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Original Research

A review of pharmacogenomics studies assessing the knowledge and attitudes of physicians and pharmacists across the Arab and Middle Eastern Region

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Abstract

The principal goal of pharmacogenomics (PGx) is to achieve the highest drug efficacy while maintaining a low toxicity profile. Historically, health care systems used to target treatment for all individuals with the same diagnosis using a standardized medication or dose that fits all. However, a recent pattern in medicine has emerged focusing on personalized and precision medicine. For effective implementation of PGx, there is a need for more collaborations between all the stakeholders in the healthcare system to integrate the pharmacogenetics concept into practice. When it comes to the knowledge and attitudes towards pharmacogenomics, the majority of medical professionals, including pharmacists and physicians, appear to lack appropriate knowledge and training. Across the Middle East and Arab Region, only few studies have addressed this topic. The current review objective is to shed light on pharmacists' and physicians' knowledge and attitudes towards PGx practice in the UAE, Arab and the Middle East region as compared to the rest of the world. Moreover, highlighting the role of the pharmacists in the application of PGx services and the educational challenges that are faced. Proposed solutions to improve the knowledge gaps will also be discussed. We also aim to provide the international readers as well as the local researchers with a summary of the trends and distribution of the results across these countries.

Keywords: pharmacogenomics; pharmacogenetics; pharmacist; physician; knowledge; attitude; UAE; GCC; Arab; MENA

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INTRODUCTION

Pharmacogenetics was first described by Friedrich Vogel in 1959 which has been initially used to describe the characteristics of phenotypic variability resulting in a variable response to specific medications and non-constant metabolism rate.[1] The medical applications of genomics including pharmacogenetics and pharmacogenomics (PGx) have been propelled to new horizons after the completion of the Human Genome Project in 2003 highlighting the importance of genetic studies across different levels of the health care industries.[2-4] PGx is a broad field that combines the science of drugs (pharmacology) as well as the science of genes, their interactions and function within the individual environment (genomics) in one unified term.[5]

Variable drug response due to altered drug metabolism is one of the key points in PGx. The big majority of the medications undergo the process of metabolism by the well know cytochrome P450 which play an important role in the oxidative metabolism of many medications. The polymorphism

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of this enzyme can majorly determine the extent of safety and effectiveness of the administered therapeutic agents. Different types of cytochrome P450 exist including CYP2C9, CYP2C19, CYP3A4, CYP3A5, CYP1A2 and CYP2D6. Those subfamilies accounts for the metabolism of 70- 80% of the approved mediations in the market. Including major drug classes used to control diabetes, cardiovascular medications, medications used in case of inflammation and much more.[6,7]

Ethnicity appears to be an important contributing factor when it comes to having an irregular response to the same drug. In the United Arab Emirates (UAE) and other similar countries, this is considered of high importance since the current population are multiethnic and of diverse origins.[8]

The principal goal of PGx is to achieve the highest possible efficacy while maintaining low toxicity for prescribed medications.[9] Traditionally, health care systems used to provide treatment for all individuals with the same disease through a standardized dose that fits all. However, this has changed in recent years with the emergence of precision medicine. Precision medicine and personalized medicine encompass several factors that enables tailoring therapy for each individual through pharmacogenetics and pharmacogenomics; with genomics being an essential component of both fields.[10]

From the pharmacology and therapeutics perspectives, genomic profiling of individuals could explain why some patients show a variable response to the same dose of a particular medication.[11] Moreover, understanding the genomic profile and its interactions within specific cells is very important for the implementation of individualized advances in treatment, control, prevention, and diagnosis of diseases.[12]

Successful implementation of PGx has a major influence on healthcare systems, shifting them towards an improved and optimized therapies which serve both the patients as well as the decision makers. This leads to faster drug selection and dispensing, lower number of unpredictable adverse reactions related to the medications, cutback in the overall costs of health care services, decreased polypharmacy and lower overall costs burden due to over prescribing unnecessary medications.[13]

The United States Food and Drug Administration (FDA) estimates that around 15% of approved medications in the market during the last several years contain information related to pharmacogenetics in their labeling. However, only limited utilization of these labels and information is made during clinical decisions[14,15] despite the fact that PGx information is constantly being added to encompass more medications. For instance, between the year 2000 and 2020, the percentage of approvals of new medications containing PGx information in their labeling have almost tripled from 10.3% to 28.2%.[16]

Warfarin - which is a blood thinning agent - received an update by the FDA in 2007 that included some changes to its label indicating the impact of genetic testing, therefore suggesting that dose adjustment is favorable prior to therapy initiation.[17] Treatment with warfarin could be altered by genetic polymorphisms in CYPC9 and VKORC1 enzymes leading to dose variability up to 18% and 30% respectively among users.[18]

Moreover, the FDA started to expand pharmacogenetic testing recommendations to include more medications such as carbamazepine, cetuximab and mercaptopurine as well as many others. The FDA further extended their recommendations toward human PGx testing by including dosing adjustment information and drug response variability warnings on the labels of more than 400 marketed drugs.[19,20]

Over the last decade, PGx testing has been gaining more momentum particularly in specific types of diseases where they showed positive clinical outcomes in terms of reducing the frequency of side effects and adverse drug reactions.[21,22]

Throughout the years, the National Institutes of Health (NIH) has been funding scientist and research through the Pharmacogenomics Research Network. They have been extensively studying how the genes affect the medications on wide range of diseases such as cardiovascular diseases, asthma, depression, and cancer. Those specialized information and findings are being collected in dedicated online resources called the Pharmacogenomics Knowledge Base (PharmGKB) and the Clinical Pharmacogenetics Implementation Consortium (CPIC). Over the past 10 years the CPIC has successfully published 23 guidelines, those guidelines have covered 19 genes alongside 46 medications which are used at various therapeutic divisions.[23] One of the primary goals of NIH initiative on precision medicine is to individualize and tailor the treatment for the patients based on the individual person's genes, lifestyle, environmental factors and other related factors. NIH is also supporting pharmacogenomics research to make sure physicians implement these findings as part of their patient care.[24-26] Recently NIH has funded several clinical trials with $42 million over a period of five years as part of Implementing Genomics in Practice project (IGNITE). One trial is examining whether granting an early access to the patient genomic data could be useful for the treatment of hypertension and chronic kidney disease. While another trial is targeted towards pain and depression. This trial is testing if patients with either chronic or acute post-surgical pain will benefit and have better outcomes if pharmacogenomics testing was used to guide prescribing opioid and antidepressant.[27]

With the rapid advancements in the genotyping technologies and bedside testing, the prospect of delivering precision medicine and individualized treatments for each patient is becoming more realistic. Nevertheless, the utilization of PGx in the clinic is considered to be relatively lagging due to the poor adoption among the health care providers. Several reasons could explain this poor implementation such as limited knowledge on pharmacogenomics, over confidence and inadequate awareness by the health care professionals.[28] Additionally, the limited access to various types of PGx testing in health care facilities could be another reason that hinders practitioners from applying genetic testing for the purpose of optimizing medication use.[29]

To successfully apply pharmacogenetics into practice, pharmacists and other health care specialists need to be prepared and empowered through knowledge and awareness.[30]

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Despite some efforts that are being put into educating pharmacists and physicians on PGx across the developed nations, most health care professionals still have inadequate knowledge at the global level.[31-33] Pharmacists who are well educated and aware of PGx can contribute by educating the multidisciplinary health care team and this is in addition to their vital contribution in applying PGx. Patient compliance could be significantly improved when pharmacists have adequate education on PGx as patients will be less prone to the adverse effects of medications.[33] Lack of PGx knowledge is common among physicians with the majority being unaware about its applications and less than 10% reporting that they are extremely familiar with this field.[34-35]

Understanding the extent of interactions between drugs and the relevant genes, in addition to educating and promoting awareness to all healthcare professionals could be blended in real world practice. This will improve clinical outcomes by offering precise individualized medicine in an approach towards a safer, more cost effective and overall, a well optimized health care system.

