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Rebooting the Electronic Health Record

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Abstract
Justifications for the widespread adoption and integration of an electronic health record (EHR) have long leaned on the purported benefits of the technology. However, the performance of the EHR has been underwhelming relative to the promises of immediate access to relevant patient information, clinical decision supports, computerized ordering, and transferable patient data. In this narrative review, we provide an overview of the historical problems and limitations of the EHR, detail the core principles that define agile processes that may overcome the barriers faced by the current EHR, and re-imagine what an integrated, seamless EHR that serves its users and patients might look like. Moving forward, the EHR should be redesigned using a middle-out framework and empowering dual-type champions to maintain the sustainable diffusion of future innovations.

Keywords Electronic Health Record · EHR adoption · Agile development · Dual-type champion · Machine learning

Abbreviations

EHR	electronic health record.
HITECH	Health Information Technology for Economic and Clinical Health.
FHIR	Fast Healthcare Interoperability Resources.
HL-7	Health Level Seven International.
ML	machine learning.

Historical context

Despite the existence of primitive electronic medical record systems in the 1960s, widespread adoption of digitized health records would not become a viable option for data storage and retrieval until the early 1990s with the development of powerful, affordable hardware, local area networks, and the Internet. In the face of rapid advances in the information technologies, early electronic systems were expected to improve care by reducing medical errors, decreasing healthcare costs, and dispensing with the immobility of paper records [1, 2]. Presumably, robust electronic

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health record (EHR) systems would improve portability of patient health data across institutions. However, astute skeptics would already be wary of the lingering effects of EHR and resist the adoption in part due to the high costs of entry, data entry errors, and lack of incentives for adoption that hindered widespread integration of the EHR's in practice [1, 3].

The HITECH Act of 2009 would serve as a turning point that motivated EHR adoption through positive and negative incentives. Despite those incentives, economic costs remained a deterrent to both the initial decision to adopt and the implementation of a successful EHR system [4]. Additional concerns included novel legal and ethical dilemmas, such as the capability to store and share virtually unlimited amounts of patient information. Further, the implementation of a large-scale EHR naturally required bureaucratic expansion to tackle issues such as compliance regulations, malpractice concerns, and information security risks. For many healthcare systems indoctrinated in LEAN quality processes and just-in-time supply chains, the high implementation costs of EHR adoption ran counter to their prevailing process management systems [4].

Mazzucato argues that the basis for US technological innovation of the past 100 years is by a government-funded mandate to build the future [5]. From the silicon transistor to the Intranet, government-supported innovation of unproven technologies enabled their development that subsequent public the studies helped translate into commercial development. In contrast, the HITECH Act ushered in an era of market segregation supported by taxpayer dollars, not unlike the land acts during the reign of the robber barons. A rapid, often non-competitive, subsidized expansion cemented the market around existing major players rather than requiring competition and best-of-breed success. Over the long run, this expansion has led to deficiencies in EHR systems that do not address the needs of those interfacing with the EHR.

We believe that the current conceptualization of the EHR is fundamentally flawed. The current framework is merely an interpolation of the methods underlying paper medical records into electronic form, reproducing a litany of associated limitations and problems. The larger medical community must re-imagine an EHR that attends to the needs of both users and patients over a stubborn, persistent compulsion for documenting interactions between physicians and patients. In this narrative review, we provide an overview of historical problems and limitations of the EHR, detail the core principles that define agile processes that may overcome the barriers faced by the current EHR, and re-imagine what an EHR that serves its users and patients might look like.

Externalities: human and technology

With the passage of the Health Information Technology for Economic and Clinical Health (HITECH) Act to incentivize EHR further adoption, early EHRs would introduce their own set of technical difficulties. The evergreen problems of reliability, costs, integration, and software updates quickly surfaced as the concept of EHRs gained popularity [1]. Reservations about standards, lack of controlled vocabulary, and interface design within available EHRs were common [6], indicative of structural deficiencies that limited efforts to develop a robust EHR [2, 6, 7]. While there are definitive indirect cost savings (i.e., fewer medical errors), the additional resources required did not necessarily justify the initial investment and the direct cost savings that serve as one of the primary justifications for EHR adoption have yet to be realized [8]. Wright has argued that the adoption of technology should improve human processes [9]. For example, the Gutenberg press transformed the production of books, previously transcribed by hand. Today, for hospitals with EHRs, individuals who are doing added work to accommodate the technology (e.g., providers, nurses, etc.) do not benefit, while the institutions they work for gain the added net revenue. This mismatch in incentives leads to institutionally-driven policies that implement workflow changes for healthcare providers that are not necessarily designed to improve clinical practice, which ultimately can make providers' lives more difficult.

