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Electronic health information in use: Characteristics that support employee workflow and patient care

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Abstract
The aim of this investigation was to assess helpful and challenging aspects of electronic health information with respect to clinical workflow and identify a set of characteristics that support patient care processes. We conducted 20 semi-structured interviews at a Veterans Affairs Medical Center, with a fully implemented electronic health record (EHR), and elicited positive and negative examples of how information technology (IT) affects the work of healthcare employees. Responses naturally shed light on information characteristics that aid work processes. We performed a secondary analysis on interview data and inductively identified characteristics of electronic information that support healthcare workflow. Participants provided 199 examples of how electronic information affects workflow. Seventeen characteristics emerged along with four primary domains: trustworthy and reliable; ubiquitous; effectively displayed; and adaptable to work demands. Each characteristic may be used to help evaluate health information technology pre- and post-implementation. Results provide several strategies to improve EHR design and implementation to better support healthcare workflow.

Keywords
data display, electronic health record, human factors, medical informatics applications

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Introduction

Health information technology (HIT) offers many advantages: centralized information, improved text readability, and mechanisms to promote evidence-based practice guideline adherence and patient safety, to name a few[1–5]. HIT has enhanced many aspects of patient care. It has also introduced new challenges that did not exist with paper medical records, such as logins, reactive alerts that interrupt workflow, and computer system downtimes. HIT has introduced new variables in an already complex medical environment, and can create different gaps and pathways to failure[6, 7].

Moreover, even when EHRs are fully implemented, paper use persists[8], suggesting that the EHR may not adequately support clinical workflow. Powsner et al. contend that information design can simplify or complicate navigation through, and interpretation of, patients' data in the EHR. Thus, information design features that increase the demand on clinicians' cognitive processes (e.g. perception, attention, and memory) need to be avoided to reduce the likelihood of using paper processes and also ensure satisfactory EHR performance[9]. Effective electronic information and EHR design may support clinical workflow and promote safe, quality care, yet there is limited knowledge of what electronic information characteristics can aid workflow and patient care goals[10].

One strategy to identify electronic information characteristics needed to support clinical workflow is to elicit the input of individuals who use these systems[11, 12]. Therefore, we analyzed employee interviews from a United States Veterans Affairs Medical Center (VAMC) to assess helpful and challenging aspects of electronic information. The VA is a successful leader in HIT development and implementation; its EHR, the Computerized Patient Record System (CPRS), is used by over 100,000 healthcare workers nationwide. CPRS is used by clinical staff as well as administrative and support staff who aid clinicians' efforts to deliver quality patient care. Employees use CPRS along with other HIT software packages outlined in Table 1. During the interviews, VA employees described work processes where they continue to use paper, some of which may reflect perceived deficiencies with the EHR design[13–16]. We qualitatively analyzed healthcare employees' experiences, as part of a secondary analysis, and identified several information characteristics that support clinical workflow. These findings may be beneficial when designing or updating other EHRs and can aid EHR evaluation pre- and post-implementation.

Methods

We collected data via 20 semi-structured interviews, which included a variety of VAMC employees: three physicians; two pharmacists; two nurse practitioners; four registered nurses (RNs); two health technicians; one dietician; three administrators; and three local IT specialists, including two clinical application coordinators (CACs) with clinical backgrounds. Both men and women were recruited, and participants represented a wide range of work experience, varying from 1 to 31 years with an average of 12 years of experience. This variation is important because the facility transitioned to an electronic health record approximately 10 years ago.

Study documents and procedures were approved by an institutional review board (IRB). Three researchers (JS, AR, and CJ) conducted semi-structured interviews between October 2007 and March 2008. (Interviews were scheduled for 30 minutes; average length was 27.5

Table 1. Overview of selected VA software packages: these systems are part of the VA's EHR or are intended to be used in coordination with the EHR.

Abbreviation	Software name	Description/function	Ref.
CP Hemo	Clinical Procedures Hemodialysis	For patients on hemodialysis; intended to transfer patient measurements (e.g. blood pressure) into CPRS real-time. Clinical procedures integrates CPRS with the clinical instrument used for dialysis; at the time of this study, CP Hemo was not widely implemented across VAMCs	
CPOE	Computerized Provider Order Entry	Incorporated into CPRS; prescribers can order most medications and some labs	[11]
CPRS	Computerized Patient Record System	A component of VistA; graphical user interface for some aspects of DHCP/VistA framework; contains patient records, CPOE functionality, lab results, alerts, progress notes, reports and reminders, etc.	[12]
DHCP	Decentralized Hospital Computer Program	DOS information framework implemented in VA in 1982, later renamed to VistA; currently used by VA outpatient pharmacists to fill medication orders	[12]
MRMS	Microsoft's Rights Management Services	Provides secure e-mail messaging; can set restrictions on document use: printing, forwarding, editing, etc.; often referred to as 'RMS' but different than RMS system described below	[13]
PISCES	Python Implementation of the SPKI (Simple Public Key Infrastructure) Certificate Standard	Provides secure system for VA software	[14]
RMS	Resource Management System	Used for scheduling patient appointments and is integrated with VistA	
VistA	Veterans Health Information Systems and Technology Architecture	Information technology framework for ~1300 care sites	[12]
VistAWeb	(see VistA)	Used by VAMCs to view remote patient data from other VAs; separate package from CPRS	[15]
VPN	One-VA Virtual Private Network	Allows remote veterans service organizations (i.e. clinics that have partnerships with VA to care for veterans) to access VA systems securely	[16]

