

INSTRUCTIONAL DESIGN AND ASSESSMENT

A Pharmacogenetics Service Experience for Pharmacy Students, Residents, and Fellows

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Objective. To utilize a comprehensive, pharmacist-led warfarin pharmacogenetics service to provide pharmacy students, residents, and fellows with clinical and research experiences involving genotype-guided therapy.

Design. First-year (P1) through fourth-year (P4) pharmacy students, pharmacy residents, and pharmacy fellows participated in a newly implemented warfarin pharmacogenetics service in a hospital setting. Students, residents, and fellows provided genotype-guided dosing recommendations as part of clinical care, or analyzed samples and data collected from patients on the service for research purposes.

Assessment. Students', residents', and fellows' achievement of learning objectives was assessed using a checklist based on established core competencies in pharmacogenetics. The mean competency score of the students, residents, and fellows who completed a clinical and/or research experience with the service was 97% \pm 3%.

Conclusion. A comprehensive warfarin pharmacogenetics service provided unique experiential and research opportunities for pharmacy students, residents, and fellows and sufficiently addressed a number of core competencies in pharmacogenetics.

Keywords: pharmacogenetics, warfarin, pharmacy service, research

INTRODUCTION

Pharmacogenetics was recognized as an important component of the doctor of pharmacy (PharmD) curriculum with the 2007 revision of the standards and guidelines for the professional program of pharmacy by the Accreditation Council for Pharmacy Education (ACPE).¹ Curricular content considered essential includes the genetic basis for drug action, alteration of drug metabolism, and individualizing drug doses. The report from the 2007-2008 American Association of Colleges of Pharmacy (AACP) Argus Commission identified advances in personalized medicine as one of the top challenges of academic pharmacy and posed that the pharmacy curricula must adequately address issues related to the topic.²

While pharmacogenetic content is included in the PharmD curriculum of most colleges, whether this content is sufficient to prepare pharmacy graduates to manage personalized therapy is questionable.^{3,4} The majority of pharmacists agree that pharmacists should be capable of applying pharmacogenetic data to drug therapy

decisions; however, few feel prepared to do so.⁵ An intensive educational effort would probably be necessary to improve pharmacists' knowledge and comfort level with pharmacogenetics, and a continuing education program alone, without hands-on experience probably would be insufficient.⁶ Similarly, some pharmacy students feel that exercises involving the direct application of genetic data to drug therapy would increase their comfort level with interpreting and applying pharmacogenetic test results.⁴

Participation on a clinical pharmacogenetics service would provide pharmacy students, residents, and fellows with firsthand experience with interpreting and applying genetic information to drug management. In addition, a pharmacogenetics service could serve as a platform for unique research opportunities. At the University of Illinois at Chicago College of Pharmacy, we used a novel and comprehensive warfarin pharmacogenetics service to provide pharmacy students, residents, and fellows with unique practical experiences and research opportunities involving genotype-guided therapy. We examined the extent to which students, residents, and fellows participating in pharmacogenetic service activities met proposed competencies in pharmacogenetics.

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DESIGN

The Warfarin Pharmacogenetics Service

Beginning in August 2012, genotype-guided warfarin dosing became the standard of care for all patients newly starting warfarin during hospitalization at the University of Illinois Hospital & Health Sciences System (UI-Health). Clinical decision support tools were built into the electronic health record (EHR) to trigger an automatic order for genetic testing in response to a new warfarin order for a hospitalized patient without a recent (<6 months) history of warfarin use. Each genotype order was accompanied by a consultation with the pharmacogenetics service, which was jointly staffed by faculty members from the University of Illinois at Chicago Colleges of Pharmacy and Medicine. The pharmacist on the service was responsible for screening each order for appropriateness and canceling orders deemed unnecessary (eg, prior warfarin use from an outside facility at the time of admission, genotype results already available in the EHR) or inappropriate (eg, history of liver transplantation, active cancer where low molecular weight heparin is preferred). Genotype was determined in the university's molecular pathology laboratory, with results made available to the service/health care team prior to the second warfarin dose. The genotypes tested include vitamin K epoxide reductase complex 1 (*VKORC1*) c.-1639G>A and cytochrome P450 2C9 (*CYP2C9*) *2, *3, *5, *6, and *11. The *VKORC1* enzyme is the target protein of warfarin, while *CYP2C9* metabolizes the more potent S-enantiomer of warfarin. The pharmacist on the pharmacogenetics service provided a genotype-guided warfarin dose recommendation, using algorithms by Gage and colleagues⁷ or the International Warfarin Pharmacogenetics Consortium⁸ as a guide. Both algorithms are freely available through the <http://www.warfarindosing.org> Web site. In the event that a patient had the *CYP2C9**11 genotype, which is not included in current dosing algorithms, the dose recommended by the algorithm was reduced by approximately 30%.⁹ The pharmacist provided a daily dose recommendation, refined based on international normalized ratio (INR) response to previous warfarin doses, for the initial 7 days of warfarin therapy or until the patient was discharged (whichever came first).