Globally studies evaluating health care professionals' level of knowledge as well as their attitudes towards such intervention are readily available. However only few of these were conducted in the middle east and Arab world.[33,36-39]

OBJECTIVES

The current review is aimed to shed light on pharmacists' and physicians' knowledge and attitudes towards PGx practice in the UAE, Arab and the Middle East region as compared to the rest of the world. Moreover, highlighting the role of the pharmacists in the application of PGx services and the educational challenges that are faced as well as proposed solutions to improve the knowledge gaps.

METHODS

An extensive search through the literature up until March 2022 was carried out with manual searching of bibliographies for relevant references by using several databases: including PubMed, EMBASE, academic journals, and Bibliographic electronic data as well as web-based researching. The language of the search was set to include papers written in English language and data searching were not restricted by any defined date.

Literature review

Knowledge and attitudes of physicians and pharmacists towards pharmacogenetic practice in the UAE

Clinical application of PGx is receiving more attention nowadays, it is predicted that by encouraging the successful implementation of this new field across the different sectors of the healthcare system, there will be noticeable improvement in the overall safety and disease control. Even though a good number of new interactions is being identified everyday between different classes of drugs and human genes, yet it is still not easy to overcome the set of challenges and limitations that may arise when trying to apply PGx in real world practice.[40]

The perception of the general public of the UAE on genetics was recently assessed in 2021 through a survey study that included 565 subjects residing in UAE. The authors reported that the majority of the studied population showed limited understanding of genetic concepts.[41]

When it comes to knowledge and attitudes, the majority of medical professionals seem to be unaware of the basics of genomic medicine. Similarly, from the patient's perspective, they are also unaware of how such testing could impose a positive outcome on their health.[42]

Several global academic institutes have already started merging PGx to be supplemented as part of their education program leading to an improved knowledge and enhance the ability of health professionals to educate patients about PGx testing, therefore integrating PGx as part of the academic curricula within our region could potentially reduce the knowledge gaps.[32,43] The availability of quick genetic testing is another limitation as they are not readily accessible by the providers when needed. Further support is needed in many aspects to overcome those limitations such as further training for the staff, financial support and sufficient evidence and data indicating its effectiveness.[44]

Meanwhile Pharmacogenetics is receiving a lot of attention in the UAE and around the region. Many practice sites in the region are already starting to recommend implementing pharmacogenetic testing to guide medication therapy. However, the actual application of rapid gene testing in real practice across this region is still lacking.

Up to this date not many studies have been published addressing this topic, therefore summing up and summarizing these few studies could provide helpful insights on the nature and extent of PGx application across this region.

In the UAE, a recent cross-sectional study in 2020 included a total of 510 students which aimed to understand this relationship more in depth among medical and health science students, of which 29.3% and 52.2% were studying pharmacy and medicine respectively. They found a noticeable difference between these studied groups, specifically there was a big gap in the knowledge level depending on the year of study these students are enrolled in, also the enrollment in training programs or interns was associated with greater knowledge. Among those who were enrolled in prior training program, 62.5% were found to be having relatively good level of knowledge.

Out of the studied group, when comparing between pharmacy and medicine students, pharmacist scored knowledge score of 5.5 whereas medicine students scored 5.6.

Over 59.7% of the students stated that they did not receive enough knowledge or sufficient training whereas 58.7% agreed that in the meantime there is poor guidance in how to apply PGx in clinical practice. Lack of knowledge but high interest seems like the case in this country as well. The deficiency or absence of having accessibility to these test as well as their

relative high cost were addressed by the enrolled students.[45] As compared to Jordan, medical and pharm-D students showed similar pattern in terms of insufficient PGx knowledge as well as low preparedness levels to conduct these tests while maintaining overall positive attitudes.[46]

In agreement to the above studies, medical students in the United States (US), stated that only 29.8% of them had covered a genetic course, and those who took a genetic course were found to be more likely to be confident and comfortable to deal and answer questions related to PGx.[47]

Similar outcomes were documented across the health professional who are involved in practice in UAE in regard to their interest and attitudes. However, compared to the previous study which included medical students, health professionals in the current study including pharmacists, nurses, and physicians, 91% of them showed that genetic testing are readily available, yet the biggest concerns were about the coverage of these kind of tests by insurance companies additional to their low level of experience and training in conducting such genetic testing. The knowledge scores among these practitioners were variable, with highest knowledge score among medicine scoring 6 followed by pharmacist with a score of 5.1 and lowest knowledge score was reported by the nurses with score of 4.8.[37] Contrarily, in Egypt, pharmacist had a better PGx knowledge score than physicians while both groups had promising positive attitudes. Egyptian pharmacists also were more likely to agree that it is their responsibility to deliver these services in clinical practice compared to the physicians from the same country.[48] In Greece, almost half of the included pharmacists and physicians evaluated their knowledge levels about PGx and personalized medicine to be poor.[49]

As mentioned earlier, PGx can potentially reduce medications adverse effect while the same time optimizing and enhancing drug efficacy. With the rapid emergence of PGx in practice, software and data becomes more complex to integrate and analyze therefore PGx becomes more user demanding. This requires the health professional staff to be more involved in its application. Therefore, knowledge and educational background about PGx becomes more crucial as the demand towards PGx and personalized medicine in the UAE is becoming more noticeable.[50]

Recently, a focus group discussion was conducted on pharmacists working in the UAE. The study outcome recommended several key factors that were concluded from the discussion with the pharmacists. Suggesting the need of an early PGx education across the universities, collaboration between universities and organizations to conduct PGx related workshops, emphasis on the importance role of the pharmacists as well as the development of an efficient electronic systems to aid with decision making. The authors believe that if pharmacists were having sufficient knowledge, they will have a significant impact on healthcare system and improving patients quality of life.[51]

Recently, the UAE has launched a new program called Emirati Genome Program as part of ministry of health & prevention initiative in collaboration with Abu Dhabi Health Services Company (SEHA). The program is currently in its initial stage inviting more citizens of the UAE to participate with either a buccal swab or a blood sample. The program vision is to develop a genetic mapping database of the Emirati genome. It is focused on providing comprehensive personalized and preventive approach to facilitate disease prevention, diagnosis, and treatment in the healthcare system of the UAE.[52] Despite the concepts of applying PGx is relatively new to the UAE, yet we can see that most of the studies have confirmed the three have been an interest in advancing with PGx concepts by both the governmental bodies as well as the health care professionals working in the UAE.