Many of these are referred to later in the text. If a reference is not provided in the right-hand column, then the information was derived from study data and/or input from a local VA IT specialist (see acknowledgements).

minutes.) As part of an initial inquiry into paper persistence, researchers asked how paper is used to supplement, support, or circumvent the EHR; questions guided the semi-structured interviews in a flexible, yet repeatable, manner[8, 17, 18]. Three examples of interview questions are shown below:

- Are there any times you use paper to supplement CPRS? If so, why?
- Have you ever manually transformed patient data from CPRS onto paper? If so, please explain.
- Can you think of any examples where information exists on paper and also in CPRS? If so, why is the information in both formats?

If the participant agreed, interviews were audio recorded to back up handwritten notes. Key-informant interviews not only provided information on paper-based workarounds, reported elsewhere[13], but also revealed problematic aspects of electronic health information. In addition, participants often provided examples of challenging HIT work processes that did not involve paper. Paper and non-paper examples naturally shed light on challenging aspects of electronic information. Therefore, interviews were a rich data source for this secondary study and revealed specific strengths and weaknesses of electronic information. Two researchers (AR and JS) independently coded the typed scripts based on emergent information characteristics using inductive qualitative analysis (i.e. without a predetermined coding scheme)[3, 8, 19] and identified themes for information characteristics across interviews. Oftentimes, a given participant provided two or more separate examples of the same characteristic. In addition, some examples clearly related to two or more distinct information characteristics and were assigned multiple codes accordingly; this approach has been used by other qualitative investigations[20, 21]. Examples were designated as positive or negative if the participant described how HIT supported or failed to support that information characteristic, respectively. The two researchers met for 12 hours spread across 11 meetings and discussed each coding discrepancy until reaching consensus.

Results

Data analysis revealed four primary domains encompassing 17 distinct emergent information characteristics (Figure 1). These characteristics were derived from 199 specific examples provided by healthcare employees. Participants provided examples of paper persistence and examples of problems with the EHR that did not involve the use of paper. Healthcare employees described 45 cases where HIT supported these characteristics and 154 cases where HIT was challenging or problematic (see Tables 2–5). Unless otherwise noted, each characteristic was described by a variety of individuals, including inpatient and outpatient clinical frontline workers as well as administrative and IT staff. Below, these characteristics are discussed and grouped by the primary domains in Figure 1. Although we examined the data for new themes during the entire data analysis, no new characteristics emerged after the first nine transcripts were analyzed: the remaining transcripts supported the characteristics revealed by the first nine interviews. This suggests that, across participants at this VAMC facility, a sufficient level of saturation was achieved[22].

Trustworthy and reliable

Consistent. Participants provided examples of how electronic information was not consistent within HIT, between HIT and paper documents, and also between HIT and individuals' personal knowledge. One pharmacist described an inconsistency within CPRS that can lead to confusion:

> Doctors often look at the orders tab instead of the medication tab. The orders tab does not get updated like the medication tab. For example, the orders tab might say medication X has three refills left while the medication tab says medication X has no refills left. This causes problems.