Pharmacists also led the research efforts involving the service. Most patients served at UI-Health were of African descent or Hispanic ethnicity for whom limited data on warfarin pharmacogenetics are available. Existing pharmacogenetic dosing algorithms perform less well in African Americans compared to Europeans.^{10,11} This is likely because these algorithms do not include variants with effects on dose requirements that occur specifically

in persons of African descent. Research by pharmacists on the warfarin genetics service was aimed at identifying unique genetic associations with warfarin dose requirements in African Americans and Hispanics in order to optimize warfarin pharmacogenetics for these populations.¹²⁻¹⁶

Training Opportunities for Students and Residents

The warfarin pharmacogenetics service was first offered as a clinical and research training opportunity for pharmacy students, residents, and fellows in August 2012. Students in their P1 through P3 years could enroll in an elective independent study course to obtain credit for their work with the service, which provided between 1 and 3 hours of credit depending on the time committed. Students in their P4 year could either complete an elective clerkship practice experience on the service, providing the opportunity to work with the service on a full-time basis, or spend 1 or more mornings per week with the service as part of their anticoagulation clerkship experience. Residents could complete a month-long clinical rotation on the service, working under the direct supervision of a pharmacy faculty member. In the absence of a resident, a residency-trained pharmacy fellow was involved in the day-to-day operations (in the same capacity as the resident), also working under the direct supervision of pharmacy faculty members.

Learning objectives for students, residents, and fellows from either a clinical or research standpoint are listed in Appendix 1 according to objective domain, Bloom's learning taxonomy, and objective achievement.¹⁷⁻¹⁹ The objectives were based on proposed core competencies in pharmacogenetics for pharmacists proposed by AACP and derived in part from core competencies in genetics for health-care professionals proposed by the National Coalition for Health Professional Education in Genetics.²⁰ Twenty learning objectives were developed that covered 3 domains: genetic basis of disease; drug discovery and disposition/drug targets; and ethical applications, social and economic implications.²⁰

Prior to working with the service from either a clinical or research perspective, students, residents, and fellows were assigned background reading material on pharmacogenetics in general and warfarin pharmacogenetics in particular.²¹⁻²³ Because an understanding of warfarin pharmacology was essential, P1 and P2 students who had not yet completed therapeutics coursework were assigned additional reading on anticoagulation management.^{24,25} Additional optional reading on warfarin pharmacogenetic dosing algorithms and genotype-guided warfarin dosing in minority populations was recommended.^{7,8,26} The student, resident, or fellow and

the faculty member spent time discussing the readings prior to applying them to patient care or research. Further, because most of the patients at the medical center were of minority descent, the faculty member devoted significant time to discussing the effect of ancestry on warfarin genetics, emphasizing the concepts of allele and genotype frequencies, haplotypes, and linkage disequilibrium. Through these discussions, ethnic differences in genetic architecture and the importance of considering ethnicity in pharmacogenetics were covered. Students and residents were also introduced to the Pharmacogenomics Knowledgebase (PharmGKB, www.pharmgkb.org) and taught how to navigate through the Web site to examine warfarin pathways, access the Clinical Pharmacogenetics Implementation Consortium (CPIC) guidelines for warfarin and other drugs, and review important publications related to warfarin pharmacogenetics.²⁷ Through this activity, the students, residents, or fellows were exposed to an important centralized pharmacogenetic resource that could be used to stay abreast of important pharmacogenetic discoveries and the release of additional CPIC guidelines.

