Evaluating the Association of Learning Health System Practicing Hospitals and other Health Information Interested Hospitals with Patient-Generated Health Data Uptake

by

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Abstract

Patient generated health data (PGHD) has been described as a necessary addition to provider generated information for improving care processes in US hospitals. This study sought to understand the distribution of US hospitals that are Health Information Interested (HII) and are more likely to capture or use PGHD. The literature suggests that HII hospitals such as Learning Health Systems (LHS), meaningful use stage three compliant, PCORI funded, and medical home/safety net hospitals, are more likely to capture and use PGHD. Their prevalence and whether they actually use and capture PGHD more than non HII hospitals has not been established. Using the AHA health IT supplement for 2013, 2016, and 2018, and other supporting data sets, the study showed that HII hospitals are prevalent within national level US hospital data representing 62.4% of AHA reporting hospitals in 2018. Hospitals meeting all LHS criteria (full LHS) and meaningful use stage three compliant hospitals and their intersections were observed to be the dominant HII subcategories in 2018. Of the HII hospitals in the study sample for 2018, full LHS and meaningful use stage three compliant hospitals represented 37.2%, and 46.9% respectively, with 33.2% that are overlapping. Cross-sectional analysis of 2018 study data showed that HII hospitals as a whole and at least three out of the four HII subcategories evaluated were associated with increased PGHD capture and use. The full LHS hospital subcategory had the most association with PGHD capture or use with a range of 67.7% to 87.2% rates of capture or use and 33.1% to 50.6% greater rates of capture or use than non-HII hospitals. A

generalized difference-in-difference model using 2013 - 2018 data indicated that hospitals changing to HII status were likely to increase PGHD capture and use. These findings show that incorporating LHS and learning organization principles seem to be the strongest driver of PGHD capture and use and this was stronger than in hospitals that were meaningful use stage three compliant. Based on this, being LHS appears to be the strongest practice and policy lever to increase PGHD capture and use.

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Chapter One – Introduction

Background

US health care organizations (HCOs) such as hospitals are becoming more interested in improving care processes for individual and targeted groups of patients and are becoming more invested in the electronic capture and use of personally generated health data such as patient generated health data (PGHD) (Foley & Vale, 2017; Seltzer et al., 2019). Patient populations are also calling for its increased use in their care processes and decisions (Seltzer et al., 2019). This is due to the pressure within the US Health Care System to improve quality while managing multi-faceted individual and population health needs, curbing costs, and reducing inefficiencies. These challenges within US HCOs have been attributed to a lack of systemic and patient centric approach to care which has led to care fragmentation (S Morain & Kass, 2017; Pronovost, Holzmueller, et al., 2015; Stangt, 2009). Hence, care fragmentation, and a lack of patient centric approach to care have been identified as two of the culprits impeding the capacity to learn and improve the quality of care within US HCOs, despite significant investment (Pronovost, Mathews, Chute, & Rosen, 2017; M. Smith et al., 2013b).

Care fragmentation has led to medical errors, low quality of care, suboptimal health outcomes, and higher costs of care (Smith, Saunders, Stuckhardt, McGinnis, & IOM 2014; Stangt, 2009). A lack of patient centric approach to care on the other hand has led to increased inefficiencies in achieving care targets,

thereby increasing the tendency for care fragmentation through the perpetuation of unmet patient needs that have to be addressed in other parts of the Health Care System (Clarke, Bourn, Skoufalos, Beck, & Castillo, 2017; M. Smith et al., 2013b). These challenges have prompted calls for systemic improvement in care processes through the development of HCOs that are highly invested in data driven continuous care improvement processes through the use of digital health information such as patient generated health data (PGHD) (Pronovost, Armstrong, et al., 2015; Smith et al., 2014). These PGHD can be obtained from digital health technologies and other provider generated electronic health data (EHD) in electronic health records (EHRs) (Pronovost, Armstrong, et al., 2015; Smith et al., 2014). By way of definition, EHD are data that are obtained through electronic submissions or transfer from digitally enabled devices or electronic health records. EHD such as PGHD can be used to inform care targets and continuous improvement in care processes. Continuous improvement in care processes uses EHD such as PGHD to inform ongoing improvements in the quality of care (Edwards, Huang, Metcalfe, & Sainfort, 2008; Kaplan, Lopez, McGinnis, & IOM, 2015).

Based on these, a good number of health care institutions are becoming more invested in EHD - driven continuous improvement in care processes through the use of PGHD. Some health care institutions have also begun to institute ways to learn from the data to drive care and continuous improvement in care processes through a patient centric approach that learns from electronically generated patient sourced health data (Bradley, 2020; Jakicic et al., 2016; Treskes et al., 2020). For

example, a feasibility study used smart phone enabled technology tools to capture blood pressure readings, patients' weight, step counts and electrocardiogram readings to monitor patients who had suffered myocardial infarction (S. M. Bradley, 2020). Also, a health care team at the University of Pittsburgh, evaluated the use of PGHD such as patients' weight and activity level to study technology enhanced weigh loss interventions (Jakicic et al., 2016). These examples show an increased interest by systems of care to use EHD such as PGHD to inform care improvement targets through a patient centric approach.

Furthermore, care approaches are also being created or adapted to incorporate this trend with one of such being the Learning Health System (LHS). The LHS is a technology and electronic data driven approach that has the potential to mitigate the care fragmentation problem and the need for patient centric approach within the US Health System through a commitment to patient focused outcome measures to drive continuous improvement in care processes (Dinh-Le, Chuang, Chokshi, & Mann, 2019; Foley & Vale, 2017).

Federal incentive programs such as the Health Information Technology Economic and Clinical Health (HITECH) act's meaningful use stage three which motivates PGHD use within HCOs such as hospitals has been an incentive for hospitals to participate in electronic data driven and patient - centric measures through the capture and use of PGHD. Other electronic data-driven and patient-focused incentivized programs such as the Patient-Centered Outcomes Research Institute funded (PCORI) hospitals, and medical home/safety net hospitals are also becoming more supportive of health IT use for patient centered care and

continuous quality improvement purposes. These Federal, organizational and program incentives that are targeted towards improved health system processes based on real-time data have made health systems and their component organizations such as hospitals to become increasingly aware of the need to continuously improve care processes for their patient populations through the incorporation of PGHD into care and continuous improvement processes.

These HCOs and hospitals that are interested in continuous improvement in care are also highly invested in data driven approaches to achieve care improvement targets through the use of EHD (Kaplan, Lopez, McGinnis, Care, & Medicine, 2015). They have also been observed to be interested in patient – centric approaches to care to achieve their care and continuous improvement targets (Coughlin, Long, Sheen, & Tolbert, 2012; Dimaguila, Gray, & Merolli, 2020; Infed, n.d.; Kerka, 1995; Reddy, 2012). Furthermore, they have also been observed to be learning focused through the incorporation of EHD into their care and improvement processes (IOM, Saunders, 2011; Runaas et al., 2017). These hospitals have also been posited to be more likely to use patient sourced data such as PGHD (CDC-CSELS, 2019; Coughlin et al., 2012; Fleurence et al., 2014; Wysham et al., 2016). The existence of these common health IT related characteristics among these HCOs and hospitals suggests that they can be grouped together.

Based on the above, I define HCOs and hospitals that are committed to electronic data-driven continuous improvement in care processes, patient centric approaches to care, and that are learning focused through the use of EHD as

Health Information Interested (HII). Some examples of HIIs include LHS, PCORI funded, medical home/safety net, and, meaningful use stage three compliant hospitals (CDC, 2019; CMS, 2013; Fleurence et al., 2014; Charles Friedman, Wong, & Blumenthal, 2010; Witgert & Hess, 2012). For the purposes of this study, I will describe these four types of hospitals as HII hospitals.

Despite the notion however, that HII hospitals that participate in the afore stated initiatives and programs are more likely to become more electronic data driven and patient - centric, it is unclear how much PGHD is used in these settings. It is known however that these electronic data driven, and patient - focused hospital types utilize EHD from EHR systems which is usually mainly provider generated. For the US Health System to become more patient centric as well as solve its care fragmentation challenge, there is the need for increased PGHD use within systems of care that are committed to electronic data driven and patient focused continuous improvement in care processes such as HII hospitals.

Patient Generated Health Data

PGHD is health-related information created by patients or their designees outside of traditional health care settings (M. Shapiro, Johnston, Wald, & Mon, 2012). PGHD has also been described as health-related data recorded by patients to inform their self-care and understanding about their own health (Cohen et al., 2016). PGHD is different from provider generated data within EHRs because it is entirely patient sourced and captured. PGHD may include health history, symptoms, treatment history, biometric data, lifestyle choices, and other health

related information that is created, gathered, recorded, or inferred by or from patients or their designees (i.e., care givers/care partners) outside of clinical settings. Patients are primarily responsible for capturing PGHD, and patients also direct the sharing or distribution of PGHD with health care providers and other parties. PGHD use within health systems complements provider-directed capture and flow of health-related data by providing a medium for patients to share their perspective of their health condition as well as their captured health data outside of clinical settings (M. Shapiro et al., 2012).

The capture and use of PGHD however, are not new phenomena; many patients record and share information on their health and wellness with care providers. However, the widespread availability of technology tools such as mobile phones have made systemic PGHD capture more widespread and it is increasingly being used formally within systems of care (Cohen et al., 2016; M. Shapiro et al., 2012; Vegesna, Tran, Angelaccio, & Arcona, 2017). Formal use of PGHD by care providers is further facilitated by the increased connectivity between patients and their health care providers through mediums such as the internet of medical things (IoMTs) (Dimitrov, 2016). The internet of medical things is a collection of physical devices and applications such as wearable, mobile, and medical devices that support fitness, symptom tracking, health education, collaborative disease management and care coordination through an exchange of data between devices, or between devices and EHR systems in real time (Dimitrov, 2016). The use of these network of devices can reduce unnecessary hospital visits and the

burden on health care systems by connecting patients to their physicians and allowing the transfer of medical data over a secure network.

The use of these data to inform continuous improvement within systems of care is posited to have the potential to result in improved patient experience, improved health outcomes and higher quality of care (Deering et al., 2013; Dimitrov, 2016). Some of the drivers of this trend include, organizational and government incentives that motivate health systems to improve care processes; and an increase in the availability of EHD from EHRs and digital health technologies such as wearable, and mobile devices (Angelique Cortez, Peggy Hsii, Emily Mitchell, Virginia Riehl, 2018; Dinh-Le, Chuang, Chokshi, & Mann, 2019; Vegesna et al., 2017).

LHS Hospitals can use PGHD as a key data source to learn from patients' experiences in order to improve clinical workflows at the point of care. LHS Hospitals can also use PGHD to support clinical decision-making; a focus on continuous care improvement and patient-centric outcomes; and cost reductions based on these practices (Kalra, Adusumalli, & Sinha, 2017). Other electronic data driven, and patient focused Federal and organizational incentives that have significant health IT investments to support these goals include investments and initiatives in HII hospitals such as PCORI funded hospitals, medical home/safety net hospitals, and meaningful use stage three compliant hospitals. These hospitals that have participated in such efforts might be more interested in PGHD use for patient care as well as to drive continuous improvement in care processes. The

next section of the background will describe in further detail some of the characteristics of HII hospitals and their relationship to PGHD capture and use.

The Learning Health System

The LHS is a concept that involves a structural commitment to a bidirectional feedback loop whereby data collection is embedded into care delivery processes, and care is changed in response to evidence generated (Morain & Kass 2017). The LHS offers the promise to improve the evidence base and care delivery while reducing costs (Smith et al., 2013). The LHS seeks to create a health system that continuously improves itself and patient health outcomes by delivering the right care to the right patient at the right time (IOM, Olsen & Saunders, 2011). The LHS can exist at any level of scale: single organizations, organizations in a region, network of organizations, an entire nation, groups of nations, or the entire world (C. P. Friedman et al., 2017; Shaygan & Daim, 2019).

