Abstract: Diagnostic error may be the largest unaddressed patient safety concern in the United States, responsible for an estimated 40,000–80,000 deaths annually. With the electronic health record (EHR) now in near universal use, the goal of this narrative review is to synthesize evidence and opinion regarding the impact of the EHR and health care information technology (health IT) on the diagnostic process and its outcomes. We consider the many ways in which the EHR and health IT facilitate diagnosis and improve the diagnostic process, and conversely the major ways in which it is problematic, including the unintended consequences that contribute to diagnostic error and sometimes patient deaths. We conclude with a summary of suggestions for improving the safety and safe use of these resources for diagnosis in the future.

Keywords: decision support; diagnosis; diagnostic error; electronic health records; health care information technology; misdiagnosis.

Introduction

The landmark report Improving Diagnosis in Health Care from the National Academy of Medicine (the NAM report) recently called attention to the unaddressed problem of diagnostic error, pointing out that 12 million Americans are misdiagnosed every year, with an estimated 40,000–80,000 deaths annually [1–3]. The report specifically emphasized the ever-expanding role that electronic health records (EHRs) play in determining the quality and safety of the diagnostic process, both for better and for worse. With electronic health records now approaching near-universal usage, it is very appropriate to review the ways that the EHR and health care information technology (health IT) support diagnosis, as well as the problems encountered in using these tools that detract from diagnostic safety and contribute to diagnostic error. Improving the safety of diagnosis will require that we identify and optimize the key benefits of the EHR that relate to diagnosis and understand and address its deficiencies going forward. Where appropriate, we will draw comparisons between the EHR and the paper record systems it replaces.

Although our focus is largely on the EHR and its functionality, the ultimate benefits and harms that accrue from using these systems are intimately related to how people use the electronic record and the particulars of the required tasks [4, 5]. A sociotechnical perspective is very helpful in understanding this complex system from a human factors perspective. In particular, these models emphasize that successful application of EHRs depend not only on the software but also on educated and careful users who understand how to get the best out of their particular medical record.

The potential benefits of health IT and electronic health records on diagnosis

The NAM report described diagnosis as a process, beginning with the patient gaining access to care and ending with assignment of a diagnosis (or a decision to defer this) and communicating the diagnosis to the patient. Health IT and the EHR have touched every step of the diagnostic process, from start to finish. We first consider the many ways that health IT and the EHR improves and benefits diagnosis at each of these steps, using the domains and examples listed in Table 1 [6]. Acknowledging that a great deal of future research will be needed to validate the benefits of these effects, each of these are now in active use at some or many health care organizations, and each has excellent potential to improve the safety of diagnosis.
Access to care

One of the most dramatic changes enabled by health IT and the EHR is that the site of care can move out of the physician’s office and into the patient’s home. By taking advantage of electronic portals [7] and asynchronous communication, patients can communicate with their health care team; new problems can be diagnosed as they arise, potentially avoiding hospitalization or readmission. Many envision the day when the scheduled “office visit” is a relic, replaced by just-in-time services provided remotely, using health IT and EHR as the vehicle for providing and documenting care. Telehealth functionality (see discussion below in “Collaboration for Diagnosis”) offers the opportunity to provide real-time consultation with experts in an ever-expanding list of subspecialties, another important demonstration of health IT improving access and quality of care.

Information gathering and access

Paper records are hard to read, easy to lose and seldom complete. Electronic health records, in contrast, potentially provide immediate, reliable and readable access to the patient’s health history. Besides these very welcome improvements, the EHR has enabled new functionalities that could not have been imagined with paper records. EHRs enable new care models, such as team-based care, where different members of a care team can contribute to clinical documentation from different sites and at different times [8]. The EHR allows team members, dispersed in location and time, to see the same information, communicate asynchronously and share in creating care plans, functionality that would have been far more challenging, if not impossible, with paper-based records. As other examples of the novel conveniences the EHR enables, images can be attached to notes to illustrate a finding, and records can be electronically searched to find a specific date or provider or diagnostic test. Many different applications are emerging to improve data collection for the electronic record. Automated tools that assist in obtaining the key elements of the patient’s history, such as “smart” clinical documentation forms in EHRs, have proven to be useful, and they complement the information gathered through in-person clinician-led interviews [9]. A further advance is to make it easier for patients to provide these data using kiosks and tablets in the waiting room. Practices are also experimenting with ways to interface with various types of patient-generated personal health records [10]. Health information exchange resources will improve

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Table 1: Ways that electronic health records and health IT improves the reliability of diagnosis, with examples of each.

