INTEGRATING INFORMATION INTO ELECTRONIC PATIENT HEALTH RECORDS

A thesis submitted by

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In partial fulfillment of the requirements

for the degree of

Master of Science in

Human Factors Engineering

TUFTS UNIVERSITY

November 2012

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Abstract

Widespread adoption of health information technologies holds the potential of transforming the way healthcare is delivered by improving quality, enhancing safety, reducing workload and reducing cost. The increased availability of patient information and decision support at the point of care has tremendous potential for reducing errors and increasing coordinated care. The goal of this research was to understand the methods of information transfer between emergency medical services and hospital emergency rooms. A design of an electronic patient chart representing the ideal of seamlessly transferred data was created and compared with a design reflecting the interoperability issues that are common. A usability test was run to rate heuristics of the design. Results indicate that integrating data supports decision making and reduces the reliance on memory making electronic health records more effective.

Acknowledgements

I would to express my appreciation to my advisor, Dan Hannon, for his guidance throughout my thesis research. He provided clarity and assistance at critical times. I also want to thank my committee members, friends and family who provided support and guidance.

Lastly, I would like to thank the Tufts Medical Center clinical study team, in particular Denise Daudelin and Manlik Kwong, who instrumental with helping me to understand the flow of patient information between an EMT and hospital emergency department.

This thesis is dedicated to my father, Dr. Peter Wong, who always believed that I could do whatever I set my mind to.

Table of Contents

List of Figures

List of Tables

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Introduction

With continuing advancements and innovations in the field of information technology, devices such as smart phones, tablets and laptop computers, have infiltrated our daily routines making some tasks easier to do and making all types of data quickly and easily accessible. These tools allow us to multi-task and provide us with a variety of ways to communicate or share information with others. It is, therefore, not surprising that technology has been identified as an important tool for improving the delivery of healthcare. As professionals in the field of healthcare make the shift to leverage emerging technological solutions to enhance patient care and maximize efficiency, one of the prominent health information technologies is the electronic health record (EHR). Historically, a patient's medical information has been recorded on paper which has made sharing data with others within the healthcare industry difficult and arduous, and it is a slow process that relies on information being delivered manually. Electronic health records have a wide-range of capabilities that mitigate many of the problems with paper records, and therefore have great potential for improving the quality of healthcare, as data in an electronic format make patient health information more easily accessible to multiple parties who each have a specific role in providing immediate and follow-up care to the patient. Figure 1 illustrates how an electronic health record system makes patient data available to multiple healthcare providers including but not only: physician offices, insurance companies, pharmacies, hospitals and specialists such as radiologists, laboratories,

and even the patient. What the image does not convey is the key benefit of electronic health records, which is that each party can have instant access to the patient's health information. In addition, the information can be tailored to their specific role within the healthcare industry.

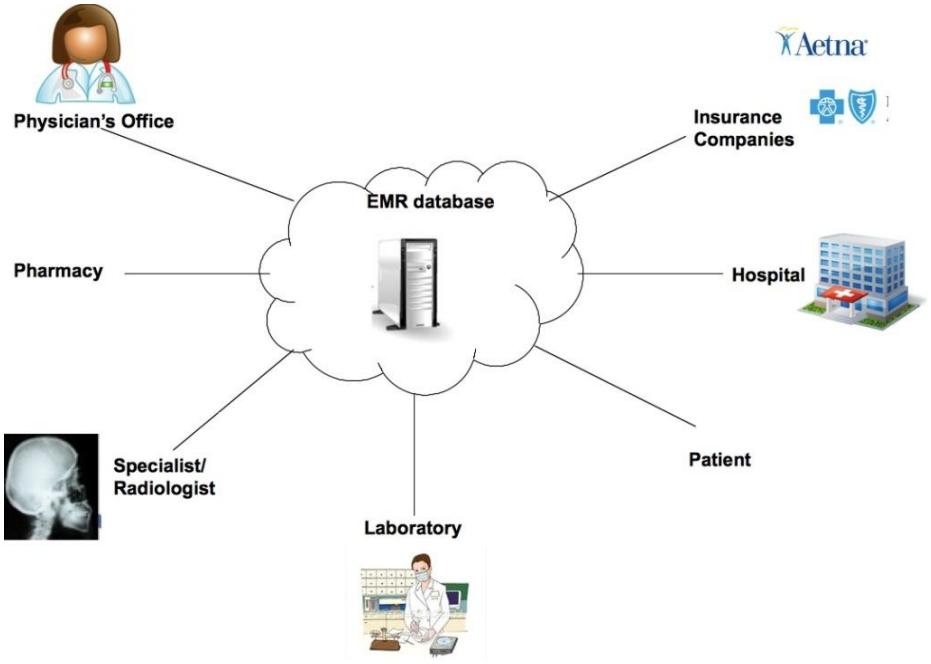

Fig. 1 Illustration of patient information access from an EHR system

Government Mandate

In an effort to improve the healthcare system, in February of 2009 an economic stimulus bill was signed into law by the United States Government, which included funding to be used to increase the adoption of EHRs by physicians and hospitals through incentive payments, loans, and grants. The government tasked the healthcare industry with having an electronic health record for each citizen by 2014. The objectives for encouraging the increased use of

EHR systems include reducing medical expenses, improving the efficiency of healthcare providers, improving coordination of patient care, improving clinical research, and enabling universal access to patient data with the goal of providing better healthcare to all.

However, there have been challenges to adoption and implementation as well as unforeseen obstacles that have kept EHR systems from having as great an impact on healthcare as hoped. Despite the potential to help healthcare professionals improve efficiency, effectiveness and medical accuracy, adoption has been relatively slow, with only about 55% of physicians, as of 2011, using an EHR system in the U.S. (Jamoom, Beatty, Bercovitz, Woodlwell, Palso & Rechtsteiner 2012) One of the main reasons for the slow adoption rate has to do with the upfront cost to switch that includes and requires the training of staff on a new system and transferring patient data from paper records into electronic format which both take time as well as money. Switching to adopt a new software also requires time away from patients which can be problematic for physicians. Other issues that have kept the adoption rate of EHR systems slow have to do with concerns around the security of personal health information in an electronic format and who has access to a patient's medical data. The Health Insurance Portability and Accountability Act (HIPAA) privacy rule gives patients the right to determine who has access to their records and how much access they are afforded and has set limits and rules on who has access to your health information. This rule makes exchanging patient data between doctors without patient consent difficult and slow but not impossible.

Another factor that has kept adoption rates lower than anticipated is the lack of standardization of electronic health records as a technology. The resulting consequence is that many existing systems are not able to communicate or share information with each other either because they use different technology or use different nomenclature making the sharing of data a difficult or almost an impossible task. Lack of interoperability also makes EHR systems less effective overall as coordination of care often means reverting back to paper records as the method for sharing patient information. This can even occur within the same facility if a department within a hospital uses a different system, especially a custom EHR that is tailored to their specialty. This forces healthcare providers to print out documents that then are scanned and attached to the electronic record or put in the patient's file folder which results in more work not less.

Literature Review

There have been many studies focused on understanding the impact of EHRs on the healthcare industry, clinicians and patients as well as how to improve their design or use to increase their level of effectiveness on the healthcare sector. Overall, studies show that EHR systems have a positive impact, but there is still a lot of work to be done for them to reach their full potential. The literature review will focus on the areas of access to patient information, errors, standardization, interoperability, and improvements.

Errors

The growing adoption of health information technologies holds the promise of a transformational change in the way healthcare is delivered by improving quality of care, enhancing safety and reducing costs. The increased availability of patient information and decision support at the point of care has tremendous potential for reducing errors, which has been a concern with healthcare but one that is difficult to address. In 1999 the Institute of Medicine issued a report "To Err is Human" which detailed the problem that doctors and other healthcare professionals can make mistakes like everyone else and revealed that the U.S. Healthcare system was not doing enough to prevent these mistakes from occurring. The report found that an estimated 98,000 people a year were killed as a result of a preventable medical error and that medical errors cost $17 to 29 billion a year (Safepatientproject.org) (Consumers Union 2009). The findings called for a comprehensive effort by health care providers, government and consumers to set a goal of a 50% reduction within five years, which as of 2007 has not been met. The studies have found that many health delivery systems could be redesigned to significantly reduce the likelihood of error. Some of the areas that have been identified for improvement include: (Leape, Berwick 2005)

- Reducing reliance on memory by minimizing the demand on human functions that are known to be particularly fallible such as short-term memory and prolonged attention.

- Improving information access by making information more readily available so that it is displayed where it is needed, when it is needed and in a form that is easy to access.
- Integrating error proofing into critical tasks.
- Standardizing drug doses and times, information display methods for common practices (such as surgical dressings) and the placement of equipment and supplies in a patient care unit. (Classen, Resar, Griffin, Federico, Frankel and Kimmel 2011)

These areas could be addressed within EHRs that contain a patient's full medical history so they reduce the reliance on a healthcare provider's memory, makes information more easily available, and can include logic that prevents prescribing conflicting medications. However, there are also other factors that lead to errors, such as variation in quality of test performance and readings, as well as communication failures between the radiologist or laboratory technician and physician. Failure of diagnosis can occur because of missing information. Critical information can also be missing either because of failures in transmission of diagnostic test results or the full set of data is not available in the patient's record within the EHR for the healthcare provider to see at the time that medical care is needed and given.

Access to Patient Information

One of the problems with the quality of healthcare in the US is the uncertainty of clinical decision-making about a patient's symptoms. Uncertainty in clinical decision-making arises from unavailable or poor quality data on the

patient's medical history. Incomplete, illegible or even unavailable patient information may necessitate a *work around* management strategy, which results in redundant or marginally productive visits, unnecessary diagnostic screening tests and interventions. Electronic health records help reduce uncertainty by providing greater accessibility, accuracy, and completeness of medical information. The data that are available through an EHR can enhance ambulatory care and emergency department visits because a complete health history for a patient is immediately available to the care provider, who most likely and usually does not have any prior knowledge of the patient, at the time care is needed. Studies show that electronic systems increase the efficiency of ambulatory care visit by reducing redundancy of healthcare services by allowing patient issues to be resolved during the first contact, enabling more services to be offered per visit and reducing the need for separate health maintenance visits since the patient's health information is immediately available through the EHR system. (Gurukawa 2010)

Use of EHRs has unquestionably had an impact on a broad scale on the care provided in the emergency department. There, the inadequacies of the paper chart are magnified because of the urgency of the problems and the attending physician's lack of prior contact with the patient. With paper records there can be a 15 to 30 minute or more delay between the request and the delivery of a patient's medical record, or sometimes the patient's record is not even available. The electronic format of the patient's record can provide instant access to the patient's full medical history, which helps to influence the physician's actions such as which diagnostic tests are ordered for the patient. Access to a patient's

complete health history prevents the request for unnecessary tests which in turn keeps the cost down for the patient and the hospital. In one teaching hospital, tests, accounted for 25% of the average patient's bill, so the EHR can be seen as a tool that will help lower that cost. (Garrido, Zhou, Wisenthal & Liang 2005) It has been found that physicians tend to order tests in proportion to their uncertainty about the patient's state of health. Again, having a full summary of a patient's previous test results, medication history and diagnoses available to the attending physician helps to reduce uncertainty about the patient in the early moments of care and in turn reduce extraneous diagnostic tests.