A successful LHS draws from best scientific evidence, while tailoring optimal care to a local healthcare setting and to each individual patient and this can be better achieved through the incorporation of PGHD into LHSs (Abdolkhani, Gray, Borda, & DeSouza, 2019; AHRQ, 2019; Mullins, Wingate, Edwards, Tofade, & Wutoh, 2018). Hence, learning from every patient within an LHS involves the use of digital health information such as PGHD as a major source of EHD and this is key to achieving LHS goals of continuous improvement in care processes, patient's experience and health outcomes. PGHD has the capacity to incorporate

the voices of patient populations into clinical decision making, and improvement of care and population health processes (Cohen et al., 2016; Menear, Blanchette, Demers-Payette, & Roy, 2019). Hence, PGHD can make LHSs evolve faster toward becoming patient driven. The “vision for a US healthcare system that draws on the best evidence to provide appropriate care to each patient, emphasizes disease prevention and health promotion, and incorporates learning throughout care delivery processes can be better achieved with PGHD incorporation into LHSs (Budrionis & Bellika, 2016; IOM, 2003).” PGHD capture within systems of care that are practicing LHS principles however still appears to be low.

Patient Centered Outcomes Research Institute

PCORI’s goal is to fund research that provides care related information that patients, caregivers, health professionals, and others need to make choices aligned with patients' desired health outcomes (Barksdale, Newhouse, & Miller, 2014; Washington & Lipstein, 2011). PCORI funded research considers patients' different life circumstances, inherent characteristics, behaviors, and other factors affecting health status. It applies rigorous methodologic standards to help ensure that the information produced is valid and can be generalized to address the preferences, decision-making needs, and characteristics of a broad range of patients (Barksdale et al., 2014). PCORI’s comparative effectiveness research aims to help answer the following questions that a patient is likely to pose: 1) “Given my personal characteristics, conditions, and preferences, what should I

expect will happen to me?" 2) "What are my potential options, and what are the benefits and harms of those options?" 3) "What can I do to improve the outcomes that are most important to me?" 4) "How can the health care system improve my chances of achieving the outcomes I prefer?"(Barksdale et al., 2014, pg 194). PCORI is also invested in health IT driven comparative effectiveness research to improve patient outcomes (Rief et al., 2017; Runaas et al., 2017).

Given PCORI's interest in patient related outcomes based on information systems and technology, it funded the development of Patient-Reported Outcomes Measurement Information System (PROMIS) that contribute complementary data to clinician-derived metrics traditionally used to inform health care decision-making (Bingham et al., 2016). Formal and standardized measures have been developed for the use of PROMs in the evaluation of patient outcomes outside of health care settings. These measures are used in the evaluation of patients' health status pre or post intervention as it relates to a health condition. PROMs are operationalized through standardized, validated questionnaires that are completed by patients to measure their perception of their functional well-being and health status (Department of Health, 2009). PROMs are different form PGHD in that they are designed to capture specific health outcome measures, while PGHD enables patients to capture the health effects they experience using their digital devices or other platforms without being limited to the specifics of a questionnaire. PCORI's interest in PROMs is indicative of its commitment to patient centered research that is data driven, it is however unclear how invested PCORI funded hospitals are in PGHD use to inform their care processes and comparative effectiveness research

(Barksdale et al., 2014; Rief et al., 2017). PGHD offers the opportunity to capture information about patients' health status outside of the clinical environment, and beyond the standardized PROMs metrics. The use of PGHD to complement PROMs within PCORI funded hospitals can provide a medium for patients to capture the health effects they experience (Dimaguila, Gray, & Merolli, 2019; Dimaguila et al., 2020). The use of PGHD in addition to PROMs can also enable the easy incorporation of patients' health effects into clinical workflows (Dimaguila et al., 2019, 2020). Hence PGHD use within PCORI funded institutions proffers the opportunity for a more robust understanding of patients' needs and preferences, thereby providing a more comprehensive avenue for delivering patient centered care with precision.

Furthermore, given PCORI's interest in the LHS concept of care delivery for patient centered care and comparative effectiveness research PGHD use is key within PCORI funded LHSs in order to fulfil the LHS goal of learning from every patient to inform care delivery and continuous improvement in care processes (Hull, 2015; UPMC, 2019). To this end in 2013, PCORI launched PCORnet, a major initiative to support an effective, sustainable national research infrastructure that will advance the use of EHD in CER and other types of research (Fleurence et al., 2014). PCORnet was designed to include institutions that are involved with the Patient-Centered Network of Learning Health Systems (LHSNet) as collaborative partners (Fleurence et al., 2014; UM, 2015). These PCORI initiatives are indicative of its interest in the LHS model as well as in learning from EHD that is obtained from EHRs and other EHD sources (Fleurence et al., 2014; UM, 2015).

Despite these commitments to learn from patient derived and patient focused EHD, it is not clear how much of the EHD that is used in PCORI funded hospitals is PGHD. A limited use of PGHD in these settings could be indicative of the need for a more inclusive approach that takes into account all important data sources.

Medical Home/Safety Net Hospitals

The medical home model is a patient - centric model of care that ensures patient engagement, care coordination, and improved quality of care through the use of health IT tools (C. J. Sia et al., 2002; Stange et al., 2010). This model was introduced into safety net hospitals to institute medical home/safety net hospitals between 2011 and 2014 (NAPHHS, 2010; Rappleye, 2017). This was to enable safety net hospitals to improve care and costs through a patient centered approach that embraces health IT use (NAPHHS, 2010; Rappleye, 2017). Safety net hospitals are hospitals that cater to the under insured and underserved population in the US. The medical-home-based safety-net hospital is a health reform effort that was part of an endeavor to address care fragmentation within the health care system by increasing integration, coordination, and access to care (NAPHHS, 2010). The medical home model and the related notion of integrated delivery systems at the time gained traction as part of strategies to address care fragmentation, thus improving care. It was described as “a coordinated continuum of services [that] is held clinically and fiscally accountable for the health status of

the population served," with the medical home as a component of such a continuum (NAPHHS, 2010, pg 1).

Safety net hospitals continue to play a critical role in the US health care system, providing care for over twenty-three million people who remained uninsured post Affordable Care Act (ACA) (Coughlin et al., 2012). Safety-net hospitals have had to reposition themselves in the marketplace to compete effectively for newly insured people who then had a choice of providers post ACA implementation. The medical home model which leveraged on health IT to enable patient engagement and improved health outcomes was incorporated into safety net hospitals to help address some of these concerns (Coughlin et al., 2012; NAPHHS, 2010). The transformation of safety nets into medical-home based safety nets with the incorporation of health IT capabilities has been associated with improved health system performance (Coughlin et al., 2012).

Despite the recorded advancements in the use of Health IT tools such as EHD from EHR systems by medical home/safety net hospitals, it remains unclear the extent to which these hospitals utilize individualized patient data in the form of PGHD to make improvements in care and hospital continuous quality improvement processes.

Meaningful Use Stage Three Compliant Hospitals

In 2009, the American Recovery and Reinvestment Act of 2009 (ARRA or Recovery Act) was signed into law. This statute includes the HITECH Act that

among other things, sets forth a plan for advancing the meaningful use of health IT to improve the quality and efficiency of care (US-DHHS & ONC, 2015). This move was due to the perception that Health IT has the potential to improve cross-system communication, and promote coordinated care in an efficient and sustainable manner, and has been widely recognized as a necessary foundation for improving the quality and outcomes of clinical care (IOM, 2003). Based on this, the Federal meaningful use program allocated more than $32 billion to support the implementation and optimizing of EHR systems (Power et al., 2016). Over time, the program increased its requirements by requiring that EHRs are linked with external sources of clinical information such as PGHD in order to achieve care and health outcome targets. Specifically starting in 2015, the stage three meaningful use requirement mandates health systems and their component organizations such as hospitals to provide avenues for PGHD submission with penalties for noncompliance beginning in 2018 (Gottlieb D & Weinstein S, 2015; Power et al., 2016). The new rule mandates that PGHD or data from a non-clinical setting is incorporated into the Certified EHR Technology for at least five percent of unique patients discharged from an eligible or Critical Access Hospital (CAH) inpatient or emergency department during the EHR reporting period (CMS, 2015). This requirement is meant to facilitate patient engagement in the meaningful use program in order for hospitals to remain eligible for CMS reimbursements. Although, hospitals must meet this requirement in order to continue to be eligible for benefits and reimbursements, It is not clear how well this requirement has facilitated or improved PGHD capture and use by eligible hospitals.

Problem Statement

The need for more inclusive EHD sources, such as patient - driven EHD sources, to drive continuous improvement in care processes is well documented. According to Cortez et al (2018), the wide availability of consumer technologies empowers patients to better capture and share their PGHD and to better manage their health and participate in their own care. While EHRs typically contain provider generated data such as patients' treatment and medical histories, EHRs can be built to go beyond clinical sourced data that is traditionally collected in a clinician's office to be inclusive of a broader view of patients' care. PGHD use by clinicians and researchers provide a more holistic view of a patient's health and quality of life over time, increase visibility into a patient's adherence to a treatment plan or study protocol, and enable timely intervention before a costly care episode. Clinicians can strengthen their relationships with their patients, and improve their experience by using PGHD to develop personalized care plans while also engaging in shared decision-making with the aim to foster improved outcomes (Angelique Cortez, Peggy Hsii, Emily Mitchell, Virginia Riehl, 2018).

According to Wood et al (2015) "Leveraging the power of multiple continuous, personalized data streams allows the research and clinical community to derive valuable and maximal insights from each patient which optimizes efficiency, generate clinical insights into behavior and treatment responses" (Wood, Bennett, & Basch, 2015). Continuous improvement in care process programs should include a focus on patients and on the data (HRSA, 2011).

Hence, important measures of quality are the extent to which patients' needs and expectations are met, and that health related services are designed to address the gaps in service delivery that is experienced by patients and their communities (HRSA, 2011).

Based on this, there is the need to be aware of and understand how current health systems provisions affect patient needs and access. There is also the need to establish health care services that are evidence-based and take into consideration the need for patient safety and the support of consistent patient engagement practices. These services also need to be flexible enough to respond to the changing needs of diverse individuals and diverse patient populations that utilize systems of care such that care delivery can occur with attention to each patient's needs. Furthermore, there is the need for care coordination with other parts of the larger health care system such that patient care is integrated and patient information is easily transmitted and accessed when needed across the health system (HRSA, 2011).

Each of these considerations is important when planning a patient focused continuous improvement in care program within hospitals, and necessitates the collection of patient-focused, driven, sourced, and generated data. PGHD capture and use is key to the achievement of continuous improvement in care processes by health systems, and it helps them to understand how well current systems are working. It also shows what happens when changes are applied, as well as facilitates the documentation of successful performance (HRSA, 2011). When patient sourced data such as PGHD is used together with provider generated

patient questionnaires such as PROMs, and other provider generated data within EHRs, systems of care are able to separate what is thought to be happening from what is really happening; establish a baseline for quality or care improvement targets; and reduce the implementation of ineffective solutions (HRSA, 2011).

