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How the Electronic Health Record Will Change the Future of Health Care

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Genetic testing is expected to play a critical role in patient care in the near future. Advances in genomic research have the potential to impact medicine in very tangible and direct ways, from carrier screening to disease diagnosis and prognosis to targeted treatments and personalized medicine. However, numerous barriers to widespread adoption of genetic testing continue to exist, and health information technology will be a critical means of addressing these challenges. Electronic health records (EHRs†) are a digital replacement for the traditional paper-based patient chart designed to improve the quality of patient care. EHRs have become increasingly essential to managing the wealth of existing clinical information that now includes genetic information extracted from the patient genome. The EHR is capable of changing health care in the future by transforming the way physicians use genomic information in the practice of medicine.

INTRODUCTION

The traditional paper-based patient chart has long been a staple at most U.S. hospitals for decades. However, as the practice of medicine becomes increasingly complex, better ways of managing patient data to reduce errors, control costs, and improve the quality of care will be needed [1]. The passage of the Health Information Technology for Economic and Clinical Health (HITECH†) Act in 2009 brought about an increased public awareness of the

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†Abbreviations: HITECH, Health Information Technology for Economic and Clinical Health; EHR, electronic health record; NIH, National Institutes of Health; SACGHS, Secretary's Advisory Committee on Genetics, Health, and Society; CPOE, computerized physician order entry; GINA, Genetic Information Nondiscrimination Act; SNOMED, Systematic Nomenclature of Medicine; LOINC, Logical Observation Identifiers Names and Codes.

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advantages of the responsible and meaningful use of EHRs [2]. As a digital replacement for the paper-based chart, it was believed that patient care could be improved significantly through the widespread use of EHRs. Expected long-term benefits of EHRs include efficient access to patient data and test results, reliable monitoring of medication order entry and administration that would reduce adverse drug events, improved quality of care through accurate documentation and adherence to clinical guidelines, and better communication and exchange of clinical information between clinicians, patients, and institutions [1,2]. In a recent study by Jha et al., between 8 percent and 12 percent of U.S. hospitals reported having a basic EHR, with fewer than 2 percent of hospitals possessing a more comprehensive system [1]. With the recent increase in hospital incentives for the meaningful use of EHRs, nationwide adoption of EHRs is expected to grow dramatically in the near future.

Just as the EHR is an important technological development that could improve health for populations, the sequencing of the human genome is a key scientific advancement that could have a powerful impact on individuals. Completed just over a decade ago as part of the Human Genome Project at the National Institutes of Health (NIH), it was believed that with the entire sequence of DNA now available, many of the biological mysteries of the human body would finally be understood and lead to practical applications to improve patient health [3]. This could include, for example, chemotherapy focused on the molecular characteristics of a patient's tumor, as well as drug dosing algorithms tuned to a patient's genetic profile that could calculate the exact amount of medication to administer for maximal efficacy and minimal side effects [3,4].

However, before the full clinical potential of the human genome can be realized, physicians first must be able to work with the more fundamental components of individual genes or groups of genes. Genetic tests provide the first important step toward the ubiquitous application of genetic and genomic information in clinical medicine. Interestingly, while the public may have a general understanding of genetic testing, a universally accepted definition remains elusive. Sequeiros et al. noted that numerous organizations and institutions have attempted to provide a clear definition that focused on a wide range of aspects of genetic testing, including its application (clinical vs. research), purpose of test (diagnostics, prognostics, screening, carrier testing, pharmacogenomics, etc.), nature of disease evaluated (Mendelian, complex), and the type of mutations being investigated (somatic vs. germline) [5]. Genetic tests can also be categorized according to the design of the assay or the nature of the sample being evaluated (molecular, biochemical, or cytogenetic) [5]. The complexity of genetic testing and the potential for categories and conditions to overlap quickly becomes evident: Cystic fibrosis is just one of many conditions where both targeted mutation analysis of a specific gene as well as a biochemical test evaluating protein products are available [6].

The Department of Health and Human Services Secretary's Advisory Committee on Genetics, Health, and Society (SACGHS) has attempted to provide a more formal definition of a genetic test:

> A genetic or genomic test involves an analysis of human chromosomes, deoxyribonucleic acid, ribonucleic acid, genes, and/or gene products (e.g., enzymes and other types of proteins), which is predominately used to detect heritable or somatic mutations, genotypes, or phenotypes related to disease and health [7].