Students, residents, and fellows received access to the EHR once they completed required training on the use and protection of medical information and signed a confidentiality agreement regarding use and disclosure of medical data. Under a faculty member's tutelage and supervision, the students, residents, or fellows involved in clinical activities were taught how to assess genetic test orders for appropriateness, how to interact with the physician on the service to discuss new patients, and how to interpret genetic test results in the context of clinical factors to provide appropriate warfarin dose recommendations. The students, residents, and fellows received instruction on using available warfarin pharmacogenetic dosing algorithms, namely the algorithms available by Gage and colleagues⁷ and the International Warfarin Pharmacogenetics Consortium.⁸ By entering both clinical and genetic data into the algorithm, the student, resident, or fellow gained perspective on how factors interact to influence warfarin dosing. There were additional interacting medications (eg, metronidazole), diseases (eg, renal dysfunction), and genotypes (eg, *CYP2C9*11*) that are not accounted for in available dosing algorithms. Thus, the students, residents, and fellows were exposed to the limitations of pharmacogenetic dosing algorithms and how clinical judgment was still necessary in final dose recommendations. Finally, the student, resident, or fellow drafted a clinical note for the patient, which was reviewed and discussed with the faculty member. Once approved, the initial consult note was entered into the patient's EHR with the faculty member's co-signature and forwarded

to the physician on the pharmacogenetics service, who added the physical and medical assessment. Because patients on the service were followed daily until discharge or day 7 (whichever was sooner), with a daily dose recommendation provided based on the INR in response to previous warfarin doses, the students, residents, and fellows gained insight into how genotype affects INR response. The students and residents composed a follow-up note with the refined dose recommendation that was cosigned by the attending pharmacist.

All PGY1 residents were involved in the service's pharmacy on-call program, and the resident was responsible for carrying the service pager during evenings, overnight, and on weekends. Involvement in this capacity included fielding calls from the clinical laboratory about the appropriateness of a genetic test order, answering pharmacogenetic-related questions, and interpreting and applying genetic test results that came in over the weekend. A pharmacy faculty member was present to supervise the service every weekend and assist or guide the on-call resident with dose recommendations as needed. Residents wishing to gain additional experience could complete an elective clinical rotation on the service. In this capacity, the resident was involved with all clinical aspects of the service under the mentorship and supervision of the attending pharmacy faculty member.

During clinical practice experiences, pharmacy students, residents, and fellows were also encouraged to attend a pharmacology journal club in which a pharmacogenetic research article was discussed. Through this activity, concepts such as population variability in genetic effects, sample size considerations for genetic studies, and the strengths and limitations of various pharmacogenetic study designs were taught. This also provided an opportunity for students, residents, and fellows to further interact with various faculty members interested in pharmacogenetics, potentially stimulating interest in research.

There were a number of research opportunities within the service. Students were generally involved with an ongoing study in which data and DNA samples were collected from consenting patients on the service to learn more about genetic determinants of warfarin response. DNA samples were brought to the pharmacy faculty investigator's research laboratory for genotyping for research purposes. The ultimate goal of this study was to tailor warfarin pharmacogenetics to urban patient populations, mainly through incorporating variants of importance in African Americans or Hispanics onto the genotyping platform. Thus, in addition to experience gained in clinical research, students learned how research findings could be directly translated to improve patient care.

Prior to beginning research, in addition to the reading described above, students and residents had to complete human subjects research training and prepare an amendment to be added as an investigator on the IRB-approved protocol. These activities provided exposure to the regulatory aspects of research. Once added to the protocol, students had an opportunity to participate in many facets of research, including patient recruitment, the informed consent process, data collection, genotyping in the investigator's laboratory, and data analysis. Students were involved in clinical-based (eg, patient recruitment, enrollment, and data collection) or laboratory-based (eg, DNA extraction, genotyping) activities. For students participating in laboratory-based research, additional training in blood-borne pathogens and laboratory safety was required. Patient recruitment activities provided students with experience interacting with and explaining difficult genetics concepts to the patient in a manner the patient could understand. Through data collection activities, the student was taught how to navigate through the EHR, an activity in which most first- and second-year pharmacy students had not participated. In the investigator's laboratory, students learned how to apply the concepts of genotyping learned from the classroom to the laboratory. Working in the research laboratory also helped students develop their reasoning skills through trouble-shooting laboratory problems or failed experiments.