HII hospitals have been observed to have a commitment to continuous improvement in care processes through the use of EHD for care improvement targets and comparative effectiveness research. It is however, unclear the extent to which PGHD is used in these endeavors. The failure to adequately incorporate PGHD into care improvement targets and comparative effectiveness research results in a health system that is out of tune with the needs of its patient population. This further leads to a lack of patient centric care and perpetuates the care fragmentation problem within US health systems. Fragmented care occurs when different health providers do not work together in addressing a patients' care needs. This often occurs due to a lack of communication between providers as it relates to patients' health needs. The challenge is further perpetrated due to a lack of holistic perspective of patients' needs outside of the traditional clinical setting. This results in partial perspectives of patients' health condition by each of the health providers that are involved in the patient's care. This leads to each provider involved with the patient having a partial perspective of the patient's condition. This further perpetuates care fragmentation when the needs of patient populations are not identified by systems of care and patients seek referral for connected health problems that could be addressed by a single physician. This further makes systems of care to be unable to meet the needs of their patient populations with

precision. Unmet patients' needs due to care fragmentation often leads to the need for patients to demand more health care services for health problems that could have been earlier addressed in a timely manner which further increases patient burden and the cost of care (Berwick, Nolan, & Whittington, 2008; M. Smith et al., 2013b). The capture and use of patient driven data such as PGHD can bridge this gap by enabling physicians to be able to better assess and address patients' needs that might not be mentioned during clinical consultations and this makes it easier for patients' needs to be addressed holistically across the spectrum of care. A comprehensive overview of patients' needs through the incorporation of the patient's voice in the form of PGHD into care improvement targets and comparative effectiveness research will help to address some of the challenges with the lack of patient centric care and care fragmentation within the US Health System.

The incorporation of PGHD from evolving technologies such as mobile and wearable digital health platforms into existing health system data systems will help to seamlessly incorporate patient sourced data into health system processes and workflows. Access to patient sourced data within systems of care increases the possibility for more patient centric care and less care fragmentation. Prior efforts to achieve PGHD incorporation into health systems' processes have been met with challenges related to the quality, usability and transferability of captured PGHD (Abdolkhani, Gray, Borda, & De Souza, 2018; Abdolkhani, Gray, Borda, & DeSouza, 2020). This is generally due to a lack of data standards and a lack of interoperable data systems across US health systems (Reisman, 2017).

The meaningful use stage three rule which is also known as the promoting interoperability rule stage three was designed to promote interoperable systems across the US (CMS, 2015). This rule also mandates the reporting of PGHD capture and use by HCOs as a requirement to qualify for CMS incentives (CMS, 2015). Three key activities were identified by the CMS as crucial to promoting healthcare interoperability and these include 1) provider to provider electronic exchange of patients' health information 2) provider to patient electronic health information exchange, and 3) provider to public health agency electronic exchange of health information. As part of the stage three meaningful use objective for patient access, CMS also included the use of application programming interfaces (APIs) as a means of enabling patients to view, download, or transmit their health information by "using any application of their choice that is configured to meet the technical specifications of the API in the provider's certified EHR technology" (CMS, 2015). "APIs enabled by a provider will empower the patient to receive information from their provider in the manner that is most valuable to the patient" e.g. receiving health information on a patients' preferred mobile device (CMS, 2015). Hence, the enablement of interoperable systems and the use of safe and Federally Certified APIs now motivate and provide avenues for PGHD use within systems of care such as hospitals that are eligible for Medicaid reimbursement (CMS, 2015; Wu, 2014). Despite this motivation, it is still unclear if PGHD capture and use has improved in Medicaid eligible hospitals that cater to underserved populations and un-insured patients (HRSA, 2018).

PGHD capture and use is important to enable a systemic approach to solving health system challenges. Also, PGHD capture and use is an important goal for hospitals that are electronic data driven and are committed to patient focused continuous improvement in care processes. Hence, it is important to understand the type of hospitals that are committed to these goals through the capture and use of PGHD. Currently, it is known that LHSs utilize data from routine clinical care by transforming it into knowledge which serves as guidance for physicians at the point of care (Smith et al., 2014). LHSs engage in comparative effectiveness research with the use of large linked administrative databases to answer comparative questions (Miriovsky, Shulman, & Abernethy, 2012). PCORI funded hospitals, medical home/safety net hospitals, and meaningful use stage three compliant hospitals are identified HII hospitals that have been observed to be interested in electronic data driven and patient focused care improvement targets, it is however unknown which of these HII hospitals utilize PGHD in these endeavors (Coughlin et al., 2012; Pourat et al., 2012).

Theoretical Framework

Senge (1990) in his book “the Fifth Discipline” detailed his account of the concept of the Learning Organization (LO). According to Senge, LOs can quickly adapt to changes and can secure more competitive advantages (Senge, 1990a). LOs have also been described as organizations that are skilled at creating, acquiring, and transferring knowledge, and modifying their behavior to reflect new

knowledge and insights, which are essentially the core objectives of a LHS (Garvin, 1993). The LHS which was designed specifically to address health systems' needs for continuous improvement in care processes is derived from the systemic approach that was described in Senge's LO model (Davis, Williams, & Stametz, 2020). Thus, the LHS presents a framework that addresses some of the needs of HCOs that seek to become LOs and can be used to assist HCOs to become LOs through technology and data-driven learning infrastructure.

LHSs or other HII HCOs, such as PCORI funded, medical home/safety net, and meaningful-use stage three compliant hospitals that are focused on learning from data to make continuous improvement in care processes, can be said to be conceptually aligned with the principles of a LO. The concept of the LO focuses on learning as a philosophy for sustainable change, innovation or renovation in the dynamic business environment typical of organizations. Senge (1990) highlighted five disciplines that are necessary to bring about a LO, and these include personal mastery, mental models, shared vision, team learning, and systems thinking which is the end point of all other four LO disciplines. The need for systemic approaches to learning within LHSs, and other HII hospitals such as PCORI funded, medical home/safety net, and meaningful use stage three compliant hospitals through the incorporation of EHD such as PGHD into health system processes can be based on Senge's theory of the LO, and the LHS framework.

PCORI funded hospitals, medical home/safety net, and meaningful use stage three compliant hospitals are HII hospitals that in addition to LHS hospitals can be described as LOs. This is because they have been observed to design

health IT and EHD driven platforms and technology infrastructure that enable them to easily adapt to changes and secure more competitive advantages thereby practicing some of the elements of Senge's LO theory. Furthermore, due to the interest of these hospital types in patient focused care, that is evidence based, through the use of health IT tools, and digitally enabled devices, they are more likely to be more open to learning from patient sourced data such as PGHD for their care improvement targets. This increases their potential for attaining a systemic approach to care which is one of the main goals of Senge's LO theory. These hospital types can be described as either directly taking their roots from Senge's LO theory (e.g., LHSs), or as reflecting the principles of Senge's LO theory in their daily operations targeted towards achieving their goal of continuous improvement in care processes, patient focused care and systemic approach to care.

Research Questions and Study Aims

This study is focused on evaluating PGHD capture and use within hospitals that practice LHS principles or identify as LHS Hospitals. This study will also identify HII hospital characteristics that are likely to capture or use PGHD with or without being a LHS, in other patient focused and electronic data driven hospitals such as PCORI funded, medical home/safety net, and meaningful use stage three compliant hospitals. Based on this, this study will identify the HII characteristics of hospitals that are committed to being LHS Hospitals or electronic data driven, and

patient focused. This study will also evaluate how these HII characteristics relate to PGHD capture and use. Based on the need for PGHD capture and use among HII hospitals that have a commitment to continuous improvement in care processes and which take an electronic data driven and patient-focused approach to care, this study asks the following research questions:

1) What is the distribution of US hospitals that have HII characteristics related to being learning focused, patient-centric, and electronic data-driven?

2) How do these identified HII hospital characteristics relate to the capture and use of PGHD?

These research questions will be evaluated based on the following aims:

Aim One:

To examine US hospitals in order to create a typology of LHS and other HII electronic data-driven and patient-focused hospitals such as PCORI funded, medical home/safety nets, and meaningful use stage three compliant hospitals. Distinct HII hospital characteristics will be elicited based on the data. These distinct HII hospital characteristics are important because of the need to create a typology of hospital characteristics as it relates to LHS practice, being electronic data driven, and patient centric which will be used to evaluate PGHD capture and use in aims

II and III. In order to achieve this, the degree of LHS practice per hospital or hospital group will be evaluated based on the data and this will be used to show the degree to which hospitals are practicing LHS principles. A descriptive analysis of other electronic data-driven and patient-focused HII hospitals such as PCORI funded, medical home/safety nets, and meaningful use stage three compliant hospitals will also be conducted to show their distribution within the data. Distinct HII hospital characteristics will then be identified which will be evaluated in aims II and III (Figure 1.1).

Aim Two:

To ascertain what HII hospital characteristics are associated with the capture and use of PGHD. It is important to this study to ascertain what HII hospital characteristics (identified in aim one), are associated with PGHD capture and use. Hence, based on the distinct HII hospital types that will be identified in aim one, aim two of this study will evaluate the hospital characteristics that are associated with PGHD capture and use (Figure 1.1).

Aim Three:

To examine the relationship between change in HII hospital characteristics and change in PGHD capture and use. In order to be able to ascertain a basic potential causal effect of HII hospital characteristic on PGHD capture and use, I will evaluate if a change in any of the identified distinct HII hospital characteristic will result in a change in PGHD capture or use within the data (Figure 1.1).

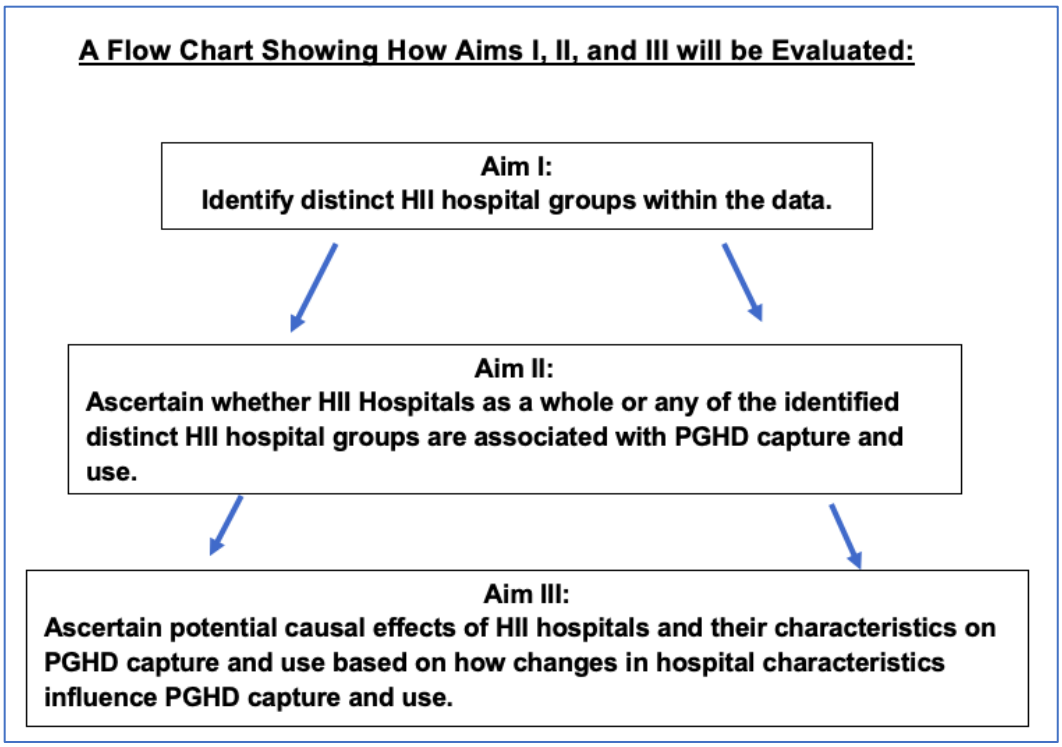

Figure 1.1 Showing the Relationship Between Aims One, Two and Three

Methods

In this study, I will conduct a secondary data analysis of preexisting health IT survey data of US hospitals to characterize HII hospitals and elicit their relationship with PGHD capture and use (Figure 1.2). Aim one will involve an assessment of multiple years of data in order to elicit the distribution of HII hospital characteristics across the data using a distribution table. In each year of data, I will characterize the distribution of HII hospital characteristics. This will enable me to assess the general distribution of HII hospital characteristics, and thereby identify

distinct HII hospital characteristics that pertain to being LHS, electronic data - driven, and patient - centric.