<table>
<thead>
<tr>
<th>How health IT improves diagnosis</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enhances access to care</td>
<td>Using portals that link patients to their physicians and their medical records, diagnosis can take place without face-to-face contact</td>
</tr>
<tr>
<td>Provides access to patient information</td>
<td>EHRs provide easy access to prior medical records, even if remote and facilitate information sharing</td>
</tr>
<tr>
<td>Augments obtaining a reliable history and accurate physical examination</td>
<td>Templates (“smart forms”) ensure all appropriate questions are asked and relevant aspects of the physical exam are completed</td>
</tr>
<tr>
<td>Enhances the organization and timely display of information</td>
<td>Well-organized records; readable and searchable content; immediate access to test results</td>
</tr>
<tr>
<td>Provides decision support</td>
<td>Web-based differential diagnosis generators</td>
</tr>
<tr>
<td>Provides tools and calculators to assist in clinical decision making</td>
<td>Prebuilt tools to determine the need for appropriate screening or testing</td>
</tr>
<tr>
<td>Supports the intelligent selection of a testing strategy</td>
<td>Online guides to help select most appropriate imaging modality</td>
</tr>
<tr>
<td>Facilitates access to key reference information and guidelines</td>
<td>Web-based access to textbooks, Medline, peer-reviewed literature</td>
</tr>
<tr>
<td>Helps ensure reliable follow up</td>
<td>Reminders for patients about scheduled follow-up; reminders for providers to check on pending test results; patient registries</td>
</tr>
<tr>
<td>Supports screening for preventive measures</td>
<td>Population-level reports to identify who is due for screenings</td>
</tr>
<tr>
<td>Facilitates collaboration for diagnosis, for example, with subspecialists</td>
<td>Ability to share notes and images and to communicate asynchronously</td>
</tr>
<tr>
<td>Facilitates communication with the patient</td>
<td>Open notes allow patients to see their test results and progress notes</td>
</tr>
<tr>
<td>Helps measure diagnostic performance and provide feedback</td>
<td>Tools to detect patients with red flag conditions not yet followed-up; identifying earlier providers who may want to know that an earlier diagnosis has changed</td>
</tr>
</tbody>
</table>

Expanded from the list of El-Kareh et al. [6]
access to remote data, expediting diagnosis and reducing unnecessary retesting [11].

The organization and display of information

EHRs have the potential to improve diagnosis by making it easier to organize and display data in more meaningful ways. Note templates can be created that allow a specialty to customize their documentation for their own purposes. A particularly welcome feature that has been shown to improve information processing is the ability to display test data as a graph, instead of as a text result or a text list. Graphic displays facilitate identification of more subtle trends and patterns [12].

Decision support

Decision support, at least in a rudimentary form, was available with paper record systems. A sticker might be taped to the front of each chart as a reminder that the patient needs a flu shot, for example. Well-developed electronic record systems allow for implementing that functionality at a new level of sophistication and reliability, providing reminders for a host of preventive services, or problems that need scheduled follow-up, or providing for prominent display of information relevant to a decision the provider is about to make.

Many of the earliest health IT products focused directly on diagnosis [13–17], and others focused on treatment and management problems, such as antibiotic selection [18], and ventilator management [19]. The most prominent examples of decision support products that support improved diagnosis are the “symptom checkers” that assist in generating a differential diagnosis. These products provide suggestions on reasonable diagnostic possibilities to consider based on the key findings in a case, and these suggestions are available within seconds. Evaluations of these products have produced mixed results [20, 21], but at least some of these products improve the accuracy of diagnosis [22–24], and improve patient care [25]. Unfortunately, even when well-designed products are available, they remain underutilized [26, 27].

Another rapidly-expanding field is computer-aided diagnosis, and these software algorithms are being used in a wide range of specialties, including dermatology, and medical imaging for breast, colon and lung cancer [28]. Using “deep learning” approaches, computer-aided diagnosis improves both detection and characterization of visual abnormalities, such as lung or breast nodules, or pigmented skin lesions, and assigning these a diagnosis.

