**Reducing Clinician Burden: Clinical Workflow and Usability**

**1.0 Scope and Definitions**

In scope:

* Physician physical and mental activities, technologies, tools, environments, teams, and organizations involved in patient care
* Directed sequences of actions
	+ Performed by physicians
	+ Consuming, transforming, and/or producing information (note patient outcomes are considered information)
	+ Performed to assess, change, or maintain the health of a patient
* Impact of reimbursement regulations on clinical work flow

Out of scope:

* Physician documentation itself (addressed in a separate document)
* Workflows of nurses and other primary healthcare professionals

The scope of this discussion includes all activities and processes carried out by physicians as they care for their patients. Such activities may include but are not limited to 1) direct interaction with patients, 2) finding, organizing, and analyzing data and information from the medical record, 3) researching information from the medical and scientific literature, 4) making diagnoses and clinical decisions, 5) writing orders and making referrals, 6) care coordination and collaboration, 7) population management, and 8) clinical documentation. While clinical documentation per se is addressed elsewhere, the impact of reimbursement regulations on the clinical documentation component of workflow is in scope.

Of note, nurses and other primary healthcare professionals are also burdened with electronic health record (EHR) workflows which disrupt care delivery and impose inefficiencies because current EHRs do not reflect the clinical work actually done at the bedside. A key workflow/usability concern for a future discussion with nurses is that EHRs’ coded data imposes inefficiencies in the nursing workflow based on arbitrary decisions about how EHRs code data, decisions that were made long before interoperability was a requirement. Given the need to exchange data with not just one but hundreds of healthcare providers, use of a standardized terminology for nursing could establish better consistency in care delivery and is an important and necessary future discussion. The details of these challenges differ significantly from those faced by physicians, and full and independent consideration in a separate document will be necessary to develop effective solutions.

**2.0 Burdens**

2.1 Summary of physician clinical workflow burdens related to healthcare information technology:

* Reimbursement regulations. To avoid accusations of billing fraud, physician documentation must include multiple components with little relevance to the encounter being documented and little contribution to quality of care. Extra-visit (non-clinical) documentation requirements divert physician time from more productive, clinically relevant activities.
* EHR systems as electronic filing cabinets. Suboptimal interfaces and navigation render searching for, accessing, and organizing relevant data difficult
* Document (rather than data) paradigm. Current efforts to improve “interoperability” concentrate on access and interchange of documents, not semantic and syntactic interoperability of data. High quality, discrete data is a prerequisite to the computational use of that data. Integration of data into the structure of the EHR without user intervention is a prerequisite for effective human use of that data.
* EHR systems that dictate rather than adapt to physician workflows. Generic, overly standardized “one size fits all” workflows are imposed across a wide spectrum of clinicians, specialties, and clinical environments, forcing end users to alter their workflows to align with the EHR system.
* Simplistic, algorithm-based interface design forcing limited sequences of choices and actions on care processes that are by nature complex, iterative, and subject to multiple constraints
* Ineffective, non-specific clinical decision support (CDS) tools which are interruptive, fail to integrate key pieces of data in the context of workflow, and inundate clinicians with low value alerts
* Lack of context-specific information preprocessing. The resulting information overload often provides more data than is needed in a particular clinical situation with no easy way to filter the data in a context- or user-determined manner

2.2 History:

When the HITECH provisions of the American Recovery and Reinvestment Act of 2009 were passed, it was believed that widespread adoption of EHRs would improve healthcare quality, improve patient safety and patient experience, and improve the cost efficiency of the American healthcare system.1 A decade later, with EHRs implemented in roughly 90% of hospitals and physician offices, studies2-5 have shown:

* Decreased efficiency (EHRs add 1-2 hours to the average physician workday)
* Modest improvement in care process metrics and guideline adherence, only weakly correlated with EHR use
* No significant change in hospital length of stay or inpatient mortality
* No significant change in 30-day readmission rates or patient safety incidents
* No improvement in average longevity, infant mortality, or other population metrics
* Continued rapid rise in annual healthcare expenditures from $2 trillion in 2009 to over $3.6 trillion in 2017 (nearly 18% of GDP)

