = 26, 41%). Among the high PGx knowledge group, 92% were able to name at least one PGx-related cardiology drug, while only 73% of the low PGx knowledge group could do so. While there appears to be a trend toward higher knowledge being associated with greater ability to name a relevant drug, the difference was not statistically significant ($\chi^2(1, N = 63) = 2.55, p = 0.11$).

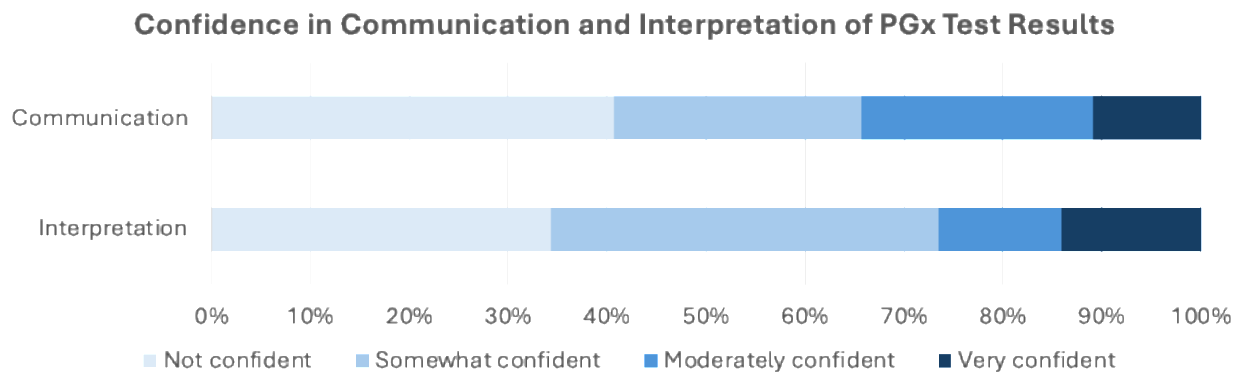
The specific drugs named by each group also differed. Among the low PGx knowledge group, the most commonly identified drug was clopidogrel (67%), followed by warfarin (30%), while 22% named other medications and 19% were able to name multiple relevant drugs. In the high PGx knowledge group, clopidogrel was still the most frequently named drug (79%), but fewer participants in this group identified warfarin (21%), and a smaller proportion listed other medications (8%) or multiple drugs (13%). Notably, both self-reported lipid disorder specialists were among those unable to identify any PGx-related cardiology drugs.

Confidence with Interpretation and Communication of PGx Test Results

Respondents expressed varying levels of confidence in communicating and interpreting PGx test results. As shown in Figure 4, self-reported confidence in communication was generally

higher than in interpretation. Only 11% of cardiologists felt very confident, 23% reported being moderately confident, 25% were somewhat confident, and 41% were not confident in their abilities to communicate PGx test results with patients. Additionally, only 14% felt very confident in their ability to interpret PGx results, while 12% were moderately confident, 39% somewhat confident, and 35% were not confident in their abilities to interpret PGx test results. These results suggest that interpretation—rather than communication—may present the greater barrier to clinical adoption of PGx testing.

Figure 3. Cardiologist self-reported confidence in communication and interpretation of PGx test results. Respondents were asked to report their confidence in interpreting and communicating PGx test results using a four-point Likert scale. Most cardiologists were either somewhat or not confident with both roles.