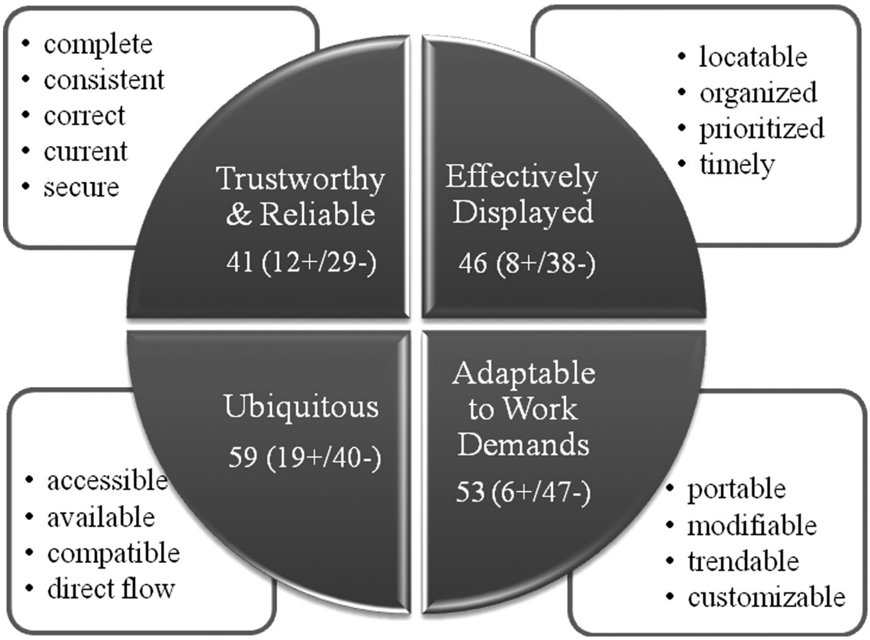

Figure 1. Primary domains and corresponding electronic information characteristics that support healthcare workflow and associated patient care. Characteristics were derived from study data. The total frequency is shown for each domain and is followed by the (positive/negative) frequencies, respectively.

A health technician described how inconsistencies in HIT ordering processes can lead to system failures. She mentioned that magnetic resonance imaging (MRI) scans, but not computerized axial tomography (CAT) scans, can be entered into CPRS and automatically scheduled. She explained, ‘Doctors don’t [always] realize this, and order a CAT scan using the same type of process they [use to] order the MRI. For the CAT scan, they put the order in but it never gets scheduled.’

Current. Obtaining current electronic information was sometimes challenging. According to a pharmacist,

> [People] have to go back in and manually document [rate changes of IV drips] … In the wards, [we] never really know what rates medically should be running unless the doctor goes in and physically changes it or the nurse changes it [in CPRS/BCMA (Bar Code Medication Administration)], but they don’t do this very often.

Complete. A nurse practitioner (NP) described how electronic information is not always complete: ‘We have to look at both hard charts and CPRS when we make rounds on [dialysis] patients. The information is not in one place. Having it in two places is a detriment to patient care continuity.’ Incomplete electronic notes were also a concern. An office manager’s example is shown in Table 2. As one physician pointed out, ‘My colleagues write notes that are more choppy. I have had nurses comment to me that my notes are very good and explain what’s going on with the patient … [Good note documentation] is not a social norm.’

Correct. In some cases, incorrect information hindered clinical workflow. Examples involved incorrect note titles, inaccurate medication lists (see Table 2), and problems with patient phone numbers. One RN explained, 'But to change the phone number, you have to do that in DHCP – it's still in DHCP [not CPRS]. I don't have time for that. And some of the phone numbers are bad [incorrect].' In addition, a CAC mentioned that it is difficult to identify the correct patient when two individuals share the same name since full social security numbers are 'no longer printing off on work copies'. According to the CAC, this was implemented as a national VA security measure and only personnel at the national level can change these features.

Secure. Participants provided more positive than negative examples of electronic information security. Participants discussed automatic electronic logouts; referral forms sent to outside clinics via the virtual private network (VPN); and future technologies for electronic signatures (see Table 2). However, one NP voiced frustration about a lack of universal e-mail security: 'I can't send information securely [to a non-VA e-mail account] so I print it off. The doctor may have e-mail here [at VA] but he uses [a university account].'

Ubiquitous

Accessible. Accessibility was influenced by both electronic and physical factors. Interviews revealed accessibility problems when secure login processes were too long, systems were running slow, or computers were down. Accessibility issues were reported by clinical workers and support staff. One health technician explained: 'We have a contingency kit: EKG, X-ray, labs, old forms. Patients can take [these] to labs.' However, not all areas of the hospital appear to handle computer system failures with ease (see Table 3). Four examples illustrated that poor accessibility was due to a lack of computer workstations in inpatient or specialty areas. One employee said she had difficulty 'access[ing] the computer' in the ICU [intensive care unit] and inpatient floors where she works because 'the terminals are often busy' and 'many computers say, "nurse use only"'. Another participant indicated that computer demand was high in psychiatry, where patient records are populated by a 'tremendous amount' of notes. Accessibility was sometimes impeded by a security measure. One participant stated,

> if I'm talking to the patient for 5 minutes, the computer will automatically log me out and then I have to log back in. I might have to do that 15 times over the course of the day. I realize it's a security measure but [it impacts computer use].

Available. Information availability was the second characteristic that was more commonly described in a positive manner. A RN provided a clear example of this:

> Now [with CPRS] all the information is at your fingertips … [Before, patients] were getting their narcotics from more than one clinic … If the pharmacist was sharp, they might catch it … [Now], we [can] say to the patient, 'No, you took your last narcotics on this date.'

The most common cause of hindered information availability involved non-VA sources, which typically are not yet integrated into the VA's EHR.

Compatible. Compatibility issues were noted between many different software packages: CPRS/DHCP; CPRS/PISCES; CPRS/CP Hemo; CPRS/RMS; and RMS/DHCP. (See Table 1 for

Table 2. Overview of emergent information characteristics, frequency, and representative examples for the 'trustworthy and reliable' domain (Figure 1); see Table 1 for software descriptions.