**A growing body of data also shows that** **poor usability and poor support for clinical workflow are among the most important factors preventing EHRs from achieving their intended goals summarized above.6,7**

2.3 Reimbursement regulations:

To be sufficiently complete and granular to meet Evaluation & Management (E&M) coding requirements, physicians commonly resort to templates and copy/paste functionalities which produce verbose, disorganized, repetitive notes that meet coding and audit requirements but make it extremely difficult for the clinician to find, process, and understand the information most pertinent for patient care.8,9 The EHR data most important for note creation is often hidden in a forest of less useful values, where poor search, navigation, organization and presentation functions make relevant information difficult to locate. Extra-visit financial requirements (e.g., preauthorizations, appeals for insurance coverage) consume physician time in unproductive activities. In sum, reimbursement regulations increase workflow steps and increase demands on physicians’ time, visual recognition processes, working memory, and concentration (together termed cognitive load), potentially resulting in slower decision making, increased risk of errors, and disruption of physician-patient relationships.

2.4 EHR systems as electronic filing cabinets:
Information is often not organized or aligned with the physician’s mental model of care and is not optimized to support clinical decision making. Too much clicking, scrolling, switching between paths and screens, and counterintuitive data presentations make it challenging to access and process important data. Critical information is obscured in a mass of less important text or values.10,11 Locating and importing data from outside a clinician’s own health system requires extensive effort by the user, when it works at all.7 Nearly 60 percent of ambulatory care providers report being dissatisfied with their EHR due to workflow and usability concerns,11 and 72 percent of primary care physicians (PCPs) think that improved interface design is necessary to improve inefficiencies and reduce screen time.12

2.5 Document interchange versus data interoperability:

Analysis of the new-found emphasis on “interoperability” suggests that most of the effort remains on improving document exchange, not on discrete data interoperability. As noted above, since a significant fraction of current document content is irrelevant to clinical care, augmenting document interchange without documentation reform may increase, rather than address clinician burden. There remains a foundational need to identify and specify core clinical data, standards, and vocabularies that enable the promises of a healthcare ecosystem that is semantically and syntactically interoperable **without requiring extra user input**.

2.6 EHR systems that dictate clinician workflow:

Current EHRs are largely designed with hard coded “one size fits all” workflows, consisting of generic tasks and steps which do not accurately reflect clinicians’ mental models or the way they actually provide care at the bedside and in the clinic.13,14 Including a wide spectrum of clinical specialties, environments, and contexts in a few common pathways produces systems which force physicians to alter their preferred workflow and cognitive style to align with the EHR’s requirements. The mismatch causes physicians to perceive their EHRs as disruptive and inefficient. Sixty percent of PCPs think EHRs need a complete overhaul, and only eight percent say the primary value of their EHR is clinically related.12

2.7 Simplistic algorithmic interface design:

Physician workflows are inherently complex, nonlinear, and dependent on a wide variety of data inputs. Workflows differ significantly between specialties, between individual providers, and even between visits and patients for a single provider. EHRs often assume a rationalized model of healthcare delivery which can be represented as algorithmic sequences of choices. In reality, clinical care is iterative, with physicians constantly reformulating goals, revising tasks, and reordering sequences as they acquire information, interact with individual patients, and encounter clinical constraints.13 For example, one detailed study of two patient visits by 10 PCPs in 10 different primary care centers observed no single or even common workflow pattern. The order and prevalence of task categories varied through the time course of a visit, with the PCPs collecting data throughout.15 In another study, providers using the same EHR developed very personalized patterns in the way they used EHR features.16 A third study of 55 Emergency Department physicians at four sites using two different EHR products showed wide variability in task durations, ordering, clicks, and accuracy when completing basic EHR functions across EHR products from the same vendor and between products from different vendors.17

 2.7.1 Difficulty addressing workflow fragmentation: Clinical workflows are frequently interrupted, for example, by emergencies, phone calls, or the need for information not yet available in the record. Time constraints, schedule changes, and revisions in care goals often make it necessary to defer tasks or decisions until more information is available.13 Current algorithmic designs are encounter-specific and do not provide optimal support for resuming work after an interruption. In addition, neither EHRs nor reimbursement regulations account for the fact that documentation and other data entry must frequently be completed at a different time and place outside the encounter, such as afterhours note completion, phone calls, follow-up on laboratory and radiology data etc. Time consumed by these nonsynchronous processes is a major cause of work-life imbalance and consequent physician burnout.