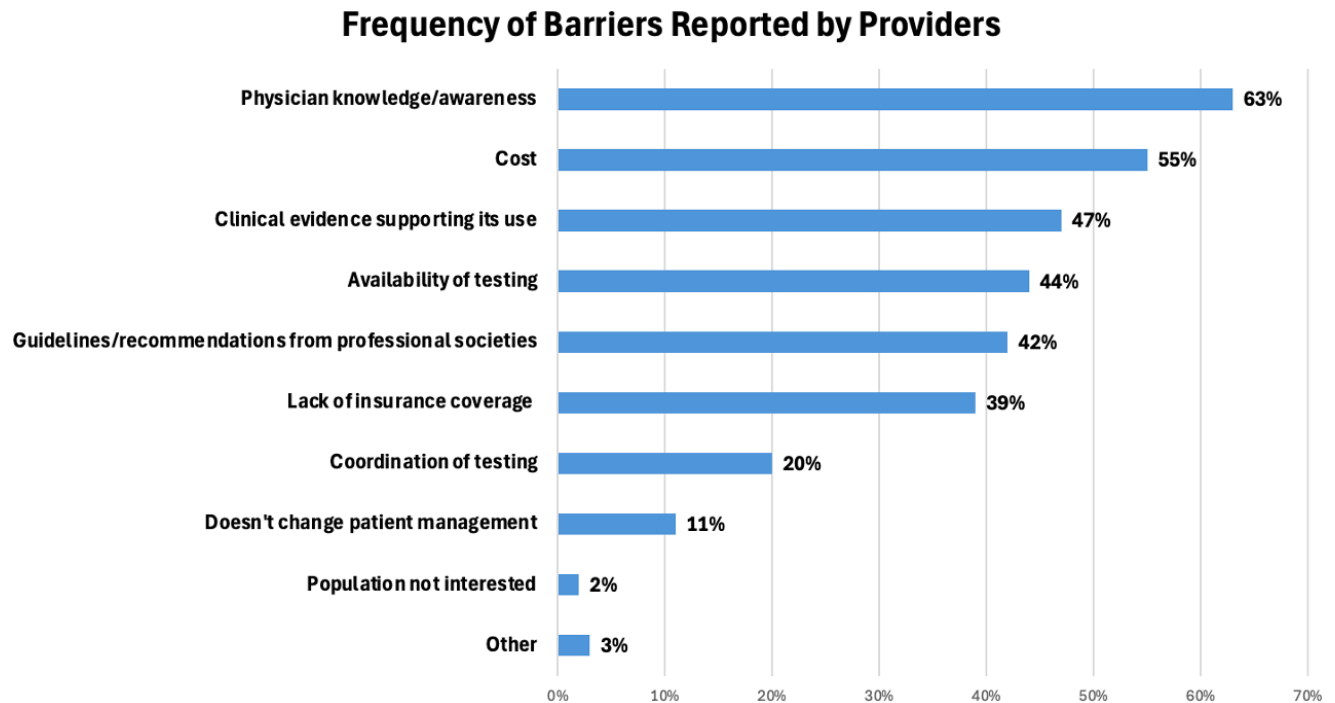


Furthermore, we found a statistically significant positive correlation between provider self-reported knowledge of PGx testing with confidence in communicating these results with patients ($\rho=0.76$, $p=3.93 \times 10^{-13}$) and interpreting the results of PGx testing ($\rho=0.82$, $p < 2 \times 10^{-16}$). These results suggest that greater knowledge of PGx testing among cardiologists increases both confidence in interpreting and communicating results to patients.

Barriers to PGx Implementation

Cardiologists were asked to identify perceived barriers to implementing PGx testing in clinical practice. The most frequently cited barrier was physician knowledge and awareness, reported by 63% of respondents. Other prominent barriers included cost, lack of clinical evidence supporting use, availability of testing, and lack of guidelines or recommendations from professional societies. Additional concerns included lack of insurance coverage, coordination of testing, a belief that PGx “doesn’t change patient management,” and lack of patient interest (Figure 5). The three respondents who selected other did not specify additional barriers.

Figure 4. Reported barriers to PGx implementation in clinical practice. Cardiologists were asked to identify barriers for implementing PGx testing into their clinical practice. Each respondent could select multiple barriers.



Overall, familiarity with the Clinical Pharmacogenetics Implementation Consortium (CPIC) guidelines among cardiologists was limited. The majority of respondents (81%) reported not being familiar at all with CPIC guidelines, while 6% were somewhat familiar, 3% were moderately familiar, and only 10% indicated they were very familiar (Supplemental Figure 2). Among those who reported a lack of professional guidelines as a barrier (n = 27), familiarity with existing pharmacogenomic guidance was low. Specifically, 89% (n = 24) were not familiar at all with the CPIC guidelines, while only 4% (n = 1) were moderately familiar, and 7% (n = 2) were very familiar. None reported being somewhat familiar.

Familiarity with Genetic Counseling and Referral Patterns

We next investigated the use of genetic counseling for PGx among cardiologists. Providers were asked to rate their familiarity with genetic counseling, the impact that a GC would have on their integration of PGx into clinical practice and the likelihood of referring to a GC for PGx testing if one was available (Table 2). As shown in Table 2, cardiologists reported varying levels of familiarity with genetic counseling and differing perceptions of its potential impact on PGx testing in clinical practice. Over half of respondents (54%) indicated they were very knowledgeable about genetic counseling, while 37% reported being aware of it but rarely or never using it in practice. A smaller portion (10%) said they had heard of genetic counseling but knew nothing about it. None of the participants indicated that they had never heard of genetic counseling (Table 2).