Coordinated Care

One of the many objectives for implementing EHR systems is to improve the coordination of patient care. Studies have examined whether and how practices use commercial electronic systems to support the coordination of tasks needed to provide quality patient care. To be able to evaluate how the EHR has impacted coordinated care, it is helpful to understand the main tasks that are necessary for effective care coordination which according to O'Malley, Grossman, Cohen, Kemper, & Pham (2009) include:

- Maintaining patient continuity with the primary care team.
- Documenting and compiling patient information generated within and outside the primary care office.
- Using information to coordinate care for individual patients and for tracking different patient populations within the primary care office.

- Making referrals and providing consultations that includes initiating contact, communicating with referrals and consultants, and tracking the patient's interactions with the other care providers.
- Sharing care for a patient with clinicians across practices and in different settings.
- Providing care and/or exchanging information for transitions and emergency care.

The studies that examined the impact of EHR systems focused on these tasks and their overall impact on coordinated care. Findings indicate that an EHR does help to facilitate within-office care coordination by providing access to data during a patient encounter and through electronic messaging which simplifies communication for all. (Garrido, Zhou, Wisenthal & Liang 2005) However, EHR systems are not always able to easily support coordination between clinicians and other settings because of their current design and the lack of standardization that is necessary in order to exchange patient information with the others providing care. Technology has the potential to improve coordination by making information electronically available at the point of care but the systems that are currently in place do not have the ability or necessary functionality to have a significant impact on the efficiency of coordinated care because of the lack of interoperability and standards which inhibit the transfer of data.

Medical Narrative

An important feature of the patient health record is the medical narrative, which is a summary of the qualitative data gathered by physicians that encompasses a patient's medical history, physical examinations, progress notes and episode summaries. However, the problem with the narrative format is that it is unstructured text so can be distorted and is not always prominently displayed. One study focused on integrating a structure to the narrative medical text to utilize the scope of an electronic record to aid the clinician in care delivery. The study suggests that finding the core component of medical text to represent and structure in an EHR would enable a non-expert to interpret patient data in a similar way as an expert. Incorporating a structure for text would organize the narrative piece of a patient record that would enable the reader to find and focus on relevant information whether that data source is the patient, a physician, a technician or a specialist. (Sharda, Das & Patel 2003) The end goal for any medical text is to make it understandable to any reader so that the interpretation is unvarying and relevant. Using a structured summary would put the focus on the most appropriate information related to patient care, improve data retrieval and make the sharing of patient information easier, especially if a standard method for summary information were used.

Standardization and Interoperability

While EHR systems have the potential to make a significant impact on healthcare and positive changes have occurred, it has been revealed that current commercial EHR systems do not fully meet the needs of health professionals.

Some of the primary features that are missing include enabling standard documentation of a patient's health record both within and outside of the practice, improving medication reconciliation and interoperability with information systems from other practices, diagnostic testing facilities and hospitals.

As the literature review showed, there have been a number of studies done on the impact of EHRs on the healthcare industry. The studies found that many healthcare delivery systems could be redesigned to significantly reduce the likelihood of error. Some of the areas identified for improvement that are more specific to the design EHR include:

- Improving information access
- Integrating error proofing into critical tasks
- Standardizing information displays

The goal of design improvements should be to make the display more intuitive while still providing immediate clinician access to a large variety of information required for patient care without increasing the user's cognitive effort. The density of the display of information must be increased while still taking into consideration the basic principles of cognition, task analysis, and interface design to enhance the visualization so that it is more effective. Improving the visualization of the display of information should take into consideration the difficulties of acquiring sufficient information from a data set to effectively apply their cognitive process in order to make a determination on treatment or next steps. (Chen, Ebert, Hagen, Laramee, van Liere, R., Ma, Ribarsky, Scheuermann, Silver 2009)

As previously mentioned, innovation in technology has had a significant impact on what we are able to accomplish and has revolutionized our ability to solve more complex problems. However, visualizing large amounts of data into graphical representations is a challenge and must be done in a manner that allows the human brain to detect patterns and make inferences. (Ma 2000) Some of the aspects of visualization that should be considered within a visual display are the clutter, visual density and use of guidance. Effectively showing abstracted data helps the user compare different data sets and enables the user to apply their own knowledge to accurately use the data. When applying the concepts of visualization to an EHR, it is necessary to consider how medical information is organized so that it supports the cognitive processes of physicians. It has been suggested that a problem-centric visualization of medical information where the EHR is tailored to the user, the task and the medical problem allow the healthcare provider to quickly absorb data and understand the interplay of multiple variables. (Bui, Aberle, and Kangarloo 2007) Improving the user interface of an EHR would enable a physician to review a medical record to understand the information being presented and then make a determination on the necessary care for the individual.

Another area of improvement of EHR systems is to address the issues of interoperability between electronic health information systemsß and the lack of standardization across the many systems currently in the market. This is a problem in healthcare information technology that requires attention as the inability to share patient data efficiently and consistently is disruptive to the ability to provide coordinated care. Standardization in information representation

and dissemination would greatly help eliminate communication gaps among healthcare providers and remove obstacles with sharing patient health information and make the transfer of data easier. (Sartipi, and Yarmand 2008)

One area within healthcare that would benefit from improved access to patient data is in emergency medical services where immediate access to patient information can be critical to decision making. Studies have emphasized the importance of EMS services and vendors to develop products that allow for the transfer of data using evolving speeds and technologies. (Brainard and Fisher 2011) When the EMS is a department of a hospital, patient data is readily available and transferred seamlessly to the ambulance team. The problem of interoperability becomes an issue when ambulance services are vendors and do not have access to the hospital EHR and the EMS hand off of information is a piece of paper. The challenge of this frequent scenario is not only a problem of interoperability between the systems but also one of semantic interoperability. (Brainard and Fisher 2011)

Interoperability represents another major problem with currently available systems, since most EHR systems do not interoperate well with each other or other applications. The result is that for many physicians and healthcare providers, even if they start using an EHR, much of the data available only will be the other data they have provided and know already. Clinicians' first priorities are for information such as laboratory and radiology results and medication lists, although moving clinical information to and from hospitals is also extremely important. A recent national analysis of the value of interoperability suggested

that fully standardized interoperability could save the nation $77.8 billion annually. Thus, implementing approaches that ensure that EHRs will be able to interoperate is a high priority. (Bates 2005)

Although many EMS providers today have successfully been able to make the transition from paper to electronic patient care reporting (ePCRs), how to securely transfer data to the physicians within a hospital is still a difficult task. Finding a solution to address the problem of interoperability would help all aspects of the healthcare sector. An integrated approach would assist an EMS provider determine the right place to take a patient, based on the treatment needed or even based on their health-care plan. In addition, physicians at receiving hospitals could be made aware of a patient's symptoms, condition, and history before arrival. Another benefit of systems that are integrated or can easily share data would be the ability to better understand trends that could help reduce costs and help physicians better understand the effectiveness of treatments. (Brainard and Fisher 2011)

There is yet another area in the healthcare sector that would benefit from solving the issues around interoperability, clinical research. The use of medical record information has focused on building medical knowledge databases to support decision-making within the healthcare environment. However, medical information could also be useful and valuable in the area of clinical research. There have been a few studies that examined the effect of EHR-supported clinical trial recruitment. The main benefits of integrating an electronic medical record system and clinical trial database would be the ease of recruiting participants and

capturing data for the clinical trial. However, there are also challenges around the mapping of clinical terminology and establishing communication standards that can be mapped to clinical research standards, and defining common core data sets in order to support multi-centric research and data exchange. (Prokoshc & Ganslandt 2009) These issues could be addressed by using standards and solving the problem of interoperability.

Hypothesis

As EHR systems become a more prevalent as tool among healthcare professionals, the need for efficient and simple data sharing across all EHR systems becomes more pressing. Studies have shown that EHRs have had a positive impact on healthcare delivery but there are still obstacles that keep them from reaching their full potential. Two of the key issues that exist are the lack of standardization and problems with interoperability. These two issues result in existing EHR systems not being able to easily share or transfer data with each other since each uses a different platform for their technology and forces people reverting back to paper records for data entry or data transfer.

The goal of this research is to study how data are and can be shared across multiple systems with a focus on the flow of patient information based on a clinical study. This study focused on identifying how information could be passed from one source to another for an approach based on study participant selection using mathematical equipoise derived from the predicted mortality rates of thrombolytic therapy and percutaneous coronary intervention for patients with a myocardial infarction.

Research concentrated initially on how information is transferred and then stored in an EHR when multiple care providers are involved, specifically the scenario where an emergency medical technician (EMT) captures patient information and hands off the information to an emergency room physician. Using this information, a design was developed with a concentration on how electronic information or a paper record could be displayed in the patient's chart within an EHR. The design focused on understanding the visualization of the information a physician needs and wants to see when caring for a patient. Research included identifying the methods in which patient information is transferred from the EMT to an emergency department physician and how paper records are handled in an electronic system. In addition, this research investigated how attachments are integrated into the patient's chart in an EHR and explored the implementation of visualization techniques to support decision making and readability.

The purpose of this research study was to identify how patient data can be transferred from end to end (EMT to hospital ED) to demonstrate the potential of displaying the patient information from the EMT, which includes data from the clinical study decision support tool, directly into the hospital EHR system helps the physician decide on the best treatment for a patient.

Methods

The methods employed for this study included observations of physicians using their EHR system, interviews with physicians on their experience with and opinions of the EHR system and interviews with researchers on necessary follow up of patient information needed for a clinical study. Research for this thesis involved understanding the flow of patient information based on a Tufts Medical Center clinical study involving a decision support tool that predicts mortality rate for myocardial infarction patients for two treatments types. This clinical study represented a scenario in which patient information needs to be shared between at least two healthcare providers. This information was then used to develop a patient workflow (figure 3) to identify the points where there is a transition of care and patient information needs to be passed along. The interviews with the healthcare professionals were used to garner information not only on the use of the EHR but also to gain an understanding of how information is shared with other healthcare providers or departments who service the facility or work within the facility. There was also an analysis of the EHR systems that are currently available to identify different design approaches. Two designs of a patient chart were developed that attempted to accommodate patient information that is transferred electronically or in paper format. There was an heuristic evaluation of the designs to identify usability issues and how the designs could be improved. The usability test to evaluate the design was run with seven participants who are experts in the field of EHR development. In addition, two clinicians with experience using an EHR system were shown the design in an interview style

setting to get their impressions. Participants were asked to evaluate the ease of use of the design, the efficiency of the layout of the page, the intuitiveness of the visualization of information and how effectively the design supports decision making. Findings from the heuristic review were compiled, analyzed and reported with recommendations for how the design could be improved.

Findings from Interviews and Observation

Observations and interviews have been conducted with physicians. Two interviews were held with primary care physicians who use the eClinicalWorks (ECW) EHR and one emergency department physician who uses multiple EHR systems including MEDITECH, an ER department system, PACS, Soarian and GE Healthcare.

In addition, a surgeon was observed during his surgical clinic hours using EPIC. The interviews consisted of a combination of scripted and unscripted questions about their experience with an EHR system and how it could be improved. Interviews were recorded in hand written notes.

The initial interview was conducted in March, 2011, with a primary care physician who is part of family practice in which the physicians are all part of the Mount Auburn Cambridge Independent Physicians Association who use eClinicalWorks for their EHR system. ECW is also used by Mt Auburn Hospital with which they are affiliated. The physician also teaches at the Cambridge Health Alliance so has access to their system which is EPIC. During the interview, she showed the benefits of each system. She said that although she does not find ECW to be user-friendly, she does believe that EHRs are better than paper charts.