Category	Freq	Description	Positive example	Negative example
Consistent	9(0+/9–)	no conflicting duplication; same across sources	no positive examples identified	"There is no consistency where people put reports [in CPRS]."
Current	11(3+/8–)	information is up-to-date	"...having all those blood pressures come across into CPRS [real-time] is a really neat thing."	"The clerks go to the 'Reports' tab page to pull up future appointments [because] the info is not synced [with cover sheet]."
Complete	7(3+/4–)	All of needed data are available, not just partial information	"Sometimes we get a [paper] list of medications, for example, if the meds weren't filled through us. They also bring herbal lists. I document these in CPRS."	"[Sometimes] they do not document in the new note what the echo is for."
Correct	7(1+/6–)	information is accurate	"It's a wonderful machine, it's very accurate in monitoring what it needs to monitor [and sending to CPRS]…"	"The medication list is not always 100% accurate."
Secure	7(5+/2–)	only the appropriate people can access or modify the information	"We are currently developing a method of using our signatures pad to get the signatures [for consents] into VistA Capture."	"Applications time out at 10 min, if a person pops in before application times out, you could put in meds under previous user."

a description of these software packages, and Table 3 for an example of a CPRS/RMS incompatibility.) In most cases, employees utilized workarounds to alleviate the incompatibility. This often involved looking up information in more than one software package. A dietician explained, 'I have stuff in both DHCP and CPRS that I have to look up.' Another participant stated, 'We use CPRS, HL7, Quattromed, dictation systems, etc. These all have to interact with CPRS. Even though they say they [commercial products] are compatible, we have to go in and correct things [related to CPRS integration].'

Direct flow. One pharmacist emphasized the benefits of automation within HIT (see Table 3); even so, interviews revealed several examples where information did not flow directly from person to computer or did not flow automatically within HIT. Three examples illustrated cases where information is 'handed off' one or more times before it enters the computer. In addition, a RN explained: '[a] doctor will write notes while a nurse writes orders in CPRS. [This helps reduce] redundant processes: notes versus orders. A lot of repeat information has to be entered into CPRS.' One NP was particularly excited about the possibility of enhancing direct information flow. She said enthusiastically, 'It would be nice if we could tag a patient – for any type of transplant – and have the packet [electronically] accumulate through CPRS and have it auto faxed to VACO [VA Central Office].' This process currently involves a lot of time and paperwork.

Effectively displayed

Locatable. One health technician was satisfied with information locatability in CPRS (Table 4). However, several negative examples involved locating scanned documents within CPRS and searching for information within these documents; these contained information for MRIs, electroencephalograms (EEGs), etc. One office manager stated, 'Sometimes physicians will get frustrated and say, "Where is it?"' An RN also expressed frustration: 'I wish the notes were titled better. If a note title said "EKG from 1967", I know to skip it. If it said "visiting nurse contact information", then I can find what I'm looking for.' According to another RN, '[We] can't search in CPRS. [There is] no help menu. [We] have to know [exact] location in CPRS, especially for consults.'

Organized. Several participants described various examples of how CPRS was not always organized well for their work. According to one interviewee, 'CPRS is bad at flowcharting. Nurses need to flowchart for a patient all day long.' Templates can be built to help with this, but the participant implied that these would not match the efficiency of paper flowcharting. A second participant explained, '[We] need tabs at the bottom of CPRS for psychiatry – psychiatry has a tremendous amount of notes – ties up the computer[s].' Furthermore, a pharmacist stated:

Table 3. Overview of emergent information characteristics, frequency, and representative examples for the 'ubiquitous' domain (Figure 1).

Category	Freq	Description	Positive example	Negative example
Accessible	15(2+/13–)	computers/EHR can be accessed	"There are some good aspects of the EHR. Now, providers' information is more accessible."	"When CPRS is down, it's like flying blind. Everyone forgets how to do things without CPRS."
Available	13(8+/5–)	information exists in system	"[Before CPRS] patients did not know the names of their medications...With CPRS, we have the data there at our fingertips."	"Patients will come to me and say they've faxed the info from outside doctors. This is somewhat risky…[it may not get in system]"
Compatible	20(7+/13–)	information is standardized/ automated and shared across systems	"The remote data function tells me data for that patient from all VA's [VAMC's]. It's even merged with DoD now."	"...sometimes when appointments are scheduled in RMS it doesn't carry over to CPRS…. CPRS doesn't show the appointment at all."
Direct Flow	11(2+/9–)	information flows directly or automatically without an intermediate step	"When we used [paper] encounter forms, the wait time in pharmacy was on the order of hours. Now, the wait is on the order of minutes due to automation."	"The order is processed from the paper form before it gets entered into the computer."

DoD: Department of Defense. See Table 1 and text for other definitions.

> In CPRS it is hard to compare inpatient versus outpatient medications since they are organized by expiration date on the orders tab … [We] really need two screens to be able to compare [them]. Instead, [doctors] have to go back and forth and scroll down in windows – this is hard.

