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INTEGRATION OF GENOMICS AND PRECISION MEDICINE IN NURSING EDUCATION

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ABSTRACT

The fast development of genomics and precision medicine has transformed the contemporary healthcare system, requiring a new nursing staff with new scientific skills. With clinical decision making, becoming more and more dependent on the use of genomic data, the incorporation of genomics into nursing education has become a necessary step to provide personalized and evidence-based care. This review explores the contemporary situation, developments, and obstacles involved in the integration of the concept of genomic and precision-medicine into nursing curricula across the educational systems of the world. It mentions the growing role of nurse in risk assessment, patient education, pharmacogenomics, disease prevention and interpretation of the genetic test results-capabilities that are now regarded as essential to quality patient care. Although this is becoming more and more recognized, there are still huge gaps in the curriculum design, faculty readiness, and access to genomic learning resources. Most facilities continue to use the traditional models of teaching which fail to embrace the scientific and technological developments that are transformed to influence healthcare. The review explains the successful means of integration such as competency-based models, case-based learning, interprofessional learning, virtual simulation, accessing genomic databases and digital tools. Ethical, legal and social issues i.e. privacy, informed consent, equity in access to genomic services are also talked about and it is in the role of the nurse to navigate these tricky situations. This review highlights the shortage of understanding on the importance of thorough genomic training to equip future nurses with precision-medicine settings by integrating new trends and best practices. The reinforcement of curriculum designs, improvement of faculty education, and the establishment of clinical collaborations can enable nurses to assume the central role in the provision of personalized healthcare. It is not only important to incorporate genomics into nursing education but it is the future of health in the world.

Keywords: *Genomics integration, Precision medicine, Nursing education, Competency-based curriculum, Clinical decision-making, Digital health technologies, Genetic risk assessment, Genomic data interpretation, Personalized healthcare..*

1. INTRODUCTION

Genomics has become one of the most radical components of contemporary healthcare that has altered the way diseases are derived, diagnosed, and treated. As opposed to the conventional genetics theory that examines one gene and the inherited characteristic, genomics investigates the entire collection of a person's DNA, the relationship among genes, environmental factors and biological pathways. Such a systems-wide perspective has now been the focus of precision medicine-a healthcare model that focuses treatment, diagnosis and prevention interventions on the individual genetic, environmental, and lifestyle factors [1, 2]. Precision medicine will not only enable treating the disease more efficiently, but also anticipating the risk, preventing the illness, and tracking the therapeutic response with accuracy never before seen. Genomic technologies are increasingly being integrated into the daily clinical practice and it is there that this is increasingly becoming urgent and thus requiring competent healthcare professionals who are competent in interpreting and applying genomic information [3].

The international need of genomics-literate medical practitioners is increasing at a high rate. Improvements like whole genome sequencing, pharmacogenomic testing, and molecular profiling are no longer the reserve of research institutions but they are also integrated into clinical practices of oncology, cardiology, obstetrics, psychiatry, management of infectious diseases and primary care [4]. Consequently, the world healthcare is experiencing the transition to the individualized care trajectories that are informed by the genetic risk scores, biomarker profiles, and gene-based treatment solutions. This development has introduced a considerable competency gap with a large percentage of the existing workforce in healthcare having been educated prior to the central role of genomics and precision medicine in clinical decision-making. These technologies cannot be fully realized unless proper education and training are done. As such, there has been a worldwide concern of developing a workforce in a position to comprehend the genomic information, convey it to the patients, and utilize it in a manner that is ethical and safe [5, 6].