2.8 Ineffective CDS tools:

As the medical and scientific knowledge base expands exponentially,18 physicians and care teams need tools to navigate this information and apply it to help interpret the complex patterns found in patient narrative, physical exam, laboratory data, and radiographic images. Current CDS interventions too often take the form of pop-up alerts notifying physicians of warnings such as drug-drug interactions (DDI), drug allergy interactions (DAI), dose ranges etc. Other CDS formats include order sets and either direct links to medical literature or links to guidelines, calculators, or knowledge summaries. Unfortunately, many DDI and DAI tools are interruptive and fail to integrate key pieces of data found throughout the medical record, resulting in large numbers of low value alerts, which can lead to “alert fatigue.” DDI alerts are overridden anywhere from 50% to 90% of the time in various studies, with over 60% of the overrides found to be clinically appropriate.19 Linked literature and knowledge summaries frequently display far more information than needed at the current point in workflow, requiring a long search to find the piece needed to complete the immediate clinical task.20

2.9 Information Overload:

Clinicians frequently work under severe time constraints in demanding environments. Excessive choices can create uncertainty and distraction leading to errors. Existing EHR systems are not designed to parse what process is underway or what information is needed at any particular point in workflow. As a result, designers tend to crowd in too many choices and too many interface elements to be sure that all use cases are covered, creating a system which users find disorganized and confusing.21,22 Better mechanisms are needed to retrieve and display information in a context- and/or user-determined manner.7

**3.0 Promise and Paradoxes of User-Centered Design**

3.1 Promise:

User-centered design (UCD) has been very successful in improving the human factors engineering of commercial and industrial IT products, and it is widely believed that more rigorous and consistent application of UCD methods during EHR software development would solve most of the problems enumerated above. Proponents of this approach envision teams of software engineers, clinician users, and user experience experts, such as human factors engineers, cognitive psychologists, and interaction designers, collaborating in an iterative process with multiple rounds of product testing and with development decisions based on both user perceptions and performance measurements. The process would focus on users and tasks (locating information, task and information flow, solving relevant clinical problems, workload, communication and coordination) throughout, leading to better user efficiency, lower error rates, and increased user satisfaction.7,13

3.2 Paradox 1—Physician Variability:

Expert clinical practitioners have highly variable workflows and many unarticulated (sometimes unconscious) thought processes, which may not be shared by most or even any other users in the field. No matter whom the design team elects to study, the healthcare IT being developed will inevitably be based on the experiences, interactions, and constraints of a small percentage of the total users.21,22 Because of the wide variability in clinical processes and workflows (see above), such results may not reflect the needs of the wider user base. In addition, careful *in situ* observation to document real workflows is often impeded by complex, time-constrained clinical environments and by privacy regulations and concerns. Testing in artificial environments and relying on surveys or participants’ descriptions rather than real-world observation of the work can miss important aspects of users’ interactions with a system. This paradox of UCD was well demonstrated by Hultman et al. who undertook a redesign of the ambulatory navigator function of a major vendor EHR with the goal of improving usability and clinician satisfaction.23 Even though the well-designed project incorporated every known UCD best practice, the results showed no usability improvement at all. The perceived workload and overall satisfaction were the same for both designs, and navigation patterns in either design were highly variable across participants, as were participants’ choices of which system they would prefer to use.

3.3 Paradox 2—Patient Variability:

At a fundamental level, it is expected that clinician workflows will be variable because patients have remarkably individual disease histories that require highly personalized care. For example, one study of Medicare beneficiaries with multiple chronic conditions found over 2 million combinations of 70 disease categories in 32 million Medicare beneficiaries.24,25 The number of comorbidity combinations would be even higher if calculated at the level of individual ICD codes.