Aim two will involve the use of linear regression models to understand how the identified HII hospital characteristics relate to PGHD capture and use in a cross-sectional analysis using the latest year of hospital data, while aim three will examine whether or not changes in hospital characteristics over the total three years of study data result in changes in hospitals' capture or use of PGHD using a difference-in-difference analysis.

Conceptual Framework

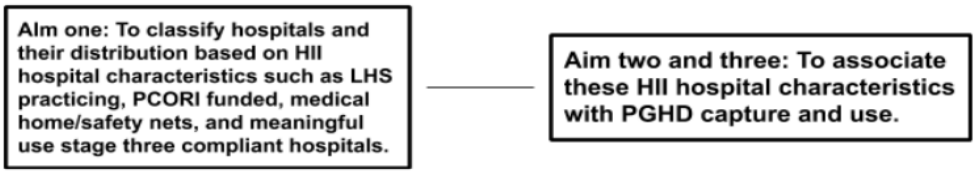

Figure 1.2: Showing the Study's Conceptual Framework

Data Sources

The American Hospital Association's (AHA) 2013, 2016, and 2018 health IT supplement data sets will be the main data source in this study (AHA-ONC, 2013, 2016; AHA, 2018). These data sets are made up of the responses of at least 50% of the 3283 to 3500 US hospitals that were invited to participate in the 2013, 2016, and 2018 AHA health IT surveys. The characterization of hospitals that practice LHS principles will be based on the 2013, 2016, and 2018 AHA data sets.

Meaningful use stage three compliance will also be based on the 2018 AHA data set (AHA-ONC, 2018). This is due to the final rule which established the requirements for stage three of the meaningful use program as optional in 2017 however, mandated it for all eligible hospitals beginning in 2018 (CMS, 2015). The evaluation of PGHD capture and use across identified hospital characteristics will also be based on the AHA data sets.

The CMS innovation award funding list and the PCORI funded projects web list which are supplemental data sets in this study will be used to identify medical home/safety net and PCORI funded hospitals respectively (CMS, 2013; PCORI, 2020). The PCORI funded projects web list contains the 1,698 PCORI funded projects from year 2012 to 2020 and shows the project start dates, end dates, and duration of funding (PCORI, 2020). The list of the 107 medical home/safety net providers that received the CMS innovation award between 2011 and 2014 which is publicly available online via the CMS web page will be used to identify the safety net hospitals that became medical home/safety net hospitals in that period of time (CMS, 2013; Finkelstein, Taubman, Allen, Wright, & Baicker, 2016).

Data Analysis

To assess aim one, I will create a HII hospital typology that relates to whether hospitals are LHSs, PCORI funded, medical home/safety net, or stage three meaningful use compliant hospitals. The practice of LHS principles will be evaluated using the AHA data sets and will be based on hospitals' 1) capacity to collect EHD; 2) commitment to evidence/data driven decision support 3) the use

of EHD for quality improvement measures and population health improvement and, 4) the use of safe and certified EHR platforms. The typology will also show the level to which each hospital that captures or uses PGHD is committed to the practice of LHS principles based on the AHA data (Table 1.1).

Table 1.1

LHS Principles and Corresponding AHA Measures (Friedman et al., 2017; Mullins et al., 2018)

LHS Principles	**AHA Measures**
Capacity to collect EHD	Capacity for Electronic Clinical documentation
Evidence and data-driven decision support	Capacity for decision support
Quality improvement Population Health improvement	Use of EHD for quality improvement measures. Capacity for reporting to public health agencies
Use of safe and certified platforms such as certified EHR platforms and validated information exchange platforms.	Use of EHRs that are certified based on Federal standards

Meaningful use stage three compliance will be evaluated based on the AHA data and will be based on CMS requirements for 2018 and these include 1) provider to provider exchange of electronic patient information, 2) provider to patient exchange of electronic information, and 3) provider to public health agency reporting (Table 1.2).

Table 1.2

Meaningful Use Stage Three Compliance will be Based on the 2013, 2016, & 2018 AHA Data (AHA-ONC, 2018; CDC-CSELS, 2019)

Meaningful use stage three compliance measures in this study	**AHA Measure (AHA- 2013, 2016, 2018)**
Public health and clinical data reporting	Has not experienced any challenges with public reporting.
Provider to patient exchange - provides patients access to their health information	Patients are able to access their medical information using applications configured to meet the application programing interfaces in their EHR.
Health information exchange - supports electronic referral loops by sending and receiving health information)	Supports Health Information Exchange (Sending and Receiving Health Information): Uses Interface connection between EHR systems (e.g. HL7 interface) to send or receive patient information or has direct access to EHRs through remote or virtual access.

Participation in PCORI and medical home/safety net hospital initiatives will be evaluated based on the list of hospitals that participated in those programs in the selected years. I will then examine the interrelationships of LHS hospitals and the earlier specified HII hospitals (PCORI funded, meaningful use stage three compliant and medical home/safety net hospitals) using tests of correlation.

For aim two, using the latest year of data (AHA's 2018 health IT supplement), I will use linear regression models to first examine PGHD capture and use among HII Hospitals in comparison to non-HII hospitals. I will then

examine the relationship among distinctly identified HII hospital characteristics and PGHD capture and/or use when other factors such as location, and teaching status are controlled for (Table 1.3). This is because urban located hospitals, or hospitals that have teaching status may be differentially enabled to capture or use PGHD when compared to other hospitals, Hence, these controls will help to prevent these confounders from contributing to the PGHD capture and use level of hospitals in the analysis. This will help to ascertain that it is the HII hospital characteristic being evaluated that is responsible for the level of PGHD capture and use per hospital.

Table 1.3

Constructs and Measures of PGHD Capture and Use

Construct	**AHA Measure**
PGHD capture	Patients can submit patient-generated data (e.g., blood glucose, weight)
PGHD use (e.g., to update or amend patient's record)	Offers support for patients to request an amendment to change/update their health/medical record

For aim three, I will use a generalized difference-in-difference model with fixed hospital and time effects to ascertain if there are changes in the capture and/or use of PGHD across the three periods based on changes in HII hospital characteristics in comparison to non HII hospitals or consistent HII hospitals. To achieve this, I will first evaluate if joining any of the specified programs (LHS, meaningful use stage three compliant, PCORI funded, and medical home/safety net subcategories) from a non HII status leads to a greater likelihood of PGHD

capture and/or use. I will then evaluate if changing to a specific subtype of HII hospitals results in more PGHD capture and/or use.

Purpose and Significance

The use of patient focused and sourced data such as PGHD is important in order to assure the system of care's orientation toward the needs and perspectives of the patient. Currently it is known that LHSs, and other specific HII hospitals such as PCORI funded, medical home/safety net, and meaningful use stage three compliant hospitals utilize provider generated EHD for comparative effectiveness research, and in their evaluation of patient and health system needs. Based on this, the use of PGHD in such endeavors is unclear. The use of provider generated data as the main source of health information when identifying patient and health system needs suggests a diminished value for adequate representation of patients' voices in highlighting patient population and health systems' needs. In order to have a system of care that operates holistically with little or no fragmentation in processes, needs, and care, - there is the need to capture patients' perspectives as well as their holistic health status outside of health care settings through the incorporation of PGHD into health system processes. Until this is achieved, health systems and their component organizations such as hospitals will continue to operate and deliver care in a fragmented manner with the potential for misalignment in health system goals and the needs of patient populations (Fowe, 2020b; Hämäläinen, Perälä, Poussa, & Pelkonen, 2003). These highlighted need

for PGHD capture and use and PGHD's integration into health system processes can have implications for policy and practice, which will be discussed in the next section.

Implications for Practice

This exploratory study will evaluate whether or not HII Hospitals are associated with PGHD capture or use. The study will then identify specific HII hospital characteristics that are associated with PGHD capture and use. Identification of HII hospital characteristics is important given the highlighted need for US hospitals to become more patient focused through the use of EHD that is now more readily available through digitally enabled technologies that patients can easily access. This study will also suggest HII hospital characteristics that might be replicated by hospitals that seek to be more patient focused through the use of PGHD.

HII hospital characteristics that enable patient input in the form of PGHD to be used to inform care targets and continuous improvement in care provide an avenue to learn from the data. This occurs by discovering associations, and understanding patterns and trends within the data, which has the potential to improve care, save lives and lower costs (Raghupathi & Raghupathi, 2014). An understanding of HII hospital characteristics that are most amenable to PGHD capture and use brings hospitals closer to being able to achieve their goal of improved care, that is delivered with precision, at a potentially lower cost and with

less care fragmentation. An understanding of such HII hospital characteristics also helps to better understand what works in order to enable PGHD capture and use and can be emulated and replicated across similar HII hospitals within the US Health System.

Implications for Policy

An understanding of HII hospital characteristics that are most amenable to PGHD capture and use will enable policy makers to enact policies that are informed by this research. Also, an understanding of the effects of HII policy driven hospital characteristics evaluated in this study will enable hospital and health system leaders to understand the enabling and limiting effects of national scale health IT policies. Findings from this study will also facilitate health system leaders' and policy experts' understanding of the effects of PGHD and health IT related organizational policies on PGHD capture and use.

An understanding of the differential effects of these policies on different HII hospital sub-categories based on health IT policy adoption will also help to provide some information on HII hospital characteristics and policy types that can be replicated by hospitals that seek to become more patient focused through the use of EHD. Furthermore, policymakers are better able to understand the disparities in PGHD capture or use that may occur due to differences in HII hospital characteristics. Based on this, policy makers can make adjustment to how resources are allocated for PGHD capture and use in US HII hospitals. For

example, medical home/safety net hospitals may need more support to attain their goals as it relates to the capacity for PGHD capture and use when compared to PCORI grant funded hospitals.

Chapter Two - Literature Review

Introduction

This chapter of the dissertation reviews the literature on the origin, uses, impacts, and challenges of Patient Generated Health Data (PGHD) as it relates to electronic data driven, patient centric, Learning Organizations (LOs). In the U.S. health system, these organizations include hospitals such as those that practice Learning Health System (LHS) principles, receive funding through PCORI, are recognized as medical home/safety net facilities, or have demonstrated compliance with stage three meaningful use criteria. First, I will discuss the concept of PGHD and its uses, impacts and challenges within systems of care. I will then discuss Senge's LO framework which will be used to describe how these organizations operate as LOs, followed by discussion of how the LHS' origin, framework and specific characteristics make that framework suitable for analyzing the use of PGHD within HCOs that are technology and electronic data driven, as well as patient centric. I will also discuss how the LHS conceptual framework has been operationalized in hospitals that practice LHS principles. Finally, I will discuss the origin and use of health information technology (health IT) tools, electronic data driven orientation and patient centric characteristics, as well as the learning orientation within PCORI funded hospitals, medical home/safety net hospitals, and meaningful use stage three compliant hospitals. Finally, I will define the concept of

Health Information Interested (HII) Hospitals and how it can serve as an umbrella term that describes electronic health data driven (EHD), patient - centric and learning focused hospitals and HCOs that are the focus of this review. This chapter will end with the gaps observed within the literature, and the need to comparatively evaluate PGHD capture and use among these types of hospitals.