She indicated that eClinicalWorks , show in figure 2, is easier to use than EPIC but at the same time she also finds it to be more cumbersome. She did think that using an EHR helps her to provide better care to her patients because she can see all encounters and every vital statistic from previous visits (i.e. blood pressure, pulse, weight) which helps her to get a picture of the patient's current health at the time of a visit. She also thought that having all of a patient's history helps with making a medical diagnosis since she can view all of a patient's medical history. She believed that one of the biggest benefits of EHRs is the legibility of patient records. She shared the story of a time when she was not able to read another physician's notes on a patient and had to interrupt her interaction with the patient to go ask the doctor what she had written about the previous encounter. With the EHR, notes are typed so she does not have to struggle with deciphering someone else's handwriting.

When asked if use of a computer during a patient visit reduced the face-to-face time with her patient's, she explained that she was able to type without looking at the keyboard so was able to pay attention to her patient while entering data. She also said that she enters data into the EHR so that the patient can see what she is typing which she finds actually helps to clarify symptoms as the patient is reading her notes as she types and will correct her. She feels that by doing this she gets a better verbatim explanation of the symptoms, which in turn helps her provide better care to her patients. She also said that she uses the EHR to enter in a plan that she reviews with the patient as she enters in the plan. This

plan can also be printed out for the patient as a reminder. She believes patients remember it better and it helps communicate the plan for care or follow-up.

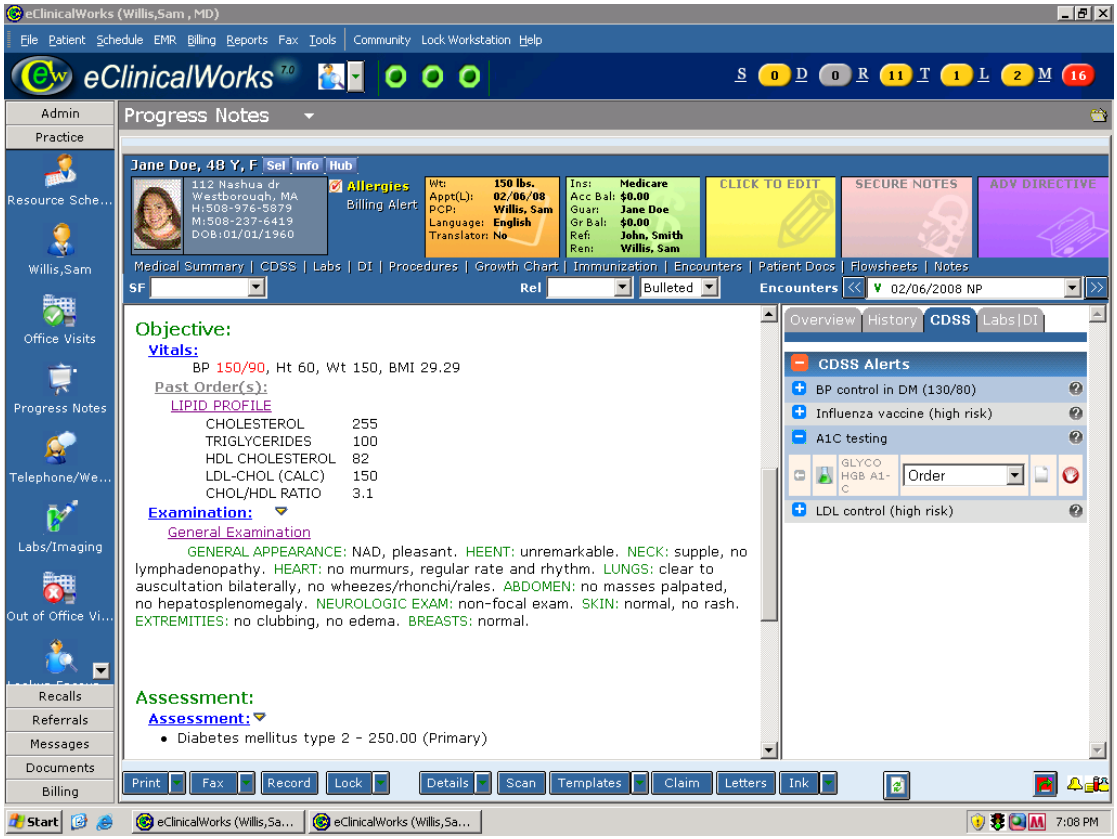

Fig. 2 Screenshot of eClinicalWorks patient record used by interviewed physician

Another feature she found to be very useful that is available in EHR systems are flow sheets. There are flow sheets for various conditions (i.e. diabetes) and each flow sheet has all the pertinent data for a specific condition that allows a primary care physician to follow up with an entire group who have a specific condition. (Example: diabetics need a food exam, or women needing follow up pap tests.) In addition, flow sheets allow for a multi-condition comparison so a physician can find patients who are asthmatic and have diabetes, and follow-up with those patients in a more customized manner.

Currently the only images in the EHR used by the physician's practice group are photos of the patient. She did indicate that she found the photos helpful as a reminder of the patient since it may be many months between visits so having a photo of the patient acts as a reminder for her. eClinicalWorks does allow them to have scanned documents associated with a record so the system does accommodate PDF files but it requires that someone manually scan a document and then load it into the system. The office is in the midst of using and integrating images more into the patient record but is in the very early stages.

Overall the physician felt that using an EHR system improved the quality of care provided to her patients. The main benefit was that using an EHR system allows her to view notes from all previous encounters and every vital statistic from past visits which helps her to establish the patient's current state of health. She found that the system overall is convenient, especially for looking up data which is easy to do but she thinks that the user interface of the system needs improvement.

Another interview was held with a physician from the same family practice in April 2011. Overall he felt that use of the EHR system resulted in better patient care. He believes that the main improvements from using electronic records instead of paper records was the legibility of patient information and the accessibility to all data on a patient. He worked in an emergency department previously and said that the EHR was critical to have when providing care to a patient whose background and medical history are completely unknown. Other features he finds to be convenient are around medications. He said that it useful to

see all of the medications a patient is taking and be able to see which medications need to be refilled at the time of the patient visit. He also found it helpful to be able to view the treatments for the diagnosis of patients of other physicians within the practice. The main improvement he believes that could be made to the EHR is to have better integration with previous lab tests and previous image scans and being able to pull reports for specific conditions to use a quality measure.

In addition to the interviews, a surgeon was observed March 2011 during his clinic hours at the Cambridge Health Alliance when he meets with patients either before a surgery is to be scheduled or after a surgery procedure has been done. During the observation, the surgeon met with six patients and accessed the patient's EHR to record the results from the examination. Because of automatic log out features of the HER, the physician was required to login at least twice during each appointment to access the EHR. The physician mainly used the system to look up notes from another physician, view the patient's vital signs; view notes from a previous visit and add notes about the current patient-physician interaction. The most frequently used feature of the EHR was the notes section where the physician entered the patient's current state and what was discussed with the patient. On a few occasions the physician printed out a document for the patient to either follow-up with the nurse or as instructions for the patient to follow himself. The physician used s standard form sheet to indicate when he next wanted to see the patient and why, which the patient was to give to the nurse when checking out. The EHR system used is EPIC, which does not seem to have administrative features or they are not used by this group.

The system does allow the physician to use the EHR to submit requests for CT-scans, x-rays, MRIs or ultrasounds so that the other departments were aware of the request for a specific diagnostic test for a particular patient. Images can be viewed from the system but are not completely integrated. With the last patient appointment, the physician was able to pull up the patient's MRI scans and review them with her. It did require accessing a different system that required a login but it was one click away from the EPIC system. The scans were able to be viewed through a drag and drop feature that also allowed the surgeon to zoom in or highlight a specific part of the scan. The report from the specialist who read the patient's images was in a different part of the EHR so the surgeon had to go to a different tab within the system in order to actually read the results from the scans.

To better understand the flow of information in the clinical study, an emergency department physician was interviewed in March 2012. His use of EHR systems was similar to the surgeons as he used multiple systems to track and record information on the patients he sees. The emergency department (ED) uses Med Host which is only available on computer terminals in the ED. This system shows which bed a patient is in with icons indicating the status of a lab and other follow-up items and the length of time the patient has been waiting. In addition to using the ED system, he also uses Soarian which is the hospital EHR system and the picture archiving and communication system (PACS) for imaging. These systems are not able to share or transfer patient information with each other so paper records are often scanned and attached to the patient's record in the hospital system. He also said that paper records are used as the method of information

from the EMT to the emergency room. Again, these documents are scanned and attached to the patient's hospital record.

Clinical Study Patient Information Workflow

A key element of any clinical study is the collection of data. Tufts Medical Center is creating a clinical trial decision support system that is based on predictions of mortality for patients with acute myocardial infarction. The study started in the autumn of 2011 and is ongoing. This mathematical equipoise study is based on predicting the mortality rate between thrombolytic therapy (TT) and percutaneous coronary intervention (PCI), the transfer of data is a critical part of collecting patient information and is complicated by the fact that all data or some data could be transferred electronically or in paper format at any point of care. Figure 3 shows the patient workflow which illustrates when information is gathered and passed along, decisions are made, and care received. In the ideal scenario, all patient information would be transferred electronically and seamlessly from the moment the EMT provides care all the way through to analysis of information for the clinical trial. In the worst case scenario, none of the systems are connected so that paper records would be used to transfer patient data leading to manual data entry throughout the timeline of patient care. The more common scenario will probably be a combination of data being transferred electronically and on paper which will be the focus of this research study as it will address the two extremes. The design of the patient chart will attempt to accommodate this patient workflow for two scenarios. The first being the situation when patient information is transferred electronically from end to end

and the scenario when paper records are used for at least one point of data transfer.

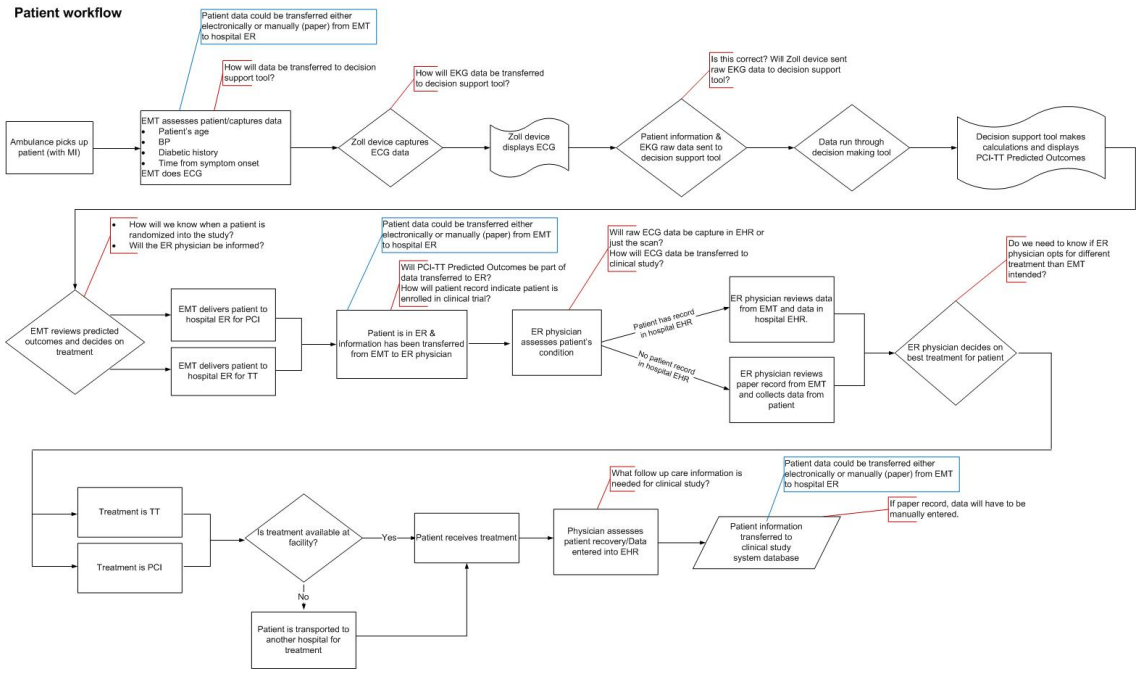

Fig. 3 Workflow of patient information transfer for clinical study

Pilot Study

Design Rationale

The pilot study consisted of developing a design of an EHR that incorporated patient information from an external system with the data elements either visible on the page or made available through a link. The design aimed to propose a solution for integrating patient information captured by an EMT and decision support information from a clinical study with the goal of improving coordination of care through information sharing and supporting decision-making

by displaying crucial elements about the patient's health together. In addition, the design presents a layout that makes clinical notes more prominent since the medical narrative was identified as a key component of the patient record during interviews and observations.