In addition to the complexity of multiple comorbidities, patients often differ significantly at the genetic and molecular level and respond differently to drugs and treatments. There is also evidence for heterogeneity within single disease groups in the current classification system (e.g., depression).26 In sum, when comparing and grouping medical histories for the purposes of informing care, most patients belong to a small (if not unique) subgroup. Commitment to patient-centered care requires physicians to confront this individual variability as they diagnose and treat each patient, resulting in highly variable workflows. How does UCD converge to a solution when the dimensionality of the problem is so high? Current paradigms for implementing both EHRs and clinical measurements for quality purposes are not designed for this level of complexity and disease granularity.27,28

3.4 Conclusion:

UCD practices work well for optimizing commercial and industrial IT designs because the processes being supported are relatively constant and well understood, and the options at each step are somewhat constrained, so the number of decisions is manageable. Clinical processes must accommodate a wide range of data types in support of an enormous range of users performing varying, highly individualized sequences of high complexity tasks, caring for highly individual patients, often with incomplete data.29 Applying usability research methods to EHR design assumes there is some standard or optimal way of thinking about each clinical process at a very granular level, and no such standard exists. In fact, most clinical processes are context-dependent and have never been thoroughly mapped or understood,30 and physicians approach them with highly variable mental models and cognitive styles.

**UCD methods, deployed across multiple specialties at a more granular and localized level, will remain vital to identify the information physicians need for optimal function within new, context-aware frameworks.** **However, the idea that any amount of usability research can derive a single consensus “one size fits all” interface model acceptable to a large proportion of physicians, even in a single specialty,** **is one of the most important factors impeding our progress toward more usable EHRs.**

**4.0 Solutions**

4.1 New Paradigms:

Current EHR human/computer interfaces continue to adopt visually complex representations derived from prior paper-based records. The current WIMP (Windows, Icons, Menus, Pointers) form-based data entry paradigm, little changed from Windows 95, “requires clinicians to navigate deeply nested menus and browse through long pull-down lists that are neither filtered nor contextualized.”31 Data is entered bit by agonizing bit requiring multiple keystrokes, points, clicks, and scrolls. One study measured an average of 216 mouse clicks or wheels and 729 keyboard clicks per 20-minute patient visit.32 The lesson of the last 10 years is that physician-patient interactions and physician physical and cognitive workflow processes are not orderly or linear enough to be well accommodated by current algorithmic methods and client server architectures, and the mismatch causes many adverse consequences.

**Disruptive innovation and real progress will require EHRs to evolve from data-centric transactional systems (essentially electronic filing cabinets) to process-centric workflow systems, designed from the ground up to be flexible and context-aware and to provide “just in time” delivery of exactly the data and functionality the physician needs at the current point in workflow. Instead of requiring clinicians to train for ever more hours and adapt their thought processes and workflows to predetermined systems, we should require designers to produce more flexible, modular systems that adapt to physicians.**

Systems must also accommodate the inevitable “disorder” involved in clinical practice and be adjustable to fit new clinician needs on very short time scales. Instead of requiring physicians to fetch each piece of information from the filing cabinet one by one, EHRs should assist in aggregating, organizing, and presenting relevant context-specific information to the clinician. Other members of the care continuum (e.g., trained medical assistants and especially patients) must be more actively included in the documentation and data entry process, freeing clinicians to keep their full attention focused on clinical care and communication. This will all be technically challenging, but many solutions, some already in development and some still out on the horizon, are possible. Several examples follow.

4.2 More practical near-term solutions:

 4.2.1 Regulatory reform: Comprehensive regulatory reform will be indispensable for reducing the impact of reimbursement regulations on workflow. “The primary purpose of clinical documentation should be to support patient care and improve clinical outcomes through enhanced communication.”8 Selecting which data to present at a particular point in care and organizing it such that the clinical thinking is easily consumed and understood by the rest of the care team is a complex, context-dependent process. It will be critical that the process of defining content and quality in clinical notes be transferred from payers and regulators back to practicing physicians, clinical specialty societies, and medical educators, allowing them to streamline documentation down to the core essentials necessary for clinical care and communication.