Tools and calculators to assist in clinical decision making

Clinical decisions can involve calculations that embedded tools embedded in the EHR can simplify and facilitate. Does a patient have renal insufficiency? The EHR can immediately calculate an estimated glomerular filtration rate knowing the patient’s age, sex, weight, and measured creatinine [29]. Does a patient have a high risk for atherosclerotic cardiovascular disease? The EHR can provide a calculated risk score using the Framingham formulas for this purpose. Hundreds of other examples can be found, for example, calculation of a risk score based on probability of a specific disease, or a clinical guideline to decide whether a patient should be further evaluated, treated as an outpatient, or requires hospitalization [30].

Intelligent selection of a testing strategy

There are currently over 4000 selectable laboratory tests, and a comparably bewildering number of imaging options. Although clinicians are highly competent in evaluating common complaints and conditions, for unusual conditions or ones where a choice of investigative options exist, electronic record systems can help simplify and guide these selections. EHRs can access and integrate, for example, recommendations on laboratory test selection from reference laboratories [31]. Similarly, preferred imaging strategies are available from online resources provided by the American College of Radiology [32]. Many healthcare organizations now require that clinicians use these electronic utilization management programs to improve appropriate test selection [33].

Reliable follow-up

Diagnosing a patient’s condition can take seconds, hours or months. EHRs facilitate reliable follow-up through reminder systems that track which patients need to be seen again and when. In some advanced EHRs, clinicians can create their own reminder list of patients and tests to follow-up on at a later date. Advanced EHRs also facilitate the creation of internal registries with the same purpose,
for example, a list of all the patients who need a follow-up colonoscopy at a later date either for screening or follow-up of a previously abnormal study.

Collaboration for diagnosis

Consultation from specialists is an integral part of many diagnostic evaluations. EHRs and health information exchange make it easier to share information back and forth between the referring and consulting physicians. Besides expediting the request for consultation, a shared EHR allows consultants and collaborators to see beyond the consult request per se and review whatever information may be relevant and necessary. Supplementation of the traditional phone call, some organizations provide direct communication in real time using secure messaging systems, or secure directed data transfer using standards such as the direct edge protocols [34].

Telehealth

Telehealth offers another approach to improve collaboration for diagnosis and to improve the quality of health care in general [35]. Timely expert consultation is a requirement for reliable diagnosis. Delays and difficulty accessing specialists have been cited as factors contributing to diagnostic error [36], problems that telehealth and electronic records can help to solve. One of the most successful applications of telehealth is to facilitate access to retinal specialists to diagnose diabetic retinopathy [37]. Teleradiology is another dramatic success story for diagnosis, providing access to appropriate specialists around the clock [38]. For teledermatology, “store and forward” remote consultation has been found to result in more timely diagnosis than the more conventional referral process, although remote consultation was inferior to “in person” examination for accurate diagnosis for pigmented skin lesion [39].

Measuring diagnostic performance and providing feedback

Electronic records make it easier to track populations of patients with the goal of monitoring diagnostic performance and safety. How many patients in our organization received appropriate follow-up of abnormal imaging? How many of my diabetic patients have not had a timely evaluation for retinopathy? Electronic records allow analysis and reporting at the level of a given physician, team, practice site or across an entire organization, functionality that provides the basis for modern organizational quality management. The SureNet program implemented in the Kaiser-Permanente Southern California system is an elegant example of how population-level monitoring of data in the EHR can detect patients at risk for harm for diagnostic error in time to prevent it [40].

Negative effects of health IT and electronic records on diagnosis

At the same time that electronic record systems contribute to successful diagnosis, specific features of EHRs have also created conditions that can degrade diagnostic safety [41]. A growing list of studies have identified issues in which health IT compromises performance, and leading examples are listed in Table 2. These go beyond inconvenience; the EHR is a major contributing factor in patient deaths and harm-related events [5, 42–50]. Automation by its nature is disruptive, inevitably creates unintended consequences and dramatically changes the nature of work.