While there is no universal consensus regarding what constitutes a genetic test in every situation, it is clear that genetic and genomic information will play an increasingly important role in health in the future.

As genomic technology continues to advance, the scope of genetic testing will expand to include newer evaluations and technologies. Direct-to-consumer genetic tests are one such development, in which patients

receive a kit in the mail directly from the company and send back a tissue specimen (e.g., blood, hair, saliva) for evaluation [8]. These patients will ultimately receive an entire panel of results commenting on hundreds of different aspects of their health and physical condition, ranging from their risks for different cancers to their carrier status for multiple hereditary diseases to even how well they metabolize certain drugs [9]. Even more advanced techniques in the future will include quick and cost-effective sequencing of the protein-coding regions of the genome ("exome") and, ultimately, sequencing of all 3 billion base pairs of every single patient genome [3].

IMPROVING THE COMMUNICATION OF GENETIC INFORMATION THROUGH EHRS

Unlike commonly used laboratory tests such as a complete blood count or glucose, genetic tests differ dramatically in their nature, cost, and complexity. As a result, these factors affect the willingness of a patient to undergo testing, their ability to seek out information that would increase their understanding and likelihood of requesting tests, and the availability of resources to proceed with actual testing. EHRs can be used to facilitate communication between doctors, patients, and institutions necessary to advance genomic medicine. In particular, EHRs are capable of integrating and organizing data to make genetic testing potentially more cost-effective, as well as providing an efficient link to relevant resources and information at the point of care.

The cost of genetic testing remains an important concern for both patients and physicians, with some individual tests exceeding $2,000 [8]. Coverage of tests by health insurance varies greatly by employer without any indication of standardization in the near future [9,10]. Further, the health insurance plan dictates which tests are available and thus reflects the ease with which a patient could obtain specific tests. Moreover, the high cost of genetic tests provides a barrier for patients who do not have the resources to cover these costs. Genetic tests are more frequently requested by individuals with jobs that earn higher salaries, although this may become less important with the expected development of the more affordable "$1,000 genome" [11,12]. Furthermore, the genetic test market is highly fragmented, with many laboratories and companies developing their own assays at varying levels of cost and quality [13]. The EHR could potentially make genetic testing more cost-effective by identifying and tracking tests covered by different insurance plans as well as providing a structured, organized, and efficient interface for connecting patients and physicians with the laboratories that provide genetic testing [14].

A patient's education may strongly influence the decision to proceed with testing because of the complexity of medicine in general and genetic diseases in particular. Indeed, studies of different populations have shown that patients who were more educated were also more likely to proceed with genetic testing [11]. One possible explanation for this could be that better educated patients are acutely aware of their health condition and willing to take the necessary steps to improve their health, including researching their condition online, proactively discussing options with their doctors, and requesting specific genetic tests be ordered [11]. Alternatively, patients with less education may be passive managers of their health, less likely to visit a physician for preventive care, and thus less likely to encounter the opportunities where genetic testing may be beneficial; at the same time, these patients may also be more susceptible to the targeted marketing strategies of companies effective at using the Internet and other resources to increase demand for their products [11,15]. Education, thus, has an important and potentially complex influence by impacting a patient's awareness, understanding, and willingness to undergo genetic testing. The EHR provides the means through which patients can receive focused counseling and targeted education on genetic testing from their physicians. In particular, the EHR could link relevant patient

information directly with electronic resources such as Genetics Home Reference, GeneReviews, or the Genetic Test Registry [16].

ADDRESSING INFORMED CONSENT AND PATIENT PRIVACY

Like many aspects of clinical care, genetic testing requires the involvement and cooperation of both patients and physicians. However, the required paperwork for genetic tests demands a greater level of interaction between both parties, making effective communication of information especially critical. In order to process genetic test orders for a patient, laboratories require explicit approval from a physician who must provide detailed documentation regarding the clinical indications for testing [17]. At the same time, a physician referral is necessary but not sufficient. Genetic test requisition forms also require explicit, written consent from the patient who must agree with the physician evaluation and attest they understand the benefits, risks, and limitations of a given genetic test [18]. The EHR is capable of facilitating doctor-patient interactions by making necessary informed consent forms easily available through electronic storage, documentation, and tracking [19,20]. Furthermore, computerized physician order entry (CPOE) is an important component of EHRs that could be implemented so physicians can quickly complete, review, and transmit genetic test requisition forms between hospitals and laboratories.