Patient Generated Health Data

In 2010, PGHD began to generate increased attention among researchers, clinicians and policy makers at the national, state, and regional level as a necessary addition to provider generated information in order to improve care processes and the quality of care for the US populace (Doornik & William, 2013; Shapiro, Mostashari, Hripcsak, Soulakis, & Kuperman, 2011; Shapiro, Johnston, Wald, & Mon, 2012). PGHD was described as necessary for the improvement of patient engagement strategies and the precision of approaches to care, and a necessary addition for addressing the fragmentation of care challenges in the US Health System (Demiris, Iribarren, Sward, Lee, & Yang, 2019; Doornik & William, 2013; Morain & Kass, 2017).

During this period of time, the use of PGHD within systems of care was further enabled and accelerated due to the increased availability of wearable and mobile technologies. These advances increased the possibility of accessing patient data unobtrusively, thereby reducing barriers related to patients' burden in

the reporting of their health effects and health status. Platforms that support PGHD capture allow individuals to collect their personal health data or information based on what is meaningful to them for managing their health, and enables them to choose whether, and with whom, they would like to share the data (Petersen, 2016).

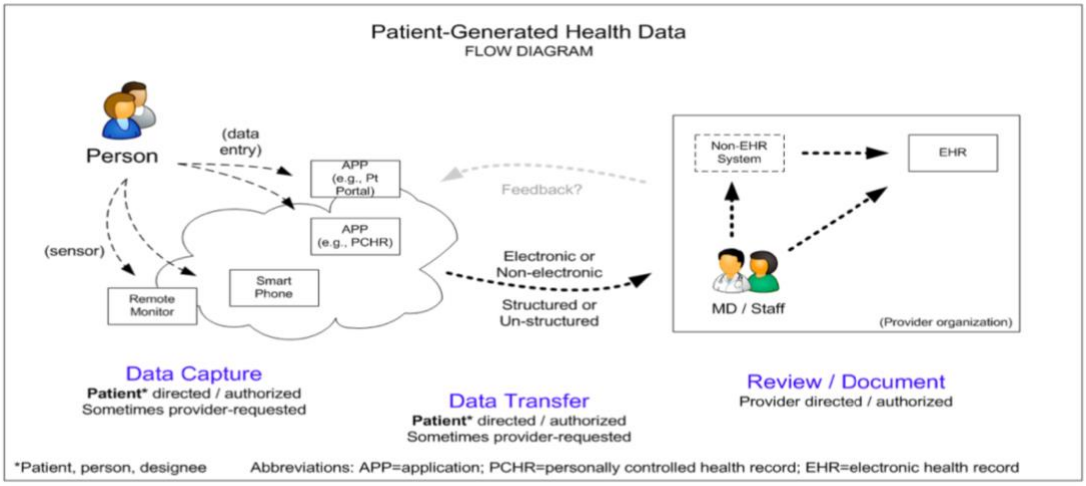

Figure 2.1: PGHD Flow (Image from: (Shapiro et al., 2012))

PGHD capture (Figure 2.1) refers to the creation and storing of health data by a patient and their care givers or designees and may include data written by hand or entered using an input device such as a computer keyboard, microphone or voice recording device. PGHD also includes physiological and/or environmental data recorded through monitoring devices such as sensors in mobile phones and wearable technologies (Shapiro et al., 2012). PGHD capture occurs when patients spontaneously record and deliver their PGHD to a provider, or when providers request that patients capture their PGHD, and patients accept to do so. PGHD

capture can be patient directed or authorized, and sometimes can be provider requested (Figure 2.1). PGHD that is captured by the patient is transmitted manually or via application programming interphases (APIs), or through mediums powered by connected devices (IoMTs) to the health provider who then reviews the information and makes recommendations or gives feedback based on it (Figure 2.1). PGHD capture is facilitated by the increased connectivity between patients and their health care providers through mediums such as IoMTs and APIs. (Dimitrov, 2016; Dinh-Le et al., 2019). Telehealth and mHealth platforms, as well as patient portals are common interphases through which PGHD is remotely collected (Vegesna et al., 2017). IoMT enables the collection of PGHD from telehealth and mHealth platforms such as applications on mobile and wearable devices, while APIs are mediums that enable the transfer of PGHD between patients and providers.

Uses of Patient Generated Health Data

Within systems of care, PGHD has been used to monitor specific health conditions, improve patient engagement in care, and improve clinical decision making (E. Austin et al., 2019; Nundy, Lu, Hogan, Mishra, & Peek, 2014). Its use in monitoring patients include the monitoring of patients with chronic conditions that affect the cardiovascular, respiratory, neurological and neurovascular systems such as heart disease, chronic obstructive pulmonary disease, Alzheimer/dementia, and diabetes (E. Austin et al., 2019; Castle-Clarke S, 2016;

Gollamudi, Topol, & Wineinger, 2016; Liaqat et al., 2016; Nundy et al., 2014). It has also been used to encourage behavior change (e.g. to increase physical activity, or to improve diet) (Nittas, Lun, Ehrler, Puhan, & Mütsch, 2019). PGHD has also been described as having the potential to be used in predicting health care utilization, predicting health status changes, and in the augmentation of remote patient monitoring (Fowe, 2020c; Wood, Bennett, & Basch, 2015).

PGHD can also be used to address specific clinical aims, some of which include assessing patient's sleep quality, or other physiological status (Petersen, 2016). PGHD can enable a holistic appraisal of the patient's health status by providing observations about aspects of the patient's health that occur outside of clinical settings. It can also help patients to identify medical needs that they can bring up during clinical encounters, thereby expanding the scope of the patient-physician interaction (Petersen, 2016). PGHD also allows the assessment of health issues that are of interest to patients, but which occur outside of the clinical environment, such as weight loss efforts, the use of stress management techniques, or adoption of dietary changes. As interest in patient engagement grows, providers in the US and beyond are increasingly recognizing the value that patient sourced data brings to clinical encounters (Fowe, 2020a; Huba & Zhang, 2012).

With advancements in digital technologies, PGHD in the form of digital phenotypes and biomarkers are beginning to be used for early disease detection and diagnosis, and to understand disease progression and the effects of treatment

or therapeutic interventions (Jain, Powers, Hawkins, & Brownstein, 2015). The use of PGHD such as digital phenotypes and biomarkers is gaining ground in understanding neuropsychological and neurocognitive challenges, as well as in understanding treatment and medication adherence. Digital biomarker and phenotyping technology incorporates and uses PGHD "from mobile sensors, keyboard interactions, voice, speech, and other streams obtained during everyday use of social media, wearable technologies, implantable or digestible devices, portable devices and mobile devices" to measure disease and therapeutic response (DBJ, n.d.; Jain et al., 2015; Koo & Vizer, 2019). PGHD collected from these devices can be used to explain, influence, or predict health-related outcomes.

PGHD has been posited to be useful in enabling the remote monitoring of an aging US population through various telehealth and mHealth platforms. Given the disproportionate burden of chronic diseases in this age group, and the disproportionate burden of care placed on family members and care givers due to the presence of multiple chronic diseases in the elderly population, the use of PGHD to augment care for this patient population is posited to improve access to care, improve the quality of care received, and reduce unnecessary health care utilization (e.g. office visits or hospital admissions), thereby decreasing health care costs and improving access and the overall quality of care (Bujnowska-Fedak & Grata-Borkowska, 2015; Fowe, 2020c; Ownby et al., 2017). PGHD use through telehealth and mHealth remote monitoring platforms is also posited to reduce care-

giver burden, and enable a higher potential for aging in place in this population (Matthew-Maich et al., 2016; Nikus, Lähteenmäki, Lehto, & Eskola, 2009).

PGHD is also posited to be important in health systems that are interested in using Electronic Health Data (EHD) to inform continuous improvement processes, improving the patient experience, and generally, learning from patient sourced data (Stoto et al., 2017). Such models of care delivery within the health system are referred to as Learning Health Systems (LHSs), due to their interest in data informed learning to improve care processes (Okun et al., 2012; Smith, Saunders, Stuckhardt, & McGinnis, 2014). Hence within a LHS, PGHD as a key data source enables the possibility of every patient's experience being available to learn from; the support of clinical decision-making by embedding of best practice and optimal patient care knowledge into clinical workflows at the point of care; a focus on continuous care improvement and patient-centric outcomes; and cost reductions based on these practices (Kalra et al., 2017).

The use of PGHD within a LHS is aimed at designing an environment where the application and generation of evidence based knowledge are a natural outgrowth of patient care (Wysham et al., 2016). To realize this requires patient-level data gathering, and real-time data aggregation and analysis to prompt changes care in delivery (Figure 2.2) (Wysham et al., 2016). These changes that are based on patient-level data allow real-time outcomes evaluation. The current state of learning from patient sourced data however is still in the development phase, and LHSs are still at the stage of designing systems that are capable of

collecting high quality patient-sourced data, and designing platforms to aggregate collected data in-order to generate actionable evidence (Figure 2.2) (Wysham et al., 2016).

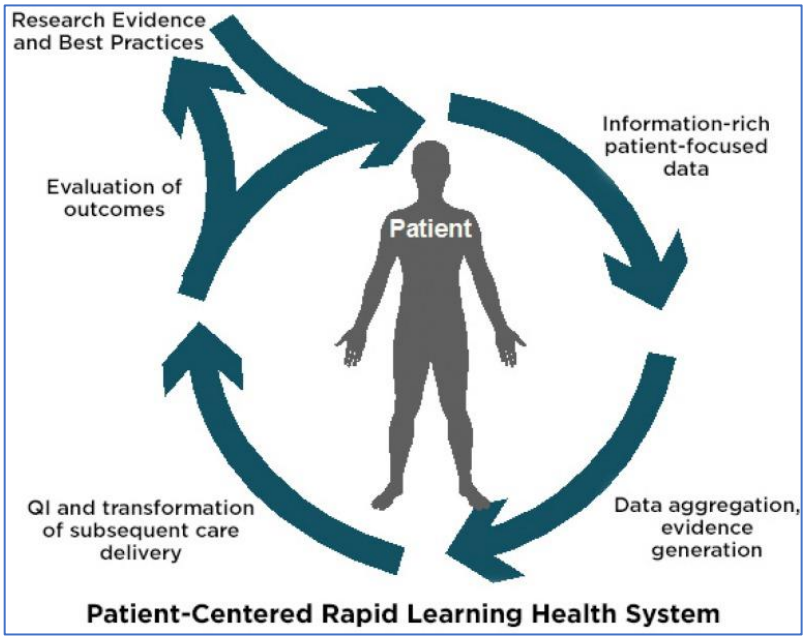

Figure 2.2 – Learning from Patient Sourced Data within a Patient-Centered Rapid Learning Health System (Wysham et al 2016)

Other electronic data driven hospital types such as PCORI funded hospitals, medical home/safety net hospitals, and meaningful use stage three compliant hospitals are also posited to be more interested in PGHD capture and use due to their emphasis on care that is patient focused, driven by electronic data, and delivered with precision.

PGHD's Impact and Challenges

In this section I will discuss the impacts and challenges associated with the use of PGHD based on health care quality, patient experience, cost of care health related quality of life and its use in research. PGHD's impact on health care quality has been observed in studies. PGHD has been observed to have the potential to facilitate reduction of hospital re-admission and clinical visits, timely patient advice and intervention, supplementation of clinical data captured during in-patient care, care delivery based on a more comprehensive picture of a patient's health status, and personalized treatment planning (Abdolkhani et al., 2018; Creswell, 1998; Kumar, Goren, Stark, Wall, & Longhurst, 2016; Lawton et al., 2018; Reading & Merrill, 2018). However, actual evidence of the impact of PGHD for these purposes is limited to small scale implementations and studies within small or few health system units (Cohen et al., 2016; Kumar et al., 2016). The lack of large-scale implementation of PGHD designed to improve healthcare quality has been attributed to a lack of confidence and consistency in the collection of PGHD, which, in turn, is due to the lack of data quality standards for managing PGHD collection and use (Abdolkhani et al., 2020; West, Van Kleek, Giordano, Weal, & Shadbolt, 2017).