Pharmacogenetics knowledge and attitude of physicians and pharmacists in the Arab world and Middle East

In this review we tried to combine those few published studies conducted across the Arab Region into one review so that this article may help to provide the readers as well as the local researchers in this region a summary of some of the trends and distribution of the results across these countries.

The population in the MENA region is quite unique and of great interest due to the fact that these countries have multi-ethnic population with diverse genetic makeup. This is because there has been continuous migration in and out of the countries in this region leading to a mixed population of different ethnicity such as Arab, Asian, African, and Caucasian.[53]

In Jordan a study included 128 pharmacists in which their knowledge scores were measured, the outcome is quite similar to previously mentioned studies where they also scored very low in regard to their knowledge, yet they showed high motivation in implementing it. Almost half of the participant answered PGx could be related to their profession.[54]

Over 64% of participant pharmacists were concerned that these types of testing could put the patient with unwanted psychological negative effect which could arise due to the discovery of other signs related to other diseases at the time of testing. Around 75% of the included pharmacist were feeling optimistic about the use of PGx in reducing the incorrect usage of medications or the use of inappropriate doses.[54] These low knowledge scores in Jordan were assessed by Al-Eitan et al. where they have reviewed different physicians and pharmacists working at different institutes and hospitals, the majority of them explained that during their studies, PGx studying were covered for not more than 10 hours throughout the whole program they were enrolled in.[55] As compared to the United Kingdom (UK), the majority of medical related schools had included at least 1-2 hours of PGx teaching in their teaching programs.[19]

Recently a cross sectional study was conducted that included 200 physicians practicing in King Abdullah University Hospital in Jordan. These physicians were assessed according to rogers' theory which aims to evaluate several factors that influences their willingness towards adopting point of care rapid PGx testing in practice. Three major factors were reported by the physicians had the most significant importance on PGx testing; ranked in order of their reporting frequency by the

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studied group, those were perceived need, relative advantage, and compatibility of PGx testing in current practice. 90% of Jordanian physicians believed that PGx testing is essential specially in case of non-response or adverse drug reactions.[35]

Similarly, another group of researchers did a larger scale study that included pharmacy students from 5 different universities located on the west bank of Palestine and Jordan. Most students were aware that genetic factors can contribute to altered drug effect despite the relativity low number of PGx lectures they have received during their study, with majority of them having received not more than three lectures in total. Unfamiliarity about the FDA recommendations for some of the medications that contain PGx properties were reported among the participants additional to the poor understanding for which PGx testing can be used in clinical settings.[56] In a more recent study conducted on pharmacists in the west bank of Palestine, over 60% of the participants stated that PGx was not sufficiently covered as part of their pharmacy curriculum. Moreover almost 90% of the included pharmacists believes that PGx testing will allow them to enhance their abilities when it comes to reducing the medication therapy expenditure.[57]

These findings were further confirmed by a recent cross-sectional study published in late 2021. The study included 900 medical and pharm-D students in Jordan. The overall percentage knowledge score was poor with a score of 46.7%.[46]

In Syria, a recent study evaluated physicians and pharmacist's knowledge concerning PGx. Years of experience had no impact on the knowledge levels between both groups. Equally to the other studies within this region, this study confirmed an overall lack of knowledge among the Syrian physicians and pharmacists. Profession had an impact on the knowledge levels, with pharmacists being better equipped with knowledge compared to physicians, an explanation was proposed by the authors is that pharmacists do receive additional PGx education in their pharmacy program curricula. furthermore, pharmacists were more aware about the patient's genotype, and its impact on medications as compared to physicians. Limited resources and economic obstacles in Syria were considered as the major obstacles that hinders the progression in this field.[31] Compared to the above study, the years of experience in the US opposingly had an impact on pharmacists knowledge and interests, those having less than 10 years of experience had the highest score in PGx knowledge assessment as well as having the highest level of interests in continuing further education in PGx.[58]

In agreement to the above study, pharmacists and physicians practicing in Egypt at Children's Cancer Hospital have shown similar results. with pharmacists' responses being more agreeable regarding statements about their responsibility to apply PGx in practice. However, the knowledge levels were still low across Egyptian physicians and pharmacist despite their positive attitudes about its clinical application. Another two major barriers were frequently addressed by the study participants, those were lack of funding and the unavailability of PGx devices in Egypt.[48]

These obstacles are quite similar from other parts of the world, for instance in Africa PGx concepts and its applications are remarkably low. Similar to Syria and Egypt, the lack of knowledge and funding as well as limited research and clinical data are the most common obstacle in Africa that hinders progression of PGx knowledge base.[59,60]

In Lebanon a group of medical students were enrolled in a survey focused on PGx testing related to a clinical scenario. The participants were against the therapeutic plan that would follow the test results of PGx testing. Additionally, the students were concerned about discussing test results with the patients in case of poor prognosis.[61] Patient confidentiality were also the focus of American Medical Association in which they examined the risks of disclosing patients' privacy and confidentially that is related to genetic testing.[62]

The scenario is quite similar for the surrounding countries and Gulf Region. A study in Qatar confirmed similar attitudes to what was mentioned earlier, in which the study participants were grouped into two groups, as pharmacist and the other group were physicians. Both groups scored relatively very low indicating poor understanding of PGx and insufficient knowledge to practice it in a sufficient and effective way. Despite both groups had low background and overall knowledge, yet the pharmacist came out to be more willing to implement PGx concepts alongside their primary duties.[38]

Another study published in 2018 in Kuwait reported even more interesting numbers about the degree of PGx education and its application. The study included 629 pharmacists and doctors, out of this study sample, only 8.9% of the studied participants had received previous orientations or education related to PGx.[39]

PGx is starting to receive some highlight in the recent years across the Gulf Region. It is now being considered as an essential domain that significantly improve the quality of health care system.

Several foundations and databases have been recognized within the Arab nations, specifically in some of gulf countries which are conducting research to facilitate PGx application, including the Catalogue of Transmission Genetics in Arabs (CTGA) which is located in the UAE that aims to provide a huge database that tend to include genetic diseases that have been documented in Arab and UAE citizens, this database is part of the Arab genomic studies.