In this fast-developing sphere, nurses occupy a special significant place. Patients often have first contact with nurses who can often become the main coordinators of care. They are at the forefront of evaluation, education, counseling and monitoring of the patient-where the genomic knowledge is becoming particularly important. A nurse with genomics competency will be able to recognize patients who could benefit genetic testing, assist him in interpreting the results of the test, recognize genetic risk factors during screening, and work in a multidisciplinary team to establish a personal care plan [7]. In pharmacogenomics, e.g., nurses contribute to the safety of medication intake relying on the genetic picture of a patient and minimize the chances of adverse reactions. Genomics is used in oncology to provide direction in targeted therapy and screening decisions on family members. Nurses are also crucial in the interpretation of complex genomic information in a manner that is comprehensible, culturally acceptable and ethically liable. They have to negotiate the problems of informed consent, privacy, and psychosocial effects of genetic information as patient advocates [8]. The nursing professionals will play a critical role in the success of precision medicine because of these duties. Their role does not stop at

clinical care; nurses are involved in research, community education, policy formulation areas, and health programs on genomics. Even in most countries, nursing leaders are demanding that genetic competencies must be standardized so that practice can be uniform in clinical settings. However, regardless of this acknowledged value, there is still much to do in order to incorporate the concept of genomic literacy into the nursing practice extensively [9, 10]. The lack of strong educational systems can make nurses feel that they are not ready to participate in genomic-based care, and they miss the chance to prevent diseases, diagnose them in early stages, and treat individuals individually [11]. Even though genomics has become an established part of contemporary healthcare, it has not been embraced in conventional nursing education. Numerous showcases still focus on traditional biological sciences and never fully incorporate the concept of genomics or connect them to clinical practice [12]. Genomics is being taught in many institutions as a shallow part of a biology or pathology course, without providing students with a substance sense of the implications of genetic information on their risk of disease, health promotion, or treatment outcomes. This piecemeal strategy leads to graduates who are not ready to handle genomic data in the clinical environment [13, 14]. The number of educators with the right level of genomic competencies is one of the most glaring gaps. It is tough to impart these fast-changing ideas to nursing faculty themselves, who might have not had much training as they pursued their degree. Furthermore, overworking of the curriculum is a longstanding issue in nursing educations; when there is already an excessive number of required courses, the introduction of any new material on genomic to the course would appear to be cumbersome. Moreover, there are limited access to a genomic laboratory, special education resources, or clinical placements with which students have an opportunity to have a practical experience in genetic testing and precision-medicine practices [15-17].

The other notable gap is found in inconsistency of genomic education among countries and even within specific institutions. Genomic competencies have been considered in the national nursing guidelines in some areas and are optional or not at all in others. This creates disproportional readiness of graduates and adds to the differences in the world in providing precision medicine. A gap in standardized testing instruments to measure the genomic competence of the students also exists and makes it hard to determine the success of the existing learning initiatives.

Moreover, most of the traditional curricula lack ethical training in relation to genomics. Students might not get proper information on how to handle sensitive matters like genetic discrimination, consent to genomic testing, or multicultural beliefs regarding genetics. The use of genomics in nursing practice cannot be complete or potentially harmful without this ethical background [18].

2. Evolution of Genomics in Healthcare

Genomics in healthcare has been one of the biggest paradigms shifts in the medical history. More conventionally, heredity and disease studies were based on the classical genetics centering on the inheritance of single-gene characteristics and Mendelian patterns. This initial period of genetics provided valuable experience on diseases like cystic fibrosis, sickle cell anemia and hemophilia, but was confined to monogenic diseases [19]. Due to the development of scientific technologies, scientists found that

the majority of human diseases are the outcome of complicated interactions between several genes, environmental influence, and lifestyle. This discovery led to the development of genomics - a science that is concerned with the complete sequence of DNA in an organism and the interaction of genes with each other [20]. Among the most revolutionary events in this development was the Human Genome Project (HGP), which was finished in 2003. This global scientific project resulted in the creation of the first complete map of the human genetic code showing between 20,000-25,000 genes and creating new potentials to innovate medicine [21]. The HGP heralded the era of modern genomics replacing classical genetics, showing that large-scale sequencing, data sharing and cross-disciplinary collaboration were possible. With the HGP, the next-generation sequencing (NGS) technologies radically lowered the costs and time of DNA sequencing. Whether it was billions of dollars needed previously or could be accomplished in under less than the cost of a standard diagnostic test, it is now possible. Such advancements helped to render genomic testing not only feasible in the research institutions but also in the clinical practice [22, 23]. With the increased affordability of sequencing technologies, healthcare was transitioning no longer to a population-based approach to healthcare, in which treatments are standardized to a large population, but an individualized or precision-based model, in which decisions are made informed by the individual genetic composition of the specific patient [24]. Precision medicine has transformed the diagnosis, treatment, and prevention strategy since it focuses on the anticipatory and individualized strategies instead of the responsive ones. Instead of managing diseases once the symptoms are noted, genomic data can help clinicians predict the existence of diseases in advance, screen at-risk patients, and choose more efficient and safer specific therapies [25].