<table>
<thead>
<tr>
<th>How health IT degrades diagnosis</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inaccurate documentation</td>
<td>Copy-paste note that contain wrong or misleading information; incomplete problem lists</td>
</tr>
<tr>
<td>Inadequate and missing information</td>
<td>Information lacking because of interoperability problems, or internal information sources that do not link to the EHR; erroneous entries that are never corrected; misplaced data; structured formats that obscure information</td>
</tr>
<tr>
<td>Information overload</td>
<td>Note bloat (excessive note length); alert fatigue</td>
</tr>
<tr>
<td>Usability issues that contribute to inefficiency and errors</td>
<td>Pick list errors; billing requirements that promote selecting a diagnosis before it is confirmed;</td>
</tr>
<tr>
<td>Impairs communication with the patient</td>
<td>The “i-Patient” problem</td>
</tr>
<tr>
<td>Impairs communication with other clinicians</td>
<td>Communicating through the EHR discourages direct communication</td>
</tr>
<tr>
<td>Consumes too much time</td>
<td>Burdensome documentation requirements</td>
</tr>
</tbody>
</table>
In this section we highlight several specific examples areas where the quality and safety of diagnosis has been compromised by EHRs.

Many of the features and functions already discussed as benefits of the EHR might also be classified as problems, depending on the particular EHR product being discussed, or how a given system is configured and used. As an example, EHR and configuration settings vary in terms of where a given test might be filed, making it harder, not easier, to locate critical information. The same diagnostic test may have different names in different organizations, creating similar problems.

### Inaccurate, inadequate and missing information

In the days of paper records, the dominant problem was simply finding it – the patients chart was too often "somewhere else". The EHR has helped solve that problem, but imperfectly. An example is the persisting problem in communicating critical test results: Appropriate follow-up does not reach 100% even in organizations with sophisticated and mature EHRs [52]. In one study, over 10% of critical alerts were never acknowledged within 30 days [53]. Similarly, a systematic review of laboratory tests pending at discharge from inpatient care found that 20%–69% lacked evidence of follow-up [54].

Information exchange to and from physicians’ office can be disrupted by problems with Internet connectivity, system security and firewall restrictions, and granting access to unlicensed personnel to access the data. Ambulatory practice sites may be only loosely associated with the organization (e.g. hospitals) responsible for legislating their practice and system functionality.

### The “copy-paste” problem

The “copy-paste” problem is one of the most ubiquitous and the most troubling concerns in using EHRs [55–57]. Electronic documentation makes it easy to reuse content from an earlier note. If modified and updated appropriately, this functionality can be a time saver for busy clinicians. Too often though, copy-paste functionality is used carelessly to summarize parts of the existing medical record, or in place of performing one’s own patient history or physical examination. Many organizations and authors have offered advice on minimizing the copy-paste problem, including comprehensive white papers recently sponsored by NIST [58], AHIMA [59] and the ECRI Health IT Partnership [60].

The copy-paste mentality degrades diagnosis in other ways as well. To the extent that documentation is inaccurate or outdated, the credibility of the entire electronic record is called into question, compromising the trust that underlies medical professionalism. “Note bloat” is a related but separate problem that impacts diagnosis by requiring the clinician to find the nuggets of key data buried in pages of unnecessary documentation. Finally, the too-facile recycling of old information tends to inhibit the ongoing questioning and reascertainment process that helps monitor diagnostic accuracy as illnesses evolve over time.

In stark contrast to the problems encountered with paper records, where charts were often incomplete or missing, EHRs create the opposite problem: information and cognitive overload. Note bloat and copy-paste problems contribute to this, along with an avalanche of alerts that providers need to digest and triage. Along with the myriad distractions and interruptions that characterize modern medicine, these factors contribute to cognitive overload, one of the major threats to reliable diagnosis.

### Usability problems

Usability problems refer to design choices that hinder efficient and effective work flow, and the current generation of electronic record systems is replete with problems of this type:

**Pick errors**: represent situations where the wrong selection is made from a long list on a drop-down menu. Similar errors were possible in the era of paper records as well (e.g. choosing the wrong chart) but have proliferated in the electronic era. It is just too easy to pick the wrong medicine from a long list, the wrong test or even the wrong patient [61]. Solutions are starting to emerge that address pick errors, for example, EHR interface terminology with improved search terms for test selection, Tall Man lettering for medication choices or using the patient’s picture as a way to ensure the correct record was selected [62], but these innovations have yet to achieve broad adoption.