Privacy concerns play a strong role in influencing a patient's decision to proceed with genetic testing. The Genetic Information Nondiscrimination Act (GINA) was passed in 2008 to protect individuals and prevent employers and health insurance companies from using genetic information from testing in a discriminatory way on health care coverage or employment [21]. For example, GINA protects an individual with a positive result for Huntington's disease or various cancers from being denied job opportunities by their employer, as well as prevents health insurance companies from increasing their health insurance premiums based on these test results [21]. However, while GINA may help reassure patients in certain situations, the legislation remains largely untested and does not address life, disability, or long-term care insurance [21,22].

The issue of patient privacy becomes more complicated for younger patients and the potential issues parents must consider prior to engaging in genetic testing [23]. Tabor and Kelley point out that genetic knowledge and findings have long-term personal, emotional, and privacy implications that could follow a child throughout his or her life [23]. In addition, online social networks have enabled the rapid and widespread dissemination of personal information, thus providing new opportunities to be either supported or stigmatized [23]. Patient privacy concerns and the potential for discrimination, social ostracizing, and long-term emotional stress are thus important factors for patients of all ages considering whether or not to pursue genetic testing. Access to genetic and genomic information must therefore be strictly controlled and balanced between the clinical needs of the physician and the confidentiality wishes of patients and their families [20,24]. The technical architecture of EHRs is capable of managing access to sensitive patient information according to the purpose of the genetic test, the credentials of the physician, and the privacy preferences of the patient [20,25]. In particular, EHRs have built-in mechanisms for filtering patient content, storing patient preferences, and restricting information access to specific health care providers through sophisticated clinical decision support tools [20,25].

ENABLING THE PRACTICE OF GENOMIC MEDICINE BY PHYSICIANS USING EHRS

Physicians clearly play an essential role in genetic testing. The human genome encompasses every gene that impacts human physiology and thus the scope of genetic testing is immensely broad. There are currently more than 2,200 tests that could be ordered by physicians, and the volume of

genomic tests is constantly growing [26,27]. Physicians commonly order genetic tests focusing on just one or a handful of genes related to a patient's chief complaint, with one study of EHRs suggesting that approximately 1 percent of all patients receive genetic testing [28]. As the complexity and volume of available tests continues to rapidly expand, the expertise and experience of physicians will become increasingly crucial.

The length and type of medical training is an important factor for physicians in their decision to order genetic testing. Studies have shown that the amount of genetics education that physicians receive strongly influences their ability to order genetic tests; in particular, physicians who received relevant training during medical school or residency felt more comfortable and were more likely to order genetic testing for their patients over the course of their care [29,30]. A physician's medical training is important because it determines the patient population for whom they will provide care and thus plays a critical role in defining the overall structure of their workflow. EHRs are highly capable of storing, organizing, and retrieving the large volumes of genomic information that different physicians must manage [16,19]. Furthermore, physician data stored in EHRs or available through online provider databases can be used to create user-customized EHR graphical interfaces designed to accommodate the varied backgrounds, experiences, and workflows of physicians from different medical backgrounds [16,19,28].

Another increasingly important concern for physicians is the perceived clinical utility of any genetic test. According to the SACGHS, clinical utility can be defined as the "balance between the benefits and harms of testing and ensuing follow-up evaluation, treatment, or prevention" [7]. The SACGHS further notes that the evaluation of clinical utility for any genetic test strongly depends on the context with which it is being applied [7]. A positive result for a prothrombin mutation, for example, would allow a physician to adjust the anticoagulant dose for patients at risk for venous thromboembolism that could lead to improved clinical outcomes [31]. Screening for genes associated with colon cancer (Lynch syndrome) or breast cancer (BRCA) have been shown to be informative for patients and their families, as well as lead to decreased morbidity or mortality when combined with appropriate treatment [31,32]. Unfortunately, strong evidence of clinical utility currently exists for only a small number of genetic tests, with the majority lacking sufficient evidence, guidelines, or support to warrant widespread, practical clinical application [7,33]. In a concordance study performed by Imai et al., for example, genetic testing performed at three different direct-to-consumer companies for the same individual showed different risk scores for the same diseases [34]. Thus, while a large number of genetic tests are available, physicians must be able to quickly identify the results that meet documented clinical significance and relevance for their particular purpose. The structure of the EHR provides a highly scalable mechanism through which physicians can navigate large amounts of clinical and genetic documentation, allowing rapid retrieval of important information at the point of care through genome-enabled clinical decision support [16,19]. This would enable physicians to tailor their care to the specific clinical context, educational needs, and primary concerns of the patient.

