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The Relationship Between Electronic Health Record Implementation and Outcomes of Care For Three Cardiovascular Procedures

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THE RELATIONSHIP BETWEEN ELECTRONIC HEALTH RECORD IMPLEMENTATION AND OUTCOMES OF CARE FOR THREE CARDIOVASCULAR PROCEDURES

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DEDICATION

This work is dedicated in memory of my grandmother, Dorothy Wood Meder, "Nana." She demonstrated what it meant to be a strong and independent woman. She inspired me to pursue a career in healthcare and was beaming with pride upon my acceptance into the Doctoral program. As she fought a host of health issues, she reminded me that she was staying strong to, "see her baby girl graduate." While she is no longer here, I know I could not have accomplished what I have without memories of her continuous encouragement.

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ABSTRACT

Background. The U.S. healthcare movement to improve quality and patient outcomes has prompted investigations into tools that can assist in these aims. Electronic health records (EHRs) are one tool proposed by the Institute of Medicine (IOM). The objective of this original dissertation research is to examine the relationship between implementation of electronic health record functionalities and two outcomes of care as proxies for quality: risk-adjusted mortality and log-transformed estimated cost per discharge for abdominal aortic aneurysm (AAA) repair, coronary artery bypass grafting (CABG), and percutaneous coronary intervention (PCI).

Methods. This study used 2009-2010 hospital inpatient administrative discharge data from the Nationwide Inpatient Sample (NIS), Healthcare Cost and Utilization Project (HCUP), Agency for Healthcare Research and Quality merged with data from the 2009-2010 American Hospital Association Information Technology Supplement. A pooled cross-sectional design was used, at the hospital-level, to determine if advanced levels of select Electronic Clinical Documentation (ECD), Computerized Provider Order Entry (CPOE), and Clinical Decision Support (CDS) functionalities implementation were associated with two outcomes of interest.

Results. Bivariate analyses revealed significant relationships for risk-adjusted mortality across levels of CDS implementation for hospitals performing AAA repair (drug-allergy alerts and drug-drug interaction alerts) and PCI (drug-allergy alerts and drug-dosing

support). Regression results revealed a significant positive relationship between level of CDS implementation and risk-adjusted mortality for AAA repair and PCI, controlling for patient-mix and hospital characteristics. The multivariate regression models for all three procedures modeled individually failed to detect a relationship among average level of ECD, CPOE, and CDS implementation and log-transformed estimated costs per discharge, all else equal.

Conclusion. Despite not knowing the exact ways in which EHR functionalities of interest are implemented and used across the inpatient setting, this study aimed to provide a foundation for future research on such relationships. While no significant relationship was detected between level of EHR functionalities implementation and log-transformed estimated cost per discharge, risk-adjusted mortality for AAA repair and PCI were found to be positively associated with increased implementation of select CDS functionalities. This study answers the 2012 call from the IOM for researchers to report any findings of the potential unintended consequences of EHR use.

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LIST OF ABBREVIATIONS

AAA .... abdominal aortic aneurysm

ACCF .... American College of Cardiology Foundation

ADEs .... adverse drug events

AHA .... American Heart Association

AHA .... American Hospital Association

AHRQ .... Agency for Healthcare Research and Quality

AMI .... acute myocardial infarction

EHR .... electronic health record

EMR .... electronic medical record

CABG .... coronary artery bypass graft

CAH .... critical access hospital

ECD .... clinical documentation

CDS .... clinical decision support

CHF .... congestive heart failure

CMS .... Centers for Medicare & Medicaid Services

COPD .... chronic obstructive pulmonary disease

CPOE .... computerized provider order entry

GAO .... United States Government Accountability Office

HCUP .... Healthcare Cost and Utilization Project

HIE .... Health Information Exchange

HIT ....Health Information Technology

HITECH ....Health Information Technology for Economic and Clinical Health

IOM ....Institute of Medicine

IMA ....internal mammary artery

IQIs .... Inpatient Quality Indicators

IT ....information technology

ICU ....intensive care unit

MedPAC ....The Medicare Payment Advisory Commission

MEs ....medical errors

MPEs .... medication prescribing errors

NIM .... National Institute of Medicine

NIS ....Nationwide Inpatient Sample

ONC-HIT ....Office for the National Coordinator

ONC-HIT-HIT ... Office for the National Coordinator for Health Information Technology

PCCU ....pediatric critical care unit

PCI ....percutaneous coronary intervention

PCTA ....percutaneous coronary transluminal angioplasty

PHRs ....Personal Health Records

RVs ....rule violations

SIR ....Society of Interventional Radiology

USPSTF ....United States Preventative Services Task Force

VA..U.S. Department of Veterans Affairs

WHO ....World Health Organization

CHAPTER 1

INTRODUCTION

In 1999 and 2001 the Institute of Medicine (IOM) issued the reports *To Err Is Human* and *Crossing The Quality Chasm*, both of which catalyzed the movement to improve patient safety and the delivery of quality health care services in the United States (U.S.) (IOM, 2012). In 1999, it was estimated 98,000 individuals in the U.S. die annually due to hospital medical errors (IOM, 1999). The following year the estimate was revised to 220,000 lives lost (Starfield, 2000). The variations in reported estimates of medical error related deaths are possibly attributable to a lack of generally accepted system for reporting errors (Rosenthal, Riley, & Booth, 2000). The recognition of these high error rates has led to realization that there are deficiencies in patient safety, prompting initiatives to investigate and improve the quality of care (IOM, 2012).

The IOM (2001) developed six aims for quality improvement, asserting that care should be: safe, effective, patient-centered, timely, efficient, and equitable. While patient safety is an element of quality, safety is also essential to an efficient and effective healthcare system. Patient safety aims to avoid adverse outcomes, while quality concerns the overall system of care delivery's impact on outcomes and strategic goals. For example, quality initiatives must also consider cost effective decision-making to achieve the financial goals that are necessary to maintain an organization's strategic plan.

Health information technology (HIT) was recently noted for the potential benefits related to the improvement of healthcare quality and patient safety, despite the lack of knowledge of the possible associated risks (IOM, 2012). HIT includes a variety of electronic tools such as personal health records (PHRs), secure patient portals, health information exchanges (HIE), electronic health records (EHRs), and electronic medical records (EMRs).

The dissertation research aimed at examining patient safety and quality of care delivery of organizations with varying levels of EHR implementation through the examination of inpatient operative mortality and cost per discharge for acute abdominal aortic aneurysm (AAA) repair, coronary artery bypass grafting (CABG), and percutaneous coronary intervention (PCI). Specifically, we investigated links among three levels of EHR implementation and (1) inpatient operative mortality for AAA repair, CABG, and PCI and (2) inpatient operative cost per discharge for AAA repair, CABG, and PCI, regardless of mortality. The three procedures of interest have been identified by both the Agency for Healthcare Research and Quality (AHRQ) and The Leapfrog Group as appropriate inpatient quality indicators (IQIs) (AHRQ, 2012; The Leapfrog Hospital Survey, 2012). In order to evaluate the hypothesized relationships, the next section will review the functionalities of an EHR and the evolution of what constitutes an EHR.

Electronic Health Record Adoption

The definition of EHRs and EMRs are evolving and the terms are often used interchangeably, despite differences in functionality. The Office for the National Coordinator for Health Information Technology (ONC-HIT) defines EMRs as the digital replacement to paper charts in healthcare organizations that contain a patient's medical and treatment history (Garrett & Seidman, 2011). However, the ONC-HIT uses the term EHR almost exclusively (Garret & Seidman, 2011). EHRs are designed to share patient record information with all clinicians involved in a patient's care in order to provide more coordinated and patient-centered care when implemented and fully functional (Garrett & Seidman, 2011). The evolving definitions have placed emphasis on specific components required to be considered a fully functional EHR (Furukawa, Raghu, Spaulding, & Vinze, 2008). In 2012, the IOM identified four main categories of functionalities that constitute an EHR: clinical decision support tools, computerized provider order entry systems, and e-prescribing systems (IOM, 2012).

The American Hospital Association (AHA) (2010) measures implementation of EHRs based on four key functionalities: electronic clinical documentation (ECD), results viewing, computerized physician order entry (CPOE) and clinical decision support (CDS). The four functionalities encompass twenty-four measured sub-functions that are implemented at varying levels, creating an array of definitions of what constitutes an EHR (Jha, DesRoches, Campbell, Donelan, & Rao, 2009).

The American Recovery and Reinvestment Act's (ARRA's) Health Information Technology for Economic and Clinical Health (HITECH) provision of 2009 seeks to incentivize providers to adopt and use EHRs in a "meaningful" way, including functions related to error reduction and cost containment (Menachemi & Collum, 2011). The ONC-HIT, along with the Centers for Medicare and Medicaid Services (CMS), has identified standards and criteria for the certification of EHRs. Achievement of these implementation criteria may be identified using the sub-functions measured by the AHA. The ONC-HIT identifies two main levels of implementation: Basic and Comprehensive (Table 1.1).

Table 1.1. Levels of EHR functionality

EHR Required Functions	Basic with Clinician Notes	Comprehensive
Electronic Clinical Information		
Patient demographics	*	*
Physician notes	*	*
Nursing assessments	*	*
Problem lists	*	*
Medication lists	*	*
Discharge summaries	*	*
Advanced directives		*
Computerized Provider Order Entry		
Lab ordering		*
Radiology tests		*
Medication ordering	*	*
Consultation requests		*
Nursing orders		*
Results Management: View…		
Lab reports	*	*
Radiology reports	*	*
Radiology images		*
Diagnostic test results	*	*
Diagnostic test images		*
Consultant report		*
Decision support		
Clinical guidelines		*
Clinical reminders		*
Drug-allergy alerts		*
Drug-drug interactions		*
Drug-lab interactions		*
Drug dosing support		*

Note: Basic EHR implementation is defined as the identified function implemented in at least one clinical unit; comprehensive is defined as the identified function implemented in all clinical units.

From 2008 to 2011, U.S. adoption of EHR has sharply increased; since 2009, hospital adoption of at least Basic and Comprehensive EHR systems has more than doubled. From 2008 to 2009, EHR adoption increased by 20 percent, 2009 to 2010 by 18.6 percent, and 2010 to 2011 by 82 percent (Charles, Furukawa, & Hufstader, 2012). The Congressional Budget Office estimates that 70 percent of hospitals will adopt Comprehensive EHR systems by 2019 (Committees on Energy and Commerce, Ways and Means, and Science and Technology, 2009). In a 2011 ONC-HIT survey of non-federal acute care hospitals, 85% of hospitals intended to attest to "meaningful use" (MU) under the CMS EHR Incentive program by 2015 (Charles et al., 2012).

The current objectives of MU are outlined in three stages from 2011-2016 (CMS, 2012). The focus varies for each stage and time period: (1) data capture and sharing for 2011-2012, (2) advance clinical processes for 2014, (3) improved outcomes for 2016 (CMS, 2012). Eligible hospitals and professionals who are "meaningfully using" CMS certified EHR technology to improve patient care can qualify for financial incentive payments (CMS, 2012). Examining HIT's relationship with improvements in quality and patient safety as well as reductions in costs, addresses the IOMs (2012) call for studies in this area. This study examined the relationships between implementation of EHR process of care functionalities and selected patient outcomes for the three conditions of interest.

Process of care

Several studies have examined the link between EHR implementation and quality, including surgical outcomes as a proxy for quality (J. D. Birkmeyer, Finlayson, & C. M. Birkmeyer, 2001; Dimick, Welch, & J. D. Birkmeyer, 2004; Khuri et al., 1997; Shamliyan, Duval, Du, & Kane, 2008). A 2006 AHRQ funded literature review found improvements in process of care delivery using EHR functions ranged from absolute increases of 5 to 66 percentage points, clustered in the range of 12-20 percent (Chaudhry et al., 2006).

Implementation of EHR systems is intended to support and simplify the process of delivering healthcare services. This study uses EHR sub-functions that are measured by the AHA Information Technology Supplement across six levels of implementation. Our analysis was restricted to include ECD, CPOE, and CDS sub-functions: problem lists, medication lists, electronic prescribing, clinical guidelines, clinical reminders, drug-allergy alerts, drug-drug interaction alerts, drug-lab interaction alerts, and drug-dosing support (AHA, 2010). These sub-functions are adopted in varying combinations across the inpatient care setting. Understanding the relationship among levels of EHR sub-functions implementation and patient outcomes and costs is necessary in furthering the HIT and patient outcomes literature. Limited sample sizes, specialized populations, cross-sectional designs, and mixed results on the relationship between EHR sub-functions and patient outcomes create limitations that prompt further investigations in this area.

Purpose

A recent review of the HIT literature found both benefits and drawbacks of EHR systems. Potential benefits include clinical outcomes (e.g., improved quality, reduced medical errors), organizational outcomes (e.g., financial and operational benefits), and societal outcomes (e.g., improved population health, improved research capabilities, and reduced costs) (Menachemi & Collum, 2011). However, the manner in which an EHR is linked to process of care, and thus its relationship to patient outcomes, is still unclear. Implementation of EHR sub-functionalities was considered as the level of measure for process of care in this study.

Research providing strong evidence of volume-outcome relationships (Dudley, Johansen, Brand, Rennie, & Milstein, 2000; Hannan, Kilburn, Brenard, O'Donnell, Lubacik, & Shields, 1991; Luft, Bunker, & Enthoven, 1979) prompted Leapfrog to include surgical mortality as a performance measure (J. D. Birkmeyer, Finlayson, & C. M. Birkmeyer, 2001). However, debates regarding volume and its associations with lower inpatient mortality have been ongoing (Christian, Gustafson, Betensky, Daley, & Zinner, 2003; Daley, 2002; Dudley & Johansen, 2001; Khuri et al., 2001). These debates, based on mixed results of the linkage between hospital and surgeon volume to operative mortality rates (Finks, Osborne, & J. D. Birkmeyer, 2011; Finlayson, Gooney, & J. D. Birkmeyer, 2003), have spurred research into the contribution of EHR process of care.

The incorporation of process of care into EHR functionalities (e.g. clinical reminders and decision support) potentially plays a mediating role (Webster & Copenhaver, 2010) among other factors (e.g., volume) that have been found to have associations with outcomes (e.g., mortality) (J. D. Birkmeyer & Dimick, 2004). This original research seeks to investigate links between EHR implementation and operative mortality and costs, if any. This research has the potential to facilitate guideline adherence for MU of EHRs or possibly detect risks of EHR implementation, for the procedures in question.

Organization of Remaining Chapters

This original dissertation research is formatted using the manuscript style. In lieu of the traditional Chapter 4 (Results) and Chapter 5 (Conclusions), two manuscripts representing the two specific research aims are included. Chapter 2 includes a review of the scholarly literature in the areas of HIT, surgical process of care for the three procedures of interest, and patient outcomes. Chapter 4 explores the relationship between the average level of implementation, across three levels, of nine selected EHR sub-functionalities and risk-adjusted mortality rate for the three cardiovascular procedures of interest. Chapter 5 examines the association between estimated cost per discharge for the three cardiovascular procedures of interest and the average level of implementation of the selected nine EHR sub-functionalities. The results and conclusions are presented in the two manuscripts that will be submitted to two peer-reviewed journals for publication. Chapter 6 concludes this dissertation by highlighting major results.

CHAPTER 2

Literature Review

Healthcare Quality and Patient Safety

Many Americans have been apt to believe that increased healthcare spending is associated with better health outcomes or quality of care. However, U.S. health outcomes have for the most part failed to match spending. The U.S. ranks number one in the world per capita for healthcare spending (World Health Organization, 2011). In fact, according to the World Health Organization (2011), per capita healthcare expenditures in the U.S. have jumped from $4,703 in 2000 to $8,362 in 2010.

Despite having the highest healthcare expenditures, the U.S. ranks 27th in the world for average life expectancy (77-79 years) (World Health Organization, 2011). Further, the U.S. ranks near the bottom on almost all health indicators when compared to other industrialized countries (Starfield, 2000). The details of these differences in spending and outcomes are complex (Starfield, 2000). The U.S. system of healthcare delivery has traditionally focused on providing “sick care.” The U.S. is recognized as excelling at treatment over prevention, despite the high costs associated with the delivery of services that are most often needed for the treatment of chronic and complex illnesses (Marvasti & Stafford, 2012). The IOM (2001) has charged U.S. healthcare organizations with improving these outcomes through the delivery of quality health services by way of a systems approach. A systems approach takes on a holistic view in solving systems problems through an interdisciplinary systems solution (Pronovost & Bo-Linn, 2012).

The prevention model, the suggested solution to the current crisis, is also meant to alleviate system fragmentation and focusing on forestalling disease development to clinical manifestation (Marvasti & Stafford, 2012). Both approaches are aimed at improving health indicators and quality of care delivery.

The IOM (1990) defines quality as “the degree to which health services provided to individuals and patient populations improve desired health outcomes and are consistent with current professional knowledge (p.128)”. In health services research there are a variety of measures used to operationalize quality. The CMS, IOM, and AHRQ have all developed measures that may be used as proxies for quality.

The quality movement initialized upon the realization that medical errors in the U.S. had staggering consequences. The report *To Err Is Human* (IOM) in 1999 estimated as many as 98,000 deaths annually as a result of medical errors. Iatrogenic causes, an adverse condition resulting from the treatment of a health care provider or institution (Miller-Keane & O’Toole, 2005), are estimated to be the third leading cause of death in the U.S. (230,000-284,000), after heart disease and cancer (Starfield, 2000). Despite these estimates, there is still ambiguity in the exact number of iatrogenic events due to a lack of standardized or mandatory reporting systems across states. States’ greatest concerns with mandatory reporting systems are potential challenges with underreporting and inadequate resource availability (Rosenthal, Riley, & Booth, 2000). Other factors acknowledged as inhibiting reporting have been fear of punitive action, cultural, perceptual, and logistical barriers (IOM, 2012).

Creating a culture of patient safety throughout the continuum of care to address these barriers at a system level is imperative in reducing the number of iatrogenic events.

One initiative aimed at addressing these barriers at a system level is the Partnership for Patients, developed by policy makers and The Department of Health and Human Services (DHHS). Partnership for Patients is aimed at creating a safer patient environment through the reduction of hospital-acquired conditions and complications and by reducing preventable complications during care transitions (IOM, 2012). Focusing on patient care transitions among various providers involved in care delivery is a systems level approach, in that all providers involved are expected to create a safer patient environment. As a host of tools have been proposed to support a safer system of care delivery, HIT is identified as instrumental in the measurement and improvement of patient safety (IOM, 2012).