When asked how the presence of a GC in their practice would impact their PGx test ordering frequency, nearly half (44%) stated it would slightly increase their ordering, and 24% said it would significantly increase it. Of the respondents, 30% felt it would have no impact, and

only one respondent (2%) indicated it might slightly decrease their use of PGx testing. None reported that it would significantly decrease their use (Table 2).

Responses were generally evenly distributed regarding the likelihood of referring patients to a GC for PGx-related support. In our survey, 33% of respondents said they would be very likely to refer, with an additional 21% being moderately likely and 24% somewhat likely, and 22% saying they would not be likely to refer (Table 2).

Table 2. Cardiologists’ Familiarity with Genetic Counseling and Clinical Impact of a Genetic Counselor on PGx Practices

Measure	N (%)
Familiarity with Genetic Counseling	
I have never heard of genetic counseling	0 (0%)
Have heard of GC but know nothing about it	6 (10%)
Know about GC but rarely/never use in practice	23 (37%)
Very knowledgeable about GC	34 (54%)
Impact of Having a GC on PGx Test Ordering	
Significantly decrease ordering	0 (0%)
Slightly decrease ordering	1 (2%)
No impact	19 (30%)
Slightly increase ordering	28 (44%)
Significantly increase ordering	15 (24%)
Likelihood to Refer to a GC for PGx Testing	
Not likely	14 (22%)
Somewhat likely	15 (24%)
Moderately likely	13 (21%)
Very likely	21 (33%)

We found a positive correlation between cardiologists' perceived impact of GCs in PGx testing and their likelihood to refer patients for genetic counseling ($r = 0.55013$, $p = 3.004 \times 10^{-6}$), suggesting that providers who recognize the value of GCs are more likely to integrate them into clinical workflows. Familiarity with genetic counseling was not significantly associated with either the impact of a GC on PGx test ordering frequency or the likelihood of referring patients for GC. Additionally, the perceived importance of education and counseling did not significantly correlate with the perceived impact of GC on test ordering. No significant relationship was observed between provider years of experience and PGx ordering frequency. Similarly, provider knowledge of PGx was not significantly associated with either the likelihood of referring patients to GC or the perceived impact of GC on PGx ordering frequency.

Qualitative Analysis of Open-Ended Responses

Perceived Role of Genetic Counselors in PGx Testing

Responses to the question, "In your opinion, what role should GCs play in cardiovascular medicine regarding PGx testing?" revealed four major themes: perceived limited or uncertain role of GCs, uncertainty rooted in evidence gaps, recognized value in counseling and interpretation support, and administrative or logistical functions. In the multiple-choice portion of the question, 41% of responses indicated interpretation of PGx test results as an appropriate role for GCs, 34% of responses selected result disclosure to patients, and 24% selected ordering PGx tests. These results indicate that while some cardiologists were skeptical about the role of GCs in PGx testing, others acknowledged their potential contributions, particularly in supporting interpretation and communication of test results. Qualitative responses also reflected this variation, with some providers emphasizing the value of GCs in patient counseling and

interdisciplinary collaboration, and others expressing uncertainty or limited familiarity with the profession's relevance in cardiovascular pharmacogenomics.

Expected Future Impact of PGx in Cardiovascular Medicine

In the survey, cardiologists were also asked “How do you think PGx will impact the future of cardiovascular medicine?” Four major themes emerged: facilitation of personalized medicine, skepticism due to limited evidence, anticipated improvements in patient outcomes, and expectations for increased integration into clinical workflows. Many respondents believed PGx would play a significant role in targeted dosing and medication safety, while others raised concerns about implementation challenges and limited supporting evidence.

Several participants anticipated that PGx testing would become more widely integrated into EHRs and AI-driven clinical decision support tools, making it more accessible and clinically relevant. However, others emphasized that for PGx to become mainstream, stronger clinical trial data and clearer professional guidelines would be necessary.