Residents and fellows could complete an independent project related to the service. For example, one resident project involved comparing the accuracy of various warfarin pharmacogenetic dosing methods, such as use of the FDA-approved dose recommendations along with clinician judgment by a pharmacist to estimate warfarin dose requirements. A fellow was involved in a more comprehensive project to identify novel genetic determinants of warfarin dose requirements in African Americans.

EVALUATION AND ASSESSMENT

From August, 2012, to December, 2012, 5 students (1 P1, 2 P2, and 2 P4 students), 2 residents (1 PGY1 and 1 PGY2), and 3 fellows completed practice experiences or elective courses involving the service. A PGY2 resident was involved in both clinical activities and a research project with the service. Two students (both P2 students) and 1 fellow were involved in research, and the remaining students, PGY1 resident, and fellows were involved exclusively in clinical activities. Both P4 students completed a practice experience in anticoagulation management and spent 20% of their time with the service.

A competency checklist (Appendix 2), was developed to assess achievement of learning objectives. The checklist was divided into core knowledge, clinical, and

research competencies. Students and residents had to achieve 90% of the relevant competencies to earn a letter grade of A for elective course credit. For example, those participating in clinical aspects of the service had to achieve 90% of knowledge-based and clinical competencies, while those involved in research had to achieve 90% of knowledge-based and research competencies. At least 80% of the competencies had to be met to earn a B, and 70% had to be met to earn a C or passing/satisfactory grade for the course. Scores for fellows were not needed for grading purposes but rather to provide faculty with a means of assessing the effectiveness of the learning opportunity. Students and residents received a midpoint and final assessment via the checklist, with the midpoint evaluation used to identify areas of deficiency that are focused on for the remainder of the experience. Competency scores are shown in Table 1; the mean competency score among all students and residents was $97\% \pm 3\%$. All achieved a score $>90\%$.

DISCUSSION

A pharmacist-led comprehensive warfarin pharmacogenetics service provided experiential and research opportunities to students and residents that addressed many of the core competencies in pharmacogenetics proposed by AACP. Based on assessment via a competency checklist, most students completing experiences and residents completing rotations with the service achieved core competencies in pharmacogenetics. To our knowledge, this is one of the first examples of an experiential approach to instruction in pharmacogenetics.

While some colleges and schools of pharmacy provide comprehensive classroom and laboratory instruction in genetics and pharmacogenetics,²⁸ this appears to be the exception rather than the norm.^{3,4} While the opportunity to solidify clinical knowledge gained from lectures by

Table 1. Competency Scores of Students and Trainees Involved With the Pharmacogenetics Service

Competency	Score, Mean (SD)
Core knowledge (n=10)	95 (9)
Clinical skills (n=7)	100 (0)
Research skills ^a	
Basic (n=4)	90 (2)
Laboratory-based (n=2)	100 (0)
Clinical-based (n=3)	100 (12)
Total	97 (3)

^a One PGY2 resident completed both clinical and research activities with the service, one student completed laboratory-based research only, one student and PGY2 resident completed clinical-based research only, and one fellow completed both laboratory-based and clinical-based research.

participating in case discussion or small group activities is available for many therapeutic areas, pharmacogenetics is notably absent in most curricula.²⁸ This is despite the desire by students for clinical experience in the area, which is presumably more ideal than classroom instruction alone.⁴

Other academic medical centers are now implementing pharmacogenetics into clinical practice, and others are expected to follow.²⁹⁻³² Thus, it is more important now than ever for pharmacy graduates to possess the knowledge and skill to manage genotype-guided therapy. Elective and advanced pharmacy practice experiences in pharmacogenetics, such as those we describe, are expected to better prepare students, residents, and fellows to manage genotype-guided drug therapy. Even though the experience centers on warfarin pharmacogenetics, the principle of applying genetic data to drug therapy decisions is applicable across therapeutic areas.