Figure 4 shows the patient record design used for the first scenario which represents the situation when the EMT and the hospital ED use the same EHR system or the systems used by each are able to exchange patient information electronically so data is transferred seamlessly end to end. In the design, the information captured by the EMT, shown in figure 5, is placed in the center of the patient chart and includes the patient's vitals, a smaller version of the ECG taken by the EMT with a link to view the full ECG, the EMT's patient assessment and the predicted mortality rate from the decision support tool. The rationale for displaying this information so prominently is to draw the attention of the user immediately so that the physician focuses on the most recent or urgent data available.

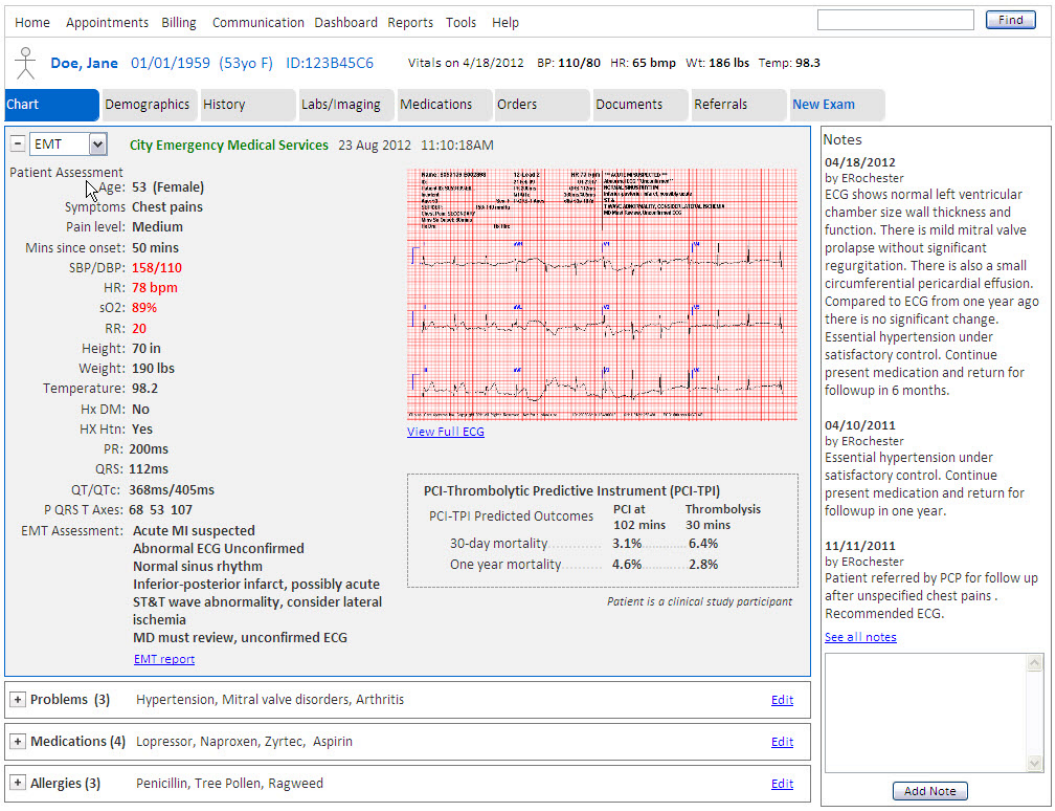

Fig. 4 Patient chart for scenario with integrated information

Within this section other design techniques are incorporated to reduce the reliance on memory. The vital signs are aligned to reduce the scan time when looking at the patient's information and vital signs outside of the normal range for a patient of that age, are highlighted in red text to indicate an abnormality in the captured data as shown in figure 10. Displayed directly beneath the electrocardiogram (ECG) are the predicted mortality rates generated by the decision support tool. The ECG and the predicted data are both meant to supplement the patient data displayed in the patient chart to support decision-making so these are placed to the right of the patient's vitals. The concept for this section is to pull in data from other departments or external systems with the

capability of sending patient information electronically into another EHR system and to display that data where it is needed and when it is needed.

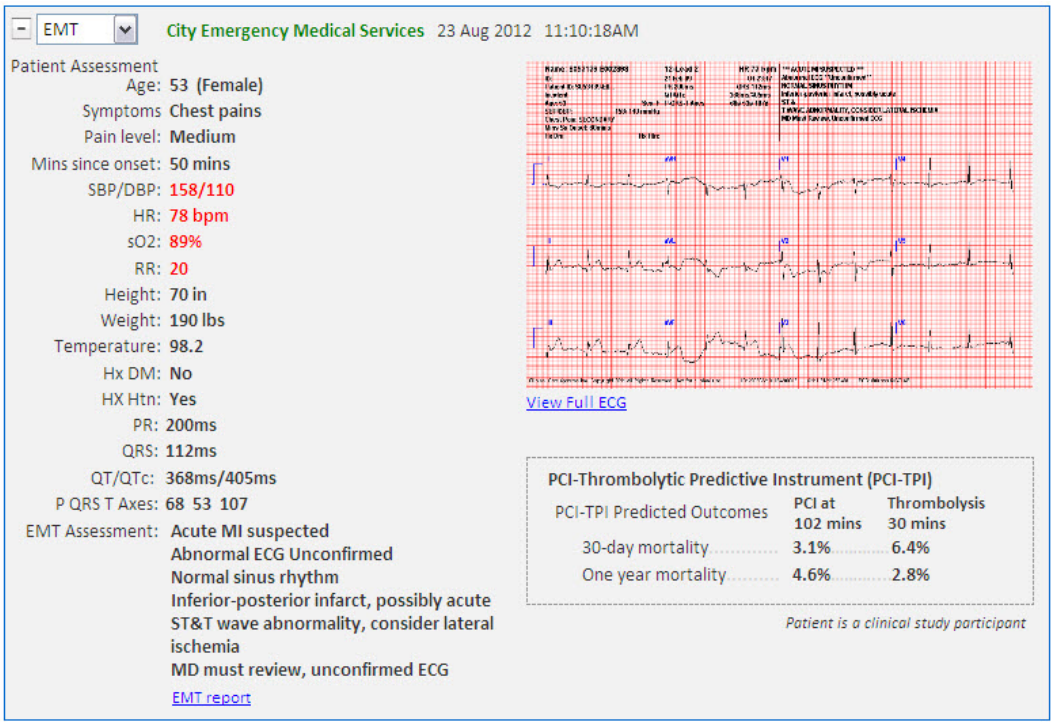

Fig. 5 Section with integrated data from EMT

The same overall design is used for the second scenario (see figure 6) but patient information from the EMT for this scenario is not transferred electronically, so captured data which includes the EMT's patient assessment and the ECG are not sent into the system electronically. Any information obtained prior to this date is available in the EHR and information captured by the EMT is only available as an attachment since the transfer of information is a paper report that was scanned and attached to the patient's record. The design includes links to the full EMT report and the ECG but viewing either takes the user away from the

patient chart to a different page so the physician must retain any data from those documents in order to compare past and recent data.

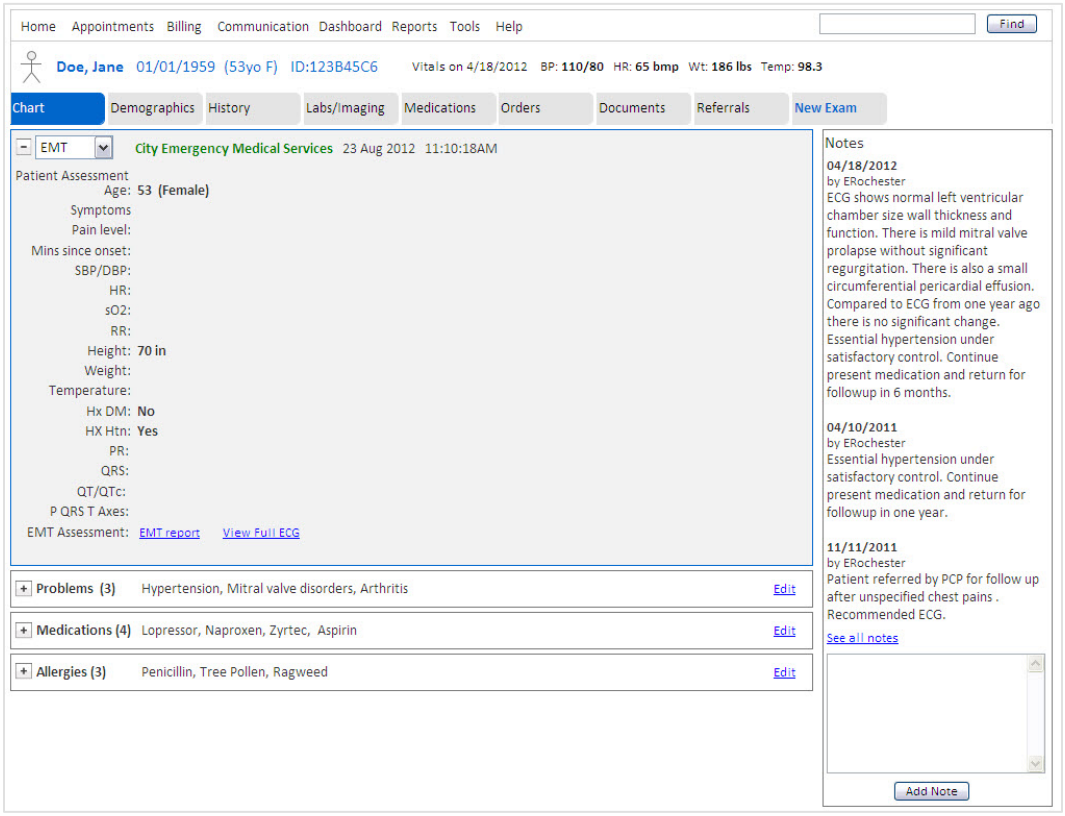

Fig. 6 Design without integrated information

The other elements of the patient chart that are important for the physician as background information on the patient, are displayed around the integrated data section. There are navigation tabs at the top of the patient chart design for demographics, history, labs/imaging, medications, orders, documents and referrals, which represent other sections that would have detailed information about the patient. Immediately below EMT information are sections displaying the patient's problems, medications and allergies as shown in figure 7. These

facts about the patient were identified as important for the physician to know when deciding on treatment. These sections are displayed in an accordion style that allows the area to be expanded or collapsed with the default being a collapsed view that shows a list of problems, medications and allergies. The expanded view seen in figure 8 allows the user to add new items or more details to the patient's record.