The other program is located in Kingdom of Saudi Arabia (KSA) called Saudi Human Genome program (SHGP) that is concerned with studying diseases on the genetic level on patients in the gulf region.[63,64] Additionally, the Centre of Excellence in Genomic Medicine Research (CEGMR) located in KSA, Jeddah at King Abdulaziz University, is another center that have been recognized to be specialized in individualized medicine.[65]

Study by Algahtani, M. showed that only one third of the hospital pharmacist in KSA had any prior training related to PGx. Half of the included pharmacist reported that their hospital organizations were naive about the advantages and positive health outcomes as a result of implementing of PGx as part

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of their daily hospital operation.[66] Similarly, a study published in 2021 was conducted on governmental hospital pharmacists from 5 different hospitals located in Jeddah, KSA. Researchers found governmental hospital pharmacists generally scored low in terms of knowledge about PGx, while moderate in confidence score for utilization of these tests, and finally a positively high score in perception about the importance of PGx testing. Undoubtedly, pharmacists who had received post graduate degrees were found out to have a statistically significant better knowledge score. Researchers recommended that the integration of the PGx into the clinical pharmacy practice could help in improving the health care system in Saudi Arabia.[67] In contrast, an observational study published in 2022 was intended to evaluate the knowledge and attitudes of pharmacy student in KSA. 41.8% out of the 522 enrolled participants were able to successfully define PGx and 81.3% were aware that genetic factors can be a reason that leads to adverse reactions. Over half of the students agreed that PGx testing are recommended for certain medications by the FDA.[68] While in another study done on 671 KSA pharmacists, 29.8% scored good PGx knowledge and 42.0% scored poor knowledge levels. PGx knowledge was also observed to be better among outpatient dispensing pharmacists in KSA.[69] These fair knowledge levels in KSA are in accordance with other PGx studies done in other countries such as in the US and UK.[70,71]

Across the Northern Cyprus, pharmacists graduated from Cyprus and Turkish universities were enrolled in the study. The findings of this study reported that pharmacists were considered as the greatest source to obtain PGx information followed by physicians and genetic lab equally. Furthermore, pharmacists in North Cyprus showed an overall positive attitude towards PGx with a mean knowledge score of 6.9 out of 10. 41.8% of the enrolled pharmacists disagreed that the starting dose of warfarin would be better determined if we had a genetic profile of the patient.[72] While in another study from developed countries, 81.5% of the health care professionals believed that PGx testing would reduce warfarin adverse drug reactions.[73]

Overall, across the Arab world and MENA region a lack of PGx knowledge was observed amongst the pharmacists and physicians yet maintaining positive interests and attitudes. Emphasis on education and training health professionals could significantly facilitate the implementation process of PGx in practice within this region.

Global Knowledge and attitudes among physicians and pharmacists towards pharmacogenetics

Some of the developed countries such as United States (US) and parts of Europe have already started conducting PGx training for their pharmacist to familiarize them with its concept, whereas in one of the studies included pharmacy student who have received a training program, the participants showed a significant improvement of 50% in capability of educating patients about pharmacogenetics and its method of testing. However, this is rarely the case in the developing countries.[32,74]

A study in Malaysia reported that the level of knowledge was poor among groups of pharmacist and general practitioner, yet they showed a strong urge to be involved in receiving further education, workshops, and training. Similarly, it was found out by another report in Africa, that over half of the study participants were lacking the awareness and deficient in knowledge towards PGx.[75,76] In one of the systematic reviews evaluating pharmacist's perception towards PGx, as reported by Yau, A. et al. showed that there has been relatively good improvement in pharmacists' knowledge about PGx among several countries with up to 12% improvement between the years 2005 and 2013.[77] Despite their low knowledge, 95% of Pharmacist in United Kingdom (UK), thinks implementing PGx will likely reflect positively on patient health, compared to only 67% in Malaysia.[75,78]

Another study carried out among Ukrainian pharmacist; two thirds of the participants were unaware that they can have a participation in PGx conductance.[79]

Likewise, a study in Australia stated that most of the pharmacist were not ready to counsel their patients as they had low confidence about their knowledge.[80]

On the other hand, study in the US and Japan which included a total of 282 pediatricians, over 75% of these had previously received some education about genetics, yet less 10% of these were aware of clinical pharmacogenetics. However, despite their poor level of awareness about this field, 80% of them believe that pharmacogenetic could improve the safety and efficacy as well as willing to apply it in their pediatrician specialty.[81]

Surprisingly in Indonesia, researchers had compared the level of pharmacists' awareness between those who works at pharmacies in hospitals and others who are involved in community pharmacies. The result showed that the former group had much lower level of awareness in comparison to the latter group.[82]

These global findings provide baseline data on the knowledge and attitudes of PGx among physicians and pharmacist globally. Few of these countries have started to introduce PGx training programs yet many remain to do so. Continuous professional development for health practitioners in PGx education is a necessity nowadays in order to develop a solid knowledge base that can be successfully applied clinically.

The role of the pharmacist in the application of pharmacogenetics services

As more pronounced advancements in clinical practice are being made, PGx services are considered an essential part of this discipline. This is thought to have a major impact on how drugs will be developed, as well as changing the traditional practice of "one dose fits all" to a more individualized regimen for each patient, thus altering decision making strategies.[83]

Pharmacists are well recognized by their broad knowledge in pharmacotherapy and pharmacology. Additionally, they serve as a vital link between patients and physicians which makes them one of the most important building blocks for the progression of PGx systems.

Also, being the most accessible health care providers, their role requires utilization of knowledge in actual dynamic clinical application. This is all for the purpose of ensuring that the medication use is optimized.

The pharmacist's role extends even further which allows them to work with different authorities such as the ministry of health, drug manufactures and other health professionals. This enables them to be involved in different aspects of the process of PGx such as data processing and application in the development and labeling of drugs prior to their approval and availability on the market.[84]

The American Society of Health-System Pharmacist (ASHP) recent statements and recommendations lists pharmacists as one of the trusted health professions who can lead the development of recommendations and guidelines in clinical pharmacogenomics.[85]

Similar to the pharmacist role in medication therapy management, recent reports suggest increasing evidence on how PGx is leading to improved patient outcomes and enhanced quality of life.[86] Given that patients are the most critical part of the using this approach, one pilot study was conducted among outpatients in the cardiology department. After implementing the use of PGx with medication therapy management service, the study reported that patients surveyed were very satisfied with this service as it was incorporated within their usual therapies.[87]

Educational challenges & proposed solutions to improve the knowledge gaps

One of the key factors that limited the application of PGx is the widespread lack of knowledge around the globe. The difficulty in transforming the acquired knowledge into practice is another barrier.[88] The educational barrier has been proposed by several studies as one of the biggest obstacles of the undergraduate programs in the Arab world countries which were done on pharmacists and physicians.[31,48,54]

Additionally, the lack of experienced faculties to carry out the teaching strategies of PGx courses is another barrier that limits the competencies of the students upon graduation.[89] Pharmacy students who were enrolled in PGx courses had a better understanding of PGx tests, additional to their higher level of confidence in adopting these methods in their daily practice.[90] Aside from pharmacists, physicians do exhibit significant gaps in knowledge as well. Half of the surveyed physicians stated their concern about not having received minimal PGx education.[91]

Another challenge that has been addressed by recent reviews, is the lack of accessibility and availability of validated PGx algorithms information additional to the searching for the appropriate PGx information is not quite easy.[92,93]