Discussion

This study sought to assess cardiologists’ knowledge, utilization, and perceptions of pharmacogenomic testing in clinical practice, as well as their perspectives on the role of genetic counselors in cardiovascular PGx. Despite growing interest in personalized medicine, the integration of PGx into cardiology remains limited. The findings of this survey indicate that many cardiologists recognize the theoretical value of PGx, but several barriers, such as limited provider knowledge, uncertainty about clinical utility, cost, and lack of awareness of professional guidelines, continue to hinder adoption.

A majority of cardiologists (54%) reported having never ordered PGx testing, and only 13% indicated ordering PGx more than 13 times annually. Despite this underutilization, strong positive correlations were observed between PGx knowledge and frequency of test ordering, as well as between knowledge of general genetic testing in cardiology and PGx knowledge. These findings suggest that improving provider education may lead to greater implementation of PGx testing and reinforce the importance of incorporating PGx concepts into cardiology training and continuing medical education.

Cardiologists were also asked to assess their awareness of gene-drug interactions in cardiovascular medicine. While 81% were able to name at least one PGx-related drug, most responses were concentrated on clopidogrel (63%) and warfarin (22%). Other drugs with well-documented PGx implications, such as statins, beta-blockers, and cardiac myosin inhibitors, were rarely mentioned. Only 3% of respondents identified statins, despite established associations between *SLCO1B1* variants and statin-induced myopathy (Cooper-DeHoff, Niemi et al. 2022). Notably, both cardiologists who specialized in lipid disorders failed to name any PGx-associated medications, which may indicate gaps in specialty-specific education even in areas with strong clinical evidence. These findings highlight an overreliance on a narrow subset of gene-drug interactions and underscore the need for targeted education to expand awareness of pharmacogenomic relevance across a broader range of cardiovascular therapies. Overall, the finding that nearly one in five cardiologists in our study could not name a single PGx-related drug highlights a potential gap in knowledge and underscores the need for further education on the role of genetic variability in drug response.

Confidence in PGx testing was also varied. While cardiologists generally reported greater confidence in communicating PGx results than interpreting them, fewer than one-third felt very confident in either domain. These gaps in confidence were strongly correlated with PGx knowledge. Self-reported PGx knowledge significantly predicted confidence in both interpreting and communicating PGx results. These results suggest that greater knowledge of PGx testing among cardiologists increases confidence in both interpreting and communicating results to patients. These findings also indicate that lack of knowledge may not only limit test utilization but also diminish providers' ability to effectively use PGx results in patient care. In addition, interventions such as embedded clinical decision support within electronic health records may assist providers by offering real-time interpretation guidance and mitigating this barrier (Morris, Nguyen et al. 2024).

When asked to identify barriers to PGx implementation, 63% of respondents cited physician knowledge and awareness, followed by cost, lack of clinical evidence, availability of testing, and lack of guidelines or recommendations from professional societies. While CPIC provides guidelines for many cardiovascular medications with PGx implications, familiarity with these resources was low. Over 80% of respondents indicated no familiarity with CPIC guidelines, and among those who cited a lack of professional guidance as a barrier, 89% were not familiar at all with CPIC recommendations. These findings suggest that a perceived lack of guidance may be rooted in lack of awareness rather than the absence of evidence-based resources. Increasing dissemination of guideline-based PGx tools, especially from cardiology-specific professional organizations such as the American College of Cardiology (ACC) or American Heart Association (AHA), may be necessary to build provider confidence and perceived utility of PGx in clinical practice.

The survey also explored cardiologists' familiarity with and attitudes toward genetic counseling in PGx workflows. More than half of respondents reported being very knowledgeable about genetic counseling, though only about one-third of them were very likely to refer patients to a genetic counselor for PGx testing. Importantly, we found a statistically significant correlation between the perceived impact of genetic counselors on PGx test ordering and the likelihood of referring to them, indicating that recognition of their value may play a central role in facilitating interdisciplinary collaboration. However, familiarity with genetic counseling did not significantly predict referral patterns, nor did it correlate with perceived impact on PGx test utilization.

Open-ended responses reflected mixed opinions about the role of genetic counselors in PGx testing. Some respondents were uncertain or skeptical, writing comments such as “not sure,” or “I do not believe they play a large role.” Others highlighted the value of genetic counselors in helping interpret test results, counseling patients and families, and assisting with insurance logistics. One respondent described genetic counselors as a “liaison for insurance billing,” while another cited their role in “counseling about implications for family.” These insights suggest that while the role of genetic counselors is not yet fully integrated or understood in cardiology, there is recognition of their potential utility, particularly in supporting test implementation, patient education, and health system navigation.