**Design features that discourage reflection and thoughtful care**: One goal of electronic record systems is to facilitate documentation that supports and optimizes billing. This can lead to design choices in the EHR that work at cross purposes with the clinical goal of promoting
thoughtful, reflective care [63, 64]. An example is the requirement in many EHR systems to identify a specific diagnosis, or symptom, for each care encounter, and to choose this designation from a discrete list of ICD codes. This approach is ideal for electronic encounter capture for billing purposes but inhibits the clinician’s ability to consider a differential diagnosis, to explain why a certain diagnosis or testing strategy was selected or to document his or her thinking about the case. These thoughts require a narrative; they cannot be captured adequately in structured data. In addition, this too-early designation of a code for diagnosis becomes a diagnostic label that is likely to stick with the patient whether it is correct or not, and that discourages further consideration by subsequent providers the patient may see [65, 66]. We need to disentangle the roles EHRs have for billing and the roles they have for clinical care.

The EHR takes too much time: The time spent attending to the documentation requirements in the EHR adds up [67], to the point that physicians are spending as much time on the computer as with the patient [68, 69]. Replacing the information gaps that were so common with paper charts, there is now too much information, too many documentation requirements and too many alerts [70], all of which require time. A recent survey of 2509 primary care physicians found that providers received an average of 63 alerts each day; 69% of the respondents felt that the number of alerts was excessive, and 70% reported receiving more alerts than they could effectively manage [71]. Many physicians have lamented that if there were one thing that would improve diagnosis the most, it would be having more time. If the EHR is consuming time, instead of saving it, this is not good for diagnosis.

The impact on interpersonal communication and relationships

One of the fundamental concerns with the electronic record is that it can distance clinicians from patients, or from each other, altering the human element that is critical to effective care [64, 72]. This is most obvious in the examination room, as the clinician simultaneously tries to use the EHR while also interacting with the patient. The personal connection to the patient suffers, starting with loss of eye contact. Unless the physician makes special efforts to combat the problem, the patient rightly feels neglected. The problem persists long after the initial encounter, especially for inpatients, where clinicians may spend an inordinate amount of time taking care of the “i-Patient,” at the expense of time spent with the real patient [73, 74]. The electronic record, inadvertently, has effectively and perhaps inexcusably compromised the patient-to-physician relationship, the foundation of effective health care.

The EHR has also created walls, electronic silos [75], that distance clinicians from each other. Before electronic records, it was commonplace for clinicians to visit the clinical laboratory, the radiology department or a consultant to discuss results from laboratory tests or imaging, or a referred patient. These rich discussions, and the personal relationships that were established as a result, have essentially disappeared as the EHR has become the de facto vehicle for communicating information [72].

The true impact of this cultural change has yet to be evaluated, but it seems likely that disrupting face-to-face communication will have negative consequences. The result will be episodes like the one illustrated by the first patient misdiagnosed with Ebola in the United States. The ER triage nurse who first interviewed the patient succeeded in obtaining a history of recent travel to an endemic region. This key finding was duly recorded in the EHR, an entry that was missed by the treating physician, who sent the patient home, delaying the diagnosis of his infection [76]. In the pre-EHR era, there is a good chance the nurse would have mentioned this key bit of data to the physician personally, or it would have been front-and-center on the paper ER note.

Ideally, the medical profession would prescribe the ideal culture to optimize the quality and safety of clinical care, and health IT products would be designed to support this. Instead, we too often are required to compromise our cultural norms, or somehow adapt them, to accommodate suboptimal health IT systems. In the Ebola case, for example, the EHR would hopefully support bidirectional nurse-to-physician communication, not inhibit it.

Other issues: Space precludes us from discussing a host of other issues that detract from diagnostic quality, including inconsistent and incomplete vocabularies for structured data elements, and variability and lack of specificity for how diseases are defined and designated. EHRs require constant maintenance. Decision support rules need to constantly updated, as an example, and failures can lead directly to errors and harm [77]. A final problem is the lack of a “gold standard” for evaluating health IT and EHR functionality. Evaluations of decision support products to assist with differential diagnosis, for example, are currently limited to comparing different systems to each other, not to a gold standard [78, 79].
The future of electronic records and diagnosis

Although clinicians are learning to balance the benefits of the EHR with the new challenges it poses, they are also considering how electronic records can improve diagnosis in the future. Researchers have presented a vision for this evolution that focuses on improved data management and documentation [6, 63, 80, 81]. The recent National Academy report “Improving Diagnosis in Health Care” also lists priorities for improving the medical record in support of diagnosis [1].

