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Learning health systems

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ABSTRACT

Healthcare organizations have invested significant resources into integrating comprehensive electronic health record (EHR) systems into clinical care. EHRs digitize healthcare in ways that allow for repurposing of clinical information to support quality improvement, research, population health, and health system analytics. This has facilitated the development of Learning Health Systems. Learning health systems (LHS) merge healthcare delivery with research, data science, and quality improvement processes. The LHS cycle begins and ends with the clinician-patient interaction, and aspires to provide continuous improvements in quality, outcomes, and health care efficiency. Although, the health sector has been slow to embrace the LHS concept, innovative approaches for improving healthcare, such as a LHS, have shown that better outcomes can be achieved by engaging patients and physicians in communities committed to a common purpose. Here, we explore the mission of a pediatric LHS, such as PEDSnet, which is driven by the distinctive goals of a child's well-being. Its vision is to create a national LHS architecture in which all pediatric institutions can participate. While challenges still exist in the development and adoption of LHS, these challenges are being met with innovative strategies and strong collaborative relationships to reduce system uncertainty while improving patient outcomes.

Overview

Healthcare organizations have made large investments in quality assessment and improvement programs to address the persistent gaps between available evidence and its application in clinical practice.[1,2] The Office of the National Coordinator of Health Information Technology and Centers for Medicare and Medicaid Services have facilitated the adoption of electronic health records (EHRs) into over 90% of office-based practices and hospitals in the U.S. as of 2016.[3] The amount of data (quantitative data, qualitative data, and transactional) being digitally collected by EHRs in the healthcare setting is vast and expanding rapidly.

EHRs can digitize healthcare in ways that allow for repurposing of clinical information to support quality improvement, research, population health, and health system analytics.[4] An important characteristic of the EHR is its potential for both creating health and healthcare data, and receiving actionable knowledge in real-time to inform clinical decision-making. The evolving promise of using *big data* in the healthcare setting to guide individual patient care, population based quality improvement metrics, scientific questions, and financial incentives has been one of the motive forces behind the emergence of a concept known as a Learning Health System (LHS).[5]

Learning health systems: capability and applications

Learning organizations seamlessly share knowledge, transparently evaluate the impact of their actions, generate new evidence to reduce clinical and system uncertainty, and continuously learn in order to improve outcomes.[6,7] This organizational model has been adopted and effectively used in several manufacturing and service industries.[7] However, the health sector has been slow to embrace it because of the immense and rapidly changing volume of medical information underlying care, the complexity of clinical decision-making, and a limited capacity to evaluate the short- and long-term effects of decisions on health, costs, and care experiences. Nonetheless, several trends are converging to accelerate the emergence of health systems that operate as learning organizations.

As defined by a 2013 Institute of Medicine report, a LHS can be any type of healthcare delivery system that combines research, data science, and quality improvement, yielding knowledge as a by-product of the patient-clinician interaction, and focused on improving patient health and system outcomes.[5] In addition to their

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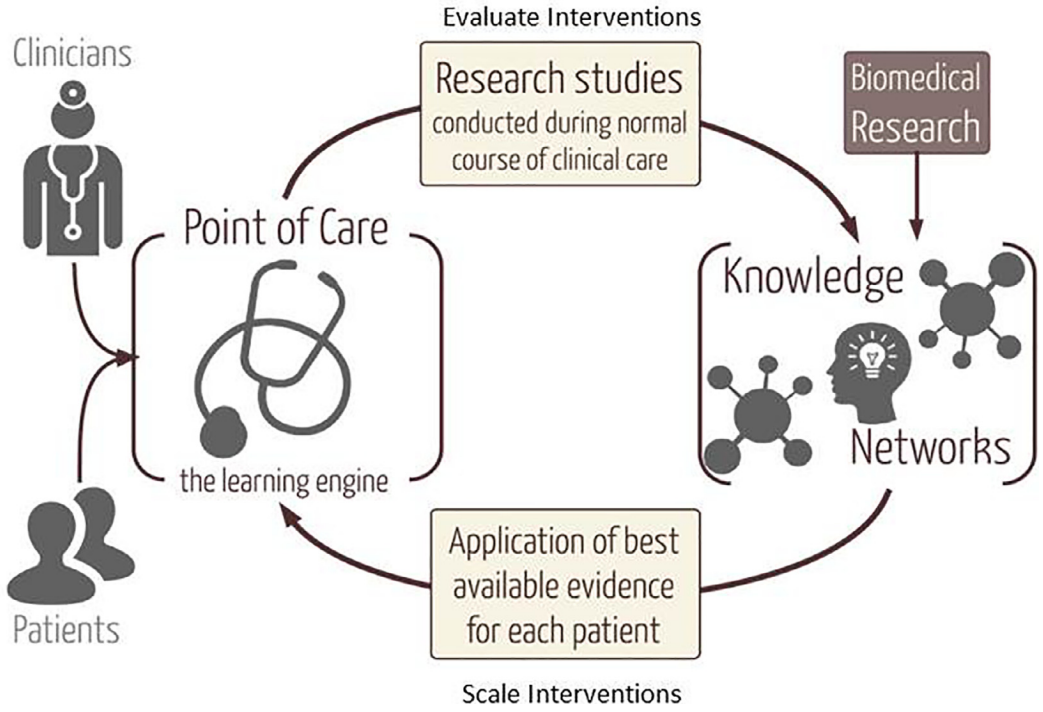