It is also worth noting that while some variables showed statistically significant associations, several others did not. Notably, there was no significant relationship between provider years of experience and PGx test ordering, nor between PGx knowledge and likelihood to refer to a genetic counselor. These results suggest that experience and knowledge alone may

not fully drive behavior, and that provider knowledge, access, and reimbursement structures may also shape PGx and genetic counseling integration.

Study Limitations

This study has several limitations. First, the sample size was relatively small ($n = 63$), which may limit generalizability. Respondents were recruited through a combination of email, social media, and professional networks using a snowball sampling approach, which could introduce selection bias. Participants with greater interest in or awareness of PGx may have been more likely to complete the survey, potentially skewing the data toward more favorable attitudes. Additionally, most respondents reported working in teaching hospitals (78%), which may further limit generalizability to community or non-academic settings where access to PGx testing and genetic counseling may differ. Lastly, the study relied on self-reported knowledge, utilization, and perceptions, which may not always align with actual clinical behavior.

Conclusion and Future Directions

The results of this study highlight both the promise and the current limitations of PGx testing in cardiology. While there is broad awareness of PGx potential, especially for clopidogrel and warfarin, test utilization remains low and knowledge gaps persist, especially around lesser-known gene-drug interactions and clinical guidelines. Confidence in result interpretation, awareness of CPIC guidelines, and perceived clinical utility remain major areas for improvement. Additionally, while some cardiologists remain unsure about the role of genetic counselors in PGx workflows, many recognize the value of interdisciplinary support.

These findings align with those of Russell et al. (2024), which also identified knowledge gaps, underutilization of PGx testing, and uncertainty regarding clinical utility as key barriers to implementation. However, while Russell et al. surveyed a broader range of cardiology providers (including nurses and GCs) and limited their analysis to California, this study focused exclusively on cardiologists and recruited participants from across the United States with 27 states represented. As such, it offers a more targeted view of cardiologist-specific perspectives on PGx testing and provides insight into national trends. Moreover, this study adds novel data on cardiologists' confidence in interpreting and communicating PGx results, as well as their attitudes toward the integration of GCs into cardiovascular care, which are topics that were not central to the Russell et al. analysis.

Future directions should prioritize improving provider education through formal training, continuing education modules, and incorporation of PGx principles into cardiology fellowships. Integrating clinical decision support tools into electronic health records and promoting interdisciplinary collaboration, particularly with genetic counselors, may also enhance implementation. As precision medicine becomes more integrated into routine care, addressing these barriers will be essential to ensure that PGx testing contributes meaningfully to evidence-based, individualized cardiovascular treatment.

Survey:

Cardiologists' Perceptions and Use of Pharmacogenomic Testing Survey

Start of Block: Informed Consent

University of Arizona Consent to Participate in Research

Study Title: Cardiologists' Perceptions and Utilization of Pharmacogenomic Testing in Cardiovascular Medicine

Principal Investigator: Erin Alexander

Consent Version: v.2023-12

You are being asked to participate in a research study. Your participation in this research study is voluntary and you do not have to participate. This document contains important information about this study and what to expect if you decide to participate. Please consider the information carefully. Feel free to ask questions before making your decision whether to participate.

Study purpose and procedure: The purpose of this study is to better understand the perceptions and utilization of pharmacogenomic testing within cardiovascular medicine by U.S. based cardiologists, and opinions on the potential implementation of genetic counselors in this field. For this study, you will be asked to answer questions about your understanding of genetic testing in general, pharmacogenomic testing (PGx), and genetic counseling. The survey should take you **approximately 5 to 10 minutes to complete**. Once you have submitted the survey, your responses cannot be withdrawn due to the anonymous nature of the survey. Up to the point of submitting, you have the right to withdraw by exiting the survey, and your survey responses will not be submitted for research purposes. Surveys which are 75% or more complete may be used for research purposes once submitted.

Risks and benefits: There are no expected risks to you as a result of participating in this study. You will not benefit directly from participating in this study.