An important area for exploration is how electronic records could facilitate the longitudinal aspects of patient care. This could begin with the ability to capture the chief complaint, the symptoms that were the reason for the patient’s visit. The inability to reliably identify and track chief complaints has seriously hampered research efforts to study and improve diagnostic quality. Second, we need tools that eliminate the need to recapture at each encounter data that are relatively static, like the family history and many aspects of the patient’s history that do not change between encounters. Some of these entries might be “red flag” conditions that could be designated and used in decision support, such as a strong family history of early coronary disease or breast cancer [81]. Electronic record systems could support longitudinal displays that better illustrate the patient’s clinical course over time and their response to treatment. Improved capture and documentation of the date and time diagnostic tests were performed, and care was delivered would also promote the goal of achieving failsafe communication and follow-up. Systems in the future could ensure that test results are communicated and acted upon so that nothing falls “between the cracks”. Patients needing periodic follow-up, for example, after successful chemotherapy, could be reliably identified and notified.

Better support of clinical reasoning

Better support of clinical reasoning would be a welcome and valuable feature in future record systems. This should begin with moving away from documentation based on menu-based selections, relying more on the richness of free text notes. Capturing the clinician’s clinical reasoning is an essential element in support of diagnostic quality. “Downstream” clinicians will have a better understanding of these earlier considerations and will have a better concept of which diagnoses are truly established and strongly supported, which are tentative and need further consideration. Clinical documentation should allow the clinician, and others reading a note, to acquire a sense of the certainties and uncertainties that existed at a particular point in time, and how these were considered. Advances in natural language processing (NLP) can bridge the gap between free text notes and the structured data needed for administrative purposes and quality management. Use of NLP could allow EHRs to retain free text narratives and the rich dialogues that capture the clinical reasoning that underlies diagnosis, while still being able to extract out the structured-data elements that are needed in support of billing and quality monitoring.

Decision support should be intelligent and able to provide context-relevant information “on the fly”, decreasing the need for ad hoc searches of the medical record [82]. Ideally, the EHR would know and anticipate the needs of the user and present the right information, organized in the right format, at the right time, to optimize clinical workflow.

Improved problem lists

Improved problem lists would also be welcome [83–85]. EHR problem lists tend to resemble their paper counterpart in being outdated and inaccurate. Ideally, assuming providers could agree on the key principles, problem lists in the future could be automatically updated, could convey some sense of the support for given diagnosis and its probability of being correct and would be cleansed of any previous diagnoses that are inactive.

Patient engagement

Medical record systems will facilitate patient’s accessing and contributing to their own medical record. There is growing evidence that engaged patients have improved care outcomes [86], and more reliable diagnosis could be one of these. Engaged patients could help populate the background information on their medical history, preventing the documentation errors that now exist with documentation that is “second hand”; it is likely that a patient’s own documentation will be more accurate than what the clinician tries to capture and record. The “open notes” initiative is expanding rapidly, providing patients with “read” functionality, and the ability to now act as their own safety net to make sure documentation is accurate and that important diagnostic test results are not
overlooked [87]. Patient-facing applications have enormous potential [88]; “open notes” is just the beginning.

**Predictive analytics**

The ability to integrate and learn from “big data” would enable several novel applications that could improve diagnosis. One possible application is to “push” reasonable diagnostic possibilities given the key findings of a patient with a new concern, for example, combining data to enhance early detection of sepsis [80]. Conversely, one can envision “error checking”, where proposed diagnoses that are in conflict with data in the EHR could be identified. Second, “big data” applications could enable population-level comparisons, where all of the patients with a given diagnosis could be compared to identify outliers that merit further investigation, or common trends that would never have been obvious in single-patient observations.