Due to the novelty of PGx testing and its newly introduced to the clinical practice, it is faced by many barriers and poor acceptance. For instance, clinician resistance against genetic testing is one of those barriers, in addition the poor communication between allied health professionals. In one of the studies, physicians were 11% less likely to offer a test if it was labeled as genetic test as compared to non-genetic.[94]

Different solutions have been proposed, one of those is to blend training programs in the post graduate education. Pharmacogenetics fellowship is another solution to prepare the post graduate students with the basic educational and practice needs. An exposure of health professionals to the research field and the advancements made through this field can be of great value.[95]

Moreover, using on demand educational resources can be another strategy. This strategy would allow pharmacists or other practitioners to learn about specific PGx services as they go over it during the testing process, this would allow to save time and ease the learning process.[96]

PGx training program with certificates issuing can promote participation, such programs can take up to 20 hours to complete and will prepare the participants with fundamental information about PGx and its applications.[97]

Education alone without a standardized program is not sufficient, since most of the programs focuses on the theoretical aspect due to the lack of training facilities that are equipped with PGx services. Therefore, there is a need of standardized protocols to modify the curricula and train the students about the applications of PGx testing in practice.

CONCLUSIONS

Based on our review of the literature, there seems to be a global as well as a local inadequate level of knowledge and awareness on PGx and its application. This is not only among pharmacists but also among practitioners from different health care sectors including physicians and nurses. However, several studies have shown that health care professionals do exhibit acceptable general knowledge about genetics despite the low level of formal education they have received on this topic, which could indicate that acceptance and application could be further improved if they receive more extensive education through workshops and trainings during their professional careers.[54,56]

Further focus on PGx in the early years of formal education for health care professionals needs to be considered and implemented within their education curricula. This will enable them to better be prepared to convert their knowledge into clinical practice upon graduation.

The emerging field of pharmacogenomics requires collaboration between all the involved multidisciplinary professionals in the healthcare system and the governing bodies. This is particularly important because even in scenarios when practitioners have the required knowledge there still remains the need for further support from the governments, policy, and decision makers to reach the desired outcome and overhaul the pharmacogenetics concept into practice.

The proper application of genetic testing could be used to not only enhance efficacy and reduce the occurrence of unpredictable adverse drug reactions but also it can be blended

with the treatment of certain conditions that may require the patient to receive polypharmacy. Therefore, proper genetic testing and dose adjustments could significantly reduce the amount of prescribed medications, hence improving patient outcomes while maintaining an overall lower cost of healthcare.

This can be used as an important key factor to encourage the insurance companies and decision makers to take in consideration these type of tests as they could significantly lead to an enhanced cost-effective therapy.[98]

PGx can be an essential field if implemented successfully. The existing available data seems to be very limited in the UAE and MENA region. The challenges and barriers which are reported by the health care professionals could be used as an initial step to build up upon further strategies. Hence overcoming the knowledge barrier first, will allow the allied health care system to develop a more in-depth integration of the genome testing into the practice. The focus on education alone is not enough, there remains the need of an additional effort by academic institutes to develop a standardized curriculum that will better equip the students with PGx practice experience during their under and post graduate studies.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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AUTHOR CONTRIBUTIONS

Conceptualization, M.K, S.A, M.B, B.A, R.B, B.S, A.K. and B.A; methodology, M.K. and S.A.; original draft preparation, M.K., S.A; writing, review and editing, M.K, S.A, M.B, B.A, R.B, B.S, A.K. and B.A; supervision, S.A. All authors have read and agreed to the published version of the manuscript.

References

1. Vogel F. Moderne probleme der humangenetik. In: Ergebnisse der inneren medizin und kinderheilkunde. Springer; 1959;52-125. https://doi.org/10.1007/978-3-642-94744-5_2
2. Collins FS, Morgan M, Patrinos A. The Human Genome Project: lessons from large-scale biology. Science. 2003;300(5617):286-290. https://doi.org/10.1126/science.1084564
3. Mota NR, Franke B. 30-year journey from the start of the Human Genome Project to clinical application of genomics in psychiatry: are we there yet? The Lancet Psychiatry. 2020;7(1):7-9. https://doi.org/10.1016/s2215-0366(19)30477-8
4. Wilson BJ, Nicholls SG. The Human Genome Project, and recent advances in personalized genomics. Risk management and healthcare policy. 2015;8:9. https://doi.org/10.2147/rmhp.s58728
5. US National Library of Medicine. What is pharmacogenomics? MedlinePlus Genetics [Internet]. [cited 2021 Sep 19]. Available from: https://medlineplus.gov/genetics/understanding/genomicresearch/pharmacogenomics/
6. Thomas RE. Improving the Care of Older Patients by Decreasing Potentially Inappropriate Medications, Potential Medication Omissions, and Serious Drug Events Using Pharmacogenomic Data about Variability in Metabolizing Many Medications by Seniors. Geriatrics. 2020;5(4):64. https://doi.org/10.3390/geriatrics5040064
7. Klomp SD, Manson ML, Guchelaar HJ, et al. Phenoconversion of cytochrome P450 metabolism: a systematic review. Journal of Clinical Medicine. 2020;9(9):2890. https://doi.org/10.3390/jcm9092890
8. Snoj J. UAEs population-by nationality. Bq Magazine. 2015;12.
9. Pisanu C, Tsermpini EE, Mavroidi E, et al. Assessment of the pharmacogenomics educational environment in Southeast Europe. Public health genomics. 2014;17(5-6):272-279. https://doi.org/10.1159/000366461
10. Johnson JA, Weitzel KW. Advancing pharmacogenomics as a component of precision medicine: how, where, and who? Clinical Pharmacology & Therapeutics. 2016;99(2):154-156. https://doi.org/10.1002/cpt.273
11. Gurwitz D, Lunshof JE, Dedoussis G, et al. Pharmacogenomics education: International Society of Pharmacogenomics recommendations for medical, pharmaceutical, and health schools deans of education. The Pharmacogenomics Journal. 2005;5(4):221-225. https://doi.org/10.1038/sj.tpj.6500312
12. Ginsburg GS, Willard HF. Genomic and personalized medicine: foundations and applications. Translational Research. 2009;154(6):277-287. https://doi.org/10.1016/j.trsl.2009.09.005
13. Klein ME, Parvez MM, Shin JG. Clinical implementation of pharmacogenomics for personalized precision medicine: barriers and solutions. Journal of Pharmaceutical Sciences. 2017;106(9):2368-2379. https://doi.org/10.1016/j.xphs.2017.04.051
14. Roden DM, McLeod HL, Relling MV, et al. Pharmacogenomics. Lancet. 2019;394(10197):521-532. https://doi.org/10.3390/books978-3-0365-2834-2
15. Ehmann F, Caneva L, Prasad K, et al. Pharmacogenomic information in drug labels: European Medicines Agency perspective. The Pharmacogenomics Journal. 2015;15(3):201-210. https://doi.org/10.1038/tpj.2014.86
16. Kim JA, Ceccarelli R, Lu CY. Pharmacogenomic Biomarkers in US FDA-Approved Drug Labels (2000-2020). Journal of Personalized Medicine. 2021;11(3):179. https://doi.org/10.3390/jpm11030179
17. Gage BF, Lesko LJ. Pharmacogenetics of warfarin: regulatory, scientific, and clinical issues. Journal of Thrombosis and Thrombolysis. 2008;25(1):45-51. https://doi.org/10.1007/s11239-007-0104-y