Financial compensation: If you complete a survey, you may provide your contact information to be entered into a raffle to have the chance to receive one of five scholarship opportunities for a Mayo Clinic PGx CME course. For any compensation you receive, we are required to obtain identifiable information such as your name and email address for financial compliance purposes. Identifiable information collected for financial compliance purposes will be collected through a separate secure link upon completion of this research survey and not be linked to your research data. If you do not want us to collect this information, you can still participate in this study, but you will not be eligible to receive CME course scholarship for your participation.

Confidentiality: The responses that you give in the study will be anonymous. Your name will not be linked to your responses.

Because of the nature of the data, it may be possible to deduce your identity; however, there will be no attempt to do so, and your data will be reported in a way that will not identify you. Information collected about you will not be used or shared for future research studies.

The information that you provide in the study will be handled confidentially. However, there may be circumstances where this information must be released or shared as required by law. The University of Arizona Institutional Review Board may review the research records for monitoring purposes.

For questions, concerns, or complaints about the study you may contact Erin Alexander at erinalexander@arizona.edu or Valerie Schaibley at vschaibley@arizona.edu.

For questions about your rights as a participant in this study, or to discuss other study-related concerns or complaints with someone who is not part of the research team, you may contact the Human Subjects Protection Program Director at 520-626-8630 or online at <https://research.arizona.edu/compliance/human-subjects-protection-program>.

By clicking the 'I agree' button below, you acknowledge:

- You are at least 18 years of age.
 - You are a licensed cardiologist currently practicing in the U.S.
 - You have read this form and voluntarily agree to participate in this study.
1. I agree (1)
 2. I disagree (2)

Skip To: End of Survey If University of Arizona Consent to Participate in Research Study Title: Cardiologists' Perceptions... = I disagree

End of Block: Informed Consent

Start of Block: Demographics

Q1 Do you currently practice in cardiology?

3. Yes (1)
4. No (2)

Skip To: End of Survey If Do you currently practice in cardiology? = No

Q2 In what zip code do you currently practice medicine?

Q3 How many years of experience do you have in cardiology?

- 5. 0-5 years (1)
 - 6. 6-15 years (2)
 - 7. 16-25 years (3)
 - 8. 25+ years (4)
-

Q4 What is your primary subspecialty within cardiology?

- 9. General cardiology (1)
 - 10. Cardiothoracic surgery (2)
 - 11. Interventional cardiology (3)
 - 12. Congenital cardiology (4)
 - 13. Transplant and heart failure cardiology (5)
 - 14. Preventive cardiology (6)
 - 15. Electrophysiology (7)
 - 16. Lipid disorders (8)
 - 17. Vasculopathies (9)
 - 18. Other (please specify): (10)
-

Q5 What is the primary population that you serve?

- 19. Adult (1)
 - 20. Pediatrics (2)
 - 21. Both (3)
-

Q6 Where is your practice located?

- 22. Rural (1)
 - 23. Urban (2)
 - 24. Suburban (3)
-

Q7 What type of practice setting do you work in?

25. Hospital, teaching (1)
 26. Hospital, non-teaching (2)
 27. Private practice (3)
 28. Outpatient clinic (4)
 29. Combination of hospital and outpatient (5)
 30. Other (please specify): (6)
-

Q8 What is your gender?

31. Male (1)
 32. Female (2)
 33. Non-binary (3)
 34. Prefer to self-describe: (4)
-

Q9 What is your race/ethnicity?

1. Black or African American (1)
 2. White or Caucasian (2)
 3. Hispanic or Latino (3)
 4. Asian (4)
 5. Native American or Alaska Native (5)
 6. Native Hawaiian or Other Pacific Islander (6)
 7. Middle Eastern or North African (7)
 8. Other (please specify): (8)
-

End of Block: Demographics

Start of Block: Genetic Testing in Cardiovascular Medicine

Q10 How knowledgeable are you with genetic testing in cardiovascular medicine?

9. Not knowledgeable - I don't know anything about it (1)
 10. Somewhat knowledgeable - I know it exists but not how to use it/order it/interpret it (2)
 11. Moderately knowledgeable - I know about it, can order it, but can't interpret it (3)
 12. Very knowledgeable - I know as much as there is to know about it (4)
-

Q11 How confident are you in interpreting genetic test results for cardiovascular conditions?

- 13. Not confident (1)
- 14. Somewhat confident (2)
- 15. Moderately confident (3)
- 16. Very confident (4)

End of Block: Genetic Testing in Cardiovascular Medicine

Start of Block: Pharmacogenomics (PGx)

Pharmacogenomics (PGx) is the study of how a person's genetic information influences their response to medications. Certain medications can have different effects depending on a patient's genetic makeup, known as gene-drug interactions. Please keep this in mind while answering the following questions.