PGHD's impact on patient experience includes the observed trend that patients are willing to become active participants in their own care by contributing to and managing their own health information (Fowe, 2020b; Huba & Zhang, 2012). PGHD has been observed to have the potential to improve patient-provider

communication, as well as the potential to contribute to quality assessment. Evidence on the impact of PGHD on patient experience include the ease of use that is provided by secure messaging that enables patients to ask questions, seek clarifications, report on adverse effects, inquire about test results, or communicate a variety of concerns (Deering et al., 2013). Also, secure messaging with physician review has been associated with a decrease in office visits, an increase in measurable quality outcomes in primary care, and excellent patient satisfaction (Deering et al., 2013). Despite these positive effects, widespread use of PGHD is still limited due to providers' concerns about the burden of reviewing large amounts of data, perceived increased potential for liability, and unrealistic patient expectations (Deering et al., 2013). There are also patient concerns of timely receipt of their PGHD by health care providers and the security of the information they have chosen to share (Abdolkhani et al., 2020; Deering et al., 2013). These concerns are also related to a lack of standard data quality measures for handling PGHD (Abdolkhani et al., 2020; Deering et al., 2013).

PGHD's impact on health care cost include predictions that it has the potential to facilitate cost reductions in health care. Although direct, large scale evidence that supports such predictions is largely unavailable, there is evidence that the use of PGHD can support preventive care, which can result in health promotion and disease prevention, thereby resulting in lower overall healthcare costs (Nittas et al., 2019). There is also evidence of cost reductions due to PGHD use for chronic disease management or improved patient engagement (Deering et

al., 2013). Promising, PGHD-related cost savings have been observed in small scale implementation studies within single health systems and at the level of individual patient care (Deering et al., 2013; Kumar et al., 2016). Measuring cost savings due to PGHD use on a systemic level might however be challenging without widespread or large-scale implementations.

PGHD's impact on Health-Related Quality of Life (HRQoL) measures is still being observed. A large United Kingdom trial that evaluated the effects of routinely collected PGHD using PROMS based on telehealth and telecare utilization recorded no substantial impacts on either generic or disease-specific HRQoL measures in a population with diabetes (Martin Cartwright et al., 2013). The study however, also showed no substantial decreases in HRQoL, and also showed moderate improvements in glycemic control which indicates some potential for PGHD from telehealth interventions (Martin Cartwright et al., 2013). The study concluded that providing PGHD from telehealth alone, without monitoring and enhancing identified mediating mechanisms such as self-care behaviors, self-efficacy, acceptability, and reducing program dropout will not necessarily lead to improvements in HRQoL (Martin Cartwright et al., 2013). The study recommended that evidenced based self-management techniques that target self-care and QoL be used in addition to PGHD collection via telehealth platforms for a potentially better outcome.

The use of PGHD for health related research purposes has been posited has promising (Perry et al., 2018). The wide availability of smartphone technology

which offers researchers the ability to enroll large numbers of study participants in a cost effective and timely manner facilitates this (Pratap et al., 2020). Study findings from a large and diverse engagement dataset on the collection of patient sourced data from mobile devices for research purposes identified two key problems. More than half of study participants discontinued participation within the first week of a study. Discontinuation rates however varied based on age, disease status, clinical referral, and use of monetary incentives. Secondly, most studies were not able to recruit a sample that was representative of the race, ethnicity or geographical diversity of the US (Pratap et al., 2020). Although these findings raise questions about the reliability and validity of data collected in this manner, they also shed light on potential solutions to overcome biases in populations using a combination of different recruitment and engagement strategies (Pratap et al., 2020). The study suggested that the final recruitment of study participants be based on a brief evaluation period aimed at identifying consistent study participants (Pratap et al., 2020). The study also suggested that the use of compensations such as monetary in the case of recruitment for research or otherwise in the case of the use of the application for clinical observations may facilitate consistent use. Finally, the study suggested that designing research applications to reflect variations in personality traits can have an effect on consistent participation (Pratap et al., 2020).

Other challenges related to PGHD capture and use include providers' concerns about the accuracy, reliability and usability of captured PGHD.

Information overload, workflow issues, and the additional time needed to review PGHD have also been highlighted (Chung & Basch, 2015). Other health system concerns over PGHD include the need for PGHD standardization, the increased need for interoperable devices and sensors for easy PGHD transmission across APIs, security and/or privacy issues, and a lack of the needed EHR functionalities or software innovations to harness the full potential of captured PGHD to enhance the usability of the data to stakeholders (Chung & Basch, 2015). Technologies are currently being designed and improved upon to address some of these highlighted challenges so that PGHD can be transformed into meaningful data from which providers can easily generate clinically relevant insights (Chung & Basch, 2015; Wood et al., 2015). Despite, these challenges, the potential of PGHD as an opportunity to learn from patient sourced data has been posited to outweigh the difficulties. Thus, hospitals and health care organizations (HCOs) that are interested in learning from patient sourced data such as PGHD by becoming more electronic data driven and patient centric continue to clamor for its use.

HCOs that seek to learn from EHD such as PGHD may be viewed as LOs or aspiring LOs. In the realm of health systems, such an organization may be characterized as a learning health system (LHS). Conceptually, the LHS is derived from the LO, and offers a framework by which learning can occur within HCOs such as hospitals, while maintaining a focus on a systems orientation to data use for care improvements targets and for improving patients' quality of care. PCORI funded hospitals and medical home/safety net hospitals, as well as meaningful use

stage three compliant hospitals can be viewed as HCOs that are aspiring to become LOs. Hence, Senge's LO theory and the LHS framework will be used to characterize HCOs and evaluate their interests and abilities to learn from patient sourced data such as PGHD in the next sections (Dumaine , n.d.; Flood, 1998; Kerka, 1995; Shaygan, 2018; Morain & Kass, 2017).

Learning Organizations

In this section I will discuss Senge's LO theory as a theoretical framework that connects the HCOs in this study through its focus on systemic thinking. I will also describe and compare other LO frameworks that have been developed in comparison to Senge's LO model. I will then discuss the LHS as a conceptual framework for learning focused organizations after which I will discuss the LHS's endeavors to learn from PGHD. The section will end with a description of other learning focused HCOs and their endeavors to learn from PGHD.

The need for data-driven and patient-focused continuous improvement in care processes within the US health system is highlighted across the literature. Based on this need, HCOs such as hospitals are adopting the practices of LOs, such as collecting and learning from data, in order to gain a competitive advantage or achieve better patient outcomes (Ainsworth & Buchan, 2015; Garvin, 1993). The need to also address the fragmentation of care problem within the US Health system has also led to patient-centric approaches to learning from the data within HCOs through the incorporation of patient driven, sourced and generated data into

health system processes (Austin et al., 2019; Morain & Kass, 2017; Stangt, 2009). These endeavors within the US health system point to the increasing need to continuously learn from both provider and patient generated health data in order to appropriately inform continuous improvement in care processes and quality improvement targets.

HCOs that are committed to improving patient outcomes through continuous learning from patient-sourced and provider-generated data can be characterized as LOs--organizations that are skilled at creating, acquiring, and transferring knowledge, and at modifying their behavior to reflect new knowledge and insights (Garvin, 1993). LOs have been described as organizations that can quickly adapt to changes and thus have the ability to secure competitive advantages (Senge, 1990b). LOs provide opportunities for continuous learning, use that learning to reach their goals, and are continuously aware of the needs and opportunities within the environment with which they interact (Infed, n.d.; Kerka, 1995). Hence, the concept of the LO focuses on learning as a philosophy for sustainable change, innovation or renovation within a dynamic business environment (Flood, 1998). Senge, identified five key disciplines of a LO, including personal mastery, mental models, shared vision, team learning, and systems thinking. According to Senge, systems thinking is the discipline that integrates the other four disciplines and enables system participants to see wholes. The whole has been described as complex due to the large amounts of information, intense interdependency, and relentless change that it is made up of (Flood, 1998). Often

times within organizations, the whole is broken up into fragments in order to make sense of it. This results in the inability to effectively picture the interrelatedness of component parts which leads to shortcomings in addressing organizational challenges effectively. Systems thinking according to Senge allows for an appropriate appreciation and evaluation of all the component parts of an organization with its varying dynamic and detail complexity and therefore has the potential to result in improved performance (Flood, 1998). Senge, posits that systems thinking is the overall goal of the four other disciplines, where every part learns holistically from individual parts to make changes that can result in continuous improvement in organizational processes (Flood, 1998; Garvin, 1993).

Systems Thinking: A Goal of Learning Organizations

Senge's LO theory provides relevant insights which can be applied to the fragmentation of care challenge within the US health care system (Stephanie Morain & Kass, 2017; Pronovost, Holzmueller, et al., 2015; Stangt, 2009). Independent and collaborative work by the Institute of Medicine (IOM) and the National Academy of Engineering (NAE) over the last two decades has called attention to the growing concerns about the need for a systemic orientation to care in order to improve patient safety and the quality of care, and address the fragmentation that has perpetuated rapidly increasing costs within the US health system (Kaplan, Lopez, McGinnis, Care, et al., 2015).

These concerns highlight the importance of a systemic approach to learning within HCOs, which are well captured in Senge's LO concept. The movement

toward a more functional US health care system has been posited to require each participating element to recognize its interdependence with all other elements (Reid et al., 2005). It has been posited by scholars that by using systems strategies and understanding system complexities and interdependencies, the organizational capacity and performance of the health care system can be dramatically improved (Kaplan et al., 2015).

Some of the key elements of a systems approach to health care include

- reorienting the system to the needs and perspectives of the patient and their family;
- creating capacity for seamless data capture, analysis and measurement strategies;
- incorporating evolving technologies;
- creating a culture of service excellence through regular quality assessments;
- committing to continuous process improvement;
- assuring accountability and transparency;
- and developing a supportive culture and organizational leadership that empowers those on the front lines to experiment, identify the limitations, and learn from data (Kaplan, Lopez, McGinnis, Care, et al., 2015).

Four of these key elements of a systems approach to health system transformation are particularly relevant for HCOs that are interested in learning from data that is

generated through the use of health IT tools that are powered by innovative digital technologies, such as PGHD. These four elements include 1) committing to continuous process improvement 2) a focus on data such as PGHD 3) incorporating emerging technologies 4) fixing the system orientation on the needs and perspectives of the patient and their family.

A commitment to continuous process improvement is one of the key building blocks of applying a systems approach to health care delivery and can be considered foundational to the other building blocks. If commitment to continuous improvement is lacking, there will be no foundation from which to motivate a systems orientation to solve health systems problems, or for systems of care to operate with a systemic focus. Similarly, a commitment to measurable continuous improvement in care processes is a key driver for the use of both provider and patient generated EHD, and emerging technologies for the collection of such data. Because the commitment to continuous process improvement is foundational to other elements, there is a need for HCOs such as LHSs that aim to learn from data to develop measurable assessments to evaluate learning through such processes.

Learning Organization frameworks and measurement models that are based on Senge's Learning Organization theory

Despite the robustness of Senge's (1990) LO model, some difficulties arise in operationalizing it as a model that can enable a systematic evaluation of the process of creating LOs (Bui & Baruch, 2010). Hence, Bui and Baruch (2010)

constructed a model that operationalizes Senge's LO theory as an explicit, testable model by developing a conceptual framework that can be used to analyze the antecedents and outcomes of Senge's five disciplines (Bui & Baruch, 2010). The model was primarily intended to develop Senge's LO model into a more applicable model that would facilitate quantitative analysis, and enable testing across different sectors, with appropriate adjustments made based on organizational types (Bui & Baruch, 2010).