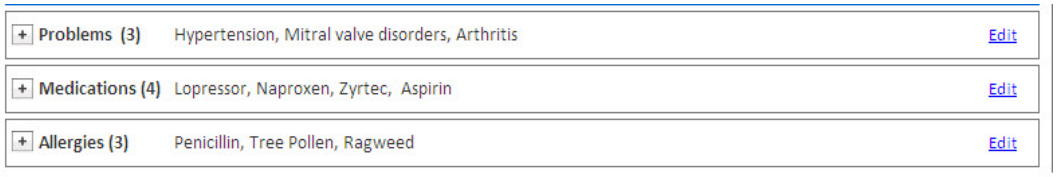

Fig. 7 Problems, medications and allergies sections collapsed

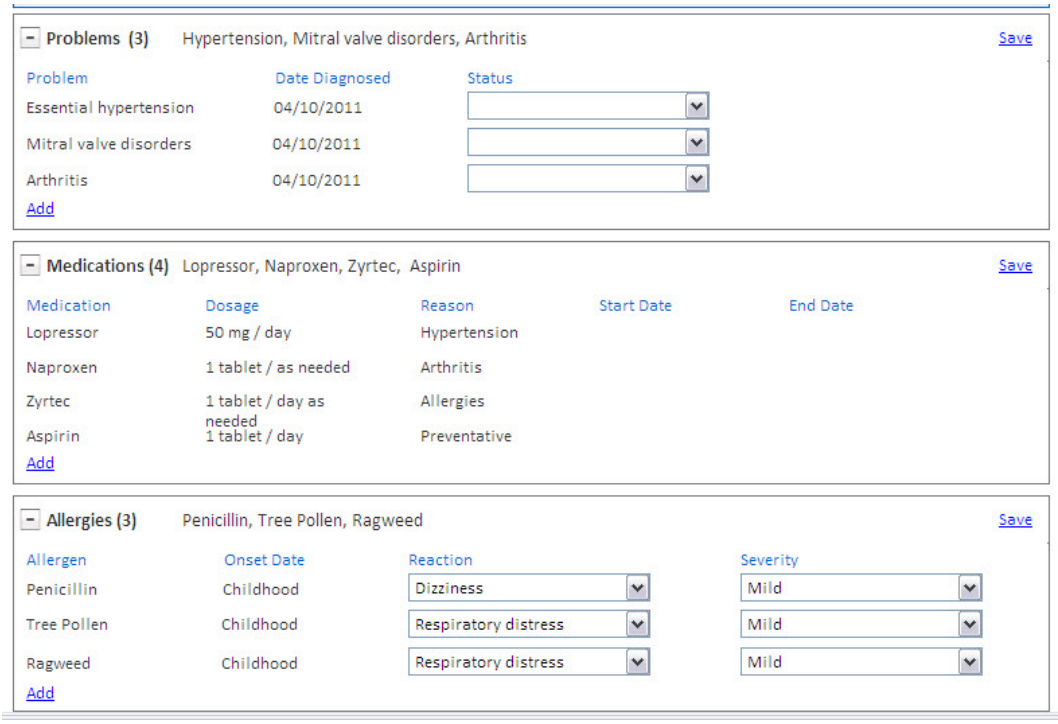

Fig. 8 Problems, medications and allergies sections expanded

Another key component of the patient's medical record that was identified during the literature review and during observations and interviews is the medical narrative or the physician's notes. To ensure that these notes are easy to find, they are displayed in the design to the right of the integrated data from the EMT or external source. The section, shown in figure 9, is approximately one fifth of the width of the screen containing the text from the most recent notes, a link to view all notes, as show in figure 10, and an input field to add a note. The rationale for presenting notes in this fashion is to make this information, which has been identified as important for the user's knowledge, to be readily available for the physician without requiring the need to hunt around the page for this information. It also allows the user to easily add a note directly from this page of the patient's record.

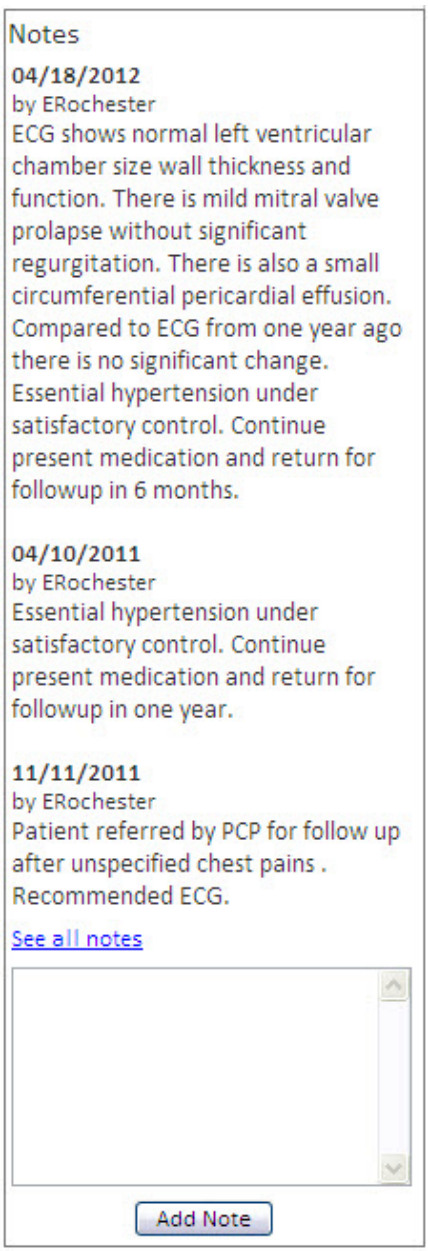

Fig. 9 Notes section

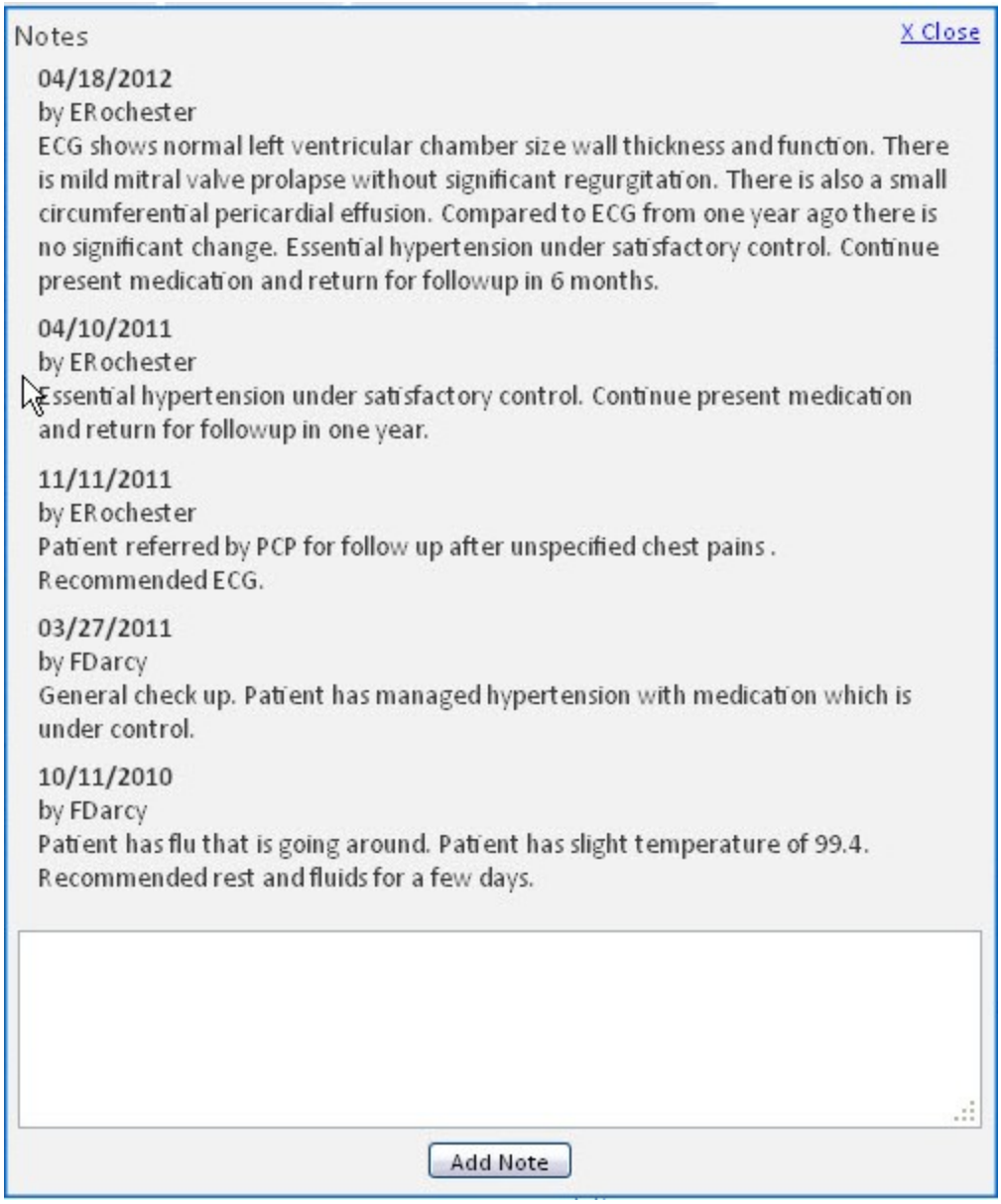

Fig. 10 Notes section expanded

The overall goal of the patient record design is to provide the physician with the necessary information to make a decision on treatment. As figure 11 shows, information is laid out in a manner meant to reduce cognitive effort by using visualization techniques that focus the user's attention by aligning labels

and data to reduce scan time and displaying abnormal findings in red to highlight them. The layout of the patient's information is meant to allow the physician to compare different data sets about the patient without relying on memory and apply their own knowledge of medicine to identify the best treatment for this individual.

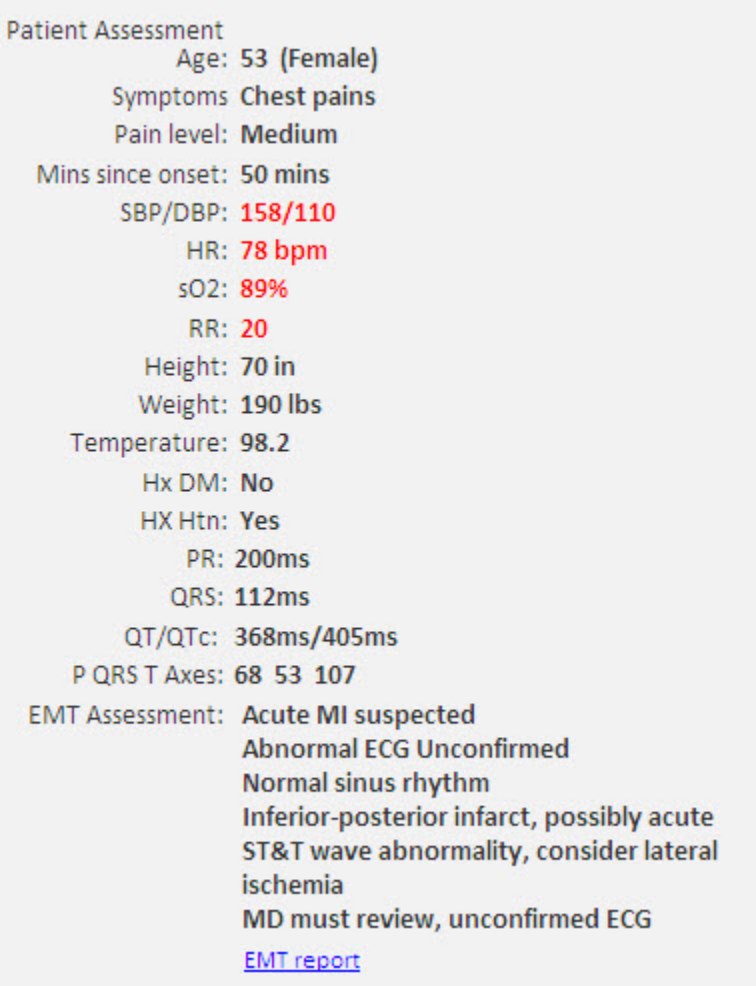

Fig. 11 Patient assessment

Usability Test Methods

To evaluate the effectiveness of the designs, usability tests were run in August 2012 with experts in the field of EHR development. The participants were given instructions that explained the setting and described two scenarios with specific tasks that focused on specific heuristics of the two designs. Each participant accessed the design prototype online from a laptop and was given the printed instructions for the usability test (see appendix B) with a pen to rate the heuristics and write down comments. Ratings for the heuristics were yes, no or n/a (not applicable). A rating of yes, meant that the heuristic was met while a rating of no meant that the heuristic was not met. A rating of n/a meant that the participant thought the heuristic was not applicable or available. The overall task for both scenarios was to assess the patient's condition in order to choose a treatment. In order for the participant to accomplish this task, they were asked to accomplish the following tasks.