18. Johnson J, Caudle K, Gong L, et al. Clinical Pharmacogenetics Implementation Consortium (CPIC) Guideline for Pharmacogenetics-Guided Warfarin Dosing: 2017 Update. Clin Pharmacol Ther. 2017;102(3):397-404. https://doi.org/10.1002/cpt.668
19. McCullough KB, Formea CM, Berg KD, et al. Assessment of the pharmacogenomics educational needs of pharmacists. American Journal of Pharmaceutical Education. 2011;75(3). https://doi.org/10.5688/ajpe75351
20. US Food and Drug Administration. Table of Pharmacogenomic Biomarkers in Drug Labeling. FDA [Internet]. 2021 Aug 18 [cited 2021 Sep 19]; Available from: https://www.fda.gov/drugs/science-and-research-drugs/table-pharmacogenomic-biomarkers-drug-labeling
21. Abul-Husn NS, Obeng AO, Sanderson SC, et al. Implementation and utilization of genetic testing in personalized medicine. Pharmacogenomics and Personalized Medicine. 2014;7:227. https://doi.org/10.2147/pgpm.s48887
22. Dickmann LJ, Ware JA. Pharmacogenomics in the age of personalized medicine. Drug Discovery Today: Technologies. 2016;21:11-6.
23. Relling MV, Klein TE, Gammal RS, et al. The Clinical Pharmacogenetics Implementation Consortium: 10 Years Later. Clinical Pharmacology & Therapeutics. 2020;107(1):171-5. https://doi.org/10.1002/cpt.1651
24. National Institute of General Medical Sciences. National Institute of General Medical Sciences (NIGMS). [cited 2022 Oct 24]. Available from: https://nigms.nih.gov/
25. PharmGKB. PharmGKB. [cited 2022 Oct 24]. Available from: https://www.pharmgkb.org/
26. Clinical Pharmacogenetics Implementation Consortium. [cited 2022 Oct 24]. Available from: https://cpicpgx.org/
27. NIH funds clinical trials using genomics to treat chronic diseases. National Institutes of Health (NIH). 2019 [cited 2022 Oct 24]. Available from: https://www.nih.gov/news-events/news-releases/nih-funds-clinical-trials-using-genomics-treat-chronic-diseases
28. Abou Diwan E, Zeitoun RI, Abou Haidar L, et al. Implementation and obstacles of pharmacogenetics in clinical practice: an international survey. British Journal of Clinical Pharmacology. 2019;85(9):2076-88. https://doi.org/10.1111/bcp.13999
29. Peterson JF, Field JR, Shi Y, et al. Attitudes of clinicians following large-scale pharmacogenomics implementation. The pharmacogenomics Journal. 2016;16(4):393-8. https://doi.org/10.1038/tpj.2015.57
30. Campion M, Goldgar C, Hopkin RJ, et al. Genomic education for the next generation of health-care providers. Genet Med. 2019;21(11):2422-2430. https://doi.org/10.1038/s41436-019-0548-4
31. Albitar L, Alchamat GA. Pharmacogenetics: Knowledge assessment amongst Syrian pharmacists and physicians. BMC Health Services Research. 2021;21(1):1-8. https://doi.org/10.1186/s12913-021-07040-9
32. Lee KC, Hudmon KS, Ma JD, et al. Evaluation of a shared pharmacogenomics curriculum for pharmacy students. Pharmacogenomics. 2015;16(4):315-322. https://doi.org/10.2217/pgs.14.181
33. Yau A, Husain R, Haque M. A systematic review of knowledge, attitude and practice towards pharmacogenomics among doctors. Int J Pharm Res. 2015;7:9-16. https://doi.org/10.5530/jyp.2015.3.3
34. Taber KAJ, Dickinson BD. Pharmacogenomic knowledge gaps and educational resource needs among physicians in selected specialties. Pharmacogenomics and Personalized Medicine. 2014;7:145. https://doi.org/10.2147/pgpm.s63715
35. Muflih S, Alshogran OY, Al-Azzam S, et al. Physicians' Knowledge and Attitudes Regarding Point-of-Care Pharmacogenetic Testing: A Hospital-Based Cross-Sectional Study. Pharmacogenomics and Personalized Medicine. 2021;14:655. https://doi.org/10.2147/pgpm.s307694
36. Klitzman R, Chung W, Marder K, et al. Attitudes and practices among internists concerning genetic testing. Journal of Genetic Counseling. 2013;22(1):90-100. https://doi.org/10.1007/s10897-012-9504-z
37. Rahma AT, Elsheik M, Ali BR, et al. Knowledge, attitudes, and perceived barriers toward genetic testing and pharmacogenomics among healthcare workers in the United Arab Emirates: a Cross-Sectional Study. Journal of Personalized Medicine. 2020;10(4):216. https://doi.org/10.3390/jpm10040216
38. Elewa H, Alkhiyami D, Alsahan D, et al. A survey on the awareness and attitude of pharmacists and doctors towards the application of pharmacogenomics and its challenges in Q atar. Journal of Evaluation in Clinical Practice. 2015;21(4):703-709. https://doi.org/10.1111/jep.12372
39. Albassam A, Alshammari S, Ouda G, et al. Knowledge, perceptions and confidence of physicians and pharmacists towards pharmacogenetics practice in Kuwait. PLoS One. 2018;13(9):e0203033. https://doi.org/10.1371/journal.pone.0203033
40. Shuldiner AR, Palmer K, Pakyz RE, et al. Implementation of pharmacogenetics: The University of Maryland personalized anti-platelet pharmacogenetics program. In: American Journal of Medical Genetics Part C: Seminars in Medical Genetics. Wiley Online Library; 2014;76-84. https://doi.org/10.1002/ajmg.c.31396
41. Alsafar H, Islayem D, Almansoori R, et al. Perceptions on Genetic and Genome Screening among College Students in the Emirates of Abu Dhabi. DMJ. 2021;4(3):263-272. https://doi.org/10.1159/000518623
42. Garrison Jr LP, Carlson RJ, Carlson JJ, et al. A review of public policy issues in promoting the development and commercialization of pharmacogenomic applications: challenges and implications. Drug Metabolism Reviews. 2008;40(2):377-401. https://doi.org/10.1080/03602530801952500
43. Streetman DS. Emergence and evolution of pharmacogenetics and pharmacogenomics in clinical pharmacy over the past 40 years. Annals of Pharmacotherapy. 2007;41(12):2038-2041. https://doi.org/10.1345/aph.1k273
44. Christaki E, Giamarellos-Bourboulis EJ. The beginning of personalized medicine in sepsis: small steps to a bright future. Clinical