Prioritized. In 13 cases, information was not adequately prioritized. All of these examples were obtained from physicians, pharmacists, and RNs. Many participants pointed out a need to 'highlight' or 'emphasize' abnormal lab results (Table 4) and information overload was a common theme. One RN suggested a special note title for patients abusing narcotics:

> [We] need a stronger narcotics warning that's easy to pick out for years to come … That [type of] note has gotten lost by all other notes. Sometimes a physician has done a lot of research – calling around outside the VA. That should not have to be repeated … [We] need some type of bold highlight or special note title. Like 'NARCOTIC WARNING' in bold.

In some cases, individuals used paper and/or other computer programs (e.g. Microsoft Word) to overcome prioritization issues.

Timely. Three participants outlined different reasons why electronic information was not always well timed. First, a pharmacist pointed out that consults are not ideal for her work: 'I print it when I see it. If you click through it [in CPRS], it's gone. I may not have time to do it right then. Or maybe I have a question for the doctor.' An NP mentioned problems with scanned documents (see Table 4), and a physician described how clinical reminders, designed to be used during the patient encounter, do not match his actual workflow processes. This physician does not use CPRS during the patient encounter and said, ' if I don't go through the right routine, if I don't look at specific reminders before the patient visit, I might miss these for the patient.'

Table 4. Overview of emergent information characteristics, frequency, and representative examples for the 'effectively displayed' domain (Figure 1).

Category	Freq	Description	Positive example	Negative example
Locatable	11(1+/10–)	can find needed information readily; searchable	"[I] know where to look [in CPRS]."	"Sometimes it's hard to find information in CPRS."
Organized	13(1+/12–)	information is arranged well for the task	"[CPRS is] organized well."	"Harder to do this [compare numbers] in CPRS, you have to click between notes."
Prioritized	18(5+/13–)	important information is highlighted or stands out	"The front page/cover sheet is *very helpful*, shows patient warnings: MRSA, allergies, etc."	"There is little marking to say the result is abnormal – not effective. The abnormals need to be highlighted more."
Timely	4(1+/3–)	timing of information presentation is appropriate	"The alert list in CPRS is reactive and informational."	"Scanning takes too long to get into the [EHR] system. My best guess is that it takes about 3 months to get into the system."

MRSA: Methicillin-resistant *Staphylococcus aureus*; see also Table 1.

Adaptable to work demands

Portable. Information portability was important to a few participants. For instance, nursing care plans were printed because 'it can be passed around and referred to right there in a patient care setting, as opposed to walking 20 ft somewhere to use a computer and not being close to the patient.' IT participants offered potential solutions to portability issues including lightweight laptop computers (Table 5) and personal digital assistants (PDAs).

Modifiable. Participants described how it was sometimes difficult to modify or manipulate electronic information (Table 5). Two participants reported difficulties changing patient phone numbers, while two others mentioned how CPRS was unable to perform necessary calculations from patient data. According to a dietician, 'I can't put formulas into CPRS. The only one it has is BMI [body mass index].'

Trendable. Many participants wanted specific CRPS data displayed in a spreadsheet format and/or a way to easily add a link to an Excel document (see Table 5). In five cases, information was documented on paper and within CPRS in parallel. According to an RN, dermatology does this for light therapy treatments because 'When this is done manually, it has the format of a spreadsheet. [It's] easy to compare numbers. [It's] harder to do this in CPRS – you have to click between notes.' Trending capabilities were needed for other medical areas as well, including oncology and anesthesia, and for tasks such as anticoagulation therapy; monitoring continuous quality improvement (CQI) indicators; and nurse flowcharting.

Customizable. The 'customizable' information characteristic was cited in a negative manner more often than any other trait. Examples were derived predominantly from staff involved in direct patient care. Participants wanted the following: personal patient lists; individualized settings for laboratory alerts and abnormal results; options for print settings, particularly for sending results to non-VA clinics; ways to create personal 'day/time' reminders in CPRS that are 'like [Microsoft] Outlook'; and templates that are easier to create and use. A dietician explained how HIT is not customized for her work: in particular, she explained, 'I work on the computer about 5 hours per day gathering the information I need and printing it out, then I spend about 1/12; hours per day with patients.' Two interviewees outlined situations where data needed to be grouped, not parsed. An NP mentioned that her department manually creates monthly reports by grouping data from ~70 patients. She stated, 'We've been told CPRS can't currently do this because we have patient driven data not lab driven data … We use [Microsoft] Excel to make the report. These reports are major – they affect a lot.'