Physicians should be free to focus attention on the patient and on clinical care, not on administrative, regulatory, and financial processes less relevant to clinical care. For example, EHRs should be required, possibly via specialized CDS systems, to submit all the information needed for routine preauthorizations and insurance determinations without user intervention. Strong incentives for payers and EHR developers to create a dedicated language or interface to handle authorization transaction sets should be implemented. EHRs should also be required, as a condition of certification, to be able to record, aggregate, and submit other required non-clinical data, (e.g., federal EHR usage data, public health syndromic surveillance data, etc.) without physician intervention, although other clinical professionals might help with this.

 4.2.2 Application Programming Interfaces (APIs): API technology certification criteria were introduced as part of ONC’s *2015 Health IT Certification Criteria*, but this technology has so far been viewed as a method to facilitate consumer access to healthcare data and provider ability to access, integrate, and report required regulatory data such as electronic clinical quality measures (eCQMs). EHR developers should be required to provide robust general-purpose APIs (and associated development platforms) allowing the use of innovative, pluggable, interchangeable apps created by physicians, healthcare organizations, and many other sources and not dependent on particular EHR products or versions.33 Based vendor resistance so far, this will only be accomplished by strong regulatory incentives. Industry standard APIs could be based on the SMART on FHIR platform34 enabling the development of an “apps based information economy,”35 where interested professionals from many disciplines, including physicians, can develop programs which fill gaps in current EHR functionality and provide a more tailored end user experience. Work on this approach has already been started as The HL7 Argonaut Project,36 but such work should receive more vigorous financial and regulatory support.

 4.2.3 More local, granular UCD: Making UCD processes more location- and context-specific could potentially preserve many of the benefits and resolve some of the paradoxes. For example, Bishop et al.37 demonstrated a library of interface functions invoked using a drag and drop interface builder. Using this design tool, a small team of clinicians and one or two engineers was able to totally control the design, appearance, and operation of every aspect of a model clinical information system for the ED at a single hospital. The design outputs were rapidly (overnight) and automatically compiled into an operational clinical information system executed in a Web browser. Through iterative testing and revision (UCD) the team converged on a system optimized for its particular workflows, data flows, and screen layouts from the ground up.37 Such a process could iterate rapidly because the software enables near real-time generation of a run-time system. Primary control by a user-led design team would increase the ability to identify and incorporate context-specific information flows and displays. Research to extend the power and specificity of UCD methods should receive strong support. It is important to note that developing more individualized interfaces can still be compatible with the presence of safety “guardrails” within systems and with the development of standardized “platform convention” representations for certain common steps in workflows.

 4.2.4 Common Patient Data Models and Clinical Portals: Currently, patient representations (the body of data representing a patient’s medical history and current medical status) exist mainly within siloed EHRs. Interoperability is poor, and representing a patient from the perspective of one EHR will invariably be limited. An emerging consensus finds that it would be superior to define and use a canonical, common patient data model to serve as the reference point for constructing and aggregating all patient data into an optimal representation for end-users. Such models would be stored in a “patient cloud,” and EHRs would access and synchronize with them using a standard interface, termed a “clinical portal.” The availability of the canonical model in a patient cloud external to EHRs could allow clinical judgment and clinical actions to be based on complete, up-to-date patient centered information, regardless of site or time of service, i.e. full interoperability. Patients would need full control over the privacy and sharing of their data and knowledge about healthcare to help them interpret the data in the models. Such functions would be provided by new and improved “patient portals” different from the clinical portals. Defining and standardizing a reference architecture for these patient clouds and demonstrating a reference implementation will be vital in accelerating progress towards this solution.