Health Information Technology

Health Information Technology (HIT) includes tools such as personal health records (PHRs), electronic patient portals, health information exchanges (HIE), EHRs, and EMRs (IOM, 2012). These tools are intended for knowledge sharing among patients and clinicians, as well as between clinicians. A PHR is a data repository maintained by the patient of their medical and treatment history, sometimes including decision support capabilities that can assist patients managing chronic conditions (Tang, Ash, Bates, Overhage, & Sands, 2006). The PHR can also contain information extracted from an EHR or other sources of clinical information (Pritts, 2010).

An EMR is a clinician's digital replacement to paper charts, typically containing medical and treatment history of patients seen in a single practice (Garrett & Seidman, 2011). Electronic patient portals, a requirement of physician practice meaningful use stage two, are meant to facilitate communication between patients and their providers (Ammenwerth, Schnell-Inderst, & Hoerbst, 2012). HIEs allow health care organizations to exchange clinical data (Rudin et al., 2012). EHRs have more capabilities than EMRs in that they can include a range of functionalities (IOM, 2012) including ECD, CDS, electronic results viewing, and CPOE, which support a variety of applications.

The role EHR functionalities play in the improvement of the delivery of quality care, as well as potential unintended consequences, is of interest to policy makers (IOM, 2012). The American Recovery and Reinvestment Act of 2009 specify three main components of meaningful use of certified EHR technology:

(1) Use in a meaningful manner as outlined in core (Table 2.1) and menu (Table 2.2) objectives

(2) Use for an electronic exchange of health information

(3) Use to submit clinical quality measures (CQM) and other measures outlined by the Secretary (CMS, 2010).

To be considered eligible for the incentives, the hospital must have one of the following designations: (1) "Subsection (d) hospitals" in the 50 states or DC that are paid under Inpatient Prospective Payment System (IPPS) (2) Critical Access Hospitals (CAHs) (3) Medicare Advantage (MA-Affiliated) Hospitals (CMS, 2012).

Table 2.1. Eligible Hospital and Critical Access Hospital (CAH) Core Objectives (CMS, 2012)

(1) Use CPOE for medication orders
(2) Drug-drug and drug-allergy interaction checks
(3) Maintain an up-to-date problem list of current and active diagnoses
(4) Maintain active medication list
(5) Maintain active medication allergy list
(6) Record demographics
(7) Record and chart changes in the following vital signs: height, weight, blood pressure, calculate and display body mass index (BMI), plot and display growth charts for children 2-20 years, including BMI

(8) Record smoking status for patient 13 years old and older
(9) Report clinical quality measures to CMS or, in the case of Medicaid eligible hospitals, the States
(10) Implement one clinical decision support rule related to a high priority hospital condition along with the ability to track compliance with that rule
(11) Provide patients with an electronic copy of their health information, upon request
(12) Provide patients with an electronic copy of their discharge instructions at time of discharge, upon request
(13) Capability to exchange key clinical information among providers of care and patient authorized entities electronically
(14) Protect electronic health information

In pursuance of incentives for meaningful use for the first of three stages, eligible hospitals must adopt and use 19 of 24 objectives (CMS, 2012). Hospitals are required to achieve all 14 of the required core objectives (Table 2.1) and at least five of the ten menu set objectives (Table 2.2). When designed, implemented, and used appropriately, it is widely believed that HIT can positively transform the way care is delivered in the U.S. (IOM, 2012).

Table 2.2. Eligible Hospital and Critical Access Hospital (CAH) Menu Set Objectives (CMS, 2012)

(1) Drug formulary checks
(2) Record advance directives for patient 65 year old or older
(3) Incorporate clinical lab-test results into EHR as structured data
(4) Generate lists of patients by specific conditions
(5) Use certified EHR technology to identify patient-specific education resources and provide those resources to the patient, if appropriate
(6) Medication reconciliation.
(7) Provide summary care record for each transition of care or referral
(8) Capability to submit electronic data to immunization registries/systems
(9) Capability to submit electronic data on reportable (as required by State or local law) lab results to public health agencies
(10) Capability to provide electronic syndromic surveillance data to public health agencies

Hospital factors associated with IT adoption and implementation

At the present, the U.S. health care system is in the early stages of HIT adoption. The U.S. has adopted clinical information systems at a slower rate than Europe (McCullough, 2008). It is essential to understand the characteristics of hospitals in the U.S. that have and will soon adopt EHRs, in order to derive interpretations of adoption- and implementation-associated effects.

Rank effect describes how hospital characteristics effect a hospital's decision to adopt HIT (McCullough, 2008). Hospital characteristics, as well as hospital market conditions, can impact the effect of HIT on marginal costs and possibly returns on adoption (McCullough, 2008). The quality-adjusted price of HIT is declining over time; consequently, institutions that expect a lower return will postpone adoption until it is available at a lower price (McCullough, 2008). Meaningful use (MU) legislation financially incentivizes early adopters of certified EHRs, whereas those who adopt after 2015 will receive reduced reimbursements. This leads to the question, what are the hospital-level characteristics of those who are early adopters that anticipate early and high returns from HIT adoption and implementation?

Structural factors, environmental factors, and interactions with other providers have been the three main mechanisms that describe the diffusion (market acceptance) and adoption of these new technologies (McCullough, 2008). Hospital characteristics or structural factors can include hospital ownership/control (government-nonfederal, not-profit, for-profit), teaching status (academic, non-academic), hospital size (specific to region, location, and teaching status), and location (rural or urban). Environmental factors and interactions with other providers can include competition and reimbursement mechanisms, measured often by multihospital system membership (yes or no) and payer mix (percentage of private pay, self-pay, Medicare, Medicaid, uninsured). These factors have all been tested for their relationship with HIT adoption, often producing mixed results across characteristics.

Adoption of HIT applications is also affected by the technology clusters to be adopted (Burke, Wang, Wan, & Diana, 2002; Fonkych & Taylor, 2005; Zhang, Seblega, Wan, Unruh, Agiro, & Miao, 2013). Clinical, administrative, and strategic are the three major IT clusters (grouping of around 52 information technologies) that are typically examined when studying hospital factors associated with IT adoption (Zhang et al., 2013). Clinical IT includes applications such as CPOE and CDS (of interest for this study). Findings have shown that administrative and strategic technologies have higher diffusion rates than clinical applications (Poon et al., 2006; Zhang et al., 2013). The following section will discuss hospital factors associated with IT adoption, as well as hospital characteristics associated with adoption of the three technology clusters.

Hospital ownership (for-profit and non-profit) has been shown to have a mixed effect on HIT adoption decisions, which has varied across application clusters. In some studies for-profit hospitals were more likely to adopt clinical, administrative, and strategic applications (Zhang et al., 2013) while in other studies only strategic applications (Burke et al., 2002; Wang, Wan, Burke, Bazzoli, & Lin, 2005) had associations with profit status. On the other hand, non-profit hospitals are more likely to adopt clinical applications (Burke et al., 2002; Fonkych & Taylor, 2005). Hospitals that are closer to achieving meaningful use objectives are more likely to be non-profit (Jha et al., 2011). The patterns of adoption may reflect the size of the IT budget in both for-profit and non-profit settings.

There are substantial differences in the amounts allocated for their IT budgets across hospital ownership type (Fonkych & Taylor, 2005). Non-profit hospitals tend to have higher IT budgets than for-profit, spending over 4 percent of their operating budget on IT as compared to 0.5 percent for-profit who spend that much (Fonkych & Taylor, 2005). In regard to adoption of specific applications, clinical application adoption has been shown to have a statistically significant positive association with greater adjusted cash flow and greater adjusted operative revenue per bed (Fonkych & Taylor, 2005). In contrast, however, McCullough (2008) found that ownership has no relationship with adoption decisions. Burke, Menachemi, & Brooks (2005) found similar results as McCullough (2008), with the exception of strategic applications (clinical and administrative have no relationship). These mixed hospital ownership results may be attributed to adoption of varying clusters of technology (clinical, administrative, and strategic).

Teaching status has also been found to be an indicator of HIT adoption. Academic hospital status has been shown to have a positive association with HIT adoption (Fonkych & Taylor, 2005; Jha et al., 2011; McCullough, 2008; Wang, Wan, Burke, Bazzoli, & Lin, 2005; Zhang et al., 2013). Larger hospital size has also been shown to have an association with HIT adoption (Burke et al., 2002; Jha et al., 2011; Palacio, Harrison, & Garets, 2010; Zhang et al., 2013; Wang, Wan, Burke, Bazzoli, & Lin, 2005). Smaller hospitals may have limited financial resources as compared to those with more beds, which may inhibit adoption (Burke et al., 2002; Palacio et al., 2010).

Findings about the relationship of hospital size are complementary to those pertaining to rural areas, in that smaller hospitals are often located in rural areas.

Hospitals with rural designations have lower adoption of HIT than those in urban designations (Fonkych & Taylor, 2005; Jha et al., 2011; Zhang et al., 2013). When compared to non-profit and urban hospitals, public and rural hospitals in 2009 were 40 percent less likely to adopt a basic EHR (Jha, DesRoches, Kralovec & Joshi, 2010). Further, significant differences across regions in the adoption of hospital HIT have also been detected (Jha et al., 2011; Zhang et al., 2013). Northeastern and Southern regions have been found to adopt clinical, administrative, and strategic HIT applications at a higher rate than Western and Midwestern regions (Furukawa, Raghu, Spaulding, & Vinze, 2006; Jha et al., 2011; Zhang et al., 2013).

Multihospital systems have been found to be more likely to proceed with HIT adoption (Fonkych & Taylor, 2005; Jha et al., 2011; McCullough, 2008; Wang et al., 2005). In regards to specific IT applications, Burke and colleagues (2002) found membership in a multihospital system to be positively associated with adoption of clinical IT and strategic IT (not administrative IT). Researchers propose that increased inter-organizational communication channels of multihospital systems as a possible explanation of this relationship (Burke et al., 2002), which has also been identified as a factor influencing IT adoption (Robertson, Swan, & Newell, 1996).

Payer mix is said to act as a proxy for age and socioeconomic position, and is frequently shown to be predictive of mortality (Caretta et al., 2012). Hospitals with a high proportion of Medicare beneficiaries are believed to benefit from the adoption of HIT, whereas the opposite is true for hospitals with a high patient mix of Medicaid beneficiaries (McCullough, 2008). Medicare beneficiaries require more intensive services than non-Medicare patients, requiring more coordination, thereby increasing returns associated with HIT adoption (McCullough, 2008). Indigent care also typically requires increased coordination, because of the complex needs of this population who typically seek sick care more frequently than preventative care. Accordingly, hospitals with a high proportion of indigent patients may also find high returns as a result of coordination. While hospitals with a high mix of Medicaid beneficiaries might have a smaller marginal benefit if the adoption decision is based on charge capture, the value as defined in this manner may decrease as reimbursement is reduced (McCullough, 2008).

Examinations of market level factors associated with IT adoption have found mixed results. Hospitals located in areas with higher HMO penetration (percent of local population covered by HMO plans) have been shown to have a positive relationship with HIT adoption (Fonkych & Taylor, 2005; Zhang et al., 2013). Contrary to these findings, Wang and colleagues (2005) did not detect a relationship between IT adoption (clinical, strategic, and administrative) and managed care penetration. Researchers believe that the influence of managed care on IT adoption may be influenced by capitation more so than by competitive pressures (Wang et al., 2005). The relationship is thought to be ambiguous due to issues in the measurement of managed care (Fonkych & Taylor, 2005).

Evaluating HIT diffusion effects

As systems of care progress toward increased diffusion of HIT, researchers should continually reevaluate the impact of HIT tools on patient outcomes as the characteristics of later adopters could translate into different effects on institutional and patient outcomes than the characteristics of early adopters. Organizations adopting technology in the later stages of the innovation process perceive the innovation as having lower risk (Meyer and Goes, 1988), assuming that by this point any glitches have been resolved.

Thus, outcomes in the early stages of adoption could be different than those during later adoption due to learning curve effects.

Early adopters may have favorable perceptions of innovation embedded in their organizational culture that influence their willingness to embrace the new technology, where later adopters might be more resistant. The resistance could impact outcomes if they eventually adopt HIT. Consequently, it could be hypothesized that organizations with an innovative culture may have better outcomes when compared to those organizations that are more resistant to change. As health-IT becomes more integrated across the continuum of care with strategies supporting Accountable Care Organizations (ACOs) and patient-centered medical homes, the functions of HIT will assist in the improvement of the delivery of complex care in a more cost efficient manner with improved patient outcomes (IOM, 2012).

Theoretical Framework

The proposed research is based on the theoretical model proposed by Donabedian (1966), as adapted by J. D. Birkmeyer and Dimick (2009), examining inpatient operative quality through evaluation of structure, process, and outcome. Using Donabedian's model, this dissertation research examined level of EHR implementation (structure), and in particular ECD, CPOE and CDS functionalities (process of care), which are hypothesized to lead to reduced mortality (outcome) (Figure 2.1). The assumption is that given the proper settings and instrumentalities, good medical care will follow (Donabedian, 2005). Noting the limitation that we cannot measure all of the potential process that exists, process was measured at the most fundamental level available. These fundamental processes are limited to EHR functionalities, as measured by the AHA. For example, hospitals vary in their customization of clinical reminders, thereby limiting the study of process of care to the level for which measurement is available. The lack of data on process that vary across settings creates limitation in the extrapolation of results in the study of care delivery. Additional structural characteristics such as overall hospital characteristics that may affect outcomes were also included as covariates. Patient-level characteristics were also included to risk-adjust outcomes.

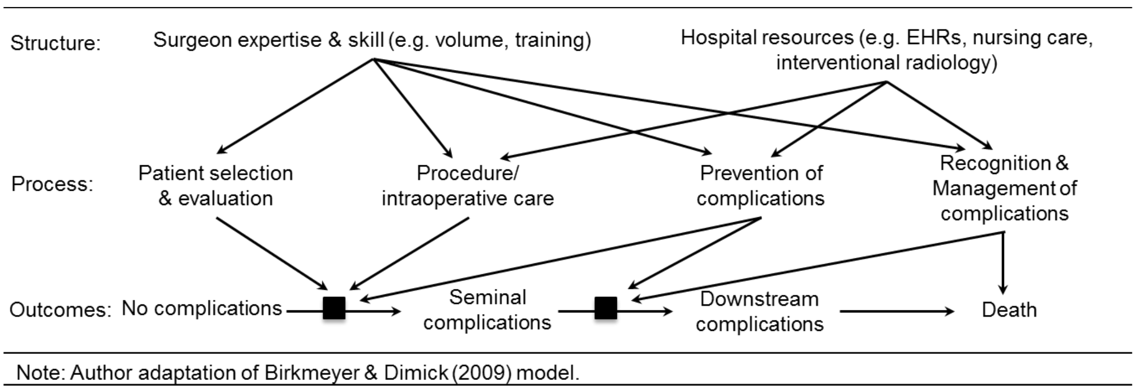

Figure 2.1. Theoretical model of the relationship between structure, process of care, complications and mortality after surgery

Structure: Electronic Health Records

Donabedian (2005) describes the structure, process, and outcome framework as "a chain of events in which each event is an end to the one that comes before it and a necessary condition to the one that follows (p.713)." This suggests a means-end relationship, meaning each component is fundamental antecedent toward achieving the targeted outcome (Donabedian, 2005).

The adoption of EHR structures across hospitals vary dramatically. EHRs have a range of functionalities which support a wide array of applications. Hospitals adopt these functionalities and their applications in different combinations. The four key categories of functionalities of EHRs associated with clinical care measured by AHA (2010) include electronic documentation, electronic results viewing, decision support and computerized provider order entry (Charles et al., 2012). These four functionalities are examined by the applications or sub-functionalities they support. IOM (2004, 2012) identifies eight functionalities of EHR systems: health information and data (clinical documentation), results management, CPOE, CDS, electronic communication and connectivity, patient support, administrative process, and reporting and population health management. The Office for the National Coordinator for Health Information Technology (ONC-HIT) and AHA measure adoption and implementation of EHRs with four of these functionalities: clinical documentation, results management, CPOE, and CDS.

The ONC-HIT recognizes 24 applications in the adoption and implementation of their definition of basic and comprehensive EHRs (Charles et al., 2012), which can be measured using the AHA Information Technology Supplement annual survey. Hospital adoption of EHRs is also measured by the number of clinical units in which the applications are implemented (Charles et al., 2012). The AHA (2010) EHR adoption survey measures stage of implementation in six phases (Table 2.3). The 24 sub-functions result in an assortment of combinations and stages of implementation.

Table 2.3. AHA measures of EHR implementation

(1) fully implemented across *all* units
(2) fully implemented in *at least one* unit
(3) beginning to implement in *at least one* unit
(4) have resources to implement in the next year
(5) do not have resources but considering implementing
(6) not in place and not considering implementing

EHR functionalities as process of care

After reviewing the structure of the Donabedian framework, how each functionality and its associated applications within the EHR structure are integrated in care process are the next step in understanding the means-end relationship between structure, process, and outcome. Process of care is a function of workflow design (IOM, 2012). HIT is not a specific system, but a collection of provider chosen applications or components (IOM, 2012). The differences in implementation have effects on care process that include care design and workflow, and ultimately impact the quality and safety of the delivered care (IOM, 2012). A recent factor analysis found that adoption of sub-functions of the four major functionalities is highly correlated, but adoption across the four functionalities is relatively independent (Balvin et al., 2010). The following sections explore the four main functionalities of EHRs and the functions or applications they support. Table 2.5 further details comparisons of studies examining the four EHR functionalities.

Electronic Clinical Documentation

The electronic clinical documentation functionalities include seven key sub-functionalities as measured by the AHA (2010): patient demographics, physician notes, nursing assessments, problem lists, medication lists, discharge summaries, and advance directives. Electronic clinical documentation is a vital component of an EHR because almost every other functionality uses some element of documentation. CPOE, CDS, and bar-coding all rely on documentation, results viewing, and management in prescribing and delivering medications (IOM, 2012).

Electronic documentation of problem lists, medication lists, consideration of relevant clinical factors in the assessment and plan, and appropriateness of the assessment and plan have been found to be significantly more complete and appropriate than paper documentation (Tang, LaRosa, & Gorden, 1999). More complete patient records are meant to improve the quality of the care process. Of the six functionalities, three are required to achieve MU guidelines: patient demographics, problem lists, and medication lists.