Q12 How knowledgeable are you with pharmacogenomic (PGx) testing in cardiovascular medicine?

- 17. Not knowledgeable - I don't know anything about it (1)
 - 18. Somewhat knowledgeable - I know it exists but not how to use it/order it/interpret it (2)
 - 19. Moderately knowledgeable - I know about it, can order it, but can't interpret it (3)
 - 20. Very knowledgeable - I know as much as there is to know about it (4)
-

Q13 Are you aware of any cardiology-related medications that could have variable responses based on the patients' genetic information (gene-drug interactions)?

- 21. Yes, please provide an example of a medication: (1)

 - 22. Yes, but can't remember which ones (2)
 - 23. No (3)
-

Q14 How often do you currently order PGx testing in your practice?

- 24. I have never ordered PGx testing (1)
 - 25. 1-5 times a year (2)
 - 26. 6-12 times a year (3)
 - 27. 13+ times a year (4)
-

Q15 What barriers do you perceive for the integration of PGx testing into your practice? (Select all that apply)

- 28. Physician knowledge/awareness (1)
 - 29. Cost (2)
 - 30. Clinical evidence supporting its use (3)
 - 31. Availability of testing (4)
 - 32. Guidelines/recommendations from professional societies (5)
 - 33. Coordination of testing (6)
 - 34. Population not interested (7)
 - 35. Lack of insurance coverage (8)
 - 36. Doesn't change patient management (9)
 - 37. Other (please specify): (10)
-

Q16 How familiar are you with the Clinical Pharmacogenetics Implementation Consortium (CPIC) Guidelines?

- 38. Not familiar at all (1)
 - 39. Somewhat familiar (2)
 - 40. Moderately familiar (3)
 - 41. Very familiar (4)
-

Q17 How important do you believe patient education and counseling are regarding PGx testing, both before and after testing?

- 42. Not important (1)
 - 43. Somewhat important (2)
 - 44. Moderately important (3)
 - 45. Very important (4)
-

Q18 How confident are you in:

	Not confident (1)	Somewhat confident (2)	Moderately confident (3)	Very confident (4)
Interpreting PGx test results for cardiovascular medicine? (1)	46.	47.	48.	49.
Communicating with patients about the implications and limitations of PGx test results? (2)	50.	51.	52.	53.

Q19 How do you think PGx will impact the future of cardiovascular medicine?

End of Block: Pharmacogenomics (PGx)

Start of Block: Genetic Counseling

Genetic counselors (GCs) have expertise in the informed consent process, educating patients on genetic testing options, explaining testing results, and going over recommendations based on results. Please keep this in mind while answering the following questions.

Q20 How familiar are you with genetic counseling?

- 54. I have never heard of genetic counseling (1)
- 55. I have heard of genetic counseling but know nothing about it (2)
- 56. I know about genetic counseling but use it rarely/never in my practice (3)
- 57. I am very knowledgeable about genetic counseling (4)

Q21 What impact would having a genetic counselor have on your integration of PGx into practice?

- 58. Significantly decrease ordering of PGx (1)
 - 59. Slightly decrease ordering of PGx (2)
 - 60. No impact (3)
 - 61. Slightly increase ordering of PGx (4)
 - 62. Significantly increase ordering of PGx (5)
-

Q22 If available, how likely would you be to refer patients to a genetic counselor for PGx testing interpretation and counseling?

- 63. Not likely (1)
 - 64. Somewhat likely (2)
 - 65. Moderately likely (3)
 - 66. Very likely (4)
-

Q23 In your opinion, what role should genetic counselors play in cardiovascular medicine regarding PGx testing? (Select all that apply)

- 67. Ordering of PGx testing (1)
 - 68. Interpretation of PGx results (2)
 - 69. Disclosure of PGx results (3)
 - 70. Other (please specify): (4)
-

End of Block: Genetic Counseling

Start of Block: Wrap Up

Q24 Would you be interested in receiving more information about the use of PGx in cardiovascular medicine?

- 71. Yes (1)
 - 72. No (2)
-

Display This Question:

If Would you be interested in receiving more information about the use of PGx in cardiovascular medi... =
Yes

Q24 - Part 2 If yes, what would be your preferred method of receiving this information?