**Using health IT to prevent diagnostic error or harm**

Electronic data create an opportunity to identify patients at elevated risk for diagnostic error and either prevent the error or mitigate harm. The SureNet (formerly the Safety Net) program at Kaiser Permanente Southern California, for example, identifies patients with red flag findings suggestive of colon cancer (positive tests for fecal occult blood, or new iron deficiency anemia) who have not had appropriate imaging or endoscopy to investigate the problem and alerts providers to make sure the findings are followed up [40]. Similarly, “trigger tools” that search out electronic data can follow the track of abnormal laboratory test results sent to providers to ensure the abnormalities are acknowledged and acted upon [89]. The value of trigger tools to improve diagnosis has been confirmed in prospective randomized trials, effectively reducing the time to evaluation for patients with prostate and colon cancer [90, 91].

**Promoting expertise and combatting overconfidence through feedback**

Developing expertise requires accurate and timely feedback on performance, and diagnostic performance would similarly benefit from improved feedback [92]. Feedback is also the best antidote to clinician overconfidence that develops in the absence of meaningful feedback [93]. In the absence of any feedback, physicians, like everyone, assume that their answers are all correct [94]. Medical record systems in the future could facilitate feedback by informing physicians that their patient’s diagnosis has changed, for example, as the patient moves from an ambulatory clinic to the ER and then the ward or the ICU. This type of automated systematic feedback on diagnostic performance has great potential but is virtually non-existent [6, 92]. El-Kareh et al. [6] found only one study reporting the impact of systematic feedback on clinical diagnostic performance [95].

**Solving the “i-Patient” problem**

A large challenge for the staff who design and use electronic records is to somehow restore the human interaction essential to the patient-clinician relationship. Thoughtful ways to incorporate the EHR in patient-focused practice may be part of the answer. One simple suggestion is to place the display screen so that both the physician and the patient can see it and interact with it equally [96, 97]. Another promising approach is to use scribes, who can interact with the EHR, freeing the clinician to focus on the patient [98]. These are just first steps, and just in the ambulatory setting. EHR designers should strive to design systems that allow us to spend more meaningful time with patients in all settings, not less.

**Summary and conclusions**

The electronic health record has had a profound impact on the diagnostic process in clinical practice. Although the benefits the EHR offers are extensive and important, the concerns and negative consequences that are increasingly identified are also very real and very problematic. The challenge moving forward will be to continue building on the power inherent in digital data and machine-aided storage, sorting and management of information to promote the reliability and safety of diagnosis by overcoming issues of usability, quickly addressing unintended consequences as they arise and somehow restoring or even promoting the human element of the clinician-patient relationship that is so critical to successful diagnosis.

There is intense interest at the present time to improve the interoperability, usability and other generic aspects of electronic health records. Progress in these areas would go towards improving diagnosis, but we are asking the vendor community, as well as the clinical users, to think
more specifically about functionality and usage that would improve the diagnostic process. Major recommendations in this regard, based on recent diagnostic process and outcome frameworks [1, 99], are summarized in Table 3. The list includes several functionalities that are not typically offered in the current generation of EHRs, including better ways to follow clinical care over time, data aggregators to be used at acute points of care, smarter decision support that is well integrated in clinical workflow and detects the risk of harm, ways to make diagnosis easier, timely feedback on diagnostic performance and functionality to make patients a partner in the diagnostic process.

Table 3: EHR and health IT functionality that would improve diagnostic quality and safety.

<table>
<thead>
<tr>
<th>Access to care</th>
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<tbody>
<tr>
<td>VC Provide communication portals to patients at home; support bidirectional secure communication</td>
</tr>
<tr>
<td>VC Support open notes</td>
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<tr>
<td>VC Support telehealth and mobile e-health applications</td>
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</tbody>
</table>