Discussion

Through this investigation, we (1) identified electronic health information characteristics that influence clinical workflow and summarized several attributes in one document; and (2) derived these characteristics systematically by analyzing healthcare workers' experiences with a nationally used EHR. A few characteristics in Figure 1 have been directly reported in the literature and are often discussed in IT circles, for instance, information security[23] and compatibility[7] between IT systems. Some characteristics have been described indirectly or mentioned briefly in commentaries, while other characteristics have received little to no attention. For instance, there appears to be a lack of information on 'current', 'modifiable', or 'trendable' characteristics in the literature. This may be because they influence workflow and/or clinical decision-making and may be more salient for individuals who directly care for patients. These characteristics also tend to correspond to more

Table 5. Overview of emergent information characteristics, frequency, and representative examples for the 'adaptable to work demands' domain (Figure 1); see Table 1 for software descriptions.

Category	Freq	Description	Positive example	Negative example
Portable	5(1+/4–)	data is mobile	"People [clinicians] need to have the data in front of them…the new lightweight notebook computers [we plan to get] is a potential solution…"	"...I have an electronic copy. But on clinic day, I print it out and….I carry it around with me on clinic day…"
Modifiable	11(0+/11–)	can change information when needed	no positive examples identified	"[PISCES]...speaks to CPRS but the values are in PDF form – not fields – cannot… manipulate"
Trendable	12(1+/11–)	can trace data and compare with previous results; trackable over time	"There is a graphing function in CPRS…. A graphing function is helpful."	"In CPRS you can't view it [serum dose/reaction data] like that. You can't put it all on one sheet.
Customizable	25(4+/21–)	individuals can change settings to meet their work needs	"[We] take requests from users for enchancements [and] build order sets to make workflow easier"	"In the computer there is a list for the [X] team but not for individual clinician....That's not the case here and it's not something I can set up myself."

advanced, second-order EHR design features. In contrast, 'secure', 'available', and 'complete' EHR information are more basic, first-order design characteristics and have been widely discussed in the literature[23–27]. These characteristics may also be more prevalent since concerns about patient privacy have heightened the awareness of EHR security issues, and a desire for available and complete information is a motivating factor for initial EHR adoption.

At least one well-known organization, the Certification Commission for Healthcare Information Technology (CCHIT), has outlined detailed design criteria that EHRs need to incorporate to support functionality, interoperability, and security[28, 29]. CCHIT also evaluates EHRs and tests them against four distinct predetermined clinical scenarios in a controlled environment. Healthcare processes are very complex; it is important to also examine IT post-implementation. Many research groups have been studying various aspects of health IT via observations, key informant interviews, etc. In this investigation, we analyzed interview data and identified several characteristics of electronic information that support healthcare employees' cognition and work processes.

Paper versus electronic health IT

Although study participants frequently shared IT examples that did not involve paper, there were also many examples that related to paper persistence. Some characteristics in Figure 1 may be readily facilitated by paper medical records and more challenging to support with HIT. For example, data can be readily altered and 'customized' via handwritten notes on paper documents; the ability to rearrange (e.g. 'trend') and 'modify' information is an issue associated with electronic formats, particularly scanned documents. In addition, while paper copies may be hard to 'access' if they are in use by another individual, computer downtimes and a finite number of computer workstations present a unique challenge to accessibility[30]. Another advantage of paper is that, at least in small volumes, it is very 'portable'[31]. Laptops and PDAs may enhance EHR portability[32] but are confounded by other issues, such as data security. For PDAs in particular, it may be more difficult to effectively display data[32].

Nevertheless, findings indicate that electronic systems also offer some clear advantages over paper-based records. In particular, participants described how the EHR enhanced information availability and improved some care processes in the VA. Improved EHR designs may help healthcare employees see current information more easily than paper records. There is also a greater opportunity to 'time' the presentation of EHR information in order to optimize its effectiveness[7, 33, 34]. Lastly, while information prioritization was problematic, electronic systems have many tools to offer and may prioritize information better than paper, if EHRs are designed and implemented in a manner that supports clinical workflow.

Competing characteristics

One of the great strengths of an EHR is information availability[23] and completeness[7]. However, increased patient data may result in information overload, a phenomenon that is problematic for many HIT systems[33, 35]. Sorting electronic data requires time and cognitive effort[36], and may add stress to work processes. In this study, participants discussed the need to highlight or emphasize certain parts of the EHR and expressed frustration about locating information tucked away in a large volume of notes; moreover, information overload has been reported at other VA sites[35]. At the time of this study, the EHR had been in use at the VAMC for about 10 years. This raises some important questions:

- What is information overload going to be like in 20 years? 50 years?
- How far back in time will healthcare employees need to look to find necessary information in HIT and how will they find it?
- How can EHR designers help prioritize critical, time-enduring information so that it stands out for as long as it is clinically relevant?

The potential for information overload not only increases with time[33], but may also increase as EHRs become more interoperable. Consequently, it may become more difficult to rapidly locate pertinent data. Well-designed search functions can help employees sort through patient data quickly. In addition, strategies involving the use of special fonts, graphics, redundant color-coding, etc. can enhance information salience[37], prioritize electronic data, and help mitigate information overload. These issues need to be examined so EHRs are sustainable and supportive to employees over time.