MU requires that 50 percent of each unique patient encounters have demographic information recorded, unless the patient declines (CMS, 2012). The required elements include gender, date of birth, patient's preferred language, race and ethnicity (CMS, 2012). One of the goals of EHR use is to reduce healthcare disparities based on race, ethnicity and language and record of this information will help in distinguishing these disparities (Rowley, 2011).

Problem lists are regarded as a key part of a medical record in that the list provides practitioners with up-to-date current and active diagnoses to aid in developing a treatment plan (Holmes, Brown, St Hilaire, & Wright et al., 2012). Problem lists are considered to be input data that can trigger CDS rules to be invoked (Wright, Goldberg, Hongsermeier, & Middleton, 2007). The use of problem lists in conjunction with CDS is used to prevent medical errors (Holmes et al., 2012; Wright et al., 2007). Wright and colleagues (2007) have identified three main issues with problem lists in the literature: (1) no standardized inclusion criteria, (2) failure to include all problems, and (3) inclusion of minor or inactive problems. Despite these challenges, high quality problem lists have been directly linked with improved compliance with best practices (Wright et al., 2012).

For example, accurate documentation of heart failure on problem lists was associated with increased likelihood of use of appropriate medications (Hartung, Hunt, Siemienczuk, Miller, & Touchette, 2004).

In 2010, 79 percent of hospitals with nine or more core Stage 1 MU functions in place reported having implemented electronic problem lists (Jha et al., 2011). However, hospitals with nine or more core functions of Stage 1 in place reported difficulties with generating problem lists and automating quality measures, as compared to those hospitals with fewer than 9 core functions required for Stage 1 (Jha et al. 2011). On the other hand, they were less likely to report CPOE or CDS implementation as a challenge (Jha et al. 2011). This finding is interesting considering that some of the CDS functions use problem list data for triggering CDS rules (Wright et al., 2007).

Medication lists, also referred to as medication reconciliation, are also noted for their benefits. A cluster-randomized trial found a decrease in the unintentional medication discrepancies with potential for patient harm using a computerized medication tool and process redesign (Schnipper et al., 2009). Significant benefit varied across the two hospitals studied, Schnipper et al. (2009) suggest the non-adherence as related to the results of a study (Turchin et al., 2008) on clinician attitudes and patterns of application use; attributing the lack of integration of medication lists in CPOE applications at admission as an explanation of the differences. This suggests that the extent of integration of medication lists in CPOE applications as a possible explanation of the differences.

Contrary to reported benefits, one study investigating VA primary care patient medication lists found 5.3 percent agreement between electronic medication lists and what the patient was actually taking, omitting an average of 3.1 drugs per patient (Hoth et al., 2004). This study also found 1.3 commissions (medications listed that are no longer being taken) (Hoth et al., 2004). Another study found that the inaccuracies are most frequently over-the-counter (OTC) and non-prescription drugs (Staroselsky et al., 2007).

Continued examination of problem lists and medication lists is important as MU criteria are implemented. It will also be interesting to determine the differences in those who adopt CDS functions prior to adoption of problem lists and medication lists, since this data can be used to create alerts or triggers for CDS (Wright et al., 2007). The role of electronic clinical documentation as a supporting functionality in prescribing and delivering medications (IOM, 2012) and potential associations with patient outcomes is of interest for this study.

Results Management Viewing

The results management *viewing* functionalities include six key sub-functionalities as measured by the AHA (2010): lab reports, radiology reports, radiology images, diagnostic test results, diagnostic test images, and consultant reports. As of 2008, results management viewing has been adopted at the highest rate among the four main categories of EHR functionalities (Jha et al., 2010; Balvin et al. 2010). Among the 28.6 percent of hospitals that have fully implemented results viewing (all results viewing functions on the AHA Information Technology Supplement annual survey) across all clinical units, 27 percent have fully implemented electronic clinical documentation, 28 percent have fully implemented CPOE, and 30 percent have fully implemented CDS (Balvin et al., 2010). Further, among 13. 3 percent of hospitals that fully implemented all of the CPOE sub-functions, 61.3% implemented results viewing functionalities (Balvin et al., 2010).

Used in conjunction with CDS, lab reports and diagnostic test results can provide alerts of abnormal test results. However, findings have shown alerts are not always read or received follow-up. A study in the outpatient setting of critical imaging alert notifications in a VA facility found that of 123,638 imaging results 1,196 alerts were generated to the ordering physician, with only 18.1 percent (217) that were acknowledged/read (Singh et al., 2009). Further, of all generated alerts for abnormal results only 7.7 percent (92) received a follow-up action (further testing or consultation) within four weeks of the alert transmission (Singh et al., 2009). Viewing of diagnostic test and imaging results include data used to confirm the presence or absence of a suspected condition such as urinalysis, blood tests, cardiac imaging, and pulmonary function. In addition, lab reports are viewable in an EHR for screening purposes to diagnose an asymptomatic individual that may have a disease (National Institute of Medicine, 2012). Electronically available for viewing diagnostic test results, diagnostic imaging, and lab report results are often studied as to their interoperability with CDS functions.

Advanced imaging has garnered the most individual investigation of the results management sub-functions for its relationship with cost; this has predominantly been studied in the outpatient setting. While radiology imaging and diagnostic test images of the six functionalities have been investigated with the highest frequency, there have been few studies examining the association of the use of results management of imaging and patient outcomes.

Of the results viewing management sub-functionalities, advanced imaging viewing has been noted as a component of HIT that has the potential for cost savings

(McCormick, Bor, Woolhandler, & Himmelstein, 2012). Technological improvements in imaging have allowed improvements in diagnosing and treating illness (MedPac, 2009). The director of the National Institute of Biomedical Imaging and Bioengineering has cited advances such as online guidance during surgery, known as “image-guided interventions”, for reducing trauma and improving effectiveness of surgical procedures (McCormick et al., 2012). Even with the potential for cost savings, costs rose steadily until 2006 when the rate slowed (MedPac, 2009). Continuing to monitor costs over to time to see if savings are realized and maintained is crucial in understanding the long-term cost benefit of advanced imaging viewing.

Technological advances, outpatient imaging centers, consumer demand, defensive medicine, and use of imaging technology across all clinical specialties have been thought to be associated with the increases in costs and use (MedPac, 2009; Inglehart, 2006). MedPac’s (2009) analysis of 2005 Medicare claims data found higher imaging use to be positively correlated with higher procedure use. However, the executive director of MedPAC, Mark E. Miller, provided testimony before the House Ways and Means Subcommittee on Health regarding the lack of a clear link between imaging volume and improved patient outcomes (Inglehart, 2006). Increases in imaging can reveal results that prompt additional diagnostics tests and interventions that increase the total episode costs (MedPac, 2009). The imaging volume and outcomes relationship questions the potential for organizations to realize savings, especially if there are no improvements for patient outcomes.

The U.S. Government Accountability Office (GAO) findings showed that in 2006 imaging spending under the physician fee schedule from physician offices increased from

58 percent in 2000 to 64 percent in 2006 (GAO, 2008). In the physician office setting, availability of electronic imaging results viewing was associated with a 40-70 percent increase in additional image tests being ordered (McCormick et al., 2012). Physicians sometimes lack adequate information on a patient and may order imaging procedures that already exist (Hendee et al., 2010). The high percentage of imaging that is conducted in the outpatient setting could add to the gap in the care continuum if a hospital lacks interoperability across the inpatient and outpatient settings.

Computerized Provider Order Entry and Clinical Decision Support

Computerized provider order entry (CPOE) functionalities include five main applications considered by the AHA (2010): laboratory tests, radiology tests, medications (e-prescribing), consultation requests, and nursing orders. CPOE is most frequently noted for its quality benefits in the reduction of medication errors (MEs) and adverse drug events (ADEs), particularly when coupled with clinical decision support (CDS) systems that include drug-allergy and drug-drug interaction check applications (Sengstack, 2010). However, there have also been results demonstrating a reduction in errors and improved patient outcome with the sole use of CPOE (Shulman, Singer, Goldstone, & Bellingan, 2005).

A meta-analysis on CPOE systems found that the majority of studies included CDS in conjunction with CPOE (Shamliyan et al., 2008), making it difficult to distinguish between CPOE and CDS effects. CPOE with CDS systems have correct medication prescribing (right patient, right drug) as a key function. The terminology related to medication related events is varied in distinguishing between events that may or may not be preventable or result in harm. Table 2.4 defines the terminology most often used regarding medication related harm and Figure 2.2 is presented to distinguish adverse drug events (ADEs), adverse drug reaction (ADRs), and medication errors (MEs). Medication related harm could occur at a variety of points in the process of care delivery. MEs can occur during prescribing, transcribing, compounding, packaging, labeling, dispensing, administering, adherence, use, or monitoring of a drug (AHRQ, 2000; Veterans Affairs, 2006; U.S. Food and Drug Administration, 2013).

Table 2.4. Medication related harm terminology

Term	Harm?	Definition
Medication errors (MEs)	possible	"any preventable event that may cause or lead to inappropriate medication use or patient harm…" (FDA, 2013)
Adverse drug event (ADE)	yes	"any injury resulting from the use of a drug" (VA-VHA, 2006)
Adverse drug reaction (ADR)	yes	requires causality of harm from the drug at normal doses (e.g., allergies) (Nebeker, Barach, & Samore et al., 2004)
Potential adverse drug event	no	MEs that are recognized before harm caused (VA-VHA, 2006)
Medication prescribing errors (MPEs)	possible	errors due to inadequate information or that require additional information to be processed or human error (e.g., missing information or illegible) (Potts, Barr, Gregory, Wright, & Patel., 2004)
Rule violations (RVs)	possible	errors that violate hospital policy (e.g., abbreviations) (Potts et al., 2004)

Also of note are nonpreventable ADEs, this is when a patient without any previous known allergies develops a reaction (Khaushal et al., 2003). Preventable ADEs are injuries resulting from the use of a drug (VA-VHA, 2006). The average length of stay (LOS) for patients who experience preventable ADEs has been shown to increase significantly by as many as 4.6 days and increase costs up to $4,685 (Bates et al., 1997). Utilizing technology systems, such as CPOE with CDS, has the potential to reduce the increased costs associated with adverse events (Bates et al., 1997).

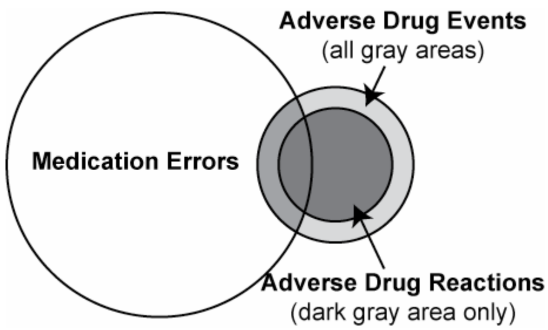

Figure 2.2. Relationship of medication related terminology
(Figure created by Nebeker et al., 2004)

The AHA (2010) measures implementation of six sub-functionalities for evaluating CDS adoption: clinical guidelines, clinical reminders, drug allergy alerts, drug-drug interaction alerts, drug-lab interaction alerts, and drug dosing support. Four of the six functions specifically address medications and are thus generally incorporated within CPOE systems. Hospitals ranked in the top decile nationally in quality by the Hospital Quality Alliance (HQA) were significantly more likely to have all clinical decision support functions than those with intermediate or lower ranked quality (Elnahal, Joynt, Bristol, & Jha, 2011). For-profit hospitals adopt clinical decision support at a slightly higher rate than non-profit (65 percent versus 58 percent) (Fonkych & Taylor, 2005). CPOE use was associated with a 66 percent reduction in medication errors in adults (Shamliyan et al., 2008).

The terminology (Table 2.3) to describe medication induced errors and harm can be difficult to differentiate. Specific CPOE functions have been found to have varying implications on different types of medication related errors. Drug safety alerts are sometimes studied as a component of a CPOE system (Kashal et al., 2003; van der Sijs, Mulder, van Gelder, Aarts, Berg, & Vulto, 2009). It is somewhat challenging to differentiate between CPOE and CDS because components of each system are often used together. The benefits related to medication use in the inpatient setting using EHRs with CPOE functionalities have been attributed particularly to CPOE use paired with CDS (Metzger, Welebob, Bates, Lipsitz, & Classen, et al., 2010).

Adoption of CPOE has been found to vary by hospital characteristics. For-profit hospitals adoption of CPOE applications (4 percent) is one-fifth the rate (21 percent) of adoption in non-profit hospitals (Fonkych & Taylor, 2005). The adoption of CPOE among rural and urban hospitals is 13 percent versus 19 percent (Fonkych & Taylor, 2005). Despite low adoption of clinical systems, for-profit hospitals have higher adoption of outcome and quality measurement applications (Fonkych & Taylor, 2005). Adoption of CPOE in different types of acute care hospitals varies: pediatric (46 percent), academic (28 percent), general medical and surgical (15 percent), general medical (11 percent), critical access (16 percent), and long-term acute (one percent) (Fonkych & Taylor, 2005). Hospital ownership (government) and teaching status (academic) are more likely to invest in CPOE (Cutler, Feldman, & Horwitz, 2005). Findings also show that hospital profitability does not have a relationship with CPOE investment (Cutler et al., 2005).

Studies that have utilized a pre-test post-test design evaluating the implementation of CPOE and MEs or ADEs have identified decreases in these rates. The rates of MEs were significantly lower for adults after CPOE implementation (6.7% versus 4.8%), results which were detected in the 37 week sampling frame (Shulman et al., 2005). A study in a pediatric teaching hospital found CPOE implementation led to a 95.9 percent reduction in overall errors, 40.9 percent reduction in ADEs, 99.4 percent reduction in medication prescribing errors (MPEs), and a 97.9 percent reduction in rule violations

(RVs) (Potts et al., 2004). The dramatic decreases were detected within two months of CPOE implementation. Both sets of findings show that benefits can be recognized early in the implementation process. Further, a recent (2013) systematic literature review by Radley and colleagues found the effects of CPOE on MEs to decrease MEs by 48 percent (95% CI = 41% to 55%) (Radley, Wasserman, Olsho, Shoemaker, Spranca, & Bradshaw, 2013).

A 2010 study found that top performing hospitals (measured by an tool developed by the Leapfrog group that assesses the ability of CPOE with basic or advanced CDS to detect and avert prescribing errors in “live” hospital settings) achieving ADE detection scores of 70-80 percent or greater were attributable to the implementation of advanced CDS (Metzger et al, 2010). However, there were many hospitals that performed poorly; the overall mean score of all sampled hospitals was 44 percent of ADEs detected (Metzger et al., 2010).

Computerized orders have also been associated with a 66 percent reduction in total hospital prescribing errors in adults (Shamliyan et al, 2008). Shamliyan et al. noted that there are results that contradict these findings. They suggested that the differences are possibly due to the beneficial effect of CPOE, which is larger in studies with greater baseline rates of medication errors (Shamliyan et al., 2008). A controlled trial found that CPOE was associated with a decrease in total costs of $887 per admission and decrease in mean length of stay of 0.89 days (Tierney, Miller, Overhage, & McDonald, 1993).

While reductions in prescribing errors, costs, and length of stay are noted, there are numerous studies that document overrides of these alerts. One study examining CDS found that drug-drug interactions were generated most frequently (56%) and also overridden 98% of the time, as compared to overrides to overdose alerts (89%) and duplicate orders (80%) (van der Sijs et al., 2009). The study also found that all drug safety alerts at the point of patient admission were overridden (van der Sijs et al., 2009). A study on a basic CDS system found that it detects 83.3 percent of drug-allergy contraindications and 52.4 percent of drug-allergy interactions (Metzger et al., 2010). Understanding how to avoid overrides is vital in learning how to maximize the benefit of decision support systems.

The current literature on CDS and CPOE use has produced mixed results, which can be due to the nature of the study designs having limited external validity. A systematic literature review of 27 studies examining CDS with e-prescribing as the intervention notes that future studies could be improved by including more generalizable clinical and geographic settings (Ammenwerth et al., 2008). Decision support capabilities vary by software products as well as by hospital customization (Metzger et al., 2010), which may explain varied results.

Table 2.5. Comparisons of studies examining EHR functionalities

Authors	Time Frame	Health IT Component	Data Source	Design	Outcome Measures	Findings
Daley et al., 1997	1991-1993	surgical technology and equipment, technical competence of staff, interface with other hospitals services	44 Veterans Affairs Medical Centers	structural survey and site visits to 20 of 44 surgical services centers with higher-than-expected and lower-than expected risk-adjusted outcomes	30 day risk-adjusted surgical mortality and postoperative morbidities occurring in the 30 days postoperatively	Significant differences in risk-adjusted surgical morbidity and mortality rates for several dimensions of process and structure of the delivery of surgical care: technology and equipment and overall quality of care. No significant difference was found for technical competence of staff and interface with other hospitals services.
Elnahal et al., 2011	2009	Clinical documentation, results viewing, CPOE, CDS	2006 Hospital Quality Alliance (HQA) program data to designate high, intermediate, and low quality hospitals and the 2009 AHA hospital IT survey	Logistic regression and factor analyses	Adoption of each individual function of clinical documentation, results viewing, CPOE, and CDS (24 functions)	Electronic nursing notes, medication lists, diagnostic test image viewing, CPOE nursing orders, and all CDS functions were adopted at a significantly higher rate by hospitals in the top decile of quality than those ranked intermediate or lower in quality.
Kaushal, Shojania, & Bates, 2003	review	CPOE and CDS	5 CPOE trials and 7 CDS trials	Systematic literature review	Medication errors, potential ADEs, ADEs, and nonintercepted serious medication errors	CPOE and isolated CDS can reduce medication errors rates. Studies examining ADEs have low power to detect differences.