Fig. 1. The learning cycle in clinical settings. In clinical settings, the learning cycle begins with generation of research questions culled from interaction between patients, clinicians, system leaders, and researchers. New knowledge is generated through LHS research, integrated into the biomedical knowledge network, then scaled to patients, taking into consideration the unique needs of each person and their local system and community contexts.[25]

interactions with clinicians, there is much to be learned about how patients manage their health in non-medical settings, interact with community-based programs, and how public health interventions affect population health. An essential and distinguishing attribute of a LHS is co-production of healthcare: patients, clinicians, family members, and health system leaders working together as partners, sharing expertise and experiences.[5,8]

Innovative approaches for improving healthcare, such as a LHS, have shown that better outcomes can be achieved by engaging patients and physicians in communities that are committed to a common purpose, such as improving the health of patients with a particular disease.[9] Designing and implementing a LHS is a formidable task that requires significant financial and organizational commitment. Experienced and agile teams of software engineers, database engineers, extract, transform, and load (ETL) experts, computer scientists, informaticists, and analysts create the digital infrastructure necessary to stand up a LHS framework. However, equal commitment on the part of clinicians, quality improvement specialists, healthcare system leadership, researchers, and patients is necessary for the LHS to fully realize its potential.

The learning health system as a cycle

The primary principle of a LHS is to improve individual patient health through collective experience in near real time. Conventional research is a linear process with start-up and shutdown phases. The process begins with the development of a research question, drafting of a proposal, and securing of funding, followed by the conduct of the study, analysis of data, and dissemination of results. This then incurs variable degrees of penetration and adoption into clinical practice. In this linear model, investigators have traditionally developed research questions with limited input from healthcare stakeholders (i.e., patients, providers, payers, and health system leaders). LHS research has advanced the mission of health care through its learning cycle involving continuous learning that generates new evidence through research (afferent arm) and application of evidence (efferent arm) to promote outcomes (Fig. 1).[10] The LHS relies on active collaboration of all members of the system, from patients to clinicians to health system leaders, and success is defined by the impact of the system on the health and lives of patients.[10]

The cycle begins at the point-of-care with the patient-clinician interaction. Data from this interaction is captured electronically and combined across patients, time, and healthcare settings to create big health data resources. When the LHS is fully operational, research influences practice, and practice influences research in an ongoing cycle.[10,11]

Challenges for the learning health system

There have been calls to create a national LHS, which would align academic medical centers around the vision of the LHS, and develop specialty-specific networks organized to promote learning across institutions.[12–15] For any of these to succeed, a cadre of researchers will be needed to build the medical evidence base and study innovations in implementation of these practices in healthcare organizations.[16] Several barriers currently challenge the development and execution of a large scale national LHS. These include:

- Privacy concerns when sharing data between organizations and linking EHR data with other data sources, such as claims data.
- EHR systems that are not interoperable.
- Missing data resulting from patients using healthcare services at multiple organizations.
- Lack of standardization of data elements and definitions.
- Underdeveloped and inadequately validated ancillary programs such as natural language processing (NLP) tools and optical character recognition (OCR) tools that are essential to interpret the vast quantity of heterogeneous data found in unstructured

fields and complicated images that contribute significant context and detail to the clinical care of patients.

Additional challenges exist for using LHS data to power clinical research. Learning Health System Research (LHSR) is concerned with generating new knowledge that can be used to improve patient health outcomes or health system performance outcomes.[16] The standards of evidence, degree of certainty, validity, and rigors of testing that organizations apply when making decisions are arguably very different from those espoused by evidence-based medicine. For example, is it appropriate to use the continuous data from these systems to help inform both clinician and patient decision-making? Is this data strong enough on which to make strategic, operational, or financial decisions? Can this data be used to populate "virtual" clinical trials, and carry the same impact for providing both efficacy data and effectiveness data as those from our "gold standard" prospective RCTs? And, if we accept the results of these virtual RCTs or large observational studies, then how do we assure data integrity, appropriate study power, determine effect size, model outcomes, and assign significance levels? Can we just apply the same methodologic standards for design and statistical testing that we use outside of the LHS? These are only a small number of the questions that need to be answered by LHS researchers, editorial boards, and professional associations. Balancing the desire of health systems for rapidly generated, practical evidence with the rigors of peer-review and scientific standards is one of the key challenges for LHS researchers.