Genetics. 2014;86(1):56-61. https://doi.org/10.1111/cge.12368
45. Rahma AT, Elsheik M, Elbarazi I, et al. Knowledge and attitudes of medical and health science students in the United Arab Emirates toward genomic medicine and pharmacogenomics: A cross-sectional study. Journal of Personalized Medicine. 2020;10(4):191. https://doi.org/10.3390/jpm10040191
46. Zawiah M, Yousef AM, Al-Ashwal FY, et al. Pharmacogenetics: a perspective and preparedness of Pharm-D and medical students in Jordan. Pharmacogenetics and Genomics. 2021;31(6):125-132. https://doi.org/10.1097/fpc.0000000000000430
47. Moen M, Lamba J. Assessment of healthcare students' views on pharmacogenomics at the University of Minnesota. Pharmacogenomics. 2012;13(13):1537-1545. https://doi.org/10.2217/pgs.12.139
48. Nagy M, Lynch M, Kamal S, et al. Assessment of healthcare professionals' knowledge, attitudes, and perceived challenges of clinical pharmacogenetic testing in Egypt. Personalized Medicine. 2020;17(4):251-260. https://doi.org/10.2217/pme-2019-0163
49. Mai Y, Mitropoulou C, Papadopoulou XE, et al. Critical appraisal of the views of healthcare professionals with respect to pharmacogenomics and personalized medicine in Greece. Personalized Medicine. 2014;11(1):15-26. https://doi.org/10.2217/pme.13.92
50. Jarrar Y, Lee SJ. Demand for Pharmacogenomics and Personalized Medicine in the United Arab Emirates. Journal of Personalized Medicine. Multidisciplinary Digital Publishing Institute; 2022;12(1):104. https://doi.org/10.3390/jpm12010104
51. Rahma AT, Elbarazi I, Ali BR, et al. Genomics and pharmacogenomics knowledge, attitude and practice of pharmacists working in United Arab Emirates: findings from focus group discussions—a qualitative study. Journal of Personalized Medicine. 2020;10(3):134. https://doi.org/10.3390/jpm10030134
52. Emirati Genome Program. [cited 2021 Dec 13]. Available from: https://emiratigenomeprogram.ae/
53. Ali Z, Elewa H. The Effect of CYP2C19 and Nongenetic Factors on Clopidogrel Responsiveness in the MENA Region: A Systematic Review. Clin Appl Thromb Hemost. 2019;25:1076029619875520. https://doi.org/10.1177/1076029619875520
54. AlEjielat R, Ejielat Z, Andrawes S, et al. An evaluation of the knowledge, opinions, expectations and concerns toward pharmacogenomics among Jordanian pharmacists. Personalized medicine. 2016;13(2):143-154. https://doi.org/10.2217/pme.15.50
55. N Al-Eitan L, A Haddad Y. Emergence of pharmacogenomics in academic medicine and public health in Jordan: History, present state and prospects. Current Pharmacogenomics and Personalized Medicine (Formerly Current Pharmacogenomics). 2014;12(3):167-175. https://doi.org/10.2174/1875692113666150115221210
56. Jarrar Y, Mosleh R, Hawash M, et al. Knowledge and Attitudes of Pharmacy Students Towards Pharmacogenomics Among Universities in Jordan And West Bank of Palestine. Pharmgenomics Pers Med. 2019;12(1):247-255. https://doi.org/10.2147/pgpm.s222705
57. Jarrar Y, Musleh R, Ghanim M, et al. Assessment of the need for pharmacogenomics education among pharmacists in the West Bank of Palestine. Int J Clin Pract. 2021;75(9):e14435. https://doi.org/10.1111/ijcp.14435
58. Roederer MW, Van Riper M, Valgus J, et al. Knowledge, attitudes and education of pharmacists regarding pharmacogenetic testing. Personalized Medicine. 2012;9(1):19-27. https://doi.org/10.2217/pme.11.87
59. Radouani F, Zass L, Hamdi Y, et al. A review of clinical pharmacogenetics Studies in African populations. Per Med. 2020;17(2):155-170.
60. Dandara C, Masimirembwa C, Haffani YZ, et al. African Pharmacogenomics Consortium: Consolidating pharmacogenomics knowledge, capacity development and translation in Africa. AAS Open Res. 2019;2(1):19. https://doi.org/10.12688/aasopenres.12965.1
61. Zgheib NK, Arawi T, Mahfouz RA, et al. Attitudes of health care professionals toward pharmacogenetic testing. Mol Diagn Ther. 2011;15(2):115-122. https://doi.org/10.1007/bf03256401
62. Thomas SM. Society and ethics - the genetics of disease. Curr Opin Genet Dev. 2004;14(3):287-291. https://doi.org/10.1016/j.gde.2004.04.014
63. Tadmouri GO, Ali MTA, Ali SAH, et al. CTGA: the database for genetic disorders in Arab populations. Nucleic acids research. 2006;34(suppl_1):D602-606. https://doi.org/10.1093/nar/gkj015
64. Team SGP. The Saudi Human Genome Program: An oasis in the desert of Arab medicine is providing clues to genetic disease. IEEE Pulse. 2015;6(6):22-26. https://doi.org/10.1109/mpul.2015.2476541
65. Abu-Elmagd M, Assidi M, Schulten HJ, et al. Individualized medicine enabled by genomics in Saudi Arabia. BMC Medical Genomics. 2015;8(1):S3. https://doi.org/10.1186/1755-8794-8-s1-s3
66. Algahtani M. Knowledge, perception, and application of pharmacogenomics among hospital pharmacists in Saudi Arabia. Risk Management and Healthcare Policy. 2020;13(1):1279. https://doi.org/10.2147/rmhp.s267492
67. Bagher AM, Neamatallah T, Balto G, et al. Knowledge, perception, and confidence of hospital pharmacists toward pharmacogenetics in Jeddah, Kingdom of Saudi Arabia. Saudi Pharm J. 2021;29(1):53-58. https://doi.org/10.1016/j.jsps.2020.12.006
68. Arafah A, Rehman MU, Syed W, et al. Knowledge, Attitude and Perception of Pharmacy Students towards Pharmacogenomics and Genetics: An Observational Study from King Saud University. Genes (Basel). 2022;13(2):269. https://doi.org/10.3390/genes13020269