Authors	Time Frame	Health IT Component	Data Source	Design	Outcome Measures	Findings
Shamliyan et al., 2008	1990 - 2005	CDS	7 effects of CPOE with different CDS systems and 4 likelihood of preventing medication errors	Meta-analysis of 252 articles including randomized trials, uncontrolled interventions, and observational studies.	Medication errors and ADEs	All studies reported reductions in medication errors after implementation of CPOE. There was no decrease in the rate of prescribing the wrong drug after CPOE implementation. Results were mixed on medication errors related to incorrect dosages. The use of CPOE lessened adverse events in most studies, but wasn't statistically significant across all studies.
Radley et al., 2013	2007	CPOE	4,701 hospitals excluding long-term care and federally owned hospitals, and hospitals outside the 50 states or District of Columbia	Systematic literature review of the effects of CPOE on MEs to estimate percentages and absolute reduction in MEs attributable to CPOE	MEs	CPOE are associated with a decreased likelihood of error by 48 percent.
Koppel et al., 2005	2002 - 2004	CPOE	One urban tertiary-care teaching hospital with 750 beds and 39,000 annual discharges	Quantitative and qualitative: intensive one-on-one interviews (32), focus groups(5), expert interviews, shadowing and	Medication errors associated with CPOE use	Identified 22 sources medication errors associated with CPOE

Authors	Time Frame	Health IT Component	Data Source	Design	Outcome Measures	Findings
				observation		
Potts et al., 2004	2001-2002	CPOE	Tertiary-care children's teaching hospital; 20-bed PCCU	Prospective cohort clinical chart review pre and post CPOE implementation	MEs, ADEs, MPEs, and RVs	Rates were reduced: overall errors (95.9%), potential ADEs (40.9%), MPEs (99.4%) and RVs (97.9%).
Shulman et al., 2005	2001-2002	CPOE	London teaching hospital; 22 bed general ICU	Prospective cohort clinical chart review pre and post CPOE implementation	MEs	MEs were significantly lower with CPOE as compared to hand-written prescribing. The proportion of errors reduced with time at a significant rate.
Chertow et al., 2001	1997-1998	CPOE & CDS	Urban tertiary care teaching hospital	control CPOE use, intervention CPOE and CDS	Appropriateness of medication dose and frequency, LOS, hospital and pharmacy costs, and changes in renal function among patients with renal insufficiency	CPOE used with CDS improves dose and frequency of prescription for those with renal insufficiency as compared to CPOE alone.
Tamblyn et al., 2003	1997-1998	CDS	107 Quebec primary care physicians with at least 100 patients aged 66<	13-month cluster-randomized controlled trial, intervention CDS use	Initiation and discontinuation rates of 159 prescription related problems	The rate of prescribing errors was 30% lower with the use of CDS, while the rate of discontinuation of an inappropriate drug was the similar in control and intervention groups.
Bates et al., 1999	1997	CPOE and CDS	Three medical units in a tertiary care hospital	Retrospective time series	MEs, excluded missed dose errors	CPOE significantly decreased the rate of non-missed does MEs by

Authors	Time Frame	Health IT Component	Data Source	Design	Outcome Measures	Findings
						81%.
Ammenwerth et al, 2008	1992-2004	CPOE with e-prescribing	27 studies with e-prescribing as the intervention independent of the level of decision support	Systematic review	MEs and ADEs	Electronic prescribing was found to reduce the risk for MEs (13%-99%) and ADEs (30%-84%).
Amarasingham et al., 2009	December 2005 to May 2006	Automated notes and records, order entry, and CDS	Urban hospitals (n=41) in Texas	Cross-sectional	Complications, mortality rates, and costs	Increased use of CPOE and CDS: Complications decreased (16%); Increased use of CPOE: 9% decrease in adjusted odds of AMI mortality, 55% decrease in adjusted odds of CABG mortality; Admission costs were lower with use of CPOE with CDS
Culler et al., 2007	August to December 2003	HIT applications identified in the CPOE and IT infrastructure Survey (COPEITIS)	Georgia hospitals (n=66) that responded to questionnaire and Georgia Hospital Discharge Data Set (2004)	Observational	Risk-adjusted incidence rate of AHRQs 15 Patient Safety Indicators (PSIs)	No statistically significant correlations between IT application availability and risk-adjusted patient safety indicators (PSIs).
Singh et al., 2010	May to December 2008	Drug alerts	Multispecialty ambulatory VA clinic and 5 satellite clinics in Texas	Retrospective review of 1,163 alerts	Acknowledgment of alerts and 30-day alert follow-up	HIT alerts on outpatient laboratory results were found to be unacknowledged (10.2%) and lack of timely follow-up (6.8%) a patient safety concern.
van der Sijs et al., 2009	25 days in wards and	Drug alerts	Large Dutch university	Observational: 2 wards, 6 residents,	Alerts rates, types, and overrides	20 percent of prescribed orders were overridden.

Authors	Time Frame	Health IT Component	Data Source	Design	Outcome Measures	Findings
	24 months in hospitals		medical center	and 515 prescriptions; Retrospective analysis of 371,261 prescribed orders		Medium level (54%) alerts were most frequently overridden, followed by low level (22%) then high level (19%).
Bedouch et al., 2009	November 2001 to April 2003	CPOE	2000-bed Grenoble University Hospital	Prospective structured medication order review conducted by seven clinical pharmacists	Drug-related problems	Drug-related problems occurred at a rate of 33 per 100 admissions. Common drug-related problems included: contra-indication (29.5%), improper administration (19.6%), drug interaction (16.7%), and overdosage (12.8%).
Han et al., 2005	October 2001-March 2003	CPOE	235-bed regional pediatric referral center	Retrospective 13 months pre-CPOE and 5 months post-CPOE implementation	Mortality rate for children transported for specialized care	Mortality rate increased from 2.80% to 6.57% after CPOE. CPOE was associated with an increased odds (OR: 3.28; 95% CI) of mortality.
Holdsworth et al., 2007	pre-CPOE 2000-2001; 36 months post-CPOE for 6 months in 2004	CPOE and CDS	Pediatric patients admitted to either the PICU or general pediatric unit in an urban tertiary care center (2 facilities) with 20-30 beds	Prospective cohort	ADEs and potential ADEs	After CPOE with CDS implementation preventable ADEs and potential ADEs reduced, 42 to 26 and 94 to 35, respectively. CPOE with CDS was associated with reductions in overall errors, dispensing errors, and drug-choice errors.
Kadman et al., 2009	September 2004-	CPOE and CDS	PICU of a tertiary-care	Retrospective pre-post CPOE and	ADEs, MPEs, and RVs	The decrease in MPEs after CPOE

Authors	Time Frame	Health IT Component	Data Source	Design	Outcome Measures	Findings
	September 2007		pediatric medical center with 12 beds	pre-post CPOE with CDS		implementation was small and non-significant. The addition of CDS significantly reduced MPEs and ADEs.
Metzger et al., 2010	April-August 2008	CPOE and CDS	Nationally representative sample of 62 U.S. hospitals	Cross-sectional	potential ADEs	CDS detection of ADEs was found to have significant variability. The mean of potential ADEs was 44%. Hospitals with advanced CDS preformed at a higher level than those with basic CDS.
McCormick et al., 2012	2008	Results viewing-imaging	National Ambulatory Medical Care Survey (28,741 patient visits and 1,187 office-based physicians)	Retrospective secondary analysis	Imaging ordering: computed tomography, magnetic resonance imaging, any advanced imaging, and any imaging	Access to computerized imaging results was associated with greater likelihood of additional imaging tests being ordered.
MedPac, 2009	2005	Results viewing-imaging	Medicare claims data (100 percent)	Descriptive analysis	imaging services, observed-to-expected imaging spending, procedure use	Self-referring physicians order higher proportions of imaging services compared to no self-referring physicians. Observed-to-expected imaging spending is higher for self-referring physicians. Higher imaging use was positively correlated with high procedure use.

Outcome: Inpatient operative mortality

Both AHRQ and the Leapfrog Group have identified several surgical procedures, or inpatient quality indicators (IQIs), for which mortality could be measured using administrative data to provide a perspective on hospital quality of care (AHRQ, 2012; J. D. Birkmeyer et al., 2004). Five of these procedures are identified by both organizations: abdominal aortic aneurysm (AAA) repair (IQI 11), coronary artery bypass graft (CABG) (IQI 12), esophageal resection (IQI 8); pancreatic resection (IQI 9); and percutaneous coronary intervention (PCI) (IQI 30). The frequencies of esophageal and pancreatic resection surgeries are low and there is no research linking the implementation of EHR process of care technologies to their surgical outcomes (J. D. Birkmeyer et al., 2004, Dimick et al., 2004). However, the number of procedures performed for the three vascular surgeries are sufficient for analysis.

The inability of hospital level procedure volume alone to explain the changes in outcomes (specifically noted for repair of AAA, CABG, and PCI) prompts the need for further research to identify other factors (J. D. Birkmeyer & Dimick, 2004; J. D. Birkmeyer, Gust, Dimick, N. J. Birkmeyer, & Skinner, 2012; Finks et al., 2011). Further, there is also a need to understand the implementation of EHR process of care technologies and the associated possible changes in cost for the three procedures.

Previous research (J. D. Birkmeyer & Dimick, 2004) estimated that the process of care and outcome measures could possibly augment or replace volume standards for the procedures of interest for this study (elective repair of AAA, CABG, and PCI) due to their potential to reduce complications and save lives. The study estimated (J. D. Birkmeyer & Dimick, 2004) that volume standards alone would save an estimated 1,388 lives per year total for all three procedures, whereas the addition of process and outcome measures has the potential to save an additional 7,461 lives per year for the three procedures. This research aimed at investigating links between EHR implementation and reduced mortality, as well as EHR implementation and inpatient surgical cost per discharge.

CPOE sub-functionalities include laboratory testing, radiology tests, medications, consultation requests, and nursing orders. Decision support sub-functionalities include clinical guidelines, clinical reminders, drug allergy alerts, drug-drug interactions alerts, drug-lab interaction alerts, and drug dosing support (Grover & Barney, 2004). Both groups of functions are relevant to guide decision-making for the process of care for AAA, CABG, and PCI. EHR technology can provide alerts for drug infusion and fluid balance levels, verify infused drugs with patient name on the order, suggest drug dosage ranges, and supply allergy information. Of particular importance for surgical procedures are notifications of patient latex allergies, the second leading cause of surgical anaphylaxis, via EHR alerts (Grover & Barney, 2004; Vervloet, Magnan, Birnbaum, & Pradal, 1999). Further, an EHR allows anesthetists real time access to clearly presented patient-related data such as history, vital signs, lab results and fluid measurements during any stage of the procedure (Grover & Barney, 2004; Springman, 2011).

Clinical guideline functions are decision support components that prompt evidence-based process of care. These reminders prompt clinicians to perform process of care that have been documented to reduce operative mortality. Examples include prompting the administration of perioperative beta-blockers for patients undergoing AAA repair or CABG, and the use of prophylactic antibiotics prior to surgical incision to prevent infections. Supporting these criteria, a cohort study found that patients who receive preoperative beta-blockers prior to vascular surgeries have a lower risk of mortality than those not receiving them, even considering the fact these patients had a higher overall risk profile (Boersma et al, 2011). The implementation of varying functionalities of EHRs is intended to increase the likelihood that these processes of care will not be missed, and therefore avoiding any related adverse outcomes. These studies justify exploring these sub-functionalities of MU that may be potential contributors to reducing surgical mortality and costs.

Operative process

The ratio of observed complications or deaths to the number of expected based on preoperative risk factors is called an O to E ratio. Hospitals with a high O to E ratio were more likely to have inferior structures and process of care, as compared to low outlier hospitals that are more likely to have superior structures and process of care (Daley et al., 1997). There are a variety of evidence-based processes of care that are recommended for improved outcomes for the three vascular procedures investigated in this study.

Preoperative beta-blocker therapy with bisoprolol, especially for those with high-risk factors, prior to vascular procedures is one of the most widely acknowledged process' that improve outcomes (Poldermans et al., 1999). Clinically intermediate- and high-risk patients undergoing major vascular surgery who receive beta-blockers perioperatively have been found to have a 0.8 percent lower risk of cardiac complications than those not receiving beta-blockers (2.3 percent) (Boersma et al., 2001).

Surgical team behaviors are a component of the three phases of surgical process (pre-, peri-, and post-operative). Patients have been found to be more likely to experience complications or death when a lower frequency of certain behaviors occurs: (1) information sharing during intraoperative phases (2) briefing during handoff phases (3) information sharing during handoff phases (Mazzocco et al., 2009).

Patients postoperatively are vulnerable to infections and complications. New infections and procedure related complications can increase a patient's risk of inpatient mortality. For example, pneumonia is the third most common postoperative complication and has a mortality of up to 40 percent (Markar et al., 2009). A study of patients undergoing elective AAA repair noted the occurrence of postoperative pneumonia in 20 percent of patients (Markar et al., 2009). Other postoperative concerns have to do with fluid balance levels, monitoring vital signs, proper diet, and wound care. These and other postoperative standard processes of care are important in averting complications and mortality.

Operative process linked with reduced mortality

Abdominal aortic aneurysm repair

An abdominal aortic aneurysm (AAA) is a localized dilation greater than 50 percent of normal diameter (≥3.0 cm) of the abdominal aorta (Johnston, Rutherford, Tilson, Shah, Hollier, & Stanley, 1991; United States Preventative Services Task Force, 2005), which supplies blood to the abdomen, pelvis, and legs. AAA's are generally asymptomatic, more frequent for males, and increase in incidence with age (United States Preventative Services Task Force, 2005). Repair involves the replacement of a section of the artery, which is either done by opening the abdomen or by percutaneous placement of a stent-graft that is fed through the patient's femoral arteries (Society of Interventional Radiology, 2004).

The American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines (ACC/AHA) has stated that overall, open and vascular repair techniques have demonstrated similar rates of mortality and morbidity (Rooke et al., 2011). Open repair of an AAA has been cited to have 4 percent to 5 percent operative mortality (United States Preventative Services Task Force, 2005). Specific process of care quality benchmarks developed by the American College of Cardiology Foundation include EHR prompt of perioperative beta-blocker therapy prior to arrival for patients undergoing AAA (Rooke et al., 2011). Beta-blocker therapy is cited as a specific example of a clinical guideline directly on the AHA hospital EHR adoption survey (AHA, 2010). In-hospital mortality for elective AAA repair has been estimated to be 5.1 percent (Finlayson et al. 2002).

Coronary artery bypass grafting

Coronary artery bypass grafting (CABG) is the most frequently performed and resource intensive open-heart surgery in the U.S. (Eagle et al., 1999; Hannan et al., 2003). This surgical procedure is performed to repair obstructed arterial regions by grafting a section of a vein or other conduit between the aorta and coronary artery below the area of obstruction (Hawkes, Nowak, Bidstrup, & Speare, 2006). The surgery improves blood flow to the heart muscle and aids in the relief of angina.

The ACC has identified several studies that have found factors that tend to increase the cost of CABG: advanced patient age, female sex, African-American race, postoperative complications, longer hospital stay, and multiple comorbidities (Hillis et al., 2011). The ACC/AHA Task Force practice guidelines recognize three consistent predictors associated with the highest risk of in-hospital mortality after CABG: operation urgency, advanced age, and one or more prior heart coronary bypass surgeries (Eagle et al., 1999).

The Leapfrog Group has identified seven process of care measures that are quality benchmarks for improved patient outcomes for CABG (The Leapfrog Hospital Survey, 2012). Of the seven process of care measures, three are related to discharge instructions, one is related to use of a surgical technique internal mammary artery (IMA), and the other three are pre/postoperative medication administration process. Use of internal mammary graft and continuing aspirin throughout surgery for CABG are process of care that have been linked to lower operative mortality (J. D. Birkmeyer et al., 2004). The preoperative process includes administration of beta-blockers within 24 hours prior to operation and receipt of prophylactic antibiotic one hour prior to surgical incision. Further emphasizing its importance, Medicare conducts quality evaluations on postoperative process that are based on the discontinuation of prophylactic antibiotics within 24 hours of CABG surgery anesthesia end time (Edwards, Engelman, Houck, Shahian, & Bridges, 2006).

Percutaneous coronary intervention

In many cases percutaneous coronary intervention (PCI) serves as an alternative to CABG and is sometimes preferred, because of its minimally invasive nature (ACCF/AHA, 2011). PCI is also referred to as percutaneous transluminal coronary angioplasty (PTCA). The procedure treats the build up of plaque in the coronary arteries in patients at risk of, or who have experienced, a heart attack (National Institute of Medicine, 2013). A CABG is often performed when patients have multiple blockages or blockages in locations where a CABG is preferable to a PCI (NIH, 2013).

During a PCI, a catheter is inserted into an artery in the leg, arm or groin area and then guided to the coronary artery, where a balloon is inflated to stretch the artery wall to restore blood flow (NIH, 2013). A stent is almost always implanted to support the stretched opening (NIH, 2013). Examples of preoperative practice guidelines developed by the ACA for PCI include aspirin use and dosage of receptor inhibitors to interfere with the blood clotting process (Levine et al., 2011).

Patient characteristics associated with operative mortality

In a study of inpatient surgical procedures it is important to examine the presence of patient- and hospital-level characteristics, which affect mortality. A study examining racial differences found that blacks were consistently more likely to die after cardiovascular surgery (including AAA and CABG) compared to whites (Lucas, Stukel, Morris, Siewers, & J. D. Birkmeyer, 2006). The American College of Cardiology Foundation has reported no significant demographic characteristics or comorbidities between patients undergoing open or endovascular AAA intervention (Rooke et al., 2011). Incidence of vascular complications from PCI increases with age greater than 70 years, body surface area greater than 2.6 meters squared, emergency procedures, and female sex (Levine et al., 2011).

A study adjusting surgical mortality rates for comorbidities found these adjustments may produce results that are protective of hospitals by penalizing providers for taking care of sicker patients (Finlayson et al., 2002). However, there are increases in reimbursement when a single comorbidity is documented, but not for documentation of any additional comorbidities. Therefore, researchers believe that chronic conditions may be undercoded for patients who have at least one comorbidity, likely placing patients at a higher risk of in-hospital mortality (Finlayson et al., 2002).

The AHRQ uses patient characteristics to risk-adjust operative mortality rates for the IQIs discussed above (AHRQ, 2012). These characteristics include age, sex, payer, and patient residence (rural or urban location). This study used additional hospital characteristics associated with EHR adoption discussed in earlier section as covariates to account for structural (hospital) characteristics.

Outcomes: Cost per discharge

Potential cost efficiencies are also important potential benefits of EHR use. A review of the EHR literature estimates the overall financial benefits to be invaluable (Goldzweig, Towfigh, Maglione, & Shekelle, 2009). The Center for Information Technology Leadership has estimated that the overall financial return from an HIE could total as much as $87 billion per year after the initial investment (Johnston, Pan, Middleton, Walker, & Bates, 2003). When augmented with clinical decision support tools, ambulatory EHRs have substantial positive financial benefits associated with reduced medication, laboratory, and radiology expenditures, as well as improved reimbursement (Johnston et al., 2003). Such benefits can lead to productivity gains for a variety of healthcare system stakeholders.