a. Open the patient's chart
b. Review EMT assessment of patient's condition
c. Expand the ECG
d. Find the patient's vitals from last visit
e. Look at the patient's problems, medications and allergies
f. Scan through the notes from previous encounters
g. Look at the predicted outcomes for the two treatments (only scenario 1)
h. Decide on treatment of thrombolytic therapy or PCI

These tasks were meant to focus the attention of participants on specific areas of the patient chart so that they could provide feedback about the effectiveness of the information display. Upon completion of the tasks, participants were asked to evaluate the design by rating heuristics that included questions to consider when determining whether or not the design met that specific heuristic. The characteristics of the overall design participants were asked to rate included: navigation, screen layout, simplicity, recognition rather than recall, consistency, feedback, content organization and controls. The rating scale used to evaluate the heuristics was yes, no or n/a (not applicable) with the option to provide additional comments for each response or to provide overall feedback at the end of each scenario. There was no specific time limit for each task. Participants worked at their own pace and accomplished both tasks within 30 to 45 minutes. Half of the participants were asked to start with scenario one while the other half started with scenario two. The usability test was run with seven participants who were selected because they had experience developing, designing, and researching an EHR system and could provide feedback on the design as an expert in the field of EHR software development. In addition, designs were shown to an ED physician in August 2012 and a registered nurse in September 2012 who is also a patient safety expert for an EHR system. These two participants were selected because they could provide feedback about the information display as representatives of the target end user.

The ratings and comments from the participants were compiled into a spreadsheet to tabulate the number of yes, no and n/a responses for each heuristic

and then a percentage was calculated based on the total number of ratings received. The percentage of yes, no or n/a ratings were then summarized for each heuristic and scenario (see table 1, table 2 and appendix C). These two summaries provided a way to compare results and responses. The comments on heuristics and scenarios also were reviewed along with the input from the two clinical experts and broken into three categories of impressions, user interface modifications or new enhancement to expand functionality.

Usability Test Results

Scenario 1

The results of the heuristic review for scenario one are summarized in table 1. Feedback from the usability test was positive overall with scenario one receiving higher percentages of approval for all heuristics except for controls. The lower rating for that heuristic seemed to be due to the prototype not being fully functional. The patient record design used in scenario one simulated the situation when the EMT and the hospital ED share and transfer patient information electronically as the two use the same system or the systems used are able to transfer and share collected and stored patient information immediately.

Overall, the heuristic ratings for scenario one were positive, with the two heuristics of simplicity and recognition rather than recall receiving positive ratings from all participants with comments that included:

- The information is displayed concisely.
- What is clickable is apparent, info organized well.

- Text in red is helpful.
- The information is readily available.

The next two heuristics of screen layout (see figure 4) and feedback received 86% positive ratings. Screen layout received 14% ratings of no while feedback received 14% ratings of not applicable. The comments for screen layout included

- Very nice alignment in patient assessment.
- The items are in consistent locations.
- Navigation spacing is wonky. Large white space in middle of chart view. Link floating in the middle.

The three remaining heuristics of navigation, consistency and content organization, illustrated in figures 5 and 6, all received 86% and 71% positive ratings and 14% and 29% ratings of not met. Comments for these heuristics included:

- I had problems finding vitals. Font sized and placement of headings are hard to decipher.
- I thought it was strange to have the predicted outcomes where they were.
- It’s very clear what will happen when the user takes an action.
- Problems, meds, allergies below the fold but the big box is chock full of info!
- Don't know how I feel about allergies below the fold and meds also below the fold. Might want height/weight/temp in a different section. Seems like separate, less important info.
- It’s very clear what the information refers to.

Table 1 Breakdown of scenario one ratings for each heuristic

Scenario 1 - Information from EMT Integrated into Patient Chart				
Heuristic	**Met**	**Not Met**	**Not Applicable**	**Total**
Navigation	71%	29%		100%
Screen Layout	86%	14%		100%
Simplicity	100%			100%
Recognition Rather Than Recall	100%			100%
Consistency	86%	14%		100%
Feedback	86%		14%	100%
Content Organization	86%	14%		100%
Controls	29%		71%	100%

Participant's general comments for the design in scenario one were positive and included some suggestions on how the design could be improved. The comments included:

- I like this much better than the other. ECG & Vitals, EMT info all visible at the same time - Bravo!
- I wonder how all the EMT goodness got into the EHR.
- Love the PCI-TPI.
- Almost overlooked "Patient is a clinical study participant.
- Does that go with PCI-TPI? or should it be 'Patient wide'.
- I like that you can see the problems, meds, allergies without having to click the bars. The information when you do click seems useful.
- Could not find the last vitals up top at first. Thought they might be in history initially.
- I like that the relevant critical info is in red. Can the EMT/doc decide what is red/critical important info? Might be cool to have that ability.
- I think the design would benefit from some shading, boxing, etc. of the various data elements. As it stands, all the data is there, but hard to parse

out from the labels, headings, users, etc. It's a lot of white with black text, and it kind of hurts. There is a lot of space wasted with the vertical layout, thus pushing problems, meds, allergies, down. I like that vitals are in red but don't know why they are so divorced from the vitals in the last visit.

- Well done. It still seems like the chart layout could be improved. Scenario 1 has a lot of information, but the ECG and predicted results seem to be slightly out-of-context. However, Scenario 2 has a bit too much blank space.
- I like this chart view better -- there was lots of info on the EMTs handwritten report I had missed in scenarios 2.

The design was shown to an ED physician to gather input from an EHR user. His feedback was constructive as he pointed out particulars that he liked and made suggestions for improvements. Overall, he thought the design looked good, was intuitive and easy to understand. He liked the expanding sections with problems, medications and allergies, the dropdown to display information from other departments who use a different EHR system since that reflects the reality at facilities where he works, and he liked how the ECG expanded on the page instead of opening in a new window but would want to see the ECG at its actual size. He liked the medical notes section and would like to see discharge notes and information as well.

A nurse/patient safety expert was also shown the design in an interview style setting. She provided helpful feedback and offered some thoughtful suggestions for improvements. Her overall impression of the design was favorable. She thought that information in the integrated information section flowed well and liked the navigation of the vitals. She suggested rearranging the order of the vitals

based on the importance and relationship with each other and would want to add history of coronary artery disease and hypercholesterolemia. Her other ideas were to add concentration to the oxygen saturation value to give the value more context, to include ‘unconfirmed ECG’ with the EMT assessment label and to change the pain level to a scale with a range of 0 to 10 which is the measurement used. She stressed that it would be useful to be able to compare not only this ECG with older versions but also the vitals as patients in the ER with a myocardial infarction have their vitals taken every 5 to 10 minutes so it is helpful for the physician or nurse to be able to compare readings. She liked how the ECG appears right on the page but would want to see it full sized. She said the bigger the better so that one could see details of the ECG. She liked the ability to add a note right on the page. From her experience, ED physicians write a paragraph summary as part of the patient handoff so found the notes entry field to be a useful feature. The part of the design that she liked the most was the accordion style sections with problems, medications and allergies. In particular, she found it extremely useful to have medications listed and the ability to see doses in the expanded view if that information is needed. Overall, she liked the design a lot and thought that it was a good representation of the facesheet with a good summary of the patient’s medical background especially in an ED setting.

Scenario 2

The results of the heuristic review for scenario two are summarized in table 2. Scenario two reflected the frequent situation in which the EMT hands a piece of paper to the ED physician with the assessment of the patient which is

then scanned and attached to the patient's electronic record in the hospital system as a PDF.

The two highest rated heuristics with 100% positive ratings were screen layout and consistency. The next three heuristics, which were given more positive ratings than negative were feedback (86%), navigation (71%) and simplicity (71%). Comments from participants on these heuristics included:

- The various fields were neatly aligned.
- Functionality is consistent within the page.
- It is very clear what something will do in the context of the task.
- Not sure since not fully functional (esp. re: feedback) but there is consistency.
- I did have trouble finding vitals and knowing for sure when last visit was.
- It was very easy to find information.
- Don't know how to get back from the EMT report. Didn't see the EMT report link at first.
- Chart section rolls up and display recent notes first.
- Have to open a new link to see anything.
- The chart view had a lot of unused space.

The remaining three heuristics of recognition rather than recall, content organization and controls all received either more negative ratings or more ratings of not applicable. Both content organization and controls received 43% positive ratings. Content organization received 57% negative ratings while controls received 57% not applicable ratings. The heuristic that received the lowest rating

was recognition rather than recall which received 25% positive ratings and 75% negative ratings.

- The content is organized in a very clear manner.
- It would be nice to have a flowsheet of vitals.
- It would be nice to see what happens when top part is collapsed.
- Don't know what big field is.
- Probs, meds & allergies below the fold.
- Critical info now trapped in imported PDFs, not consistently next to field labels.
- The units are included. However, the spacing between lines should probably be clearer. (See Zyrtec units.)
- You need to remember info from the EMT report and ECG.
- Have to flip to EMT/ECG pdfs and back to screen.
- Have to remember info from EMT report when reviewing rest of chart. May require duplicate entry.
- I think for someone who knows the medical content better, yes users can work without having to go back but I wasn't able to do that.

Table 2 Breakdown of scenario two ratings for each heuristic

Scenario 2 - Information from EMT Available from Link to PDF				
Heuristic	**Met**	**Not Met**	**Not Applicable**	**Total**
Navigation	71%	29%		100%
Screen Layout	100%	-		100%
Simplicity	71%	29%		100%
Recognition Rather Than Recall	14%	86%		100%
Consistency	100%			100%
Feedback	86%		14%	100%
Content Organization	43%	57%		100%
Controls	43%		57%	100%

There were more general comments for scenario two which included questions, suggestions and opinions about the lack of information since it was necessary in this scenario for the participant to search for the EMT assessment. The feedback listed below provided useful ideas on how the design could be improved and raises interesting questions especially considering scenario two reflects the existing problems with interoperability.

- Probs, meds and allergies are below the fold in this prototype. The info above the fold is sparse. I don't see where it came from or why it deserves so much real estate. I'm not sure what it is. Is this for me/my staff to fill out? Or info from EMTs?
- I really like the summary view of problems, meds and allergies. What's the capacity? (What happens when patient has 15 problems?)
- It seemed like info was missing. Didn't see the attachment link at first. Cumbersome to go to a new page. Didn't know how to get back from the report or ECG.
- Clearly it seems like it's easier to make a clinical decision when all the information is in one place and you don't have to click onto attachments. Otherwise information density is good!
- I like how the notes are on the side - it's like a narrative that gives the data more meaning.
- So this one incorporates some of my recommendations from the previous version. Still a lot of wasted space on the assessment pane. I also can't find a way to make my treatment decision. In tables, headings are blue, but on vertical forms, labels are black. It is better that the ECG opens as a full PDF but I should be in a new window so I can flip to and fro.
- Lots of un-imported info, so looks very blank.
- Is it possible for a user to have more than one reaction to an allergy?