4.3 More disruptively innovative long-term solutions:

 4.3.1 User-Composable EHR Platforms: Another approach to achieving the needed flexibility is the development of widget-based EHR platforms, where a “widget” is defined as a single draggable window containing exactly the data selected by a particular physician. For example, a widget could contain a lab panel, text from a note or report, a graph of lab results, or a radiographic image, and custom widgets could be created by dropping individual chunks of information onto a blank widget. A physician could populate one or more screens, in real time, with exactly the widgets needed at a particular point in workflow and save them for reuse and sharing with others.38 Screens composed of information elements selected or created by the user increase the chance that all relevant items are on screen and exclude distractions, decreasing keyhole effect and reducing the need for screen transitions. Externalizing some of the information the user has to consider utilizes distributed cognition to reduce cognitive load. Spatially arranging the elements to construct a representation which better fits the user’s mental model and/or the external features of the task (e.g., problem priorities, diagnostic categories) facilitates clinical thinking and decision making.38 Significant research support for developing EHRs which can adapt to end users “on the fly” would be very useful.

 4.3.2 Artificial Intelligence: The most promising long-term approach to improving clinical workflow (and also the most technically challenging) is the application of machine learning (ML), natural language processing (NLP), and artificial intelligence (AI) methods. Current speech recognition and NLP systems are already close to having the capability to convert physician-patient discussions to text and to allow the physician to control many system functions by voice commands. ML should soon be capable of extracting the topics covered in the discussion, and then AI could become IA (intelligence assistance) designed collect, sort, and present clinical information related to those topics from multiple sources (previous notes, laboratory results, radiology reports, pharmacy records, etc.), organized to support clinical thinking and decision making.39,40 AI-enhanced CDS would also semantically search relevant scientific literature to present real-time evidence based recommendations such as differential diagnoses, suggested evaluations, risk calculators and clinical guidelines.39 It will be vital for AI-enhanced functionalities to present information and recommendations in a non-disruptive way, with minimal, if any, pop-ups, keystrokes, or mouse clicks. Despite the enormous amount of work necessary to make progress, strong research support in this area is justified by the potential gains.

4.4 Overall conclusion:

Relieving the physician burdens associated with clinical work flow will be extraordinarily challenging. Problems with technical complexity, high development costs, patient privacy, legal ramifications of system-related errors, unavoidable “black box” problems41 associated with AI and deep ML, and other issues will have to be solved. Many will likely argue that the concepts expressed here are too aspirational, too expensive, too revisionist, too risky in abandoning sunk costs, and too disruptive to traditional medical frameworks. However, we should accept the evidence of our own eyes. **Further incremental steps based on the current paradigm will not achieve our stated goals: better care quality/safety, better patient experience, and better cost efficiency. Only a combination of well-informed, empathetic physicians and sophisticated predictive tools that free them from clinical workflow burden and help them focus on patients and reason more accurately will achieve the high quality, patient-centered, cost-effective healthcare system we all desire.**42 Reaching this goal will require strong investment in clinical and academic health informatics research and comprehensive regulatory reform which frees physicians and EHR developers from current constraints and provides powerful incentives for them to explore more novel, creative solutions.

**References**

1. Hillestad R, Bigelow J, Bower A, et al. Can electronic medical record systems transform health care? Potential health benefits, savings, and costs. *Health Aff (Millwood).* 2005;24(5):1103-1117.

2. Sinsky C, Colligan L, Li L, et al. Allocation of Physician Time in Ambulatory Practice: A Time and Motion Study in 4 Specialties. *Ann Intern Med.* 2016;165(11):753-760.

3. Krenn L, Schlossman D. Have Electronic Health Records Improved the Quality of Patient Care? *PM R.* 2017;9(5S):S41-S50.

4. Kellermann AL, Jones SS. What it will take to achieve the as-yet-unfulfilled promises of health information technology. *Health Aff (Millwood).* 2013;32(1):63-68.

5. Arndt BG, Beasley JW, Watkinson MD, et al. Tethered to the EHR: Primary Care Physician Workload Assessment Using EHR Event Log Data and Time-Motion Observations. *Ann Fam Med.* 2017;15(5):419-426.

6. Belden JL, Grayson R, Barnes J. *Defining and Testing EMR Usability: Principles and Proposed Methods of EMR Usability Evaluation and Rating.* Chicago, IL: HIMSS EHR Usability task Force;2009.