The HITECH act is meant to reduce some of the costs of EHR implementation by incentivizing provider adoption of HIT. This allows the government, as a large payer of healthcare, potential savings in the long-run. Medicare payments have been found to be higher per patient for CABG ($5,353) and AAA ($5,279) surgeries at hospitals with higher rates of complications, thus providing the opportunity to reduce costs by improving surgical quality (J. D. Birkmeyer et al., 2012). Initially this may imply that higher quality hospitals have lower expenditures, however the increased costs associated with advanced technology adoption could result in the alternative. Thus, research linking level of EHR implementation to potential changes in cost per discharge is needed.

Limitations of Previous Research

Several studies have examined the link between EHR implementation and quality, including surgical outcomes as a proxy for quality (J. D. Birkmeyer et al., 2001; Dimick et al., 2004; Khuri et al., 1997; Shamliyan et al., 2008). However, these studies are limited by their examination of specialized populations (Bourgeois & Yaylacicegi, 2010; Daley et al., 1997; Del Baccaro, Jeffries, Eisenberg, Harry, et al., 2006; Han et al., 2005) and limited statistical power (Khuri et al., 1997). It is also important to note previous studies, including those with nationally representative samples (J. D. Birkmeyer et al., 2012; J. D. Birkmeyer & Dimick, 2004), were cross-sectional. This weakens the potential causal link between EHR functionality and surgical outcomes.

Literature on the impact of each sub-function of CPOE and decision support on quality outcomes is also sparse; most studies examine the association between EHR implementation, broadly defined, and outcomes. A 2006 AHRQ funded literature review found improvements in process of care delivery using EHR functions ranged from absolute increases of 5 to 66 percentage points (clustered in the range of 12-20%) (Chaudhry et al., 2006). Two single-hospital studies have examined CPOE as a distinct EHR functionality, with conflicting results as regards to pediatric mortality (Del Baccaro et al., 2006; Han et al., 2005).

A cross-sectional study of 72 Texas hospitals found hospitals with automated notes and records, order entry, and clinical decision support had fewer complications, mortality rates, and lower costs (Amarasingham et al., 2009). Limited sample sizes, specialized populations, cross-sectional designs, and mixed results on the relationship between CPOE and other decision support functionalities prompt further investigations regarding the identification of specific sub-functions within the CPOE and decision support functions relationship with operative mortality.

Innovation

This research is novel methodologically in three ways. First, the planned research examined the association of EHR functionalities across three levels of implementation and risk-adjusted operative mortality rates at the hospital level. Rather than using one year of data or less, to maximize the sample a pooled cross-sectional design was used. The analysis was conducted using two years of the National Inpatient Sample linked to two years of the American Hospital Association EHR survey. Functionalities and sub-functions were studied across three dimensions, the types of EHR functionalities implemented and degree of implementation (presence in all, some, or no clinical units).

Second, this study examined the association of EHR functionalities across three levels of implementation and estimated cost per discharge. This addresses the financial and contextual gaps in data exploration expressed in a 2006 AHRQ funded literature review (Chaudhry et al., 2006).

This work also investigated the relationship between level of EHR clinical documentation, CPOE and CDS functionality implementation, in accordance with Meaningful Use guidelines, and risk-adjusted inpatient operative mortality rates as well as the estimated cost per discharge for AAA repair, CABG, and PCI (irrespective of patient mortality). As hospitals increasingly deploy EHRs in response to federal mandates and incentives, ascertaining the levels and functions most associated with quality improvement will assist healthcare administrators and clinicians improve patient outcomes. In order to examine the associations presented the following specific aims were investigated:

(1) *Examine the relationship between EHR functionalities across three levels of implementation and risk-adjusted operative mortality rates for inpatient AAA repair, CABG, and PCI.*

Hypothesis 1: Higher EHR functionality will be associated with decreased risk-adjusted mortality for inpatient AAA repair, CABG, and PCI.

(2) *Examine the relationship between EHR functionalities across three levels of implementation and estimated cost for inpatient AAA repair, CABG, and PCI.*

Hypothesis 2: Higher EHR functionality will be associated with decreased estimated cost per discharge for inpatient AAA repair, CABG, and PCI.

CHAPTER 3

METHODS

Purpose

The aim of the analysis was to investigate the relationship between EHR functionalities across three levels of implementation and outcomes of three inpatient vascular procedures: AAA repair, CABG, and PCI.

To examine the proposed relationships, the analysis included discharge records for patients who underwent one of the three-selected AHRQ IQI procedures within a two-year period.

The specific aims were:

(1) *Examine the relationship between EHR functionalities across three levels of implementation and risk-adjusted operative mortality rates for inpatient AAA repair, CABG, and PCI.*

Hypothesis 1: Higher EHR functionality will be associated with decreased risk-adjusted mortality for inpatient AAA repair, CABG, and PCI.

(2) *Examine the relationship between EHR functionalities across three levels of implementation and estimated cost for inpatient AAA repair, CABG, and PCI.*

Hypothesis 2: Higher EHR functionality will be associated with decreased estimated cost per discharge for inpatient AAA repair, CABG, and PCI.

Institutional Review Board

The University of South Carolina Institutional Review Board (IRB) approved this study on April 10, 2013. The approved study received "exemption status." The study utilized de-identified secondary data on patient discharges that met Health Insurance Portability and Accountability Act (HIPPA) privacy standards of a Limited Data Set (LDS).

Data Sources

Data for the presented research was drawn from the 2009-2010 Nationwide Inpatient Sample (NIS), Healthcare Cost and Utilization Project (HCUP), AHRQ and the AHA Information Technology Supplement annual survey. The NIS was used to obtain discharge level data including patient diagnosis, procedures, AHRQ comorbidities, and hospital characteristics. Data from the 2009-2010 AHA Information Technology annual survey, a supplement to the AHA Annual Survey, was used to identify the key independent variable, level of EHR functionality (Table 3.1) for clinical documentation, CPOE, and CDS (based on MU guidelines). Data from the linked NIS-AHA file were merged with the cost-to-charge ratio files supplied by HCUP to investigate level of EHR functionality association with estimated cost per discharge for the procedures and condition of interest (Aim 2).

The NIS data contain an estimated 7.8 million hospital administrative discharge records per year, representative of approximately 20% of all acute care hospitals in the U.S. To conduct the statistical analyses the two datasets were merged. The NIS data contains discharge records for 1,050 hospitals in 2009 and 1,051 in 2010. The AHA hospital identification number is the common link between the two files, but only a subset of reporting NIS hospitals (68% of hospitals) provide this value. Seventeen states have laws that prohibit the identification of hospitals for confidentiality reasons.

This sample was further limited by hospital non-response to the EHR adoption supplemental survey. Although there are over 6,500 respondents for the AHA Annual Survey, fewer respond to the AHA Information Technology Supplement annual survey with only 3,615 hospital respondents in 2009 and 3,168 hospital respondents in 2010.

Table 3.1. Levels of EHR implementation

Level used for analyses	Levels measured in AHA survey
3	(1) fully implemented across all clinical units
2	(2) fully implemented in at least one clinical unit
1	(3) beginning to implement in at least one clinical unit
	(4) have resources to implement in the next year
	(5) do not have resources but considering implementing
	(6) not in place and not considering implementing

Study Sample

Outcomes were studied across three inpatient surgical procedures, AAA repair, CABG, and PCI. The risk-adjusted inpatient mortality rates at the hospital level for selected procedures were calculated using the Inpatient Quality Indicators Software supplied by AHRQ, version 4.4, March 2012 (Table 3.2). These rates were calculated for each hospital that had a discharge record with one of the selected procedures. The IQI software was only used for Aim 1. Specific Aim 2 examined estimated cost per discharge for these three procedures, irrespective of mortality. IQI procedures criteria include the procedures (15 NIS fields) and diagnoses (25 NIS fields) in any clinical field of the discharge record (Table 3.2) using corresponding ICD-9 codes outlined in AHRQ's technical specifications for each IQI (Table 3.3). AAA repair is the only of the three procedures that has criteria for a diagnosis (see Table 3.2).

IQI criteria require discharges to have at least one of both the procedure and diagnosis codes for inclusion. All participating HCUP organizations allow at least 9 diagnoses and 6 procedures. However, the more fields used, the more quality-related events that can be captured, but the variation is unlikely to have much effect on results (Coffey, Barrett, Houchens, R., & Andrews, et al., 2006).

Table 3.2 AHRQ IQI procedure and diagnosis (Version 4.4; March 2012)

Procedure	Procedure ICD-9-CM code names	Diagnosis
AAA	• Resection of vessel with anastomosis: o aorta o abdominal • Other excision of vessels, aorta, abdominal • Endovascular implantation: o other graft in abdominal aorta o branching or fenestrated graft(s) in aorta • Temporary (partial) therapeutic endovascular occlusion of vessel	• Ruptured AAA • Intact AAA
CABG	• Aortocoronary bypass: o not otherwise specified o one coronary artery o two coronary arteries o three coronary arteries o four+ coronary arteries • Internal mammary-coronary artery bypass: o single o double • Abdominal-coronary artery bypass • Other bypass anastomosis for heart revascularization	• None
PCI	• Single vessel percutaneous transluminal coronary angioplasty: o without mention of thrombolytic agent o with mention of thrombolytic agent • Multiple vessel percutaneous transluminal coronary angioplasty	• None

The sample was limited to patients affected by AHRQ quality indicator specifications by including only acute care patients, excluding hospice or swing bed patients (AHRQ, 2012). Additional recommended exclusion criteria include suppression of IQI rates for instances with less than 10 cases in the denominator and estimates with a relative standard error (RSE) of more than 30 percent (Coffey et al., 2006). The lower the RSE, the more precise the measurement will be since there is less variance around the mean. A RSE less than 30 percent is consistent with the guidelines for inclusion for data reliability used by the National Center for Health Statistics (Klein, Proctor, Boudreault, & Turczyn, 2002).

Table 3.3. International Classification of Diseases, Ninth Revision (ICD-9), procedure and diagnosis codes used to determine selected* procedure and condition for principal diagnosis

Inpatient Quality Indicators Selected Conditions	***Procedure codes***	***Diagnosis codes***
IQI 11: Abdominal aortic aneurysm (AAA) repair	38.34, 38.44, 38.64, 39.71, 39.77, 39.78	44.13, 44.14
IQI 12: Coronary artery bypass graft (CABG)	36.10, 36.11, 36.12, 36.13, 36.14, 36.15, 36.16, 36.17, 36.19	n/a
IQI 30: Percutaneous coronary intervention (PCI)	00.66, 36.01, 36.02, 36.05	n/a
*Selected procedure and condition ICD-9 Codes were identified by AHRQ QI Software version 4.4 (AHRQ, 2012)		

Missing values

The AHRQ IQI software (Aim 1) excludes cases from analysis that are missing data in fields used for risk-adjustment or if the value for the outcome variable is missing (AHRQ, 2012). Table 3.4, created from the AHRQ (2012) IQI software instructions, details variable-specific treatment of missing data. Variables that have missing values treated as "excluded from all analysis" are dropped from the denominator of the discharge based indicators and from the numerator of all population based measures

(AHRQ, 2012). Aim 2 excluded discharges with missing data for age, sex, or principal diagnosis code. This aim investigates estimated cost per discharge irrespective of mortality.

Table 3.4. Missing data treatment using IQI software

Variable	Treatment of Missing Data
Age	Case excluded from all analysis
Admission source	Case excluded from denominator where used in specification
Disposition status	Case excluded from denominator where used in specification
Discharge quarter	Case excluded from analysis
Principal diagnosis code	Record excluded from analysis
Patient gender	Case excluded from all analysis
Payer	Classified as "Other"
Location of patient residence or location of modified FIPS State/County code	Dropped from denominator in area level calculations. Present in the calculation of the overall rate
Race	Classified as "Other"
Discharge year	Excluded from all analysis

Study Variables

Independent variables

The three key independent variables were level of EHR implementation of 9 select sub-functions of ECD, CPOE, and CDS. The sub-functions were selected from those that aligned with MU guidelines, have hypothesized relationships with the procedures of interest, and were measured in the AHA Information Technology Supplement annual survey. The AHA Information Technology Supplement annual survey allows measurement of these nine sub-functions implementation across six levels (Table 3.1).

This study focused on functions linked with processes of care and associations with selected procedures using six of the eight measurable core MU criteria, excluding patient demographics and discharge summaries. Maintaining records of patient demographics and discharge summaries are not thought to have a link with patient outcomes for the selected inpatient procedures. The study sample used a conservative estimate of implementation by focusing on those hospitals that had *fully* implemented the selected functions across *all* clinical units (Table 3.1., see Level 1). This conservative criterion is consistent with that used by Jha et al. (2010) in the examination of a *comprehensive* EHR.

Table 3.5. Selected functionalities and sub-functions of interest for key independent variables

Electronic clinical documentation (ECD)
Problem lists
Medication lists
Computerized provider order entry (CPOE)
Medications
Clinical decision support (CDS)
Drug-allergy alerts
Drug-drug interaction alerts
Clinical guidelines (e.g. beta blockers)
Clinical reminders
Drug-lab interaction alerts
Drug dosing support

Dependent variables

The dependent variable for Aim 1 was risk-adjusted inpatient mortality rates at the hospital-level. The dependent variable for Aim 2 was the estimated cost per discharge for each of the three inpatient procedures, regardless of mortality.

The dependent variable for Aim 1 was calculated using AHRQ Quality Indicator Software version 4.4 standardized algorithms. The software is based on coding specifications used in the State Inpatient Databases (SID) in the HCUP, funded by AHRQ (AHRQ, 2012). The procedure specific IQIs (AAA repair, CABG, PCI) used ICD-9-CM procedure codes for denominator calculation. The numerator is calculated using the number of inpatient deaths among cases meeting the inclusion and exclusion criteria for the denominator.

The AHRQ Quality Indicator software provides SAS files that can be used with hospital discharge administrative data to generate observed, expected, risk-adjusted and smoothed IQI rates (AHRQ, 2012). The observed rates (raw rates) are the count of discharge records including the health outcome of interest divided by the count of discharge records in the patient population at risk (AHRQ, 2012). The risk-adjusted and expected rates are calculated by taking into account the average case mix of the reference population in order to be reflective of the more generalizable U.S. hospitalized population (AHRQ, 2012). The risk-adjusted are based on the average case mix of the individual hospital, while the expected are adjusted based on the U.S. hospitalized population. The software also calculates 95% confidence intervals for risk-adjusted rates (AHRQ, 2012). The software only calculates IQI rates for a minimum of three cases.

Study Design

This study used a pooled cross-sectional design using 2009-2010 NIS and AHA data. The pooling of hospitals sampled in two years of data strengthened the statistical power of the sample. AHA identification number was used to merge NIS data with corresponding years of AHA data. Independent hospital observations of the most recent year of data were used in the analyses. When determining which year of data to use for a hospital the following guidelines were used:

- Available in 2009 & 2010, 2010 data were used
- Available only in 2010, 2010 data were used
- Available only in 2009, 2009 data were used

Analytical method

A univariate analysis was performed to provide descriptive characteristics of the study population at both the hospital and discharge level. This analysis presented the description of hospital characteristics including the hospital size, control/ownership, teaching status, and census region. At the discharge level, the description included race, age, sex, patient's rural/urban residence, patient APR-percent of discharges with DRG severity of moderate or major loss of function (quartiles), and percent of discharges with 3 or chronic conditions (quartiles). A bivariate analysis of hospitals characteristics by the selected EHR functionalities of interest for the independent variable of interest and the three procedures of interest are also presented. Further, the number and percentage of hospitals across all three levels of implementation of the selected nine functionalities (Table 3.5) are presented.

Chi square tests and simple analyses of variance were used to determine if EHR implementation across the three levels (Table 3.1) of interest varied by hospital characteristics for inpatient operative mortality. Chi square tests and simple analyses of variance were also used to determine if the mean estimated cost per discharge for each of the three procedures differed by the level of EHR functionalities implementation and hospital characteristics. All analyses were conducted at 95% confidence interval ($\propto$ = 0.05). IQI mortality observed, expected, risk-adjusted and smoothed rates and cost per discharge are displayed for each procedure, using two charts for each, across hospital characteristics.

This study was designed to test the hypothesis that variation in hospital level mortality rates and estimated cost per discharge, using three of AHRQs IQIs six selected procedures, are explainable by hospital differences in the implementation select ECD, CPOE, and CDS functionalities.

Approach Aim 1:

This Aim was examined at the hospital level. The calculation of risk-adjusted mortality rate excluded hospitals with <30 cases in the denominator. The three key independent variables were ECD, CPOE, and CDS measured at three levels of EHR implementation. Hospital-level covariates included hospital size, location, ownership, multi-hospital system membership, and teaching status. The IQI software risk adjusts based on patient characteristics when calculating mortality rates. The patient-level covariates were adjusted using AHRQ risk-adjustment software that is specifically designed by a task-force for use on IQIs (AHRQ, 2012). These patient-level covariates included age, sex, discharge quarter, principal diagnosis code, and discharge year.

Bivariate analyses were performed to test for differences for each procedure of interest by level of EHR implementation. Multivariate analyses were used to determine if variation in risk-adjusted inpatient mortality rates, for the procedures of interest, is associated with the three levels of implementation of the selected EHR functionalities.

Approach Aim 2:

The dependent variable was estimated cost per discharge for each of the three procedures of interest, regardless of mortality. Cost per discharge was calculated at the discharge level, using total charges (adjusted), multiplied by the hospital all-payer inpatient cost/charge ratio (APICC). The total charges are adjusted by HCUP using the following inclusion criteria: total charges allowed are between $100 and $1.5 million. The three key independent variables were ECD, CPOE, and CDS measured across three levels of implementation. Hospital-level covariates included hospital size, ownership, and teaching status. Patient level covariates included race, age, sex, patient APR-percent of discharges with DRG severity of moderate or major loss of function (quartiles), and percent of discharges with 3 or chronic conditions (quartiles). The number of chronic conditions present was used for patient case-mix risk-adjustment. Evidence by Elixhauser and colleagues (1998) has shown that comorbidities are associated with substantial increases in LOS, hospital charges, and mortality for both heterogeneous and homogeneous disease groups.