- Generally speaking, the page appeared to be fine. There was some functionality not implemented, so I wasn't certain exactly how some things should work. Any concerns I have are reflected in the comments. My greatest concerns were the amount of blank space in the chart section.
- Lack of the decision support information makes the decision on therapy much more difficult and subject to error. Without this information each clinician has to formulate their own judgment, which may be based on their own clinical experience rather than on population data. The decision support is helpful. It might be useful to provide clinicians access to detailed information about how the projections were derived.
- It took me way longer than expected to find vitals. I clearly missed it (it's obvious to me now) but I was expecting it to be more structured like the other sections.
- I like being able to see past notes but it might be good to include additional info on who/what it's from. Or maybe it's the note from what appears to be the ER doc scheduling a follow-up for 1+yr that's throwing me off.

Overall heuristic ratings varied slightly between the two scenarios with the exception of recognition rather than recall and content organization. These two heuristics reflected the difference in the designs, in particular recognition rather than recall. When the EMT information was integrated into the patient record, the heuristic of recognition rather than recall was rated as met by all participants. In contrast, with scenario two when the EMT report and ECG PDFs that are links outside of the patient record, recognition rather than recall was rated as met by only one participant. To ensure that these results were significant a 7 x 2 chi square test was done. Full results are shown in appendix D. The overall chi square result is 25.509526 with 7 degrees of freedom and a critical value of 14.07. This

shows a statistically significant result in favor of scenario one that is accounted for primarily by the recognition rather than recall heuristic in which more participants believed that the interface design of scenario met that heuristic more than scenario two.

Discussion

The approach for the design of the patient chart was to apply techniques to the overall page layout and use standards common to technology to organize content with the goal of supporting readability, highlighting significant facts and making information easy to find. The results and responses from the usability test indicate that the goal was met as feedback indicated that data was well organized and arranged in a simple consistent manner. The response to the central component of the page containing recently obtained patient data from the EMT, indicate the section was helpful for participants as they completed tasks focused on finding various pieces of patient data. Surrounding the section with integrated information are the other details necessary to provide more context on the patient to the physician, who is most likely not familiar at all with this patient. This organization and display of the patient's medical background helped the participants complete the tasks. The nurse/patient safety expert liked the flow of this section, in particular the way the vitals are listed. Participants reported that they were able to locate the information identified as crucial for making a decision on treatment. The one area that a few participants had trouble finding initially was vitals from the last visit which were at the top next to the patient's

name. This would be an area of the design that could be improved since a few people mentioned having trouble finding this information.

Alignment of all other patient details and sections had a positive effect on the readability of the page as data elements and sections were displayed using formats and standards commonly used to increase the intuitiveness and ease of use of the page. Participant's comments on these stated that data was concisely displayed, information density is good and alignment was nice. Other comments indicate that it was obvious what would occur based on the use of consistent standards so users knew when text or a section was actionable. One participant also liked how the medical narrative was incorporated into the page. The nurse who reviewed the design, also commented on the usefulness of the notes field. She liked the feature that lets the user add a new note directly from either view of the notes section.

The goal the first design was to create a user interface of a patient chart that included information captured from another healthcare provider and to improve coordination of care through information sharing and to support decision-making by displaying crucial elements of a patient's health on a single page. It represented the ideal workflow in which there are no interoperability obstacles so all care providers are able to seamlessly transmit and view patient data regardless of the EHR system in use. In contrast, the second design used the same overall structure but information captured from an external source was only available as a link that took the user to a different screen reflecting the situation that is common with the currently available EHR systems. Participant feedback on

the second design was slightly less favorable but that was expected as information from the EMT was not integrated. The responses and comments from scenario one denote that the design with content from an external source or system integrated into the patient chart was well organized and information was concisely displayed in a simple style. Patient information both past and present were readily available allowing a user to compare data such as vitals. This removed the need to retain information from a previous page or document in order to compare specific data to the recent reading. Highlighting abnormal findings in red also seemed to support recognition of an abnormality. Availability of the ECG, vitals, EMT collected information together in a structured display made the page intuitive and easy to understand. Users were able to find information without requiring extensive searching on the screen.

Organizing the user interface by making integrated data the central aspect of the patient chart gave the page a focus that drew the attention of the user to the most recently captured information. The contrast of the designs for scenario one and scenario two demonstrate that completeness of information with the ability to compare recent statistics and notes with previously obtain details reduces the mental workload for the user as inclusion of recently captured data removes the need to remember facts from two different places. Emphasizing abnormal figures within the current data set also calls attention to specifics without requiring the user to rely on recall of knowledge or to do any calculations.

The usability test revealed some areas for improvement in the patient record design while also showing that the design techniques used in the

information display resulted in supporting less reliance on memory. The usability test also supported the hypothesis that displaying integrated information supports informed decision-making better than using a paper record in combination with an electronic record. A few comments underline specific areas of the design that could be modified to increase the effectiveness of the design. One update would be to display the ECG full sized in a PDF reader to accommodate a zoomed view. The other updates to consider include changing the order of the vitals to better match the healthcare provider's mental model and incorporating multiple instances of data for vitals for comparison over a timeline.

Design Recommendations/Improvements

The response to the designs were positive but there were suggestions from the usability test participants, both comments and questions, as well as suggestions from the ED physician and nurse/patient safety expert that could be assimilated to improve the user interface. Design recommendations fall into two categories of user interface modifications to improve readability and content organization, and feature enhancements to expand functionality to make the page more useful to the targeted end user.

One participant suggested including units with each vital sign. The thinking behind this suggestion is to reduce the need for the field labels as the physician could infer the specific vital sign based on the unit. The labels for vital signs could then be displayed in a smaller font size or even in a different font placing greater emphasis on the actual specific numbers. Another modification to the vitals is based on a few participants having difficulty finding information from

the last visit. The data from the last visit could be incorporated into the integrated data section to tie these elements together and simplify comparison of the sets of information. The nurse who reviewed the design shared that in the ED vital signs may be taken at 5 to 10 minute intervals if it is a patient has acute myocardial infarction so that it would be useful to be able to compare the readings for the various intervals. She also suggested displaying multiple pain scale inputs as well as what relieved the pain. In order to incorporate multiple vitals readings, the layout of the integrated information display section would have to be reworked to display sets of data for comparison. One way to accommodate the additional data is to reduce the size of the ECG to gain display real estate, and move the predicted mortality rates to a different place on the page. Reducing the ECG would not negatively impact the design since multiple people expressed the need and importance of viewing the ECG in its true size. Another option for viewing data sets would be to display them in rows that only appear in an expanded view when needed. The default would be to show the most recent numbers with the ability to see a full list for one specific vital. This option would reduce confusion and maintain the list of vitals together as a whole. Reducing the size of this section would also mean increasing the visibility of problems, medications and allergies so that it appears above the fold which at least one participant mentioned.

There was also a suggestion to add background color or more color to the design. A little more color could be incorporated into the design, specifically when the user accesses a section to indicate a change to the state of that section. Use of color, however, should be implemented judiciously since an EHR is a tool

with a vast amount of information so the focus should be on using color to highlight features or information. Color should be incorporated purposefully and not just for aesthetics.

An important suggestion voiced by a usability test participant who is a designer and by the ED physician was to display the full version of the ECG. The physician liked being able to enlarge the ECG on the page but said he would like to see it in its actual dimensions. Also one of the developers who participated in the usability test suggested using a PDF reader that opens PDF attachments in a new window so the physician does not lose his place on the patient's chart. In addition, there could be a delay when the PDF loads into in the same window as the EHR. The PDF reader would also allow the physician to zoom in to regions of the ECG to see details up close.

The ED physician made suggestions that are new features that would improve the functionality of the design. He suggested incorporating old ECGs for reference. In the design, previous ECGs would be accessible from the Labs/Imaging tab but it would be an enhancement to simultaneously display both old and new ECGs for comparison. If this feature were to be incorporated, it would be beneficial to understand how the PAC system used by radiologists handles viewing of multiple images. Another feature enhancement suggested by the ED physician was to highlight important terms in clinical notes so he is assured of seeing important information about the patient. This would require building a knowledge base of terms that would be presented in a different way to

draw attention. This could be accomplished using color or a different font style or size for emphasis.

The nurse/patient safety expert made a number of suggestions that center around further integration with other systems. One idea is to incorporate a tracking system into the patient chart design to include the patient's actual location within the facility. She mentioned that it is difficult to locate patients once they are transitioned into another department for care so being able to see where the patient is right now would be very helpful. Other information that she suggested incorporating into the design is communication with nurses and other staff and the status of orders especially around imaging. In regards to actions, she would like to see a feature that displays order sets based on the patient's chief complaint or presenting symptoms.

The comments, questions and suggestions from the usability test and reviews of the design provide a number of ideas and areas where the information display could be further improved and be more effective. The design also acted as a platform that generated innovative ideas for new features that could greatly enhance electronic health records. It would be interesting to pursue both types of feedback.

Limitations and Future Work

Although this research showed that integration of patient information from other sources into an EHR does support decision-making, reduces the reliance on memory and ultimately makes EHR systems more useful, this study was limited

to one scenario where data is transferred from an EMT to a hospital ER for myocardial infarction patients. The design focused specifically on integrating patient information for this condition so limited the usability test to one particular situation. Only one iteration of the design was tested due to time constraints. It would be useful to study what information would be relevant to display for patients with other conditions or symptoms that require EMT services or to identify the data set that is needed for another system such as an operating room system and further develop the design. Incorporating more scenarios into the prototype would all for a more extensive usability test to compare the information display changes based on the data source or the presenting symptoms to accommodate other scenarios.

Conclusion

Information technology in the medical field holds great promise in supporting the transformation and improvement of the delivery of healthcare. Widespread adoption of health information technologies holds the potential of transforming the way healthcare is delivered by improving quality, enhancing safety, reducing workload and reducing cost. The increased availability of patient information and decision support at the point of care has tremendous potential for reducing errors and increasing coordination of care. In 2009 the US government made funding available to health care providers to encourage the use electronic health records so the role of EHR systems in patient care is evolving significantly as adoption is incentivized; health information exchanges operationalized and new features are made available for clinical decision support. Improving the

usability of the EHR display is critical as it will support care of the whole patient and improve the quality, safety, efficiency and effectiveness of how care is delivered through greater coordination and information availability.

Studies, however, show that limitations exist with EHR specifically with the usability or more broadly, the information design of EHR systems. The presentation of patient information has a direct effect on decision-making whether it is in paper or electronic format. Clinical decision-making is a product of the integration and interpretation of multiple pieces of patient information and medical knowledge. Variability in medical decisions can be expected when incomplete or inconsistent display of information is combined with variability that inherently exists in physician knowledge of the patient.