The ACPE standards that govern accreditation emphasize scholarship and research as important components of pharmacy education.³³ In addition to achieving competency in many aspects of pharmacogenetics, there are other benefits for students participating in research with the pharmacogenetics service. In addition to leading to important scholarly contributions, involvement in clinical research helps students, residents, and fellows foster relationships with faculty members who will be in a position to provide future letters of recommendation. Through participation in pharmacogenetic research-related activities, students and trainees may gain a better understanding and appreciation of the evidence necessary to inform genotype-guided therapy in addition to the nuances and limitations of such an approach. In particular, students, residents, and fellows may gain a better grasp on study design for pharmacogenetic research, including the importance of considering allele frequencies and genotype distribution in interpreting study results.

Moving forward, the university plans to expand both its pharmacogenetic efforts and opportunities for clinical and research training with the service. Along these lines, we recently began offering *CYP2C19* genotyping to guide antiplatelet therapy. We also plan to offer training opportunities for visiting pharmacists from within and outside the United States. Thus, a variety of clinical and research opportunities centered on pharmacogenetic principles will be available for students and pharmacy graduates to gain important experience in managing genotype-guided therapies.

SUMMARY

A pharmacist-led warfarin pharmacogenetics service provided a unique opportunity for pharmacy students, residents, and fellows to gain clinical experience

with personalized medicine and become involved in pharmacogenetic research. While the service is one of the first examples of a comprehensive warfarin pharmacogenetic service, other academic centers are beginning to implement pharmacogenetic programs for other medications.²⁹⁻³¹ Broader implementation efforts are expected as further data supporting personalized medicine emerge. The experiential and research opportunities described in this paper may thus serve as models for other institutions as they establish clinical pharmacogenetics programs of their own.

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Appendix 1. Learning Objectives for Students, Residents, and Fellows Completing Experiential or Research Activities With the Warfarin Pharmacogenetics Service

Objective Domain	Cognitive Domain^a	Learning Objective^b	How Objective Is Achieved
Genetic Basis of Disease	Knowledge, Comprehension, Evaluation, and Application	Discuss basic genetic concepts and nomenclature	Completing assigned readings; Preparing and participating in journal club; Discussing pharmacogenetic concepts relevant to patient cases or research with the preceptor; Interpreting results from genotyping experiments
	Knowledge and Comprehension	Obtain credible, current information about genetics	Locating information and guidelines related to pharmacogenetics from the Pharmacogenomics Knowledgebase Web site; Identifying relevant pharmacogenetic articles in the context of research questions
	Comprehension and Application	Seek coordination and collaboration with an interdisciplinary team of health professionals	Participating as a member of the interdisciplinary pharmacogenetics service; Communicating with the physician on the clinical service during the initial consultation for a patient; Contributing to discussion with members of the interdisciplinary members of the research team
Drug Discovery and Disposition/Drug Targets	Knowledge and Comprehension,	Identify multiple proteins that influence drug response	Completing assigned reading; Locating warfarin pathways in the Pharmacogenomics Knowledgebase; Interpreting results of pharmacogenetic tests for clinical or research use
	Comprehension and Evaluation	Explain the contribution of genetic variability to inter-individual variations in drug response.	Interpreting and explaining the effects of genotype on warfarin dose requirements; Assessing genetic determinants of warfarin dose requirements and bleeding risk for a patient on the clinical service; Evaluating the effects of genotype on warfarin dose requirements or other warfarin-related phenotypes in research
	Analysis and Evaluation	Recognize the drugs/drug classes/clinical situations where pharmacogenetic testing is likely to be most useful clinically	Screening clinical genetic test orders for appropriateness; Analyzing results of genotype experiments in the context of genotype frequencies and the magnitude of effects on warfarin response

(Continued)

Appendix 1. (Continued)