Ironically, high expectations for health IT combined with a demonstrably underperforming EHR system – all operating under the low-incentive and high-risk environment created by the HITECH Act – leaves the future of EHR in a difficult place. Here, the problem is one of externalities. There is an underlying, optimistic assumption that a functionally integrated EHR will refine clinical workflows, minimize any operational burden borne by healthcare providers, and provide a user-friendly clinical interface that improves access to information for all stakeholders. However, the continual financial pressure to adopt and maintain such an EHR system forces health care systems to invest annually in a sunk cost that leaves scarce resources to proactively use the EHR to address the salient issues of quality of care and patient safety, and prohibits any cost reductions under scrutiny [10]. The EHR must be redesigned incorporating a design-thinking mindset where direct clinical involvement and patient care drives decision-making to adequately serve as both repositories of patient information and tools for healthcare providers to engage with patient data and care plans.

Creating agile processes: a different perspective

The promise of the EHR lies not in its technology, but rather its service as a platform that leverages hard-earned creative insights and organization learning among healthcare providers – the implementation of which requires targeted executive leadership. Hospital administrators should understand that continued EHR implementation and development, like any innovation, requires coordination across multiple silos, divisions and departments; changes to internal political structures; and substantial commitments of financial resources. Given the encompassing nature of an EHR, Ventkataraman et al. have argued that multiple champions – notably, the dual-type champion archetype – are necessary to overcome the barriers to the innovation [11].

As agents of sustainable diffusion, dual-type champions who have expertise in both the technology and its impact on front-line providers, are the ideal agents to provide insights in guiding the implementation and maintenance of an EHR [12, 13]. Optimally placed in an environment where problems and their solutions change quickly, these champions should be responsible for breaking complex long-term projects into smaller modules, developing concrete plans to accomplish the new targets, and guiding cross-functional teams that will achieve well-defined end points. The dual-type champion is the ideal person because they are in the middle and can moderate the needs of both the institution and the providers. They are consequently in the best position to adjudicate among conflicting sets of priorities and thereby, set forth a strategic direction for an organization.

By focusing on the most salient level of understanding for the modelling project at hand, the middle-out framework attempts to fully integrate information in a manner that evades both top-down models that provide a structural framework of any operational system and bottom-up model that understands what is required on the front-line of clinical care [14]. In many respects, the data in an EHR is like DNA, code that provides building blocks for function but is unable to produce any changes without external actors. At the most basic level, DNA can have no influence without the proteins that govern DNA transcription and translation [15]. Similarly, without the healthcare workers that directly interface with EHR systems and translate the information captured there into patient care, the EHR is obsolete. Therefore, any changes intended to improve the function of an EHR may be best focused on how to best serve those that are operationalizing the static data rather than the form of the data itself.

Healthcare systems must adapt to realize the implications of a middle-out framework applied to its own contexts [15]. Leadership and labor structures must be restructured to support the dual-type champion, which can respond to the demands of mundane daily operations and overarching administrative decisions. Dual-type champions chosen from the appropriate groups in healthcare systems have the clinical expertise and operational know-how necessary to build coalitional support and mobilize resources where top-down champions are unable to. We must apply the same principles that will address the issues underlying general EHR systems, which follow the same patterns of diffusion, by installing middle-out approaches to system engineering and dual-type championship. Ultimately, the synthesis of these aspects requires institutional buy-in spearheaded by principled leadership with appropriate financial backing.

Communication: a comment on interoperability

With the variability inherent in billing code representations among institutions, automation within healthcare is limited because patient information cannot be consistently validated across a healthcare system that spans more than one institution [16, 17]. At the population health level, the millions of data points for patient information should represent the largest accumulation of useful medical data. This observation defines the central problem underlying the current network of EHRs. Yet, there are currently no easy methods to coordinate data exchange amongst a wide network of EHRs [18]. Efforts to improve interoperability have been attempted in the past. For example, the third generation Fast Healthcare Interoperability Resources (FHIR) [19] standards proposed by the Health Level Seven International (HL-7) has provided a comprehensive framework for the integration, exchange, and retrieval of electronic health information. Despite similar efforts, major improvements in the US healthcare data dilemma have been limited in the past few decades.

To achieve interoperability, three systems levels need to be considered: Basic, Functional, and Semantic [20]. At the Basic level, EHR systems can safely transfer digital data between one another without errors and does not require the ability for the receiving computer to interpret data. At this level, the technical ability itself already exists, easily adaptable by most healthcare entities with their existing IT infrastructure. At the Functional level, EHR systems can exchange and interpret digital data bytes so that parsed data fields at the receiver end can be appropriately stored in comparable fields. To achieve this level of interoperability, comprehensive standards that require slow development cycles such as FHIR will be necessary, placing stress on the economic constraints present in many health systems. Therefore, there has been little motivation from major EHR vendors for such changes without legislative pressure or financial incentive [21].

Lastly, at the Semantic level, EHR systems must share the same medical terminologies between and across all institutions, universalizing data field exchange and information representation. For with an existing EHR, implementation will require that administrators and healthcare providers recognize the importance of prioritizing data and understand some data may be difficult to merge due to incompatibility of data fields or coding systems. Constantly switching between EHR environments in the context of delivering clinical care reduces workflow efficiency, introduces the potential for clerical errors, and exacerbates physician burnout [22, 23]. Without data interoperability, the task of deploying up-to-date data mining and machine learning algorithms requires starting from scratch to ensure data validity.