69. Alhaddad ZA, AlMousa HA, Younis NS. Pharmacists' Knowledge, and Insights in Implementing Pharmacogenomics in Saudi Arabia. Int J Environ Res Public Health. 2022;19(16). https://doi.org/10.3390/ijerph191610073
70. Salari K, Karczewski KJ, Hudgins L, et al. Evidence that personal genome testing enhances student learning in a course on genomics and personalized medicine. PLoS One. 2013;8(7):e68853. https://doi.org/10.1371/journal.pone.0068853
71. Higgs JE, Andrews J, Gurwitz D, et al. Pharmacogenetics education in British medical schools. Genomic Med. 2008;2(3-4):101-105. https://doi.org/10.1007/s11568-009-9032-6
72. Alsaloumi L, Abdi A, Tosun Ö, et al. Pharmacogenomics-based practice in North Cyprus: its adoption by pharmacists and their attitudes and knowledge. Int J Clin Pharm. 2019;41(5):1299-1306. https://doi.org/10.1007/s11096-019-00868-6
73. Dodson C. Knowledge and attitudes concerning pharmacogenomics among healthcare professionals. Personalized Medicine. 2011;8(4):421-428. https://doi.org/10.2217/pme.11.28
74. Kuo GM, Ma JD, Lee KC, et al. Institutional profile: University of California San Diego pharmacogenomics education program (pharmgened™): bridging the gap between science and practice. Pharmacogenomics. 2011;12(2):149-153. https://doi.org/10.2217/pgs.10.213
75. Bannur Z, Bahaman S, Salleh MZ, et al. Pharmacogenomics based practice in Malaysia: the attitude, knowledge and adoption by the healthcare professionals. IIUM Medical Journal Malaysia. 2014;13(1). https://doi.org/10.31436/imjm.v13i1.491
76. Muzoriana N, Gavi S, Nembaware V, et al. Knowledge, attitude, and perceptions of pharmacists and pharmacy students towards pharmacogenomics in Zimbabwe. Pharmacy. 2017;5(3):36. https://doi.org/10.3390/pharmacy5030036
77. Yau A, Abd Aziz AB, Haque M. Knowledge, Attitude and Practice Concerning Pharmacogenomics among Pharmacists: A Systematic Review. Journal of Young Pharmacists. 2015;7(3). https://doi.org/10.5530/jyp.2015.3.3
78. Newton R, Lithgow J, Li Wan Po A, et al. How will pharmacogenetics impact on pharmacy practice? pharmacists' views and educational priorities. London: NHS, NGEDC and RPSGB. 2007;
79. Zembles T. An inservice program on pharmacogenetics to individualize drug therapy. American journal of pharmaceutical education. 2010;74(1). https://doi.org/10.5688/aj740110
80. McMahon T, Tucci J. Percepciones de los farmacéuticos en Victoria, Australia sobre la farmacogenética y sus implicaciones. Pharmacy Practice (Internet). 2011;9(3):141-147.
81. Rahawi S, Naik H, Blake KV, et al. Knowledge and attitudes on pharmacogenetics among pediatricians. Journal of Human Genetics. 2020;65(5):437-444. https://doi.org/10.1038/s10038-020-0723-0
82. Perwitasari DA, Novitasari SL, Septiantoro BP, et al. Knowledge awareness and attitude of pharmacists toward pharmacogenetic practice: perspective of community and hospital in Yogyakarta, Indonesia. J Community Med Health Educ. 2017;7(568):2161-2711. https://doi.org/10.4172/2161-0711.1000568
83. Cavallari LH, Lee CR, Beitelshees AL, et al. Multisite investigation of outcomes with implementation of CYP2C19 genotype-guided antiplatelet therapy after percutaneous coronary intervention. JACC: Cardiovascular Interventions. 2018;11(2):181-191.
84. Feero WG, Kuo GM, Jenkins JF, et al. Pharmacist education in the era of genomic medicine. Journal of the American Pharmacists Association. 2012;52(5):e113-121. https://doi.org/10.1331/japha.2012.12149
85. Russell Teagarden J, Stanek EJ. On pharmacogenomics in pharmacy benefit management. Pharmacotherapy: The Journal of Human Pharmacology and Drug Therapy. 2012;32(2):103-111. https://doi.org/10.1002/phar.1039
86. Owusu-Obeng A, Weitzel KW, Hatton RC, et al. Emerging roles for pharmacists in clinical implementation of pharmacogenomics. Pharmacotherapy: The Journal of Human Pharmacology and Drug Therapy. 2014;34(10):1102-1112. https://doi.org/10.1002/phar.1481
87. Haga SB, Allen LaPointe NM, Moaddeb J. Challenges to integrating pharmacogenetic testing into medication therapy management. Journal of Managed Care & Specialty Pharmacy. 2015;21(4):346-352. https://doi.org/10.18553/jmcp.2015.21.4.346
88. Caudle KE, Gammal RS, Whirl-Carrillo M, et al. Evidence and resources to implement pharmacogenetic knowledge for precision medicine. American Journal of Health-System Pharmacy. 2016;73(23):1977-1985. https://doi.org/10.2146/ajhp150977
89. Crabtree B, Bootman JL, Boyle CJ, et al. Aligning the AACP Strategic Engagement Agenda with Key Federal Priorities in Health: Report of the 2016-17 Argus Commission. AJPE. 2017;81(8). https://doi.org/10.5688/ajpes15
90. Nutter SC, Gálvez-Peralta M. Pharmacogenomics: From classroom to practice. Mol Genet Genomic Med. 2018;6(3):307-313. https://doi.org/10.1002/mgg3.417
91. Physicians' Preparedness for Integration of Genomic and Pharmacogenetic Testing into Practice Within a Major Healthcare System | Genetic Testing and Molecular Biomarkers. [cited 2021 Dec 16]. Available from: https://www.liebertpub.com/doi/full/10.1089/gtmb.2012.0165
92. Sheldon J, Ou W. The real informatics challenges of personalized medicine: not just about the number of central processing units. Personalized Medicine. 2013;10(7):639-645. https://doi.org/10.2217/pme.13.16
93. Hippman C, Nislow C. Pharmacogenomic Testing: Clinical Evidence and Implementation Challenges. J Pers Med. 2019;9(3):40. https://doi.org/10.3390/jpm9030040
94. Physician Barriers to Incorporating Pharmacogenetic Treatment Strategies for Nicotine Dependence Into Clinical Practice - Schnoll - 2011 - Clinical Pharmacology & Therapeutics - Wiley Online Library. [cited 2021 Dec 16]. Available from: https://ascpt.onlinelibrary.wiley.com/doi/abs/10.1038/clpt.2010.267

95. Haidar CE, Hoffman JM, Gammal RS, et al. Development of a postgraduate year 2 pharmacy residency in clinical pharmacogenetics. American Journal of Health-System Pharmacy. 2017;74(6):409-415. https://doi.org/10.2146/ajhp160174
96. Chang A, Nelson R, Brixner D. Advancing pharmacy practice by reducing gaps in pharmacogenetic education. American Journal of Health-System Pharmacy. 2019;76(5):320-326. https://doi.org/10.1093/ajhp/zxy066
97. Edana Holliday P, Mandy Irvin P. Educational Pharmacogenetics Resources for Pharmacists. 2016 Oct 19 [cited 2021 Dec 16]; Available from: https://www.pharmacytimes.com/view/educational-pharmacogenetics-resources-for-pharmacists
98. Mayhew M, Jablonski M, Li J, et al. Combinatorial pharmacogenomics reduces polypharmacy and medication cost in elderly patients with anxiety and depression. The American Journal of Geriatric Psychiatry. 2017;25(3):S143-144. https://doi.org/10.1016/j.jagp.2017.01.165