7. Azar AM, Rucker DW, Verma S. Strategy on Reducing Regulatory and Administrative Burdens Relating to the Use of Health IT and EHRs. 2018; <https://www.healthit.gov/sites/default/files/page/2018-11/Draft%20Strategy%20on%20Reducing%20Regulatory%20and%20Administrative%20Burden%20Relating.pdf>. Accessed January 8, 2019.

8. Kuhn T, Basch P, Barr M, Yackel T, Medical Informatics Committee of the American College of P. Clinical documentation in the 21st century: executive summary of a policy position paper from the American College of Physicians. *Ann Intern Med.* 2015;162(4):301-303.

9. Payne TH, Corley S, Cullen TA, et al. Report of the AMIA EHR-2020 Task Force on the status and future direction of EHRs. *J Am Med Inform Assoc.* 2015;22(5):1102-1110.

10. Schlossman DM, Staggers N. Five Usability Barriers Preventing Health IT From Supporting Clinician Needs. 2016; <https://www.himss.org/news/five-usability-barriers-preventing-health-it-supporting-clinician-needs>. Accessed January 8, 2019.

11. Patterson ES, Lowry SZ, Ramaiah M, et al. Improving Clinical Workflow in Ambulatory Care: Implemented Recommendations in an Innovation Prototype for the Veteran's Health Administration. *EGEMS (Wash DC).* 2015;3(2):1149.

12. How Doctors Feel About Electronic Health Records: National Physician Poll by Stanford Medicine and The Harris Poll. 2018; <https://med.stanford.edu/content/dam/sm/ehr/documents/EHR-Poll-Presentation.pdf>. Accessed January 8, 2019.

13. Karsh BT, Weinger MB, Abbott PA, Wears RL. Health information technology: fallacies and sober realities. *J Am Med Inform Assoc.* 2010;17(6):617-623.

14. Friedberg MW, Chen PG, Van Busum KR, Aunon FM, Pham C, Caloyeras JP. *Factors Affecting Physician Professional Satisfaction and Their Implications for Patient Care, Health Systems, and Health Policy.* Santa Monica, CA: RAND Corporation; 2013.

15. Holman GT, Beasley JW, Karsh BT, Stone JA, Smith PD, Wetterneck TB. The myth of standardized workflow in primary care. *J Am Med Inform Assoc.* 2016;23(1):29-37.

16. Ancker JS, Kern LM, Edwards A, et al. How is the electronic health record being used? Use of EHR data to assess physician-level variability in technology use. *J Am Med Inform Assoc.* 2014;21(6):1001-1008.

17. Ratwani RM, Savage E, Will A, et al. A usability and safety analysis of electronic health records: a multi-center study. *J Am Med Inform Assoc.* 2018;25(9):1197-1201.

18. Van Noorden R. Nature News Blog: Global Scientific Output Doubles Every Nine Years. 2014; <http://blogs.nature.com/news/2014/05/global-scientific-output-doubles-every-nine-years.html>. Accessed January 8, 2019.

19. Bryant AD, Fletcher GS, Payne TH. Drug interaction alert override rates in the Meaningful Use era: no evidence of progress. *Appl Clin Inform.* 2014;5(3):802-813.

20. Caban J, Gotz D. Visual Analytics in Healthcare--Opportunities and Research Challenges. *J Am Med Inform Assoc.* 2015;22(2):s260-262.

21. Morita PP, Cafazzo JA. Challenges and Paradoxes of Human Factors in Health Technology Design. *JMIR Hum Factors.* 2016;3(1):e11.

22. Carter J. User-Centered Design "Gotchas"— Glad It's Not Just Me. 2016; <https://www.ehrscience.com/2016/03/07/user-centered-design-gotchas-glad-its-not-just-me/>. Accessed January 8, 2019.

23. Hultman G, Marquard J, Arsoniadis E, et al. Usability Testing of Two Ambulatory EHR Navigators. *Appl Clin Inform.* 2016;7(2):502-515.

24. Sorace J, Wong HH, Worrall C, Kelman J, Saneinejad S, MaCurdy T. The complexity of disease combinations in the Medicare population. *Popul Health Manag.* 2011;14(4):161-166.