Objective Domain	Cognitive Domain^a	Learning Objective^b	How Objective Is Achieved
	Analysis	Recognize how associations between genetic variations and drug response are investigated and uncovered	Participating in journal club; Participating in research related to warfarin pharmacogenetics
	Knowledge and Evaluation	Be able to identify important issues in pharmacogenetic study design, particularly those that differ from non-genetic clinical studies	Participating in journal club; Participating in research related to warfarin pharmacogenetics.
	Knowledge	Know where/how to find pharmacogenetic information	Searching for primary literature on pharmacogenetics; Navigating through the Pharmacogenomics Knowledgebase
	Comprehension and Analysis	Recognize that pharmacogenetic testing is like all other clinical testing in that it is used along with other clinical information	Interpreting genetic results in the context of clinical variables to make a warfarin dose recommendation; Analyzing genotype results from research in the context of clinical variables affecting warfarin response
	Comprehension and Knowledge	Recognize the potential of behavioral, social, and environmental factors to modify or influence genetics	Incorporating smoking status and dietary considerations in warfarin dosing recommendations in the clinical setting or analysis of genotype results in the laboratory.
	Comprehension	Explain the influence of ethnicity in genetic polymorphisms and associations of polymorphisms with drug response	Discussing differences in allele/genotype frequencies and linkage disequilibrium by ethnicity; Discussing variants occurring almost exclusively in African Americans and affecting warfarin dose requirements
	Knowledge and Evaluation	Be able to critically evaluate information obtained from pharmacogenetic clinical trials and identify limitations in study design, technology, and data interpretation that will influence patient care	Participating in journal club. Participating in research related to warfarin pharmacogenetics.
	Knowledge	Be able to identify those patients in whom pharmacogenetic testing is indicated	Screening genetic test orders for appropriateness.
	Comprehension, Knowledge and Synthesis	Interpret the results of pharmacogenetic testing to synthesize an appropriate dose recommendation	Interpreting genetic results in the context of clinical variables to make a warfarin dose recommendation

(Continued)

Appendix 1. (Continued)

Objective Domain	Cognitive Domain^a	Learning Objective^b	How Objective Is Achieved
	Knowledge	Identify patients who have undergone pharmacogenetic testing in the past so that a specific test is not repeated unnecessarily	Screening genetic test orders for appropriateness
Ethical Applications, Social and Economic Implications	Knowledge	Maintain the confidentiality and security of patient health records	HIPAA training prior to access to clinical records for either clinical or research use.

^a Based on Bloom's learning taxonomy¹⁹

^b From the AACP proposed competencies in pharmacogenetics¹⁷

Appendix 2. Competency Checklist

I. Core Knowledge

- Discussion of assigned reading
- Retrieval of information from the Pharmacogenomics Knowledgebase (PharmGKB)
- Calculation of allele and genotype frequencies
- Participation in journal club (accurate and insightful presentation or asking meaningful questions)
- Explanation of genetic differences by race

II. Clinical Skills

A. Assessment and Documentation

- History of Present Illness
- Anticoagulation Related History
- Past Medical History
- Problem List
- Procedure History
- Medication History
- Allergies
- Anticoagulation Indication
- Anticoagulation Intensity (Goal INR)
- Anticoagulation Intended Length of Therapy
- Risk Factors and Risk of Thrombosis
- Risk Factors and Risk of Bleeding
- Pertinent Laboratory tests
- Clinical Factors for Dose Calculation: age, height, weight, renal function, recent INR, race, smoking status, liver disease, interacting medications
- Genetic Factors for Dose Calculation: *CYP2C9*, *CYP4F2*, *VKORC1* genotype

B. Interpretation and Documentation

- Genotype and impact on dose
- Anticoagulation Status

C. Selection and Recommendation of Treatment Plan

- Appropriate initial dose guided by clinical factors
- Appropriate subsequent doses guided by genotype and clinical factors
- Timing of next INR and/or other pertinent laboratory tests

III. Research Skills

A. Basic Skills

- New investigator training
- HIPAA research training
- Blood borne pathogens training
- Completing IRB application or amendment
- Retrieving literature relevant to research question
- Presentation of research results

B. Laboratory-based skills^b

- Completing lab safety training
- Pipetting exercise^a
- DNA isolation
- PCR
- Interpreting results of genotype experiments

C. Clinical research skills^b

- Screening for eligible subjects
- Obtaining written informed consent
- Collecting data from the subject and/or medical record
- Navigating electronic research databases
- Data analysis

CYP2C9, cytochrome P450 2C9; INR, international normalized ratio; PharmGKB, VKORC1, vitamin K epoxide reductase complex 1

^a Available upon request

^b Students may complete either laboratory based or clinical research or a combination of the two