False positive genetic test results introduce an additional layer of complexity for physicians and important risks for patients. In particular, false positives often require invasive or risky follow-up confirmatory tests, in addition to putting psychological and social stress on patients and their families [35]. Furthermore, a positive test result (whether false or true) for a psychiatric condition could lead to stigmatization and have a long-term negative impact on relationships with family and friends, as well as an individual's sense of self [35]. As larger fractions of the population begin to be tested, even tests with near perfect sensitivity and specificity could still potentially lead to large numbers of false positives [36]. Furthermore, many genetic tests are not regulated by the Food and Drug Administration but instead developed

in-house by specific laboratories, companies, or institutions through proprietary procedures [13]. The risks associated with false positives combined with the lack of widespread regulation and standardization could introduce deeper skepticism toward the generalizability and usefulness of genetic tests.

However, EHRs provide a structured technical environment that would effectively demand the application of organized terminologies and standards that could help address these risks [37]. For example, the Systematic Nomenclature of Medicine (SNOMED), Logical Observation Identifiers Names and Codes (LOINC), and RxNorm are coding standards and ontologies used in EHRs to effectively classify diseases, laboratory results, and medications, respectively [19]. Genetic test results could similarly be classified using LOINC or the Clinical Bioinformatics Ontology in EHRs, providing an organized structure for reports that could be integrated into effective clinical decision support, transforming disparate pieces of clinical data into an integrated patient care system [16,19].

FUTURE DIRECTIONS

Patients who undergo genetic testing receive extensive counseling and education from their physicians. As patients begin to better understand the importance of genetic testing, they will pass on their knowledge and experience to an extensive social network of patients, family, and friends [38,39]. Furthermore, as patients begin to directly benefit from genetic testing through an early diagnosis of a treatable disease, peace of mind from a negative result, or a better understanding of their health, they may want to increase awareness of these benefits to the general population. The spread of this information could ultimately lead to the establishment of new social norms where genetic testing becomes an integrated component of a patient's health and clinical care [40-43].

Advances in genetic testing, particularly large scale genomic sequencing, have the ability to drive the spread of knowledge and innovation through the pooling of large volumes of relevant data [38]. The collection of data across multiple dimensions (clinical, genetic, environmental, social) being stored in EHRs could provide dramatic new insights into how genetics interacts with the physical and social environments of diverse populations [3,44]. In order for this to be achieved, existing data in EHRs must be transformed into more structured formats consistent with newer data sources, enabling more comprehensive analysis and evaluation [45]. EHR-driven genomics research will therefore likely accelerate the translation of discoveries into widespread practical application by clinicians [46].

As the number of genetic mutations directly applicable to patient care grows from tens to hundreds to millions of variants, new methods of organizing and interpreting this data will likely be developed [3,36,47,48]. EHRs will not only store genetic test results, but will be capable of performing analyses on whole exomes as well as entire genomes [3,14]. Further, genome-enabled EHRs in the future will integrate information from multiple external or online knowledge bases and provide dynamic reinterpretation of genomic results [14,28]. Ultimately, the EHR will provide a sophisticated clinical reporting interface that organizes genetic findings by clinical context and presents physicians with a comprehensive view of results focused on dramatically improving the patient's health [3,14,28,47].

CONCLUSION AND OUTLOOK

Genetic and genomic information will play an increasingly important role in the public's health in the near future. Genetic information is available through the sequencing of exomes and entire genomes, direct-to-consumer tests, and more commonly, genetic testing. The process of ordering genetic tests can be understood as a mutual decision between a doctor and patient influenced by multiple, complex factors. The electronic health record will undoubtedly play a central role in addressing important issues for both doctors and patients as well as in managing, interpreting,

and reporting on the wealth of complex genomic information that will lead to highly effective, personalized patient care in the future.

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