Imagining the future of EHR

"Learning algorithms are the seeds, data is the soil, and the learned programs are the grown plants." – Domingos, The Master Algorithm [24].

The simplistic nature of current user interfaces results in input and output problems that produce the most plainly obvious errors and inefficiencies of EHRs. Rather than a digitized file cabinet containing patient facts, EHR user interfaces could be presented in storyboard format – dynamic and visual processes that allow healthcare providers understand what is happening with patients, simplify workflows by presenting important information and decision-making trees, engage dynamically with input and output information from patients and providers [25]. While science fiction has long envisioned visual and interactive dashboards that present fully integrated information sets that do not rely solely on text, current EHR systems do not remotely resemble a visual dashboard, much less one that sorts or presents relevant patient data. Intuitively, an information display should be customizable by clinicians to fit their varied between different clinical services. In many current rudimentary implementations of such a dashboard, the emphasis is placed on primary care providers' workflows, which handicaps the ability of specialists to optimize their practice.

Adopting new technologies has always been a major challenge, regardless of industry or profession, with healthcare further challenged given its high initial knowledge threshold requirement. However, with the advent of machine learning and artificial intelligence, it may be possible to improve EHRs continuously. AlphaZero and AlphaGo have put in practice the potential of machine learning in the context of chess and go, respectively. By playing games against themselves and training the underlying neural network, each program was able to surpass the skill level of previous game engines, providing both improvements to existing strategies and ground-breaking novelties [26, 27]. A future EHR may employ a similar scheme in which the EHR continuously challenges itself with new patient encounters and finds opportunities to improve the patient's health by coordinating team activities within the simulations.

Currently, machine learning (ML) in clinical decision support is limited in its applications because there are no real-time platforms. For example, ACR Care Select scores the appropriateness for advanced imaging appropriateness scoring but is unclear whether "true" ML is performing chart review to support an order or the natural language processing algorithms merely match searches [28]. Clinical risk prediction for sepsis is limited because the notification window does not go beyond the 24-hour window, thereby minimizing its impact on patient length of stays [29]. In some respects, it is like predicting the weather, where predictive value has a limited utility depending on chronological proximity to definitive events.

There are several unique challenges when we consider the application of machine learning. A sophisticated ML platform contains adjustable weights ranging from hundreds to thousands (i.e., VGG16) to tens of millions (i.e., Google's Inception) available for training [30, 31]. Training from scratch requires millions to billions of examples to converge on a stable state. In the medical field, each individual research and engineering groups faces the same dilemma: limited datasets secondary to HIPPA and the lack of interoperability. With small data sets and poor labelling, researchers and clinicians run the risk of either underfitting or overfitting the machine learning models [32]. For example, the NIH dataset examining malignant lung cancer nodules, benign lung lesions, and tuberculosis nodules, number in the low thousands [33]. ML has clear utility for Natural Language Processing (NLP) and other transactional activities around healthcare processing (i.e., Qventus, HealthTensor), but the challenge will remain to build a fundamentally different EHR that overcomes the limitations of the current EHR that both plays to the strengths offered by ML and improves operator functionality.

Eventually, the treatment paradigms of a machine learning EHR, synthesizing the principles of neural network sciences and big data, may be mapped onto existing care teams. One significant benefit of a true AI system embedded within an EHR will be the potential ability to identify and address biases in datasets [34]. By identifying failure modes, establishing trust and confidence in users, and teaching humans to make better decisions, EHRs might approach the scope of precision medicine: predictive, preventative, personalized, participatory, and patient initiated decision making.

Fine-tuning machine learning platforms is not an automated process. It requires a myriad of human interventions through reiterative process across multiple cycles.

In medicine, should the engineers who know little about medicine train the program or should the physician, among who only a very few likely understand the mathematics and architecture, lead? We return to the dual-type champion and argue that we need individuals who can collaborate with the engineers, understand the clinical implications, and adjust to continuously evolving landscapes of healthcare delivery and technology.

Conclusions

Despite many years of refinement, EHR development remains frustrating and helpful only in specific circumstances. Retreading the ground of how EHR function, behavior, and interactions contribute to the failure of EHRs to live up to their expectations remains a crucial aspect in the descriptive project of understanding health systems. The more impressive, generative task at hand is imagining a better EHR – one that not only addresses the immediate problems noted here, but also ushers in a wave of developments across all aspects of healthcare delivery. The EHR's technological contemporaries have already illuminated the path forward; identifying and integrating existing technologies are a key next step in developing a better EHR. The evolving attributes of EHR systems may be optimally addressed by implementing middle-out approaches to system engineering, in which decision-making ability can react efficiently to systemic deficiencies and exert control over relevant stakeholders. Ultimately, whether we continue stumbling down the road for another ten years or not, EHR adoption and implementation will require redesigning and empowering the technology to make amends for broken promises.

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