In addition, the current funding paradigms for traditional research studies may not appreciate the unique challenges of LHSR. For example, LHSR may not fit the timeline of conventional 5-year R01 research awards. LHSR often capitalizes on an imminent change in the system needing evaluation and study using a rapid cycle approach. It is often an iterative process with continuous cycles of analysis and feedback, rather than a one-and-done study. The types of staffing and the bodies of knowledge and training needed to be innovative in the LHSR space are different than those in traditional clinical research. Disease-specific content expertise may be less valuable than the technical knowledge needed to understand and adapt these systems. In addition, a larger view on informatics outside of the field of *biomedical* informatics is critical to facilitate this type of research and move the field forward. Currently, there are few training opportunities for junior faculty members that fill these knowledge deficits. Training in LHSR broadly entails attaining proficiency in several key areas including patient-centered outcomes research using quasi-experimental, observational, and interventional designs (knowledge generation), quality improvement (knowledge application), informatics (digitization of healthcare interactions and health), and leadership (both research and institutional).[16] Because of the relative novelty of LHSR, mentorship can be particularly challenging to obtain. Trainees need to build multi-disciplinary teams across medical and non-medical fields that may not co-exist at a single institution. In addition, developing proficiency in the *language* of LHSR is time-consuming. It entails varying degrees of understanding within computer science, medical informatics systems, epidemiology, health services research, quality improvement, outcomes research, statistics, and clinical care.

Learning health system for pediatrics

The physical, cognitive, and behavioral development of childhood provides the foundation for well-being in adulthood. Thus, the mission of a pediatric LHS should be driven by the distinctive goals of a child's well-being. Creating learning health systems that address the unique developmental and health needs of children requires a new generation of pediatric researchers embedded in health systems' clinical operations and who are committed to co-producing research with health system stakeholders in order to improve child health and health system performance. The evidence base they create may inform decisions of patients and providers that affect not only immediate health outcomes, but also long-term health trajectories.

PEDSnet: a national pediatric learning health system

PEDSnet (www.pedsnet.org), a national pediatric LHS, was founded in 2014 as a research network organized to share EHR data for the purposes of LHS research. Its vision is to create a national LHS architecture in which all pediatric institutions can participate. The maturation of PEDSnet from the Institute of Medicine's concept of a LHS to its prototype, a disease-specific network called ImproveCareNow, to its national scaling was described in the July 2014 issue of Health Affairs.[10,17]

The network is a collaboration of 8 large academic pediatric health systems, including Children's Hospital of Philadelphia, Cincinnati Children's Hospital Medical Center, Children's Hospital Colorado, Nemours Children's Health System, Nationwide Children's Hospital, St. Louis Children's Hospital, and Boston Children's Hospital. This community works together to identify the most important research questions that can reduce children's suffering and support their healthy development.

PEDSnet conducts observational research and clinical trials across multiple pediatric specialties in both inpatient and outpatient settings, and has produced reusable and expandable governance, logistical, informatic, regulatory, scientific, and training resources. Over the years, PEDSnet has created a longitudinal data resource of over 6.5 million children, and serves as a model pediatric LHS that integrates research and clinical care into one system.[10] The database includes information for children seen since 2009 and is updated on a quarterly basis by extracting data from the member institutions and transforming the data into a common data model. Data domains include demographics, encounter data for primary care, specialty care, emergency department and inpatient visits, procedures, prescribed medications, laboratory results, diagnoses, anthropometrics, and vital signs. PEDSnet not only leverages this data for large clinical trials and their feasibility, it also engages a distributed network of stakeholders who work collaboratively to generate meaningful research questions.

Since its inception, the network has published numerous multi-institutional studies examining topics such as effectiveness of bariatric procedures among adolescents, antibiotics and childhood growth, and effectiveness of anti-TNFα for Crohn's disease.[18–20] PEDSnet members have also published many articles detailing multi-site collaborative groups, examining data quality and handling data quality issues in these networks, as well as examining a longitudinal analysis of data quality in large pediatric data networks.[21–24] As the network matures, its next phase involves repurposing its infrastructure for knowledge application (quality improvement) and marked expansion throughout the United States. PEDSnet will ultimately enable the rapid implementation of new evidence into clinical practice and will address fundamental questions of clinical effectiveness for children and their families.

Conclusions

Learning health systems have the potential to enrich communities of patients, clinicians, researchers, and health system leaders by directing clinical practice, guiding research priorities, and informing organizational strategy. Formidable challenges still exist in the development and adoption of these systems. However, there are endless opportunities for innovation, leadership, and

investigation into learning health system research that are likely to be realized in the upcoming decade.

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