Applications of genomics in the field of medicine grew rapidly. Genomic profiling of tumors in oncology is used to determine the exact mutations behind cancer progression, and therefore oncologists prescribe targeted therapies to tumors, including EGFR inhibitors or BRAF inhibitors [26]. Genomics is also used to guide the selection of immunotherapy and predict the response of treatment. Genetic variations responsible in drug metabolism are applied in the field of pharmacogenomics to personalize medication regimens to reduce adverse reactions and enhance the treatment effect. Indicatively, the differences in the CYP450 enzyme family determine how individuals process antidepressants, anticoagulants and chemotherapeutic agents [27]. Likewise, genomics is a revolutionary concept in the diagnosis of rare diseases in which whole exome sequencing and whole genome sequencing have become critical instruments in understanding the underlying pathophysiology of diseases that could not be diagnosed over the years prior. Genomic sequencing is applied in infectious diseases to characterize the pathogens, follow the outbreaks, and evaluate the antibiotic resistance. COVID-19 showed the efficacy of real-time genomic surveillance in detecting new variants and guiding the responses of the general health care [28, 29]. Collectively, these changes demonstrate a radical change in healthcare provision. Genomics has revolutionized itself into a core aspect of contemporary medicine and touches the decision making in most clinical applications. The growth of uses of the genomic

applications has posed an acute demand on the need to train healthcare professionals, including nurses to interpret the genomic data and implement it in their scope of practice. With the ongoing improvement of genomics, the dilemma facing the healthcare systems is to make sure that every person in the clinical workforce is ready to engage in precision-based care [30, 31]. The figure 2.1 is a chronological timeline of the historical development of the evolution of classical genetics into modern precision medicine. It, also, mentions a lot of scientific advances, including the completion of the Human Genome Project and the development of AI-assisted genome interpretation.

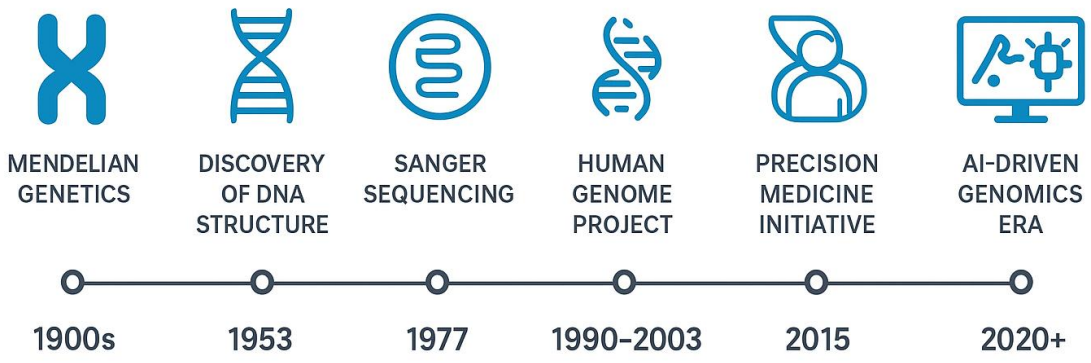

Figure 2.1: The history of the development of genetics to precision medicine.