In some cases, information security decreased healthcare workers' computer use and/or their ability to access information. The challenge for EHR designers is to block individuals who may abuse or misuse health data and simultaneously allow appropriate individuals to rapidly access necessary information at all times. Others have noted the challenge of designing a secure system that simultaneously allows rapid patient identification across settings[33]. IT designers and hospital leaders should work closely with front-line staff to identify the potential unintended consequences of security parameters pre- and post-implementation: that is, decision-makers should consider how information security and login/time-out settings might impact EHR accessibility and patient care, the ultimate goal of healthcare delivery.

Finally, there is also some tension between fixed, automated information within HIT and the need for a flexible, adaptable interface. This investigation revealed some benefits of 'direct flow' or automation within VA HIT (e.g. enhanced efficiency). In other instances, healthcare employees could not modify data or customize the display: IT failed to support their workflow. To respond to these needs, some EHR developers are beginning to provide a wider range of customization options [23]. In particular, participants wanted to be able to 'trend' data, and were sometimes resorting to paper processes to achieve this. Employees have also described this at other VA facilities[35]. Notably, CCHIT recognizes the need to graph data and display numerical values over time[29]. Enhancing the 'trending' capability of CPRS and other EHRs may promote quality care[33] since trends often influence clinical decision-making.

Patient safety

This study provides insights into several characteristics of electronic information and may also have some implications for patient safety. Each problem area, or 'gap', in electronic information could potentially impact safety during patient care. Many examples herein may be small patient safety risks, but if combined could lead to significant harm in some cases. This scenario is described by Reason's Swiss cheese model for accident causation[38].

Instances where key information is available on paper but not within the EHR and/or is divided between hard charts and electronic charts[39] are particularly concerning. This can create information inconsistencies, and consequently it may not be clear which source is reliable. If usability is improved via interface redesigns[40] this may improve patient safety by encouraging healthcare employees to enter data directly into the computer rather than processing tasks, such as orders, via paper. However, a safe, effective system may *not* be one that is 100 percent paper-free in every way. Paper use may have negative consequences in some cases, but in other instances may have a neutral or even positive effect on clinical workflow[13, 15, 31, 41]. Examples from this analysis suggest that getting rid of paper altogether, especially for work processes that are not well supported by an EHR, may actually be detrimental to patient care and safety. Other research groups have voiced this sentiment as well[14, 42].

HIT has the potential to protect patients and also introduce new, unexpected pathways that lead to harm[43, 44]**.** Literature reports have just begun to recognize and document unintended consequences of HIT and more efforts are needed in this area[10, 33, 43–47]. Some aspects of electronic information may pose greater risks for patient safety. For instance, it is critical that EHR data are correct, consistent, and current. Additionally, if critical information cannot be accessed or located, particularly in events that call for rapid action, then risks may be elevated. There are some critical cases where security restrictions may be trumped by the need to prevent patient harm. For example, in the case where social security numbers were omitted (see earlier section 'Correct'), one could argue that it is more important to be able to quickly identify the correct patient. Moreover, individuals may be able to find information more rapidly if scanned documents and PDFs are supported by a search function. This was mentioned by participants and similar issues have been reported at other VA facilities[35] and within non-VA EHRs[30]. If information is not found, the quality and safety of care may be compromised[24, 48]. Results from this study may aid HIT assessment and trigger redesigns to better support clinical workflow, which in turn may enhance patient safety. To prevent harm, HIT patient safety issues should be considered before deployment; assessed in the field; and mitigated via continuous redesigns[10, 49]. These approaches have been discussed elsewhere[12, 50–52]; assessment methods need to be refined so IT designers can easily incorporate them during their work.

Healthcare considerations for advancing IT

In the VA, CPRS is updated annually nationwide. Priority is given to redesigns that can protect patient safety and prevent harm; safety redesigns are implemented before the annual updates whenever possible. The VA, including the VAMC herein, actively addresses some characteristics identified by this study, including security and access to workstations. Nonetheless, interviews revealed cases where characteristics, such as computer access, remain an issue in certain areas of the hospital. There may be several reasons for this in healthcare: space, funding, and IT support staff constraints; unclear pathways to request IT changes; and the use of workarounds rather than permanent solutions[51]. Some aspects of health IT may be readily improved (e.g. adding computer terminals), whereas for other enhancements, designers may be faced with the challenge of coordinating multiple software packages, integrating many different workflow processes, etc. It may also be difficult for IT support to identify healthcare employees' IT needs. If healthcare employees identify a need for IT improvement, the pathways to report and address software design issues may not always be clear or expedient. Healthcare employees may also become frustrated and disinterested in providing input if they do not receive feedback, if they do not notice timely IT changes, or if their ideas are dismissed. This was apparent from a few of our interviews, is supported by literature findings[51], and could slow the advancement of HIT.