- 73. Professional organizations (1)
 - 74. Conferences/seminars (2)
 - 75. Online forum/communities (3)
 - 76. Continuing medical education (CME) course(s) (4)
 - 77. Colleagues/peer discussions (5)
 - 78. Print materials (6)
 - 79. Online materials (webpages) (7)
 - 80. Other (please specify): (8)
-

Q25 How did you hear about this survey?

- 81. Social media (1)
 - 82. Email (2)
 - 83. Professional organization (3)
 - 84. Colleague (4)
 - 85. Other (please specify): (5)
-

Display This Question:

If How did you hear about this survey? = Professional organization

Q25 Part 2 If you heard about this survey from a professional organization, please specify which one:

- 86. American College of Cardiology (1)
 - 87. American Society of Preventive Medicine (2)
 - 88. American Heart Association (3)
 - 89. Other (please specify): (4)
-

End of Block: Wrap Up

References

Al-Mahayri, Z. N., et al. (2022). "Pharmacogenomics implementation in cardiovascular disease in a highly diverse population: initial findings and lessons learned from a pilot study in United Arab Emirates." Human Genomics **16**(1): 42.

Cooper-DeHoff, R. M., et al. (2022). "The Clinical Pharmacogenetics Implementation Consortium Guideline for SLCO1B1, ABCG2, and CYP2C9 genotypes and Statin-Associated Musculoskeletal Symptoms." Clin Pharmacol Ther **111**(5): 1007-1021.

Haga, S., et al. (2012). "Primary care physicians' knowledge of and experience with pharmacogenetic testing." Clinical Genetics **82**(4): 388-394.

Johansen Taber, K. A. and B. D. Dickinson (2014). "Pharmacogenomic knowledge gaps and educational resource needs among physicians in selected specialties." Pharmgenomics Pers Med **7**: 145-162.

Johnson, J. A., et al. (2017). "Clinical Pharmacogenetics Implementation Consortium (CPIC) Guideline for Pharmacogenetics-Guided Warfarin Dosing: 2017 Update." Clin Pharmacol Ther **102**(3): 397-404.

Kabbani, D., et al. (2023). "Pharmacogenomics in practice: a review and implementation guide." Front Pharmacol **14**: 1189976.

Kim, W.-Y., et al. (2020). "Survey of physicians' views on the clinical implementation of pharmacogenomics-based personalized therapy." Transl Clin Pharmacol **28**(1): 34-42.

Link, E., et al. (2008). "SLCO1B1 variants and statin-induced myopathy--a genomewide study." N Engl J Med **359**(8): 789-799.

Mega, J. L., et al. (2009). "Cytochrome p-450 polymorphisms and response to clopidogrel." N Engl J Med **360**(4): 354-362.

Mills, R. and S. B. and Haga (2013). "Clinical Delivery of Pharmacogenetic Testing Services: A Proposed Partnership Between Genetic Counselors and Pharmacists." Pharmacogenomics **14**(8): 957-968.

Morris, S. A., et al. (2024). "Integrating pharmacogenomic results in the electronic health record to facilitate precision medicine at a large multisite health system." JACCP: JOURNAL OF THE AMERICAN COLLEGE OF CLINICAL PHARMACY **7**(8): 845-857.

Phillips, K. A., et al. (2001). "Potential Role of Pharmacogenomics in Reducing Adverse Drug Reactions: A Systematic Review." JAMA : the journal of the American Medical Association **286**(18): 2270-2279.

Russell, C., et al. (2024). "Knowledge and attitudes on implementing cardiovascular pharmacogenomic testing." Clin Transl Sci **17**(3): e13737.

Shaaban, S. and Y. Ji (2023). "Pharmacogenomics and health disparities, are we helping?" Front Genet **14**: 1099541.

Zierhut, H. A., et al. (2017). "Collaborative Counseling Considerations for Pharmacogenomic Tests." Pharmacotherapy: The Journal of Human Pharmacology and Drug Therapy **37**(9): 990-999.

The data analysis for this paper was generated using Qualtrics software, Version February-March, 2025 of Qualtrics. Copyright © 2020 Qualtrics. Qualtrics and all other Qualtrics product or service names are registered trademarks or trademarks of Qualtrics, Provo, UT, USA.
<https://www.qualtrics.com>