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<thead>
<tr>
<th>Patient-physician encounter</th>
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<tbody>
<tr>
<td>V Support patient engagement in the encounter (e.g. patient-friendly displays)</td>
</tr>
<tr>
<td>V Provide smart templates for patients to enter static (family and social history) and dynamic data (reason for the visit, past history, medications, review of symptoms)</td>
</tr>
<tr>
<td>VC Provide decision support to assist physicians in asking all the right questions and gathering all of the relevant data in the history and physical examination</td>
</tr>
<tr>
<td>V Support team-based diagnosis</td>
</tr>
<tr>
<td>V Improve ways to capture documentation and preserve face time with the patient</td>
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<table>
<thead>
<tr>
<th>Clinical reasoning</th>
</tr>
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<tbody>
<tr>
<td>V Develop ways to organize data and present it optimally at the point of care</td>
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<tr>
<td>VC Incorporate decision support functionality to aid in calculations</td>
</tr>
<tr>
<td>VC Incorporate decision support functionality to generate an appropriate differential diagnosis; facilitate documentation of the differential diagnosis</td>
</tr>
<tr>
<td>V Allow free text entry to document clinical reasoning</td>
</tr>
<tr>
<td>VC Provide access to relevant medical knowledge at the point of care</td>
</tr>
<tr>
<td>V Facilitate data searching (e.g. finding all notes, visits, and tests in reference to a patient’s cardiovascular problems)</td>
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<tr>
<td>VC Improve the problem list; be able to designate uncertainty about a diagnostic assignment; use decision support to optimize problem list accuracy</td>
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<table>
<thead>
<tr>
<th>Diagnostic testing and consultation</th>
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<tbody>
<tr>
<td>VC Provide decision support for appropriate selection of diagnostic tests</td>
</tr>
<tr>
<td>VC Facilitate communication to appropriate expertise at the point of care (consultants, librarians, radiology and clinical lab liaisons)</td>
</tr>
<tr>
<td>V Display time-based data graphically (lab tests, disease activity, medications utilization, etc.) and in relation to other selectable clinical information</td>
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<tr>
<td>V Utilize computer-aided diagnostic algorithms to improve detection and classification of X-rays and other visual data</td>
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<tr>
<th>Follow-up</th>
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<tbody>
<tr>
<td>VC Support clinicians being able to generate their own reminder list of items needing follow-up</td>
</tr>
<tr>
<td>VC Support test-result communication and ensure the feedback loop is closed</td>
</tr>
<tr>
<td>V Support registries and reminders to identify patients who require screening or follow-up (e.g. diabetics due for retinal screening, patients with colonic polyps who need follow-up screening for colon cancer)</td>
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<tr>
<td>V Develop functionality to automate feedback on changes in diagnosis or harm</td>
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<tr>
<th>Diagnostic safety functionality</th>
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<tbody>
<tr>
<td>V Facilitate use of trigger tools to identify patients at risk for harm</td>
</tr>
<tr>
<td>V Support interoperability so that all relevant medical information can be gathered and used effectively at the point of care</td>
</tr>
<tr>
<td>V Be able to capture presenting complaints and descriptors as structured data elements, or extracted from free text by natural language processing</td>
</tr>
<tr>
<td>V Discourage designation of a diagnosis prematurely; allow as-yet-undiagnosed problems to be designated as such (e.g. NYD = not yet diagnosed)</td>
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<tr>
<td>V Facilitate ways to monitor diagnostic performance (timeliness, accuracy)</td>
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<tr>
<td>VC Support high-quality documentation and preclude inappropriate copy-paste usage; support ways to discourage inappropriately long notes</td>
</tr>
<tr>
<td>V Consider how to combat information overload; minimize inappropriate alerts</td>
</tr>
<tr>
<td>V Develop predictive analytic approaches to suggest likely diagnoses not considered, and identify inconsistencies between assigned diagnoses and existing data</td>
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</table>

Responsibility for each item is indicated in the first column as residing primarily with EHR vendors (V) or the clinical users (C) as well.
Although the EHR is fundamental to achieving these high levels of reliability, it goes without question that culture, system redesign and full provider participation will also be critical elements in efforts to realize the highest levels of performance. Ensuring that the EHR performs optimally in clinical settings requires not just optimizing the software but also consideration of all the sociotechnical factors that determine performance in using health IT applications [4, 100, 101]. The user is critical in determining optimal performance, which can obviously be compromised if clinicians and patients do not take advantage of features that are available. Patients are slow to use communication portals, for example, and physicians have a reputation for underutilizing and disregarding electronic help and suggestions [26, 27, 102]. Overconfidence in their abilities may underlie the observation that clinicians do not take advantage of resources that could help them make better decisions [93].

EHR designers need to continue focusing on the how the EHR can meet the needs of clinicians, instead of providing products and functionality that clinicians need to adapt to. Similarly, clinical users need to use these tools appropriately. Ideally, at that point, the EHR will become “a life raft for improving care, not an anchor” [72].

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