Bivariate analyses were used to test for differences in cost per discharge, at the hospital level, for each procedure of interest by level of EHR implementation. Since the distributions of the costs per discharge were positively skewed, the multivariate models utilized a log-transformed version of the dependent variable, costs per discharge. Each discharge cost was log transformed, and the mean of all such transformed variables was calculated at the hospital level. The multivariate analyses were used to determine if variation in cost per discharge, for the procedures of interest, is associated with the three levels of implementation of the selected EHR functionalities.

CHAPTER 4

MANUSCRIPT ONE

THE ASSOCIATION OF EHR PROCESS OF CARE FUNCTIONALITIES TO IMPROVE SURGICAL MORTALITY[1]

[1] Leonhirth D.A., Probst J.C., Bennett K.J., Hardin J.W., Vyavaharkar M., & Stinson M.S. To be submitted to *Surgery, Circulation, or Journal of the American Medical Informatics Association*

Abstract

Background . The Agency for Healthcare Research and Quality (AHRQ) developed a set of indicators computed from hospital administrative data as a measure of inpatient quality. Evidence indicates an inverse relationship between procedure volume and mortality for some of the AHRQ-developed inpatient quality indicators (IQIs). Process of care measures are also be important for select procedures. The objective of this study was to examine the relationship between implementation of selected electronic health record (EHR) functionalities and risk-adjusted surgical mortality for three cardiovascular procedures.

Methods. Using a pooled cross-sectional study design, data from the 2009-2010 Nationwide Inpatient Sample were linked with the 2009-2010 American Hospital Association Information Technology Supplement. The AHRQ inpatient quality indicator (IQI) software was used to generate hospital-level risk-adjusted operative mortality for abdominal aortic aneurysm (AAA) repair, coronary artery bypass graft (CABG), and percutaneous coronary intervention (PCI). The key independent variable was the average EHR implementation level of selected clinical documentation (ECD), computerized provider order entry (CPOE), and clinical decision support (CDS) functionalities.

Results. Bivariate analyses revealed significant relationships for risk-adjusted mortality across levels of CDS implementation for hospitals performing AAA repair (drug-allergy alerts and drug-drug interaction alerts) and PCI (drug-allergy alerts and drug-dosing support). The multivariate regression results revealed a significant positive relationship between implementation of CDS and risk-adjusted mortality for AAA repair (0.5337, SE 0.23, p=0.0228) and PCI (0.1960, SE 0.07, p 0.0105), adjusting for patient and hospital characteristics. Compared to rural locations, urban hospital locations were found to have a significantly lower CABG mortality (-0.0898, SE 0.04, p 0.0455).

Conclusions. Contrary to our hypothesis, the results identified potential risks, increased risk-adjusted surgical mortality, associated with higher levels of CDS implementation. Although some hospitals might implement the same EHR functionalities, variations in the use of these functionalities limits investigating them as process of care measures.

Keywords: Electronic health records, process of care, surgical mortality

Background

Hospital investments in health information technology (HIT) have increased in recent years in an effort to achieve anticipated benefits related to costs and quality of care (IOM, 2012). Current health policy includes provider incentives to implement and use HIT in a "meaningful" way, known as meaningful use (MU) (CMS, 2012). The Office for the National Coordinator for Health Information Technology (ONC-HIT), along with the Centers for Medicare and Medicaid Services (CMS), has identified standardized criteria for the certification of EHRs. The support surrounding the adoption and implementation of HIT is due to the potential to promote a safer system of care delivery

(IOM, 2012). Recent literature asserts initiatives aimed at the improvement of quality of care and patient safety in the U.S. as imperative, and is also outlined by the Institute of Medicine in their six aims of improving the quality of care delivery in the 2001 report *Crossing the Quality Chasm*.

The movement to improve quality has led to the development of a variety of metrics to evaluate quality. The Agency for Healthcare Research and Quality (AHRQ) has developed a set of indicators that can be used with hospital administrative data as a proxy for inpatient quality (AHRQ, 2012). Early research demonstrated an inverse relationship between procedure volume and outcomes for selected inpatient quality indicators (IQIs), including AAA repair, CABG, and PCI (Dudley et al., 2000; Hannan et al., 1991; Luft et al.,1979).

Process of care measures to either augment or replace existing volume standards for these procedures have been suggested to evaluate the potential improvements in outcomes for the procedures of interest (J. D. Birkmeyer & Dimick, 2004). According to J. D. Birkmeyer & Dimick (2004), estimated volume standards alone would save an estimated 1,388 lives per year total for all three procedures. The inclusion of process and outcome measures has the potential to save an additional 7,461 lives per year (J. D. Birkmeyer & Dimick, 2004). Supporting the importance of process measures, The Leapfrog Group's standards revisions in 2003 for the procedures of interest included process of care as a function of an EHR within their quality metrics. An EHR supplied reminder to administer beta-blockers for patients undergoing an AAA, CABG, or PCI is an example of a process of care measure as a function of an EHR.

In 2010, surgical care accountability measures were developed (JACHO, 2013), such as prophylactic antibiotic receipt one hour prior to surgical incision. With the addition of surgical care accountability measures and the potential for process measures to save lives, this study seeks to provide preliminary findings on EHR as a structure that supplies and supports improved process of care delivery standards and its relationship with patient outcomes. The objective of this study was to examine the relationship between level of implementation of three EHR functionalities and risk-adjusted procedure mortality for AAA repair, CABG, and PCI.

Methods

Theoretical Framework

The study was based on Donabedian's (1966) structure, process, and outcomes model, as adapted by J. D. Birkmeyer and Dimick (2009), to examine inpatient surgical mortality. The assumption is that given the proper settings and instrumentalities, good medical care will follow (Donabedian, 2005). Believed to be associated with reduced surgical mortality (outcome), we specifically examined level of EHR implementation (structure), particularly clinical documentation (ECD), computerized provider order entry (CPOE), and clinical decision support (CDS) functionalities (process of care).

Examples of structure, processes of care, and outcomes in the context of this study and the possible associated benefits, challenges, and limitations are presented in Table 4.1. In this study, the processes analyzed were limited to EHR functionalities, as measured by the American Hospital Association (AHA). We did not have additional detail on EHR implementation. For example, hospitals vary in their customization of clinical reminders, thereby limiting the study of process of care to the level for which measurement is available. The lack of data on EHR processes that vary across settings creates limitations in the extrapolation of results in the study of care delivery.

Table 4.1. Theoretical Framework of an EHR's Processes of Care to Improve Surgical Outcomes with Select Benefits, Challenges, and Limitations (adapted from Dimick & Upchurch, 2008)

	Example	Benefits	Challenges	Limitations
Structure	Implementation of EHR	Systems of care delivery approach	Implementation costs are a barrier	Standardization of what constitutes an EHR is needed
Process of Care	Clinical Documentation: • Problem Lists • Medication Lists	Provider awareness of patient's current and active diagnosis	Free text entry or missing information limits the usefulness if used in conjunction with clinical reminders and decision support	Keeping the lists "up-to-date" for the entire inpatient stay, admission to discharge
	Computerized provider order entry (CPOE): • Medications	Process improvement and eliminate transcription errors	Technology related error entry (e.g. accidentally clicking wrong dose from a drop down list)	Potential to improve *preventable* adverse drug events (ADE), yet the exact proportion of ADEs that are preventable is unknown (IOM, 2000)
	Clinical decision support (CDS): • Drug-drug allergy alerts • Drug-drug interaction alerts • Clinical guidelines • Clinical reminders • Drug-lab interaction alerts • Drug dosing support	Providing alerts, reminders, and support that are evidence-based to aid decision-making	Provider alert fatigue that can lead to ignoring alerts	Hospital variation in the degree and types of decision support used
Outcome	Lower risk-adjusted	Improved patient	Small hospital level sample size	Outcomes are also a function of patient characteristics,

	mortality rates	outcomes and quality of care	to generalize results	quality (hospital and surgeon factors), and chance (random variation) (Dimick & Upchurch, 2008)

Study Design and Data Sources

Using a pooled sample design, at the hospital level, we examined the association between level of implementation of three EHR functionalities, clinical documentation (ECD), computerized provider order entry (CPOE), and clinical decision support systems (CDS), and risk-adjusted inpatient mortality for AAA repair, CABG, and PCI procedures. We sought to determine if higher levels of implementation were associated with lower risk-adjusted inpatient surgical mortality, adjusting for patient and hospital characteristics. Hospital inpatient administrative discharge data were drawn from the Nationwide Inpatient Sample (NIS) 2009-2010, sponsored by AHRQ as a part of the Healthcare Cost and Utilization Project, and was merged with the American Hospital Association (AHA) Information Technology Supplement 2009-2010 for the analysis.

Independent variable: EHR functionalities and levels of implementation

The AHA Information Technology Supplement measured the level of hospital implementation (6 levels) of four main functionalities: ECD, CPOE, results viewing, and CDS. Our analysis is restricted to nine select sub-functions of ECD, CPOE, and CDS. There are 24 sub-functions within these four functionalities that are measured: problem lists, medication lists, electronic prescribing, clinical guidelines, clinical reminders, drug-allergy alerts, drug-drug interaction alerts, drug-lab interaction alerts, and drug dosing support (AHA, 2010). These sub-functions are adopted in varying combinations across the inpatient setting. We used a conservative criterion for defining highest level of implementation (Table 4.2), defining implementation of the sub-functions of interest across *all* clinical units as the highest level of implementation.

Table 4.2. Levels of EHR functionalities implementation

Level used for analyses	Levels measured in AHA survey
3	(1) fully implemented across all clinical units
2	(2) fully implemented in at least one clinical unit
1	(3) beginning to implement in at least one clinical unit
	(4) have resources to implement in the next year
	(5) do not have resources but considering implementing
	(6) not in place and not considering implementing

Nine stage 1 MU sub-functions were selected that can be measured using the AHA Information Technology Supplement and that may be associated with process of care for patients undergoing the procedures of interest. The ECD functionalities of interest included problem lists and medication lists. The CPOE functionality of interest was electronic medication ordering. The six CDS functionalities of interest included clinical guidelines, clinical reminders, drug-allergy alerts, drug-drug interaction alerts, drug-lab interaction alerts, and drug-dosing support. We make the assumption that these key sub-functions have some relationship with the process of care delivery for patients undergoing the procedures of interest.

As operationalized, the key independent variables were the average score of the nine sub-functions of interest calculated within each functionality (ECD, CPOE, and CDS). Implementation of the sub-functions could take on a score of one to three. The scores were summed for each functionality and divided by the total possible achievable score. Thus, the numerator for ECD values could range from 2-6, CPOE from 1-3, and

CDS 6-18. Final scores were divided by the highest possible score, standardizing scores across functionalities.

Dependent variable

The dependent variable was risk-adjusted inpatient mortality for AAA repair, CABG, and PCI at the hospital level. Risk-adjusted mortality was calculated using AHRQ Quality Indictor Software, version 4.4 (AHRQ, 2012), standardized algorithms. Utilizing AHRQ quality indicators provides a uniform definition of quality that have been systematically identified and grounded based on input from experts, literature reviews, and empirical evaluations of national, regional, and state-level data (AHRQ, 2006). The software is based on coding specifications used in the State Inpatient Databases (SID) in the HCUP, funded by AHRQ (AHRQ, 2012). The procedure specific selected IQIs (AAA repair, CABG, PCI) used ICD-9-CM procedure codes for denominator calculation. The numerator was calculated using the number of inpatient deaths among cases meeting the inclusion and exclusion criteria for the denominator.

The AHRQ Quality Indicator software are SAS program files that are coded for use with hospital discharge administrative data, based upon NIS data, to generate observed, expected, risk-adjusted and smoothed IQI rates (AHRQ, 2012). The observed rates (raw rates) are the count of discharge records including the health outcome of interest divided by the count of discharge records in the patient population at risk (AHRQ, 2012). The risk-adjusted rates are calculated by taking into account the average case mix of the reference population to be reflective of the more generalizable U.S. hospitalized population (AHRQ, 2012). The software also calculates 95% confidence intervals for risk-adjusted rates (AHRQ, 2012). Cases were excluded from the analysis and dropped from the numerator and denominator if there were missing data on age, sex, discharge quarter, principal diagnosis code, and discharge year.

Covariates

For the regression analysis, hospital-level covariates included hospital size (small, medium, large), ownership (government nonfederal, private not-for-profit, private investor-owned), and teaching status (nonteaching or teaching). Hospital size categories are based on the number of short-term acute beds and are specific to the hospital's location (urban versus rural) and teaching status (HCUP-NIS, 2008). Teaching status is used to assess the size of urban teaching and urban nonteaching hospitals using different ranges of the number of beds (e.g., small: urban nonteaching, 1-99 beds vs. urban teaching, 1-299 beds) (HCUP-NIS, 2008). While there are other potentially relevant factors, such as volume of procedures performed by the surgeon, these factors unavailable in the data.

Final Sample and Analytical Approach

The initial sample included all hospitals (n=631) with data from both the NIS and the AHA Information Technology Supplement, 2009 and 2010 (regardless if they performed one of the three procedures). Independent hospital observations from 2010 were used in the analysis if there were also data for the hospital in 2009. The AHRQ software calculated IQI rates only for hospitals in the input sample of 440 that had a minimum of three cases for each procedure. We exercised a more conservative criterion by excluding hospitals with less than 30 cases in the denominator. Consequently, the final resulting sample (n=278) of hospitals used in the regression analyses: AAA (n=98), CABG (n=74), and PCI (n=106). Seventy-one hospitals performed all three procedures. Characteristics of the input hospitals are shown in Table 4.3, below.

Table 4.3. Characteristics of input hospitals, 2009 - 2010 NIS

Hospital Characteristics	AAA repair	CABG	PCI
	Study Hospitals No. (%)	Study Hospitals No. (%)	Study Hospitals No. (%)
Total number of hospitals	131	76	110
Hospital control			
Government, nonfederal	6 (6.1)	3 (4.1)	9 (8.5)
Private, non-profit	83 (84.7)	61 (82.4)	84 (79.3)
Private, investor-owned	9 (9.2)	10 (13.5)	12 (12.3)
Hospital size			
Small	7 (7.1)	3 (4.1)	7 (6.6)
Medium	32 (32.7)	25 (33.8)	35 (33.0)
Large	59 (60.2)	46 (62.2)	64 (60.4)
Region			
Northeast	27 (27.6)	12 (16.2)	25 (23.6)
Midwest	18 (18.4)	17 (23.0)	22 (20.8)
South	30 (30.6)	22 (29.7)	29 (27.4)
West	23 (23.5)	23 (31.1)	30 (28.3)
Teaching status			
Non-teaching	53 (54.1)	36	59
Teaching	45 (45.9)	38 (51.4)	47 (44.34)
*The Healthcare Cost and Utilization Project hospital size designations of small, medium, and large based on number of beds varied by region, rural/urban locality, and teaching status.			

Generalized linear models adjusted for hospital characteristics were used to estimate the relationship between average EHR implementation level score for the three functionalities of interest and risk-adjusted mortality for three cardiovascular procedures. Because we were using a small purposive subset of all NIS hospitals, we did not attempt to use sampling weights to generate nationally representative estimates. The hospital-level analysis was conducted using SAS statistical software, version 9.3 (SAS Institute

Inc, Cary, NC). One model was estimated for each of the three cardiovascular procedures. Utilizing an index *i* = 1, 2,….; for the cross-sectional unit (hospital) and index *k* = 0,1,2,…; for the list of covariates. Accordingly, y_i refers to the dependent variable (outcome) and x_i refers to the independent variables for the *i*th hospital. Random error is e_i and β_k refers to the coefficient (slope) of the *k*th independent variable.

Results

Mean hospital-level estimates of inpatient surgical mortality for AAA repair, CABG and PCI are presented in Table 4.4. Bivariate analyses (Table 4.5) revealed significant positive relationships between levels of implementation of certain CDS functions and risk-adjusted mortality for hospitals performing AAA repair (drug-allergy alerts and drug-drug interaction alerts) and PCI (drug-allergy alerts and drug-dosing support).

Table 4.4. Mean hospital level mortality estimates for AAA repair, CABG, and PCI

	AAA repair	**CABG**	**PCI**
Inpatient numerator	2.31	13.05	13.16
Population denominator	254.21	2528.86	4984.36
Risk-adjusted* rate	0.4077	0.0802	0.1931
*Rate adjusted for each hospital's average case-mix			

The multivariate regression results (Table 4.6) revealed a significant positive relationship between implementation of CDS and risk-adjusted mortality for AAA repair ($\hat{\beta}$=0.4767, SE=0.22, p=0.0341) and PCI ($\hat{\beta}$=0.1979, SE=0.08, p=0.0103), adjusting for patient and hospital characteristics. Further, large hospitals were found to have a significant positive relationship with risk-adjusted PCI mortality when compared to small hospitals ($\hat{\beta}$=0.1345, SE=0.06, p=0.0377), all else equal. There were no significant relationships detected in the model for CABG.