This thesis research focused, first, on understanding the problem of accessibility of information that is the result of healthcare providers using different EHR systems that are unable to share data, then studied the impact of integrating patient information from multiple systems and applied human factors methods and theories to develop a design of a patient chart. The information display incorporated patient health information from other sources in conjunction with patient information already available in the base EHR. The goal of the design was to demonstrate an ideal scenario when data in electronic format is transferred seamlessly from end to end and compare it with a design that mimicked the common scenario when the use of paper records is unavoidable. The design of the patient interface applied design techniques meant to support less reliance on memory and improve information access by showing data where it is needed and

when it is needed. The results from the usability test of the design support the hypothesis that integrating information from an external source with known specifics about a patient's medical background reinforces informed decision making more effectively than using a paper record in combination with an electronic record. On the whole, the design succeeded in presenting an example of an ideal model with information shared seamlessly between two systems and also showed that there are numerous ways that electronic health records could be further expanded as a tool that could have a positive impact on healthcare.

Appendix A: Feature Requirements for Thesis Patient Chart Design

Research Goal
Goal is to identify how information could be passed from healthcare provider to healthcare provider and how to display patient health information to support decision making, reduce workload and improve ease of use.

Design Goal
Develop a design to display patient information and predicted outcomes so they can be easily understood to support decision-making on treatment.

Intended User
Healthcare providers including physicians, nurses and possibly emergency medical technician.

Feature Requirements
The patient chart design will include the following features:

- Patient's name
- Patient's date of birth (DOB)
- Record number
- Vitals
    - Blood pressure
    - Heart Rate
    - Oxygen saturation
    - Blood rate
    - Respiratory Rate
    - Temperature
    - Height
    - Weight
    - Time since onset of symptoms
- ECG scan (specific to the clinical study)
- Allergies
- Medications
- Illnesses
- Data from decision support tool
- Notes from previous encounters
- Link to edit information
- Accessible from patient chart
    - Demographics (address, insurance etc.)
    - Full health history (medical, social, family & appointments)
    - Labs/imaging
    - Orders
    - Documents
    - Referrals
    - Top navigation
    - Search

Appendix B: Usability Test Instructions

Usability Test Instructions

Scenario

You are an emergency room physician. Your next patient is a female who was brought in by ambulance because she is experiencing chest pain. As the ER physician these are the things you would look for before treating the patient.

- EMT assessment with brief history of symptoms (nature of pain and how long in onset, association with other symptoms, etc.)
- Vital signs (i.e., blood pressure, heart rate, respiratory rate, temperature, oxygen saturation)
- Significant medical history (e.g., diabetes, heart disease, hypertension, etc.)
- Medications
- Allergies
- Information from previous visits

Scenario 1:

- You are an emergency room physician at a hospital.
- New patient was just brought in by an EMT.
- EHR system used by EMT is able to send data directly to the hospital EHR.
- EMT is participating in a clinical study to evaluate a predictive decision support tool.

Task: Assess the patient's condition to choose a treatment
i. Open the patient's chart
j. Review EMT assessment of patient's condition
k. Expand the ECG
l. Find the patient's vitals from last visit
m. Look at the patient's problems, medications and allergies
n. Scan through the notes from previous encounters
o. Look at the predicted outcomes for the two treatments
p. Decide on treatment of thrombolytic therapy (medication) or PCI (angioplasty)

Heuristic	Questions to Consider	Rating	Comment
Navigation	• Does the system use a consistent navigational hierarchy? • Is it easy to understand where to find information?	Yes No N/A	
Screen Layout	• Are items in consistent locations across screens? • Are text fields, checkboxes, radio buttons, menus, tables, etc. neatly aligned?	Yes No N/A	
Simplicity	• Is information displayed concisely? • Does important information stand out? • Are function options straightforward?	Yes No N/A	
Recognition Rather Than Recall	• Do you have all the information needed to complete a task? • Can users work without having to remember something from a previous window or screen?	Yes No N/A	
Consistency	• Are the contents and layout consistent? • Is the behavior of the functionality consistent within the page?	Yes No N/A	
Feedback	• Is it clear what clicking on something will do in the context of the task? • When performing an action, is there feedback that something has changed?	Yes No N/A	
Content Organization	• Are tables and graphics used to facilitate understanding? • Is the meaning of displayed information either obvious or explained? • Is frequently used critical information (allergies, active medications) visible on the screen in a consistent location?	Yes No N/A	
Controls	• Are units (milligrams, pounds) included with the information entry fields so users aren't required to type them in?	Yes No N/A	

Scenario 2:

- You are an emergency room physician at a hospital.
- New patient was just brought in by an EMT.
- EHR system used by EMT is **not** able to send data directly to the hospital EHR.
- EMT is participating in a clinical study to evaluate a predictive decision support tool.

Task: Assess the patient's condition to choose a treatment
a. Open the patient's chart
b. Review EMT assessment of patient's condition
c. Expand the ECG
d. Find the patient's vitals from last visit
e. Look at the patient's problems, medications and allergies
f. Scan through the notes from previous encounters
g. Decide on treatment of thrombolytic therapy (medication) or PCI (angioplasty)

Heuristic	**Questions to Consider**	**Rating**	**Comment**
Navigation	• Does the system use a consistent navigational hierarchy? • Is it easy to understand where to find information?	Yes No N/A	
Screen Layout	• Are items in consistent locations across screens? • Are text fields, checkboxes, radio buttons, menus, tables, etc. neatly aligned?	Yes No N/A	
Simplicity	• Is information displayed concisely? • Does important information stand out? • Are function options straightforward?	Yes No N/A	
Recognition Rather Than Recall	• Do you have all the information needed to complete a task? • Can users work without having to remember something from a previous window or screen?	Yes No N/A	
Consistency	• Are the contents and layout consistent? • Is the behavior of the functionality consistent within the page?	Yes No N/A	
Feedback	• Is it clear what clicking on something will do in the context of the task? • When performing an action, is there feedback that something has changed?	Yes No N/A	
Content Organization	• Are tables and graphics used to facilitate understanding? • Is the meaning of displayed information	Yes No N/A	

	either obvious or explained? • Is frequently used critical information (allergies, active medications) visible on the screen in a consistent location?		
Controls	• Are units (milligrams, pounds) included with the information entry fields so users aren't required to type them in?	Yes No N/A	

Appendix C: Detailed Heuristic Review Results

Scenario 1

Heuristic	Questions to Consider	Yes	No	N/A	Comments
Navigation	· Does the system use a consistent navigational hierarchy? · Is it easy to understand where to find information?	71%	29%	0%	I had problems finding vitals.
Screen Layout	· Are items in consistent locations across screens? · Are text fields, checkboxes, radio buttons, menus, tables, etc. neatly aligned?	86%	14%	0%	Very nice alignment in patient assessment. The items are in consistent locations. Nav spacing is wonky. Large white space in middle of chart view. Link floating in the middle.
Simplicity	· Is information displayed concisely? · Does important information stand out? · Are function options straightforward?	100%	0%	0%	The information is displayed concisely. Much better than in scenario 2. What is clickable is apparent, info organized well. Text in red is helpful.
Recognition Rather Than Recall	· Do you have all the information needed to complete a task? · Can users work without having to remember something from a previous window or screen?	100%	0%	0%	The information is readily available

Consistency	· Are the contents and layout consistent? · Is the behavior of the functionality consistent within the page?	86%	14%	0%	Font sized and placement of headings are hard to decipher I thought it was strange to have the predicted outcomes where they were.
Feedback	· Is it clear what clicking on something will do in the context of the task? · When performing an action, is there feedback that something has changed?	86%	0%	14%	It's very clear what will happen when the user takes an action.
Content Organization	· Are tables and graphics used to facilitate understanding? · Is the meaning of displayed information either obvious or explained? · Is frequently used critical information (allergies, active medications) visible on the screen in a consistent location?	86%	14%	0%	Problems, meds, allergies below the fold but the big box is chock full of info! Don't know how I feel about allergies below the fold and meds also below the fold. Might want height/weight/temp in a different section. Seems like separate, less important info. It's very clear what the information refers to.
Controls	· Are units (milligrams, pounds) included with the information entry fields so users aren't required to type them in?	29%	0%	71%	The units are fine. However, the spacing between lines could be improved. (See Zyrtec.)

Scenario 2

Heuristic	**Questions to Consider**	Yes	No	N/A	Comments
Navigation	· Does the system use a consistent navigational hierarchy? · Is it easy to understand where to find information?	71%	29%	0%	I did have trouble finding vitals and knowing for sure when last visit was It was very easy to find information. Don't know how to get back from the EMT report. Didn't see the EMT report link at first.
Screen Layout	· Are items in consistent locations across screens? · Are text fields, checkboxes, radio buttons, menus, tables, etc. neatly aligned?	100%	0%	0%	The various fields were neatly aligned.
Simplicity	· Is information displayed concisely? · Does important information stand out? · Are function options straightforward?	71%	29%	0%	Chart section rolls up and display recent notes first. Have to open a new link to see anything The chart view had a lot of unused space.
Recognition Rather Than Recall	· Do you have all the information needed to complete a task? · Can users work without having to remember something from a previous window or screen?	14%	86%	0%	You need to remember info from the EMT report and ECG. Have to flip to EMT/ECG pdfs and back to screen. Have to remember info from EMT report when reviewing rest of chart. May require duplicate entry. I think for someone who knows the medical

					content better, yes users can work without having to go back but I wasn't able to do that
Consistency	· Are the contents and layout consistent? · Is the behavior of the functionality consistent within the page?	100%	0%	0%	Functionality is consistent within the page.
Feedback	· Is it clear what clicking on something will do in the context of the task? · When performing an action, is there feedback that something has changed?	86%	0%	14%	It is very clear what something will do in the context of the task. Not sure since not fully functional (esp. re: feedback) but there is consistency
Content Organization	· Are tables and graphics used to facilitate understanding? · Is the meaning of displayed information either obvious or explained? · Is frequently used critical information (allergies, active medications) visible on the screen in a	43%	57%	0%	The content is organized in a very clear manner. It would be nice to have a flowsheet of vitals. It would be nice to see what happens when top part is collapsed. Don't know what big field is. Probs, meds & allergies below the fold

	consistent location?				Critical info now trapped in imported PDFs, not consistently next to field labels.
Controls	· Are units (milligrams, pounds) included with the information entry fields so users aren't required to type them in?	43%	0%	57%	The units are included. However, the spacing between lines should probably be clearer. (See Zyrtec units.) I see units but not sure where to type them in

Appendix D: Chi Square Test

Heuristic	**Scenario 1 (obs)**	**Scenario 1 (exp)**	**Secenario 2 (obs)**	**Scenario 2 (exp)**
Navigation	5	5.308641975	5	4.691358025
Screen Layout	6	6.901234568	7	6.098765432
Simplicity	7	6.37037037	5	5.62962963
Recognition Rather than Recall	7	4.24691358	1	3.75308642
Consistency	6	6.901234568	7	6.098765432
Feedback	6	6.37037037	6	5.62962963
Content Organization	6	4.777777778	3	4.222222222
Controls	2	2.654320988	3	2.345679012
Column totals	43		38	
			Overall Chi^2	
1	0.142857143		**Chi^2**	**23.50952599**
2	0.285714286		**df**	**7**
3	0.428571429		**critical**	**14.07**
4	0.571428571			
5	0.714285714			
6	0.857142857			
7	1			

Row totals			**Chi^2 (w/Yates' correction)**	**Chi^2 w/o Yates' correction**	**Critical**
10	0.12345679		0.020406671	0.038249694	3.84
13	0.160493827		0.13139276	0.250870916	3.84
12	0.148148148		0.055724449	0.132649939	3.84
8	0.098765432		**3.073060358**	**3.804238066**	**3.84**
13	0.160493827		0.13139276	0.250870916	3.84
12	0.148148148		0.019096542	0.045899633	3.84
9	0.111111111		0.411141371	0.666462668	3.84
5	0.061728395		0.147741126	0.343818849	3.84
81					

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