Karthikeyan and Savarimuthu (2015), applied Bui and Baruch's LO framework to hospitals in order to develop a model that conceptually represents how hospitals can operate as LOs. Their model focused on specific factors that are unique to health systems and outlined a causal mechanism that links variables in the LO to outcomes such that HCOs can achieve competitive advantage (Karthikeyan & Savarimuthu, 2015). Karthikeyan & Savarimuthu's work, which is primarily based on Bui and Baruch's LO model and Senge's five disciplines of a LO has shown that HCOs can indeed learn, and that learning within HCOs that identify as LOs can be analyzed and measured. Their work also shows that HCOs that practice the principles of LOs can achieve systems thinking despite the many peculiarities of the health care environment which make HCOs different from other organizations (McGuire, 2019; Abdolkhani, Gray, Borda, & De Souza, 2018; Dias & Escoval, 2015; Nyström, 2009). Their work however, also indicated the need for the development of more appropriate methodologies for utilizing Senge's LO theory in the health care environment. This work which seems to be the genesis

of the LHS is central to the theoretical basis of the application of Senge's LO theory to conceptualize the LHS given its focus on HCOs and hospitals.

The need for more targeted and robust methodological tools was the genesis of the LHS as a conceptual framework, which was designed specifically to address health systems' needs for continuous improvement in care processes. The National academy of medicine series that was developed based off of the IOM's 2007 workshop called attention to the limited incorporation of data beyond EHRs into health system processes (Olsen, Aisner, & McGinnis, 2007). The series highlighted the need for the development of a LHS that could incorporate patient sourced data obtained from practice based research networks, and ambulatory care practices to inform continuous improvement in care within HCOs and hospitals (Olsen et al., 2007). The LHS conceptual framework which took some of its root from the systemic approach that was described in Senge's LO model presents a framework that addresses some of the needs of HCOs that seek to become LOs. The LHS framework can be used to assist HCOs to become LOs through its technology and data-driven learning infrastructure (Harrison & Shortell, 2020). The LHS also has broader applicability and is systematically designed to assist HCOs to become data and technology driven LOs (Harrison & Shortell, 2020).

The LHS Technology and Data Driven Learning Organization Theoretical Framework

The LHS offers a conceptual framework to assess and measure learning within HCOs, and provides a systemic focus that is technology and data driven (Davis et al., 2020; Harrison & Shortell, 2020). The LHS framework, which was conceptualized specifically to address health systems' needs for continuous improvement in care processes, exhibits a systemic approach similar to that described in Senge's LO model. As a conceptual framework, the LHS addresses the needs posed by the complexity of the healthcare environment and can be used to assist HCOs to become LOs through a technology and data-driven learning infrastructure (Harrison & Shortell, 2020). HCOs that embrace technology and data-driven learning derive information from three sources, including: 1) EHD within EHRs (which is generated mainly during clinical encounters); 2) PGHD from digital technologies (that is submitted via patient portals, EHRs or other platforms); 3) other learning platforms (such as worker's training, seminars, and staff/organizational development workshops) (Figure 2.3)

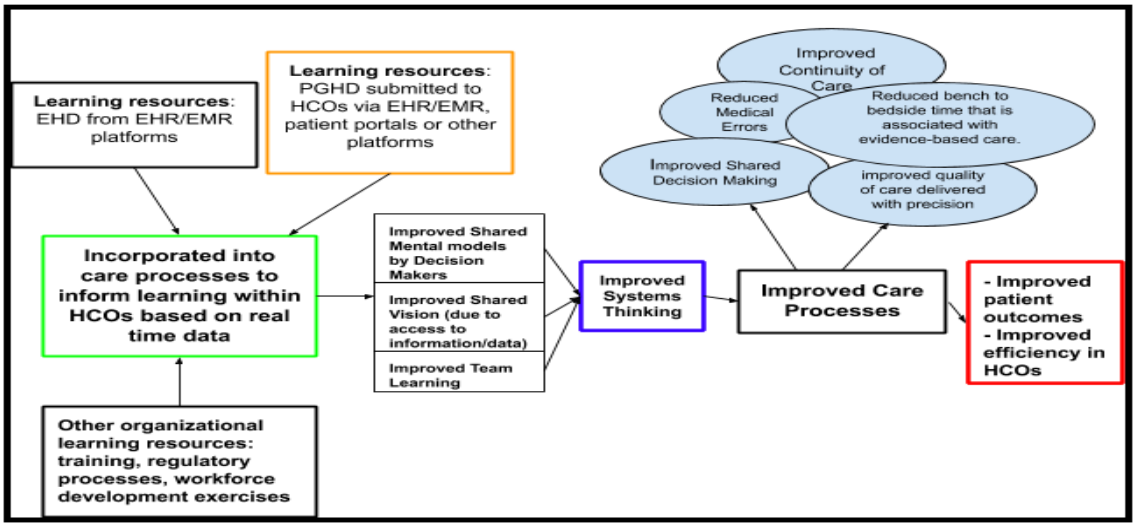

Figure 2.3: Flowchart showing data-driven learning from EHD such as PGHD and other EHR/EMR associated patient population data for continuous improvement

Within the LHS conceptual framework, the information derived from these sources is incorporated back into care processes and facilitates the creation of shared mental models to inform learning with resultant improvements in shared mental models by decision makers, shared vision, and team learning, all of which enable systems thinking (Figure 2.3). Improved systems thinking, which is foundational to both the LO and the LHS, has been posited by scholars to be at the core of solving the fragmentation of care challenges in US health systems (Pronovost, Armstrong, et al., 2015; Pronovost et al., 2017; Stangt, 2009). Improved systems thinking in HCOs will improve care processes, enhance shared decision making, reduce medical errors, and decrease the time for research-based practices to be implemented. Improved systems thinking is also associated with greater use of evidence-based care and higher quality and continuity of care, all of

which contribute to better patient outcomes and greater efficiency in HCOs (Figure 2.3).

Learning in today's HCOs differs from that in past eras due to the availability of technologies that enable digital health information such as PGHD to be obtained from patients outside of the health care setting, and to embed that externally generated data into organizational learning processes alongside data that is generated during clinical encounters. In combination, internal and external sources of EHD form the core of the learning resources that LHSs leverage to enable continuous improvement in care processes.

HCOs, including those that may not identify specifically as LHS (as shown in Figure 2.3), have nonetheless adopted elements of the LHS conceptual frameworks, such as the use of Health IT tools and EHD to drive learning in order to improve their patient engagement strategies, care processes, and quality of care. In addition to HCOs that have embraced LHS principles, these HCOs include PCORI grant funded hospitals, medical home/safety net hospitals and meaningful use stage three compliant hospitals, all of which are posited to be technology and electronic data driven and patient - centric LOs. These HCOs, due to their focus on the need for continuous improvement that is both patient and provider data driven, enable improvements in the systemic approach to care within the US health system. Starting with the LHS, each of these hospital types will be discussed in more detail below.

LHS Origin, Component Parts, and Purpose

The conceptual framework of the LHS has been operationalized through organizational characteristics which offer the promise to improve the evidence base and care delivery while reducing costs (Smith et al., 2013). The term was coined by the National Academies of Medicine in 2007 following a two-day workshop that addressed a broad range of issues that were important to re-organizing clinical research and healthcare delivery such that evidence is available when it is needed, and applied in a timely manner for the development of a Health care System that is both more effective and more efficient (Olsen et al., 2007).

The operationalization of the concept of the LHS in the context of organizations is best understood by examining each of the component words (Friedman et al., 2017). Learning refers to the capacity for continuous improvement through the collection and analysis of real time data, such as PGHD and provider-generated data in EHRs, thereby creating new knowledge, the application of which has the ability to influence practice. Health is a universally recognized end goal that humanity pursues through HCOs and other means, while a system is made up of component parts that act in unison to achieve goals that might not be attainable by any subset of the component parts working by itself (Friedman et al., 2017). By integrating these terms, health systems become learning health systems when they acquire the ability to continuously, routinely, and efficiently study and improve themselves (Friedman et al., 2017).

A LHS seeks to create an organization that continuously improves itself and its patient's health outcomes by delivering the right care to the right patient at the right time (IOM, Olsen & Saunders, 2011). Learning from every patient within an LHS necessarily involves the use of digital health information, including PGHD as a major source of EHD, which is key to achieving LHS goals of continuous improvement in care processes, patient's experience and health outcomes. Hence, six features of the LHS are identified. These include:

- the availability of every patient's characteristic and experience as data to learn from (in protected and secure formats);
- the immediate availability of best practice knowledge that is derived from these data to support health-related decisions by care providers, individuals, and planners of health services;
- a commitment to continuous improvement through ongoing study that addresses multiple health improvement goals;
- the availability of a socio-technical infrastructure that enables this to happen routinely, with a significant level of automation and with economy of scale;
- and a cultural shift toward stakeholders within the system viewing these characteristics as part of their culture (Friedman et al., 2017; Shaygan & Daim, 2019).

Given that LHSs are defined as health systems in which internal data and experience are systematically integrated with external evidence and the resulting

knowledge is put into practice, patients are afforded access safer and more efficient care of higher quality, whilst systems of care become better places to work (AHRQ, 2019; Maddox et al., 2017; Rubin et al., 2018). US HCOs and hospitals are gradually becoming LHSs, although the term LHS is not widely used yet, even in systems actively doing this work (AHRQ, 2019; Maddox et al., 2017; Rubin et al., 2018).

LHS Core Foundational Elements and Principles

The three core foundational components of the LHS include an infrastructure for health-related data capture, care improvement targets and a supportive policy environment (Mullins et al., 2018). Ten core LHS values have also been identified as important for incorporating LHS tenets into population health improvements, and these include adaptability, scientific integrity, person centeredness, inclusiveness, value, accessibility, governance, privacy, transparency, and cooperative and participatory leadership (Friedman, Rubin, & Sullivan, 2017; Rubin et al., 2018).

Based on the LHS definition, core foundational components, and values four key LHS principles were derived. These include 1) capacity to collect and use EHD (such as PGHD); 2) commitment to evidence/data-driven decision support, and shared decision making between patient and provider; 3) patient centered/data driven quality improvement measures; and, 4) use of safe and certified EHD platforms (Dinh-Le, Chuang, Chokshi, & Mann, 2019; Foley & Vale, 2017; Friedman et al., 2017).

HCOs within the US that are data-driven and patient focused are increasingly adopting these LHS principles, although some are yet to self-identify as LHSs. LHS principles have also been adopted by organizations who are affiliated with complementary initiatives. Such organizations share the goal of systemic thinking and continuously learning from technology driven EHD to achieve their goals of high quality and patient focused care that is delivered with precision. PGHD capture and use within these learning focused HCOs enables them to fulfil their goal of patient focused care and continuous improvement in care processes through a systemic approach.

The LHS, and other Patient Centric, EHD Driven, Learning Focused HCOs and PGHD

Success within the LHS involves the use of timely, accurate and data driven scientific evidence to make patient focused continuous improvements in care processes as well as enable a systemic orientation to care. These goals are best achieved when optimal care is tailored to a local healthcare setting and focused on each individual patient, and this can be better enabled through the incorporation of PGHD into LHSs (Abdolkhani et al., 2019; AHRQ, 2019; Mullins et al., 2018). PGHDs, because they are often patient sourced, driven and captured, PGHD can enable systems of care to move faster toward becoming patient driven LHSs through the incorporation of patients' voices into clinical decision making, care

improvement processes and targets, and population health improvement (Cohen et al., 2016; Menear et al., 2019).