Table 4.5. Risk-Adjusted mortality rate for AAA repair, CABG, and PCI by level of implementation of EHR selected functionalities

	AAA Repair			CABG			PCI		
	Level 1 (no. hospitals)	Level 2 (no. hospitals)	Level 3 (no. hospitals)	Level 1 (no. hospitals)	Level 2 (no. hospitals)	Level 3 (no. hospitals)	Level 1 (no. hospitals)	Level 2 (no. hospitals)	Level 3 (no. hospitals)
Clinical documentation									
Problem lists	0.39 (44)	0.29 (21)	0.50 (33)	0.09 (32)	0.07 (20)	0.08 (22)	0.19 (47)	0.19 (23)	0.22 (35)
Medication lists	0.29 (12)	0.30 (15)	0.45 (71)	0.08 (13)	0.10 (12)	0.08 (49)	0.18 (20)	0.15 (18)	0.22 (68)
Computerized provider order entry									
Medications	0.39 (40)	0.38 (33)	0.47 (25)	0.08 (30)	0.08 (22)	0.08 (22)	0.20 (42)	0.19 (34)	0.21 (29)
Clinical decision support									
Clinical guidelines	0.42 (35)	0.31 (23)	0.47 (39)	0.08 (25)	0.09 (15)	0.08 (34)	0.17 (41)	0.19 (22)	0.23 (43)
Clinical reminders	0.33 (32)	0.31 (19)	0.50 (47)	0.08 (23)	0.08 (14)	0.09 (37)	0.18 (35)	0.17 (21)	0.22 (50)
Drug-allergy alerts	*0.17 (15)**	*0.25 (12)**	*0.48 (71)**	0.07 (11)	0.07 (11)	0.08 (52)	*0.15 (20)**	*0.14 (17)**	*0.23 (69)**
Drug-drug interaction alerts	*0.15 (14)**	*0.33 (15)**	*0.48 (69)**	0.08 (12)	0.08 (14)	0.08 (48)	0.15 (22)	0.18 (20)	0.22 (64)
Drug-lab interaction alerts	0.34 (32)	0.27 (11)	0.47 (55)	0.08 (25)	0.08 (10)	0.08 (39)	0.16 (35)	0.16 (16)	0.25 (53)
Drug-dosing support	0.29 (26)	0.37 (15)	0.47 (57)	0.08 (23)	0.09 (11)	0.08 (40)	*0.16 (34)**	*0.16 (18)**	*0.24 (54)**
*$p < 0.05$									

Table 4.6. Regression coefficients for risk-adjusted AAA repair and PCI mortality rates

Parameter	AAA repair			PCI		
	$\hat{\beta}$	SE	P value	$\hat{\beta}$	SE	P value
Average EHR implementation score						
Intercept	-0.0461	0.32	0.8859	-0.0285	0.11	0.7870
ECD	0.1436	0.22	0.5187	0.0498	0.08	0.5208
CPOE	-0.1541	0.20	0.4377	-0.1178	0.07	0.0767
CDS	0.4767	0.22	*0.0341**	0.1979	0.08	*0.0103**
Hospital control						
Government, nonfederal	-	-	-	-	-	-
Private, non-profit	-0.0560	0.17	0.7407	0.1251	0.05	0.3013
Private, investor-owned	-0.1337	0.21	0.5246	0.0520	0.06	0.0492
Hospital size						
Small	-	-	-	-	-	-
Medium	0.0833	0.18	0.6422	0.1222	0.07	0.0679
Large	0.1055	0.18	0.5504	0.1345	0.06	*0.0377**
Hospital teaching status						
Nonteaching	0.0497	0.09	0.5825	-0.0514	0.03	0.0987
Teaching	-	-	-	-	-	-
Hospital region						
Northeast	0.0309	0.12	0.7978	-0.5294	0.04	0.2102
Midwest	-	-	-	-	-	-
South	-0.0181	0.12	0.8795	-0.0529	0.04	0.2184
West	0.0713	0.07	0.5693	-0.0133	0.04	0.7454

*$p < 0.05$
Note: Referent levels were determined by categories that occur with the least frequency.

Discussion

We sought to explore possible links between ECD, CPOE, and CDS implementation and quality, using surgical mortality as a proxy for quality. Overall, we found no significant links between ECD or CPOE and risk-adjusted surgical mortality for AAA repair, CABG, or PCI. Contrary to our hypothesis, CDS use was associated with increased surgical mortality for AAA repair and PCI. The availability of a measure of actual utilization creates limitations in adequately adjusting for these differences.

The results of the bivariate analyses of the individual functionalities of CDS detected a significant positive relationship across implementation levels for AAA repair for drug-allergy alerts and drug-drug interaction alerts. Similarly, CDS drug-allergy alerts and drug-dosing support also were found to have significant positive variation for PCI risk-adjusted mortality across implementation levels. It is interesting that with a greater level of implementation, these alerts that should be preventing adverse outcomes, have higher mortality. What factors that might lead to these differences are unclear and warrant further investigation as to how they are being used. Future research examining both volume and processes of care using EHRs and the relationship with mortality could also provide insight into this research area.

Limitations

This study was limited by its use of a single indictor of hospital quality: mortality for three select cardiovascular procedures. The results should be extrapolated with caution across settings, populations, and time. AHRQ evaluates the selected IQIs by examining discrimination, forecasting, and construct validity. Discrimination is the ability of the measure to differentiate variations in performance by statistically significant deviations from the average. Forecasting is the ability of the measure to predict performance. Construct validity is the degree of association between the composite and other measures of quality. Another broad approach to analyzing construct validity would be to examine the relationship between these composites and external measures of quality or other factors that influence quality (AHRQ, 2011).

The pooled cross-sectional design of this study presents further limitations. Now that CMS will begin to measure IQIs in 2013, hospitals could possibly use EHRs to help improve these measures. Improvement of these measures is needed as CMS moves toward quality based reimbursement. If the IQI mortality rates decrease, it may be attributable to financial motivations and not just EHRs as a tool for their improvement alone. This study was based on the assumption that hospitals with the same level of measured implementation use the technology in the same way. The true use and implementation of the functionalities is likely to vary across and within hospitals. Maturation and learning curve differences based on culture might also be a factor. Further, the hospitals in this sample are limited to those who answered the AHA Information Technology Supplement to the AHA annual survey; responding hospitals may have different characteristics than non-respondents.

Despite the limitations, the results of this study have important implications and it is vital to consider how they might be extrapolated outside of this time period as new adopters of EHR technology overcome any effects due to a possible learning curve. Further, there are limitations related to this study in that it was conducted under the assumption that all hospitals that have similar implementation use the technology in the same way. An exact measurement of the use of the technology limits the precision of measuring process of care.

Conclusion

These results should be used as a foundation and motivation for further investigations in this area, as major changes in meaningful use have taken place to improve these rates since this data was collected in 2009 and 2010. Changes in CMS reimbursements based on rates of complications since the years of data used may yield different results. Using EHRs and the related process of care as a tool to improve patient outcomes will require ongoing investigation. As stated in a recent IOM (2012) report, investigations are required to determine potential unintended consequences of EHR use. Understanding how the functionalities are used when implemented will be an important step in determining the effects of EHRs. Policy makers may consider continued more specific policies around EHR use standards as future stages of meaningful use are developed or improved methods for measuring how EHRs are used.

CHAPTER 5

MANUSCRIPT TWO

THE RELATIONSHIP BETWEEN ELECTRONIC HEALTH RECORD IMPLEMENTATION OF PROCESS OF CARE FUNCTIONALITIES AND OPERATIVE COST PER DISCHARGE[2]

[2] Leonhirth D.A., Probst J.C., Bennett K.J., Hardin J.W., Vyavaharkar M., & Stinson M.S. To be submitted to *Surgery, Circulation, or Journal of the American Medical Informatics Association*

Abstract

Background. Electronic health records have been promoted as a tool to streamline processes of care, reduce patient complications, and improve patient outcomes all while realizing a cost savings in the long-run. The Surgical Care Improvement Project (SCIP) is one of the hospital inpatient quality initiatives of the Value-Based Purchasing Program that uses clinical standards or process of care to achieve these improvements. The objective of this study was to determine the relationship between the level of EHR process of care implementation and estimated cost per discharge for three inpatient coronary surgical procedures: abdominal aortic aneurysm repair (AAA), coronary artery bypass graft (CABG), and percutaneous coronary intervention (PCI).

Methods. Hospital inpatient administrative discharge data from the Nationwide Inpatient Sample (NIS) 2009-2010 were merged with the American Hospital Association Information Technology Supplement 2009-2010 for analysis. Using a pooled sample design, at the hospital level, we examined the association between level of implementation of select functionalities of clinical documentation (ECD), computerized provider order entry (CPOE), and clinical decision support (CDS) and estimated log-transformed cost per discharge for the three procedures of interest to determine whether advanced levels of EHR implementation were associated with lower log-transformed estimated cost per discharge (adjusting for patient and hospital characteristics).

Results. A multivariate regression for all three cardiovascular procedures modeled individually failed to detect a relationship among average level of ECD, CPOE, and CDS implementation scores and estimated cost per discharge for all three models, adjusting for patient and hospital characteristics. Academic hospitals as compared to nonteaching hospitals performing AAA repairs were found to have significantly lower estimated log-transformed cost per discharge. Hospitals performing PCI's had significantly lower log-transformed estimated cost per discharge in the South than the Northeast and those in the 2nd quartile of chronic conditions greater than three than those in the 1st quartile.

Conclusions. Bivariate analyses revealed relationships between estimated log-transformed cost per discharge and hospital size, location, teaching status, region, number of chronic conditions, and patient severity for some of the procedures of interest. No relationship was detected between estimated cost per discharge and average implementation score of ECD, CPOE, and CDS. Despite not knowing the full extent of how the EHR functionalities of interest are implemented, there were no significant relationships detected between level of implementation and estimated log-transformed cost per discharge. These preliminary findings prompt further investigation to determining how EHR implementation can generate lower costs in this context and how future policy may be shaped to realize these savings.

Keywords: Cost per discharge, surgical mortality, electronic health records

Background

U.S. health policy currently seeks to reduce healthcare costs and financially motivate hospitals to improve outcomes through changes in reimbursement strategies

(CMS, 2011). Section 1886(o) of the Affordable Care Act, Hospital Value-Based Purchasing (VBP) Program, introduced a quality incentive program built upon the Hospital Inpatient Quality Reporting (IQR) measures. The Centers for Medicare and Medicaid Services (CMS) consider this the next step in promoting higher quality care for Medicare beneficiaries by reimbursing for care that rewards improved value, patient outcomes, and innovations as an alternative to service volume-based reimbursement (CMS, 2011).

The Surgical Care Improvement Project (SCIP) is one of the hospital inpatient quality initiatives of the value-based purchasing program. The SCIP aims to substantially reduce surgical mortality and morbidity, as well as reducing the incidence of surgical complications. In 2010, a variety of surgical care accountability measures were designated to improve outcomes. Some of the selected standards of care measures include: prophylactic antibiotic receipt one hour prior to surgical incision, prophylactic antibiotic selection for surgical patients, discontinuation of prophylactic antibiotics within 24 hours of surgery end time, beta-blocker therapy prior to arrival for those who received a beta-blocker during the perioperative period, and percent of cardiac surgery patients with a controlled 6 a.m. blood glucose on postoperative day one and postoperative day two (JACHO, 2013).

Improvements in process of care measures are important for cost-savings as well as quality. Medical errors, postoperative complications, and longer hospitals stays are all factors that could lead to increased costs when a patient undergoes an inpatient procedure. Clinical process of care (e.g., workflow) paired with the use of electronic health records to support the delivery of care processes are one set of tools proposed to achieve cost savings (IOM, 2012).

Health information technology (HIT) use, specifically "meaningful use" of electronic health records (EHRs), is encouraged for its potential to deliver safer systems of care and contain costs through improvement in the delivery of the process of care (Menachemi & Collum, 2011; IOM, 2012). The Health Information Technology for Economic and Clinical Health Act (HITECH) is in part meant to aid in long-term cost containment by incentivizing providers to adopt such EHR systems. The next step after EHR implementation is to determine whether the system is providing the intended benefits and if it's not, how the systems should be modified to achieve the outlined gains.

Employers have also taken notice to the importance of process of care and care outcomes. The Leapfrog Group, a coalition of employers that combined to leverage quality health care for employees, has identified quality and safety standards to define a referral hospital. These standards include process of care and risk-adjusted mortality rates as standards for elective abdominal aortic aneurysm (AAA) repair, coronary artery bypass grafting (CABG), and percutaneous coronary intervention (PCI). Some of these process measures for The Leapfrog Group are similar to SCIP. For example, perioperative beta-blockers use for AAA and CABG.

The American College of Cardiology Foundation has identified a variety of factors that increase the cost of a CABG other than patient characteristics alone, such as postoperative complications and longer hospitals stays (Hillis et al., 2011). Medicare payments for CABG and AAA surgeries have been found to be higher for those with complications, $5,353 and $5,279, respectively (J. D. Birkmeyer et al., 2012). This may imply that hospitals with higher quality have lower expenditures. Technology implementation may be able to improve quality without increasing costs; a 2003 study found that CPOE was associated with a decrease in total costs of $887 per admission and decrease mean length of stay by 0.89 days (Tierney et al., 1993). Projections by J. D. Birkmeyer & Dimick (2004) have estimated that adding process of care standards can save an additional 1,388 lives for AAA, CABG, and PCI. Further investigation is needed to determine whether these process of care standards, as implemented through EHR's, have the ability to improve patient outcomes while reducing costs per discharge.

There have been a variety of studies examining the link between EHR implementation and quality, including some studies that have used surgical outcomes as a proxy for quality (J. D. Birkmeyer et al., 2001; Dimick et al., 2004; Khuri et al., 1997; Shamliyan et al., 2008). This research addresses the IOMs call for studies examining the ability of HIT to improve quality, safety and cost of health care, while also identifying any associated unintended consequences related to its use (IOM, 2012). The objective of this study was to determine the relationship between the level of EHR process of care implementation and estimated cost per discharge for three inpatient coronary surgical procedures: AAA, CABG, and PCI.

Methods

Hospital inpatient administrative discharge data from the Nationwide Inpatient Sample (NIS) 2009-2010 was merged with the American Hospital Association (AHA) Information Technology Supplement 2009-2010 for analysis. Using a pooled sample design, at the hospital level, we examined the association between level of implementation of select functionalities of clinical documentation (ECD), computerized provider order entry (CPOE), and clinical decision support (CDS) and estimated cost per discharge for AAA repair, CABG, and PCI procedures to determine if higher levels of implementation are associated with lower estimated cost per discharge (adjusting for patient and hospital characteristics).

Independent variable: EHR functionalities and levels of implementation

The AHA Information Technology Supplement measured the level of hospital implementation (6 levels) of four main functionalities: clinical documentation, computerized provider order entry (CPOE), results viewing, and clinical decision support (CDS). Our analysis is restricted to nine select sub-functions of ECD, CPOE, and CDS. The nine sub-functions selected within these three functionalities that are measured include: problem lists, medication lists, electronic prescribing, consultation requests, nursing orders, clinical guidelines, clinical reminders, drug-allergy alerts, drug-drug interaction alerts, drug-lab interaction alerts, and drug-dosing support (AHA, 2010). These sub-functions are adopted in varying combinations across the inpatient setting.

For the purposes of this analysis, a conservative criterion for defining the highest level of implementation was used (Table 5.1), focusing on those who have implemented the sub-functions of interest across *all* clinical units. The nine sub-functions fall into three categories of key EHR functionalities.

Table 5.1. Levels of EHR functionalities implementation

<table>
<tr><th>Level used for analyses</th><th>Levels measured in AHA survey</th></tr>
<tr><td>3</td><td>(1) fully implemented across all clinical units</td></tr>
<tr><td>2</td><td>(2) fully implemented in at least one clinical unit</td></tr>
<tr><td rowspan="4">1</td><td>(3) beginning to implement in at least one clinical unit</td></tr>
<tr><td>(4) have resources to implement in the next year</td></tr>
<tr><td>(5) do not have resources but considering implementing</td></tr>
<tr><td>(6) not in place and not considering implementing</td></tr>
</table>

Nine stage 1 MU sub-functions were selected (Table 5.2) that can be measured using the AHA Information Technology Supplement and that may be associated with process of care for patients undergoing the procedures of interest. Because information on how use of each implemented function is not available, we are assuming that these key functions have some relationship with the process of care delivery for patients undergoing the procedures of interest. The key independent variables were average score of the nine sub-functions (Table 5.2) of interest categorized and calculated in their respective functionalities ECD, CPOE, and CDS. Implementation of the sub-functions could take on a score of one to three. The scores were summed within each functionality and divided by the total possible achievable score. Thus, the numerator for ECD values could range from 2-6, CPOE from 1-3, and CDS 6-18.

Table 5.2 Key independent variables: Three key functionalities with nine sub-functions

Electronic clinical documentation
Problem lists
Medication lists
Computerized provider order entry (CPOE)
Medications
Clinical decision support
Drug-allergy alerts
Drug-drug interaction alerts
Clinical guidelines (e.g. beta blockers)
Clinical reminders
Drug-lab interaction alerts
Drug dosing support

Dependent variable

The dependent variable was estimated cost per discharge for each of the three procedures of interest at the hospital level. Estimated cost per discharge was calculated at the discharge level and then averaged for each hospital for use in analysis and results reporting. Total adjusted charges for each discharge were multiplied by the hospital all-payer inpatient cost/charge ratio (APICC). Adjusted total charges sets zero charges to missing, sets total charges that are excessively low or high to inconsistent. The variable was adjusted by HCUP using the following inclusion criteria: total charges allowed are between $100 and $1.5 million. HCUP recommends estimating the cost of inpatient care for a discharge by multiplying the total charges adjusted from the discharge record by the APICC or the group average all-payer inpatient cost/charge ratio (GAPICC). The GAPICC is a weighted average for the hospitals in a group that is defined by state, urban/rural, ownership, and hospital size. We chose to use the APICC because it is hospital specific.

Covariates

The model was risk-adjusted using hospital and patient mix covariates. Hospital-level covariates included hospital size (small, medium, large), ownership (government nonfederal, private non-profit, private investor owned), and teaching status (nonteaching or teaching). Hospital size categories are based on the number of short-term acute beds and are specific to the hospitals location (urban versus rural) and teaching status (HCUP-NIS, 2008). Teaching status is used to assess the size of urban teaching and urban nonteaching hospitals using different ranges of the number of beds (e.g., small: urban nonteaching, 1-99 beds vs. urban teaching, 1-299 beds) (HCUP-NIS, 2008). There are other factors that could be potentially relevant, such as treating physician volume of procedures performed, however data on these factors are currently unavailable in the data used.

To adjust for patient mix at the hospital level, discharge covariates included percent of patients with an APR-DRG assigned severity with major or extreme loss of function (quartiles) and percent of discharges with three or more chronic conditions (quartiles). Evidence by Elixhauser and colleagues (1998) has shown that comorbidities are associated with substantial increases in LOS, hospital charges, and mortality for both heterogeneous and homogeneous disease groups. Percent of discharges with a high APR-DRG severity and high percentage of discharges with three or more chronic disease are meant to control for hospital patient mix that require more complex care. Other patient covariates included: age, race, and, sex.

Final Sample and Analytical Approach

We used a pooled cross-sectional design to identify the sample population. The sample included all hospitals that contained data from both the NIS and the AHA Information Technology Supplement for the respective years, 2009 and 2010 (440 hospitals and 5,916,499 discharges). Hospital characteristics are found in Table 5.3. Independent hospital observations from 2010 were used in the analysis if there were also data for the hospital in 2009.