25. Rezaeee ME, LeRoy L, White A, Oppenheim E, Carlson K, Wasserman M. Understanding the High Prevalence of Low-Prevalence Chronic Disease Combinations: Databases and Methods for Research. 2013; <https://aspe.hhs.gov/pdf-report/understanding-high-prevalence-low-prevalence-chronic-disease-combinations-databases-and-methods-research>. Accessed January 15, 2019.

26. Lamers F, Beekman AT, van Hemert AM, Schoevers RA, Penninx BW. Six-year longitudinal course and outcomes of subtypes of depression. *Br J Psychiatry.* 2016;208(1):62-68.

27. Rudin RS, Gidengil CA, Predmore Z, Schneider EC, Sorace J, Hornstein R. Identifying and Coordinating Care for Complex Patients: Findings from the Leading Edge of Analytics and Health Information Technology. *Rand Health Q.* 2017;6(3):2.

28. Nyweide DJ, Weeks WB, Gottlieb DJ, Casalino LP, Fisher ES. Relationship of primary care physicians' patient caseload with measurement of quality and cost performance. *JAMA.* 2009;302(22):2444-2450.

29. Carter J. Fixing EHR Usability Requires More Than Doubling-Down on Usability Testing and UCD. 2016; <https://www.ehrscience.com/2016/10/31/fixing-ehr-usability-requires-more-than-doubling-down-on-usability-testing-and-ucd/>. Accessed November 2, 2018.

30. Carter J. EHR Design: Unintended Consequences and Irreconcilable Differences. 2017; <https://www.ehrscience.com/2017/03/06/ehr-design-unintended-consequences-and-irreconcilable-differences/>. Accessed November 2, 2018.

31. Street RL, Jr., Liu L, Farber NJ, et al. Provider interaction with the electronic health record: the effects on patient-centered communication in medical encounters. *Patient Educ Couns.* 2014;96(3):315-319.

32. Street RL, Jr., Liu L, Farber NJ, et al. Keystrokes, Mouse Clicks, and Gazing at the Computer: How Physician Interaction with the EHR Affects Patient Participation. *J Gen Intern Med.* 2018;33(4):423-428.

33. Evans RS. Electronic Health Records: Then, Now, and in the Future. *Yearb Med Inform.* 2016;Suppl 1:S48-61.

34. Mandel JC, Kreda DA, Mandl KD, Kohane IS, Ramoni RB. SMART on FHIR: a standards-based, interoperable apps platform for electronic health records. *J Am Med Inform Assoc.* 2016;23(5):899-908.

35. Mandl KD, Mandel JC, Kohane IS. Driving Innovation in Health Systems through an Apps-Based Information Economy. *Cell Syst.* 2015;1(1):8-13.

36. Welcome to the Argonaut Project. 2018; <http://argonautwiki.hl7.org/index.php?title=Main_Page>.

37. Bishop RO, Patrick J, Besiso A. Efficiency achievements from a user-developed real-time modifiable clinical information system. *Ann Emerg Med.* 2015;65(2):133-142 e135.

38. Senathirajah Y, Bakken S, Kaufman D. The clinician in the Driver's Seat: part 1 - a drag/drop user-composable electronic health record platform. *J Biomed Inform.* 2014;52:165-176.

39. Lin SY, Shanafelt TD, Asch SM. Reimagining Clinical Documentation With Artificial Intelligence. *Mayo Clin Proc.* 2018;93(5):563-565.

40. Mehta N, Devarakonda MV. Machine learning, natural language programming, and electronic health records: The next step in the artificial intelligence journey? *J Allergy Clin Immunol.* 2018;141(6):2019-2021 e2011.

41. Knight W. MIT Technology Review: The Dark Secret at the Heart of AI. 2017; <https://www.technologyreview.com/s/604087/the-dark-secret-at-the-heart-of-ai/>. Accessed January 8, 2019.

42. Verghese A, Shah NH, Harrington RA. What This Computer Needs Is a Physician: Humanism and Artificial Intelligence. *JAMA.* 2018;319(1):19-20.