3. Importance of Genomics Competency in Nursing

The requirement of genomics-competent nurses has never been more acute as genomics is becoming much more built-in into clinical practice. Nurses form the biggest part of the healthcare workforce and in most cases have a longer time with patients than any other worker. Their roles in evaluation, teaching, care organization, and support make them central to the process of healthcare provision using genomes. Thus, genomic competency is no more an option but a necessity of safe, effective, and ethical nursing practice [32]. Patient education is one of the most important tasks of nurses. The genomic information is complicated and frightening to most people, particularly the ones with poor health literacy. Nurses can play a role in eliminating this knowledge gap by providing an explanation of genetic concepts, the reason why genomic tests are administered, the consequences of genomic tests, and the effects test results may have on other family members [33, 34]. They assist patients to make informed choices on whether or not to undergo testing, interpretation, and both medical and emotional implications. In the world where genetic testing is becoming more and more widespread without proper knowledge of genomics, nurses will not be able to offer the necessary guidance to patients.

Assessment of risk and early prediction of the disease are also critical roles of a nurse. Nurses can identify people who are at risk of being tested further by gathering comprehensive family history, risk patterns that are hereditary, and the red flags that indicate the ability or probability of being diagnosed with a genetic disorder. This is crucial to such disorders like hereditary breast and ovarian cancer syndrome, familial hypercholesterolemia, and genetic cardiomyopathies. Nurses can help in early intervention, preventive measures and better patient outcomes through risk assessment [35, 36]. Nurses use genomic information in the

individualized pathway of the treatment in clinical care planning; this way, care is aligned to each patient genomic vulnerability profile. This has been especially valuable in chronic disease management where genetics determine susceptibility, existence, and response to treatment. The nurses also have an important role in treatment monitoring that is, the patients receiving treatment on the basis of genomic are closely monitored to determine the effectiveness and possible side effects [14].

Genomics in the management of medications has gained a lot with the advancements in the field of pharmacogenomics. Nurses have the duty of giving medications, checking back and educating the patient about the medications that have been given. The difference in drug metabolism is related to genetic diversity that may make a drug either safe or not effective against a specific patient [37]. Deficiency of pharmacogenomic understanding can result in wrongful dosage, adverse drug reaction, or sluggish therapeutic advantages. Pharmacogenomic principles should also be known with nurses in order to understand when genetic testing can be required and be able to work with prescribers [38]. In addition to clinical duties, nurses have an ethical duty to learn how genomic information can affect the family and the patient. Psychosocial, cultural, and privacy issues can be held by genetic data. Nurses are forced to deal with delicate matters like consent to genetic testing, confidentiality, revealing the results to the family members, and genetic discrimination. In the absence of proper education, nurses might violate ethical principles on inadvertent basis or not safeguard the rights of patients [39]. On the whole, genomic competency enhances the capacity of nurses to provide high-quality evidence-based and personalized care. Nurses with good exposure to genomics will be instrumental in the future of medicine, as it advances, and they will contribute to equity in access and safe, informed, and compassionate care delivery to patients [40].

4. Current status of Genomics in Nursing Education.

Although genomics continues to gain relevance in clinical practice, there is still inconsistency in the incorporation of genomic education in nursing in the world. Other countries have gone a long way and have developed genomic competency frameworks whereby they have modified the accreditation standards and some countries are still using old curricula which are not sufficient to equip nurses to deliver care based on genomics [41, 42]. Elsewhere, including in the United States, the Essentials of Genetic and Genomic Nursing, a description of the core competencies of nurses, have been developed by organizations like the American Nurses Association (ANA) and the National Human Genome Research Institute (NHGRI). Genomic content is now taught in many BSN programs with dedicated modules, integrated coursework and simulation-based learning. Nevertheless, there are still vast differences in how it is applied across institutions, and faculty experience and evaluation plans still have lapses [43, 44]. The United Kingdom has come a long way in the implementation of genomics in nursing education via efforts by the National Health Service (NHS) and Genomics England. The formation of the NHS Genomic Medicine Service has challenged universities to restructure learning and offer a steady stream of professional development (CPD) courses to working nurses. Likewise, in European nations like the Netherlands, Germany and Sweden,