Each of the characteristics identified in this study can be incorporated into questions to help evaluate HIT pre- and post-implementation. For example, HIT developers and/or clinical facilities with EHRs could ask healthcare employees: 'Are there any times you have trouble "accessing" electronic information when you need it? Why?'; 'How can the "organization" of electronic data be improved for your work?'; 'Have you ever needed to "modify" EHR data but were unable to? Please explain'; and so forth. In addition, HIT developers could examine specific examples of paper use, and then use this information as a resource to improve EHR functionality[13, 31, 41, 53].

Health IT designs, ideally, should support the workflow, tasks, and goals of all types of healthcare employees[12, 34, 54]. Based on the results of this study, and EHR shortcomings described elsewhere in the literature, many opportunities remain to enhance EHR design. In this study, participants indicated that areas such as psychiatry, dialysis, and dietetics may require special attention from IT designers to maximize EHR utility. It may be possible to tailor the interface style and presentation for different specialties but maintain one consistent, underlying architecture. It may not be possible to design an EHR that fully satisfies all of the individuals who use the system, but from a human factors perspective, efforts to work towards this goal are worthy of pursuit.

The VA has committed a tremendous amount of time, energy, and resources to develop and enhance HIT and is viewed as a leader in HIT implementation. However, it is difficult to identify all the workflow needs and technology-related patient safety concerns in such a large, complex healthcare organization. Unfortunately, even changes that are intended to improve health IT can have other unintended, negative consequences[8, 44, 46]. According to recent literature, the number one challenge for clinical decision support is to create a human–computer interface model that supports clinical workflow[55]. Healthcare organizations may enhance some aspects of health IT by designing HIT based on data from natural workflow processes; incorporating tools, such as usability testing[52], to help mitigate potential problems prior to implementation[50]; and increasing the available funding and computer support staff for long-term IT improvement. Healthcare employees are a rich resource for HIT ideas and may currently be underutilized in IT development.

Limitations

This study provided many valuable insights, although there are some limitations to take into account when considering the findings from this work. Participants were not directly asked to comment on characteristics that they believe are important for electronic health information; questions were framed around paper-based workarounds, which naturally elicited responses about problematic aspects of computer systems. Therefore, data are biased towards negative, rather than positive, examples of HIT characteristics; positive examples are likely underreported. Similarly, this study did not directly measure how IT characteristics influence workflow efficiency, quality of care, or patient safety; additional qualitative and quantitative work is needed to provide a more comprehensive view of how these, and other potential characteristics, influence healthcare.

We expect that many of the characteristics in Figure 1 are relevant to other EHRs. For example, EHRs at non-VA facilities have been reported to insufficiently support current[43], consistent[43], and locatable[30, 56] electronic information. The 17 characteristics identified in this study may be particularly valuable for the design and implementation of other large-scale EHRs, such as the United Kingdom's planned National Health Service Care Records Service (NHS CRS). However, since some findings could be unique factors of the VA's EHR, the characteristics themselves, rather than their positive and negative frequencies, are more likely to be generalizable to clinical workflow involving non-VA EHRs. For example, some non-VA EHR systems may be more advanced and better support some of these characteristics. In addition, the sample was specific to one VAMC and results may not always be generalizable to other sites or non-VA medical centers and their associated HIT, even though the VA's EHR and associated HIT is recognized as one of the most comprehensive and integrated electronic health systems and, therefore, an ideal system to derive generalizable health information characteristics[57]. Research is needed to further verify and expand these findings to other healthcare settings. Larger, multisite studies involving VA and non-VA EHRs may reveal new, additional characteristics and/or domains that are not captured by Figure 1. We believe that future studies will help refine or reframe our results, as well as help guide the potential application of our findings. In addition, the relative importance of some characteristics may vary across specialties, staff groups, and facilities, while other characteristics (e.g. those in the 'trustworthy and reliable' domain, see Figure 1) may be more essential to healthcare employees in general. Finally, hospitals are complex systems; IT usage patterns and healthcare employees' needs can change over time. Therefore, it is important to assess IT post-implementation and implement redesigns in a timely fashion to encourage employee feedback and promote EHR effectiveness.

Conclusions

We identified four primary domains and 17 characteristics of electronic information that may help support healthcare workflow and associated patient care. Some characteristics are likely fundamental: e.g. *correct* information that is *accessible* and *locatable*, but is also *secure*. In contrast, the relative importance of some characteristics, such as *portable* and *customizable*, may vary across individual employees, specialties, and/or facilities, etc. Additional characteristics may be identified by larger, multisite investigations of VA and/or non-VA EHRs. Study results may be valuable when assessing HIT pre- and post-implementation, and may promote IT utility and effectiveness in healthcare delivery. Each characteristic can be integrated into assessment questions to help evaluate HIT. The findings from this investigation underscore the value of obtaining input from healthcare employees and may be used to enhance HIT design, clinical practice, and patient safety.

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Conflict of interest statement

The authors report no conflicts of interest.

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