Table 5.3. Characteristics of the sample hospitals

Hospital Characteristics	**Total No. (%) of Hospitals** n=440
Hospital control	
Government, nonfederal	69 (15.7)
Private, non-profit	332 (75.4)
Private, investor-owned	39 (8.9)
Location	
Rural	164 (37.3)
Urban	276 (62.7)
Hospital size	
Small	151 (34.3)
Medium	119 (27.1)
Large	170 (38.6)

Region	
Northeast	88 (20.0)
Midwest	119 (27.1)
South	140 (31.8)
West	93 (21.1)
Teaching status	
Nonteaching	343 (78.0)
Teaching	97 (22.0)
Multihospital membership	
No	188 (45.1)
Yes	229 (54.9)
Missing	23
*The Healthcare Cost and Utilization Project hospital size designations of small, medium, and large based on number of beds varied by region, rural/urban locality, and teaching status.	

Since the APICC and total charges variables are required to calculate the estimated cost per discharge, discharge records with missing data for APICC were excluded (158 hospitals; 1,505,099 discharges) from the sample, as well as discharges with missing total charges data were excluded (n=7,398), reducing the number of discharges to 4,404,002. The sample was further reduced (n=4,267,494) to discharges that underwent one of the three procedures of interest. The final sample included 136,508 discharge records from 440 hospitals. The NIS data is at the discharge-level. Thus, may include multiple observations for each patient. Discharge characteristics across hospital characteristics of the final sample are shown in Table 5.4. These discharges form the population from which hospital-level means were calculated.

Table 5.4. Discharge characteristics by hospital characteristics

	Total		**Abdominal aortic aneurysm (AAA) repair**		**Coronary artery bypass graft (CABG)**		**Percutaneous coronary intervention (PCI)**	
	n	%	n	%	n	%	n	%
Total	†136,508		28,968		28,884		81,023	

Hospital control								
Government, nonfederal	7,754	5.7	1,895	6.5	1,108	3.8	4,894	6.0
Private, non-profit	118,922	87.1	25,023	86.4	25,609	88.7	70,357	86.8
Private, investor-owned	9,832	7.2	2,050	7.1	2,167	7.5	5,772	7.1
Location								
Rural	8,487	6.2	3,269	11.3	1,238	4.3	4,082	5.0
Urban	128,021	88.3	25,699	88.7	27,646	95.7	76,941	95.0
Hospital size								
Small	8,442	6.2	3,159	10.9	1,289	4.5	4,092	5.0
Medium	28,150	73.2	6,758	23.3	5,759	19.9	16,115	19.9
Large	99,916	20.6	19,051	65.8	21,836	75.6	60,816	75.1
Teaching status								
Nonteaching	62,983	46.1	15,775	54.5	12,119	42.0	36,236	44.7
Teaching	73,525	53.9	13,193	45.5	16,765	58.0	44,787	55.3
Region								
Northeast	28,225	20.7	7,185	24.8	5,320	18.4	16,051	19.8
Midwest	21,829	16.0	5,399	18.6	4,288	14.9	12,543	15.5
South	60,665	44.4	11,709	40.4	12,586	47.0	36,551	45.1
West	25,789	18.9	4,675	16.1	5,690	19.7	15,878	19.6
Multihospital membership								
Yes	42,006	32.4	10,687	38.8	7,827	28.4	24,212	31.4
No	87,756	67.6	16,828	61.2	19,683	71.6	52,786	68.6
Missing	6,746		1,453		1,374		4,025	

†The total of number of discharges that underwent one of the three procedures is lower than the sum of the discharges that underwent each of the three procedures, because 2,894 of the total discharges underwent more than one of the three procedures during a single stay.

Bivariate analyses were used to test for significant differences in mean estimated costs per discharge and level of implementation (three levels) for each of the nine sub-functions of interest. A generalized linear model was used to estimate the associations between average EHR implementation level score for the three functionalities of interest and estimated log-transformed-transformed cost per discharge, holding other patient and hospital characteristics constant. The analysis was conducted using SAS statistical software, version 9.3 (SAS Institute Inc, Cary, NC). Three models were estimated, one for each of the three procedures individually Where *i* = 1, 2,….; is the cross-sectional unit (hospital) and *k* = 0,1,2,…; refers to the covariates. Accordingly, y_i refers to the dependent variable and x_i refers to the independent variables for the *i*th hospital. Random error is e_i and β_k refers to the coefficient (slope) of the *k*th predictor.

Results

Mean and median estimated cost per discharge by hospital characteristics are presented in Table 5.5. Unadjusted bivariate analyses detected a significant difference between estimated cost per discharge and teaching status (academic or non-academic) for hospitals performing AAA repair.

Table 5.5. Mean and median estimated cost per discharge ($) for AAA repair, CABG and PCI by hospital characteristics

N=136,508 procedures & 440 hospitals	**Abdominal aortic aneurysm (AAA) repair Mean (Median)**	**Coronary artery bypass graft (CABG) Mean (Median)**	**Percutaneous coronary intervention (PCI) Mean (Median)**
No. Hospitals	315	29	96
Mean	12,863	59,449	22,556
Median	(7,799)	(40,021)	(18,702)
Hospital control			
Government, nonfederal	13,924 (7,829)	53,237 (53,237)	28,685 (12,816)
Private, not-profit	12,624 (7,798)	62,430 (40,508)	23,046 (19,663)
Private, investor-owned	12,530 (7,790)	28,403 (28,403)	12,229 (12,085)
Hospital size			
Small	12,476 (7,370)	67,871 (67,871)	16,819 (15,248)
Medium	12,367 (8,069)	49,131 (39,883)	24,426 (20,606)
Large	13,902 (7,780)	62,907 (35,746)	22,673 (18,612)
Region			
Northeast	14,290	50,176	21,793

	(8,791)	(40,508)	(18,203)
Midwest	12,883 (8,037)	74,209 (37,504)	26,015 (20,783)
South	11,790 (6,825)	50,898 (38,424)	17,177 (14,757)
West	13,072 (7,879)	61,508 (64,662)	26,008 (20,606)
Teaching status			
Nonteaching	*12,071* (7,389)*	67,228 (33,435)	22,033 (18,813)
Teaching	18,471 (10,531)	51,115 (40,561)	23,173 (18,452)
**Significance tested at p < 0.05 for means*			

Mean estimated cost per discharge for AAA repair, CABG, and PCI individually by level of implementation of EHR selected functionalities are presented in Table 5.6. Relationships between estimated cost per discharge and levels (three) of implementation for sub-functions were detected for those hospitals that performed CABG and PCI for drug-lab interaction alerts and drug-drug interaction alerts, respectively. Hospitals that performed CABG which had drug-lab interaction alerts implemented across all clinical units had lower cost per discharge than those who had implemented it in one clinical unit, while those who didn’t implement it costs fell between the other two levels. Significance was determined at $\alpha = 0.05$.

Table 5.6. Mean estimated cost per discharge for AAA repair, CABG, and PCI by level of implementation of EHR selected functionalities

	AAA Repair			**CABG**			**PCI**		
	Level 1 $ (no. hospitals)	Level 2 $ (no. hospitals)	Level 3 $ (no. hospitals)	Level 1 $ (no. hospitals)	Level 2 $ (no. hospitals)	Level 3 $ (no. hospitals)	Level 1 $ (no. hospitals)	Level 2 $ (no. hospitals)	Level 3 $ (no. hospitals)
Clinical documentation									
Problem lists	14,298 (144)	12,862 (57)	11,283 (109)	52,075 (4)	54,109 (8)	63,697 (17)	20,823 (45)	26,113 (14)	23,317 (37)
Medication lists	11,076 (78)	12,560 (62)	13,978 (171)	85,568 (1)	51,699 (8)	61,243 (20)	22,261 (18)	32,540 (11)	20,996 (67)
Computerized provider order entry									
Medications	11,857 (175)	12,915 (65)	15,245 (74)	29,338 (5)	80,689 (12)	50,755 (12)	21,546 (40)	24,260 (27)	22,505 (28)
Clinical decision support									
Clinical guidelines	11,675 (190)	13,985 (49)	15,532 (69)	49,829 (10)	52,175 (6)	70,207 (13)	22,085 (39)	27,051 (17)	21,105 (40)
Clinical reminders	11,750 (173)	14,334 (56)	14,884 (79)	46,264 (7)	55,371 (7)	67,505 (15)	22,196 (33)	28,539 (18)	20,427 (45)
Drug-allergy alerts	10,943 (89)	12,584 (67)	14,156 (157)	54,262 (2)	60,682 (4)	59,686 (23)	20,863 (23)	26,168 (10)	22,600 (63)
Drug-drug interaction alerts	10,294 (89)	13,269 (67)	14,279 (156)	46,748 (3)	94,231 (7)	48,640 (19)	_21,867 (24)_*	_33,297 (12)_*	_20,683 (60)_*
Drug-lab interaction alerts	11,007 (130)	13,983 (54)	14,369 (129)	_58,868 (7)_*	_116,679 (5)_*	_42,856 (17)_*	23,171 (32)	27,890 (12)	21,067 (48)
Drug-dosing support	12,604 (138)	12,262 (59)	13,604 (114)	49,265 (8)	71,726 (3)	61,929 (18)	23,473 (32)	25,403 (16)	21,613 (45)

*$p < 0.05$

Multivariate regression models were run for AAA and PCI; too few hospitals performed CABG procedures, (29) for valid estimation across multiple variables. We failed to detect a relationship among average ECD, CPOE, and CDS implementation score and log-transformed estimated cost per discharge for the two procedures, adjusting for patient and hospital characteristics. Regression coefficients are presented in Table 5.7. Nonteaching hospitals performing AAA repair compared to academic hospitals performing AAA repair were found to have a significantly different estimated cost per discharge ($\hat{\beta}$=-0.3539, SE=0.17, p=0.0344), all else equal. Further, hospitals performing AAA in the south region had significantly different log-transformed estimated cost per discharge than those in the west region ($\hat{\beta}$ = -0.3197, SE= 0.15, p = 0.0350). Hospitals performing PCIs in the 2nd quartile of average patient-mix with chronic conditions greater than three had significantly different estimated costs per discharge than those hospitals in the 1st quartile performing PCIs ($\hat{\beta}$ = -0.4971, SE = 0.23, p = 0.0415), all else equal.

Table 5.7. Regression coefficients for AAA repair and PCI log-transformed cost per discharge,
NIS 2009-2010

	AAA repair			**PCI**		
Parameter	$\hat{\beta}$	SE	P value	$\hat{\beta}$	SE	P value
Intercept	9.4071	0.36	<0.0001	9.6677	0.39	<0.0001
Average EHR implementation scores						
ECD	-0.3045	0.27	0.2648	0.3236	0.32	0.3102
CPOE	0.1121	0.24	0.6371	-0.0002	0.27	0.9994
CDS	0.5698	0.31	0.0714	-0.2132	0.30	0.4743
Hospital control						
Government, nonfederal	-0.0932	0.21	0.6642	-	-	-
Private, non-profit	-0.0645	0.19	0.7388	0.3352	0.23	0.1430
Private, investor-owned	-	-	-	-0.1278	0.29	0.6574
Hospital Size						
Small	-0.0601	0.13	0.6350	-	-	-
Medium	-	-	-	0.2955	0.22	0.1794
Large	0.0092	0.14	0.9474	0.2286	0.20	0.2480

Hospital teaching status						
Nonteaching	-0.3539	0.17	*0.0344**	0.1227	0.12	0.3235
Teaching	-	-	-	-	-	-
Hospital region						
Northeast	0.0026	0.17	0.9882	-	-	-
Midwest	-0.0635	0.16	0.6922	-0.0413	0.17	0.8031
South	-0.3197	0.15	*0.0350**	-0.2595	0.17	*0.1396*
West	-	-	-	-0.0536	0.18	0.7617
Quartiles of patient chronic conditions >3						
4th	0.0584	0.17	0.7272	-0.4893	0.31	0.1220
3rd	-	-	-	-0.3207	0.29	0.2667
2nd	0.0905	0.16	0.5570	-0.4971	0.23	*0.0415**
1st	0.0286	0.19	0.8820	-	-	-
Quartiles patient ADR DRG severity major or extreme loss of function						
4th	-	-	-	0.1280	0.28	0.6544
3rd	-0.0812	0.16	0.6153	-0.0252	0.25	0.9184
2nd	-0.0728	0.19	0.7063	0.2107	0.22	0.3435
1st	-0.1675	0.22	0.4467	-	-	-

*$p < 0.05$
Note: Referent levels were determined by those which occur with the least frequency.

Discussion

We detected no significant relationships between average level of implementation score for ECD, CPOE, and CDS at the hospital level and log-transformed estimated cost per discharge. These preliminary findings are of importance in evaluating the early effects of EHR implementation on estimated cost per discharge. Using EHRs as a tool to achieve improvements in quality and costs will require ongoing investigation. The variations in the combinations of functionalities implemented and the time since initial implementation present complexities in the evaluation of the effects of EHR. Further, an exact measurement of the use of the technology is lacking to allow true precision in process of care measurement.

As future policy shapes the standardization of EHR functionalities and care process, greater internal validity may be achieved by reducing the influence created by extraneous variables. This will allow policy makers to hone in on what is and isn't useful in achieving the desired improvements. The IOM, in a November 2012 report, set forth a call to investigators to research and report the potential unintended adverse consequences, quantifying the risk, of EHR implementation in order to take strides toward building a safer system of care.

One major challenge in improving preventable adverse outcomes and adopting technology to do so is providing financial motivation for providers. The current reimbursement system frequently is considered lacking in its ability to incentivize healthcare organizations to make improvements. There also might be increases in costs as EHRs are implemented because providers have the potential to more easily detect complications that previously went unidentified. Thus, allowing them to charge for events that were previously unnoticed.

A recent study found that hospitals may be financially unmotivated to prevent complications. The study examined the effect of surgical complications on finances and found that postsurgical complications were associated with higher per-encounter hospital contribution margin (Eappen et al., 2013). The results also showed that the contribution margin for postsurgical complications varied drastically among privately insured patients ($16,936 vs. $55,953) and Medicare patients ($1,880 vs. $3,629) (Eappen et al. 2013).

Health economist Uwe Reinhardt (2013) responded to these results by saying that "readers may infer that the associated financial losses may discourage hospitals from reducing avoidable postsurgical complications as vigorously as they could." It seems like the easy answer is for payers to reimburse for higher quality care that is free of preventable complications, yet this solution is not void of challenges. While there are policies beginning to take this stance, it is going to be a hurdle to overcome as the U.S. health care system continues to become more complex. Similarly to complexities of changing the American care model from being a superior provider of sick care, to a model based on prevention. It will be necessary for organizations to have a strategic, long-range perspective to see beyond the initial challenges change inevitably presents.

Future considerations

While the paucity of the effects of EHR implementation and its measurement presents challenges, preliminary studies such as this one are vital in determining how to achieve benefits and identify the associated risks for all stakeholders. Caution will be required in the extrapolation of findings across settings, populations, and over time. Yet, one of the most notable benefits of EHRs is the long-term potential for a data rich environment that may possibly help in strengthening the external validity of studies by offering evidence that is more representative.

Chapter 6

Conclusion

The U.S. healthcare movement to improve quality and patient outcomes has prompted investigations into tools that can assist in these aims. Electronic health records (EHRs) are one tool proposed by the Institute of Medicine (IOM) (2001). The original dissertation research examined the relationship between level of implementation of selected EHR functionalities and two outcomes of care as proxies for quality: risk-adjusted mortality and log-transformed estimated cost per discharge for abdominal aortic aneurysm (AAA) repair, coronary artery bypass grafting (CABG), and percutaneous coronary intervention (PCI).

Results presented in manuscripts one and two were based on analyses of 2009-2010 hospital inpatient administrative discharge data from the Nationwide Inpatient Sample (NIS), Healthcare Cost and Utilization Project (HCUP), Agency for Healthcare Research and Quality merged with data from the 2009-2010 American Hospital Association Information Technology Supplement. A pooled cross-sectional design was used, at the hospital-level, to determine if advanced levels of select ECD, CPOE, and CDS functionalities implementation scores were associated with two outcomes of interest. Using AHRQ's IQI indicators as a proxy for inpatient quality using administrative claims data, three cardiovascular procedures of interest were selected for the analyses: AAA repair, CABG, and PCI.

Bivariate analyses revealed significant relationships for risk-adjusted mortality across levels of CDS implementation for hospitals performing AAA repair (drug-allergy alerts and drug-drug interaction alerts) and PCI (drug-allergy alerts and drug-dosing support). Examination of both aims revealed no significant relationships between ECD and CPOE level of implementation and the two outcomes of interest, all else equal. Regression results for Aim 1 revealed a significant positive relationship between level of CDS implementation and risk-adjusted mortality for AAA repair and PCI, controlling for patient-mix and hospital characteristics. Regression results for Aim 2 failed to detect a relationship between level of CDS implementation and the outcomes of interest. The three multivariate regression models for each of the procedures modeled for Aim 2 failed to detect a relationship among average level of ECD, CPOE, and CDS implementation and log-transformed estimated costs per discharge, controlling for patient and hospital characteristics.

Despite not knowing the exact ways in which EHR functionalities of interest are implemented and used across the inpatient setting, this study aimed to provide a foundation for future research on such relationships. While no significant relationship was detected between level of EHR functionalities implementation and log-transformed estimated cost per discharge, risk-adjusted mortality for AAA repair and PCI were found to be positively associated with increased implementation of select CDS functionalities. While we hypothesized that the nine sub-functions of interest in this study would have a relationship with the outcomes of interest, there are potential unmeasured confounders that should be considered when interpreting these results. Organizational culture could play a role in how readily new technology is adopted. Learning curve effects may also vary across hospitals. Data on the length of time the sub-functions of interest have been implemented would helpful in future studies examining these associations. Further, within hospital implementation of varying sub-functions could vary by clinical unit, creating limitations with maturation. There may also be limitations in the differences among hospitals that answered the AHA Health Information Technology Supplement annual survey. Survey respondents may have hospital characteristics that vary from non-respondents, as this survey is a supplement to the annual AHA survey.

Currently, CMS is beginning to reduce reimbursements for providers that have higher rates of complications in certain areas; these policies were not in place for the time periods examined. Therefore, an examination of these same questions with future data might yield different results. As implementation increases investigations should continue to examine the association with patient outcomes. Further, examining hospitals that currently have the technology over time would be of additional benefit to policy makers when developing and modifying policies aimed at improving patient outcomes with the use of EHRs. This study answers the 2012 call from the IOM for researchers to report any findings of the potential unintended consequences of EHR use.

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