systems of encouraging the idea of genomic literacy among medical practitioners have been put in place, even though their integration varies by area [45, 46]. The integration is diverse in Asia. Other countries such as Japan, South Korea, and Singapore have gone a long way in integrating genomics in the medical and nursing curriculum because of high national investment in genomics research. Conversely, most developing nations such as those in South Asia and Middle East remain at an initial phase and have little in their curricular content, limited faculty education and clinical facilities that provide genomic services. This brings about a great discrepancy between high-income and low-middle income nations [47, 48]. There are a number of frameworks that are used to guide the implementation of genomics in nursing across the world, such as the international council of nurses (ICN) and the different national nursing associations. These frameworks focus on important knowledge domains i.e., genetic risk assessment, genomic testing, ethical considerations, patient communication and interprofessional collaboration [49]. Nonetheless, integration between nursing programs is still not equal. Genomics is currently provided as a separate course in certain institutions, and as part of the basic sciences or clinical courses in others. The provision of continuing education to practicing nurses is also improving, and a number of professionals are still reporting that they are poorly knowledgeable about genomic concepts despite experiencing genomic-based care within the clinical environment [50].

5. The Vitality of Technology in Genome Instruction.

Virtual patient simulation enables nursing students to engage in real life cases that may relate to a genetic disorder, genetic testing decisions, or a pharmacogenomic intervention. The simulations assist the learners to rehearse communication skills, clinical reasoning and ethical decision-making within secure and regulated settings [51]. The comparatively popular genomic databases like ClinVar, gnomAD and PharmGKB are required to ensure that students comprehend the concept of variants classification, population frequency and drug-gene interactions. By being exposed to these tools, nurses are equipped to engage in real clinical workflows whereby genomic databases are applied on test interpretation on a regular basis [52]. In contemporary nursing, there is a great need of digital competencies. Nurses should be taught how to interpret the genetic reports, how to understand the results of sequencing, and what are the terms pathogenic variants, variants of uncertain significance (VUS) and polygenic risk scores. Practical activities based on simulated reports have the potential to develop the student confidence in comprehending genomic data [11]. The e-learning platforms and mobile applications promote continuous learning with the help of video demonstrations, interactive cases, pharmacogenomic look-up applications, and clinical decision-support alerts. Applications such as MyCancerGenome or drug interaction checkers may serve as examples of how genomic information can be used in the real-time clinical practice. These online tools also enhance accessibility particularly to the low-resource students [53].

6. Precision Medicine and Clinical Practice in Nursing

Precision medicine and genomics are becoming embedded in the routine nursing practice in a wide range of specialties. Oncological nurses are involved in the

processes of tumor profiling, patients receiving targeted therapy, treatment side effects, and the education of families on the hereditary cancer syndromes. Genomic knowledge can be used in cardiology in the treatment of inherited diseases, including hypertrophic cardiomyopathy and familial hypercholesterolemia, where nurses can help in the screening of potential at-risk family members. Pharmacogenomic testing in psychiatry is to maximize the prescription of antidepressants and antipsychotics. The nurses are in the center stage of checking on therapeutic response and advising patients on their choice of medication [8, 48]. Genetic risk assessment tools such as family history questionnaires, risk calculators, and screening algorithms are commonly used by the nurses. These devices assist in screening potential clients of genetic counseling or testing so that the earlier intervention and prevention techniques can be implemented [54]. One of the most important roles is to lead the patients through genetic testing routes. This involves pre-test education, testing logistics, documentation assistance and informed consent. Once the results are provided, the nurses assist in interpreting the results, emotional support, and refer families to specialists [55]. Though the nurses do not practice genetic counseling, they incorporate the concepts of genetic counseling in the form of non-directive communication, autonomy, emotional support, and culturally sensitive advice.

Practical cases of genomic interventions coordinated by nurses are screening programs in hereditary cancer, pharmacogenomic-controlled medication administration centers, novel born screening follow-up coordination, and carrier screening in reproduction centers. The examples reveal the growing role of nurses in precision medicine [56]. The Figure 7.1 is a summary of the main clinical domains in which nurses utilize genomic information such as oncology in tumor profiling, cardiology in inherited cardiac diseases, psychiatry in pharmacogenomic drug choice and infectious disease genomics.

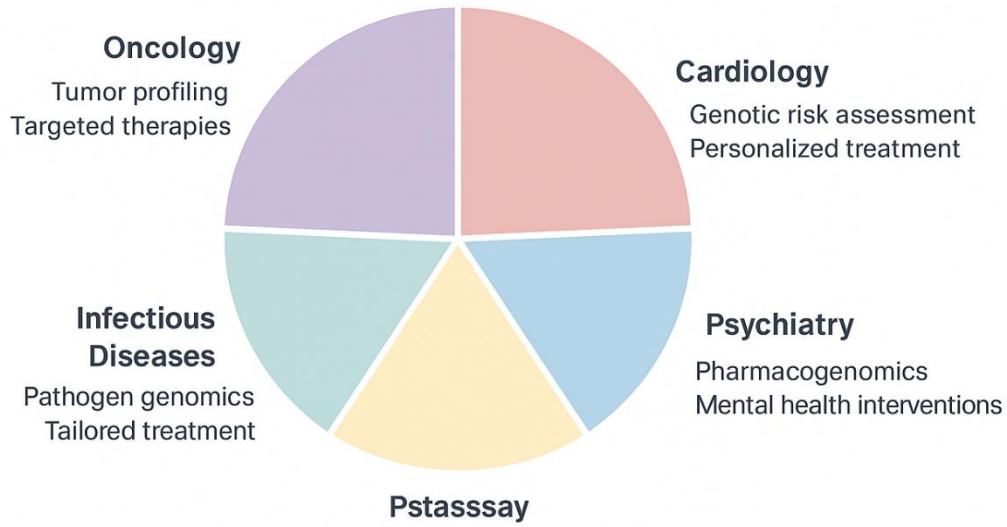

Figure 7.1: Radial chart that shows key clinical areas where the nurses use the knowledge of genomic and precision medicine.

9. LIMITATIONS

The implementation of genomics in nursing education encounters a number of challenges that have remained as barriers to its widespread implementation. The shortage of qualified faculty that is formally trained in genetics or precision medicine is one of the greatest challenges. Lots of teachers are not ready to instruct complicated genomic terminology, and they deliver superficial or aired teachings. Also, clinical placement sites where students of nursing can observe or gain practice in genomic-based practice are absent. The lack of exposure to the real world could also cause students to be unable to put the theoretical knowledge into clinical competence.

There are still institutional barriers as well. There are programs that are based on old curricula and show unwillingness to adopt new material because of the inertia of administration or competing academic agendas. The implementation is even more blocked by cost and technological constraints (such as a lack of access to sequencing technologies, simulation programs, and digital materials), especially when it comes to low-resource institutions.

International standards, regulatory expectation and accreditation standards vary greatly between the world and therefore there is an uneven development of competencies among different countries. Such discrepancy makes it difficult to develop a worldwide-ready nursing workforce that can provide genomic-informed care.

10. FUTURE DIRECTIONS

The next stage is to develop genomic skills to work in advanced nursing positions and have nurses engage in precision-medicine, genomic-counseling, and data-driven care coordination. The advent of precision nursing that incorporates AI, multi-omics, wearable health and predictive analytics shall transform the clinical practice and require a new educational model.

Increasingly, there is a necessity to establish the uniform, worldwide set of guidelines that would streamline the genomic competences of educational systems. The improved partnership between academic institutions, clinical environments, and genomic laboratories will facilitate experience-based learning and research. Also, the capacity building in low and middle-income countries such as Pakistan, is necessary to guarantee the fair access to genomic literacy and accurate healthcare. Infrastructure, development of the faculty and digital learning tools will invest increase progress in these areas.

10. CONCLUSION

Precision medicine and genomics are changing the medical field and nursing education must adapt to these changes quickly. This review has identified both great strides and lingering gaps concerning the development of the curriculum, the willingness of the faculty and access to the genomic resources. There is the need to reform immaturely in order to enhance competency-based education, the integration of technology, and the evidence-based teaching methods. Genomic knowledge enables the empowerment of nurses to become the leaders in the field of delivering personalized healthcare, assisting the patients in making complicated decisions, and promoting equal access to new technologies. Educators, policymakers and healthcare systems should work together to create a priority that will integrate genomic and help the workforce in nursing to be future ready.

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