PGHD can help LHSs and other patient centric and EHD driven HCOs within the US health system to better position themselves to achieve their vision for a healthcare system that utilizes the best evidence to provide the best care to each patient, emphasizes disease prevention, health promotion and precision approaches to care, and incorporates learning throughout care delivery processes (Budrionis & Bellika, 2016; IOM, 2003). PCORI funded hospitals, medical home/safety net hospitals, and meaningful use stage three compliant hospitals, are some of the learning focused hospitals within the US health system that are interested in improving their care processes through the incorporation of patient sourced and electronic driven data such as PGHD.

PCORI Funded Hospitals

PCORI was created by the US Congress as part of the Patient Protection and Affordable Care Act of 2010 to fund patient directed research aimed at assisting patients, caregivers, researchers, clinicians, and other stakeholders to make informed health decisions (Barksdale et al., 2014). PCORI is funded by the US Treasury, Medicare general fund, and some small fee assessed from private health insurers or self-insured employers (Barksdale et al., 2014). Despite its creation by the government, PCORI is a private, independent nonprofit organization rather than a government owned and directed organization

(Barksdale et al., 2014). Based on this, PCORI is better enabled to reflect the perspectives of the health care communities and patient populations that it engages with. PCORI is also better able to be known as a trusted source of information for populations (Barksdale et al., 2014).

PCORI funds Comparative Effectiveness Research (CER) that evaluates and compares the effectiveness, outcomes, risks and benefits of two or more interventions, treatments, or services within the health care domain through a focus on patient centered outcomes. PCORI funded research also provides information that patients, caregivers, researchers, clinicians, and other health professionals need in order to make or suggest choices that are aligned with patients' desired outcomes for their health (Barksdale et al., 2014; Washington & Lipstein, 2011). PCORI funded research takes into consideration variations in patients' life circumstances, behaviors, characteristics, and other factors associated with health status or health effects in order to ask CER questions, or make recommendations to enable health systems to learn from the data (Barksdale et al., 2014).

From inception, developments within PCORI have shown the organization's interest in innovative, technology driven approaches to achieve its goals (Fleurence et al., 2014). Based on this, PCORI has laid an innovative foundation for producing and disseminating clinical research, and engaging multiple stakeholders, while ensuring that clinical research is patient focused and

embedded within health care systems and patient communities (Barksdale et al., 2014; Selby & Lipstein, 2014).

Three strategic goals were adopted by the PCORI board of directors to meet PCORI's Affordable Care Act mandate and these include 1) "to increase the quantity, quality, and timeliness of usable, trustworthy comparative research information; 2) to accelerate the implementation and use of research evidence; and 3) to exert influence on research funded by others to make it more patient-centered and useful" (Selby & Lipstein, 2014, Pg 592). These goals are indicative of PCORI's interest in learning from patient focused data to inform care improvement targets. To address its goal of improving the reliability and trustworthiness of CER, PCORI funds CER in relation to five national priorities 1) "evaluating prevention, diagnosis, and treatment options; 2) improving health systems; 3) enhancing communication and dissemination of evidence; addressing disparities in health and health care; and improving CER methods and data infrastructure" (Selby & Lipstein, 2014, Pg 592). These priorities are further indicative of PCORI's interest to create learning HCOs based on validated scientific evidence. PCORI funded hospitals conduct patient centric research such as CER that is patient focused and data driven, and can enable patients and those that care for them to make better-informed decisions about their day to day healthcare choices, while being guided by those who will use that information, such as health providers (PCORI, n.d.).

Learning within PCORI Funded Hospitals

Some characteristics of LOs include creating, acquiring and transferring knowledge, and modifying organizational behavior to reflect new knowledge and insights (Garvin, 1993). PCORI funded hospitals, due to their interest in CER, can be described as LOs that aim to create, acquire, and transfer new knowledge, as well as modify their practices to reflect new knowledge and insights based on data. PCORI funded hospital, based on their need to learn from data to inform patient centered care, have been observed to adopt health IT tools that enable learning. The inclusion of patient centric health IT tools in these hospitals as components of routine care is an example of organizational modifications that are typical of LOs. The use of these tools in such institutions also suggests that they are LOs and are invested in learning from patient related data to inform care and continuous improvement in care processes.

Furthermore, one of the goals of learning within patient focused HCOs such as PCORI funded hospitals has been the aim to foster effective patient, caregiver, and healthcare provider interactions which has been shown to improve clinical outcomes (Gentles, Lokker, & McKibbon, 2010; Runaas et al., 2017). Studies have shown that patients who report good communication with their healthcare providers are often more likely to be satisfied with their care, and are often more likely to share pertinent or key information that can enable a more accurate diagnosis of health problems (Nci, DCCPS, & Arp, n.d.; Street, Mazor, & Arora, 2016). They are also more likely to follow treatment recommendations, and comply

with prescribed treatment regimen (Nci et al., n.d.; Street et al., 2016). Health IT tools have been used to facilitate patient engagement in this regard within PCORI funded institutions, which allows for a continuous, two-way communication between patients and care givers and health care providers (Gentles et al., 2010; Runaas et al., 2017). Furthermore, Health IT tools have been shown to be useful in facilitating treatment and treatment outcomes by allowing for easy access to test results, daily routines such as food intake, and activity logs that can inform effective and timely access to care.

Through the use of Health IT tools and CER, PCORI funded hospitals have sought ways to learn from patient data to improve care and potentially improve the chances of better health outcomes. This is particularly true among patient groups that may require recurrent care such as those with chronic or debilitating conditions that are undergoing complex or multiple treatments (Rief et al., 2017; Runaas et al., 2017). One such Health IT tools was deployed among caregivers of patients undergoing hematopoietic cell transplant to support the use of patient centric data. The health IT tool was observed to support patient's and caregivers informational needs, and provided an avenue for health providers to engage with patients and learn how to support them better based on their day to day encounters and interactions with the tool (Runaas et al., 2017). This study also showed that patient-centric HIT tools not only assist care providers to learn from patient data to inform care or enhance patient engagement, but also enhance patient and care giver satisfaction (Runaas et al., 2017).

PCORI's effort to create LOs is also observed in its adoption of LHS practices, with PCORI funded LHS institutions such as PCORnet and LSHNet emanating from that endeavor (Finney Rutten et al., 2017; Fleurence et al., 2014). PCORnet was designed to enable collaboration among partner institutions in order to inform patient centered CER (Fleurence et al., 2014). PCORnet's advanced networking, data querying and data sharing capabilities among member institutions was designed to enable the prioritization of rapid testing, development, and safe use of data, with incorporated feedback learning cycles (Fleurence et al., 2014). This process is to enable learning from data through experimentation in networking approaches, and the safe and secure use of network operations, that are able to identify potential data sharing and learning barriers as early as possible (Fleurence et al., 2014).

The LHSNet leverages existing health IT infrastructure and data standards to connect multiple collaborating sites to enable the facilitation of patient-centered outcomes research; CER that is embedded within the health-care system to enhance learning, and; the dissemination and implementation of research efforts to improve population health. One key feature of the LSHNet is its commitment towards the integration of different players and stakeholders that can enable learning in order to advance the LHS vision of progress in science, care culture, and health informatics aligning seamlessly to create new knowledge based on daily care experiences (Finney Rutten et al., 2017; Friedman, Wong, & Blumenthal, 2010). This new knowledge is then seamlessly refined and integrated into care to

inform best practices for continuous improvement in care processes (Finney Rutten et al., 2017; Friedman, Wong, & Blumenthal, 2010).

Based on these examples, organizational learning can be said to be central to PCORI's goals and guides its approach to CER and learning from the data to inform continuous improvement in care processes. However, despite PCORIs interest in learning from patient sourced data and its commitment to the LHS approach to care, the extent to which PGHD is used in PCORI funded hospitals for CER or to achieve other care related targets remains unclear (Bingham et al., 2016; Fleurence et al., 2014; Hull, 2015; UPMC, 2019).

PCORI and PGHD

PGHD enables patients' health status to be viewed and analyzed holistically through the incorporation of relevant health related experience data from outside of the clinical environment into health care or treatment related decision making. This is different from the use of standardized patient questionnaires such as PROMs or PROMIS (Patient-Reported Outcomes Measurement Information System) which is used within PCORI institutions (Bingham et al., 2016). PROMs (PROMIS) queries patients' health outcomes or experiences based on sets of standardized questions, which are still guided by providers' perspectives (Bingham et al., 2016). PGHD on the other hand, reflects more of the patients' voice and perspective than the physicians' voice or perspective. This is because PGHD allows patients to control the information they choose to share and requires little

to no input from the care provider in streamlining the health information. This allows for a near absolute capture of patients' perspectives about their health or treatment outcomes and the inclusion of those perspectives in treatment decisions. The collection of PGHD alongside PROMIS data can facilitate a better understanding of the patient information acquired through PROMIS, further empowering the patient as a participant in their own care (Fowe, 2020b; Huba & Zhang, 2012).

Furthermore, within PCORI, one of PCORnet's goal is the collection, use and harmonization of a wide range of patient-reported data such as personal patient histories, family medical histories, or information obtained from the use of remote monitoring devices which is posited to have the potential to improve care and health outcomes (Abernethy et al., 2008; Canterberry et al., 2019; Fleurence et al., 2014). PCORI through PCORnet aims to empower patients or care providers to provide health related data that more fully describe their experiences, and preferences in the treatment and management of their health conditions such as PGHD (E. Austin et al., 2019; Dimaguila et al., 2019, 2020; Fleurence et al., 2014). PCORI has however used more of PROMIS rather than PGHD in these endeavors (Fleurence et al., 2014; Miriovsky et al., 2012). The use of PGHD in addition to PROMIS can also enable health systems to easily incorporate patients' health effects into their clinical workflows (Dimaguila et al., 2019, 2020). Based on this, PGHD use within PCORI funded institutions proffers the opportunity for learning from patient sourced data to improve care experiences, thereby providing a more

robust understanding of patients' needs and preferences, and an avenue to deliver patient centered care comprehensively and precisely.

Medical Home/Safety Net Hospitals

The "medical home" terminology was first used in 1967 by the American Academy of Pediatrics in the publication "Standards of Child Health Care (NAPHHS, 2010)." It was used to describe a centralized source of pediatric records for each child that required complex or recurrent care (NAPHHS, 2010; C. Sia, Tonniges, Osterhus, & Taba, 2004). It was aimed at addressing the fragmentation of care challenges experienced by children with chronic or debilitating conditions that required care in different settings, and would benefit from the harmonization of their care (C. Sia et al., 2004). The phrase has evolved over the years to describe a model of health care delivery in which patients have a continuous personal relationship with a physician who provides coordinated, patient-centered and high-quality care that is supported by a payment system that provides compensation for all of the care received (C. Sia et al., 2004). Safety net providers have been defined as "providers that organize and deliver a significant level of both health care and other health-related services to the uninsured, Medicaid, and other vulnerable populations," as well as providers "who by mandate or mission offer access to care regardless of a patient's ability to pay and whose patient population includes a substantial share of uninsured, Medicaid, and other vulnerable patients" (Cunningham & Felland. Laurie, 2013; IOM, 2000, Pg 1).

Transformations within the health care marketplace and Medicaid have resulted in market-driven focus on competition, cost control, consolidation of assets and resources and the growth of managed care, and have led to financial challenges within safety net systems whose major source of revenue was Medicaid (IOM, 2000). Many states have converted their Medicaid programs to managed care in an effort to control their budgets and expand coverage (IOM, 2000).

Although Medicaid managed care potentially could allow safety nets to form networks that could result in improved efficiency, customer service, and improved accountability to patients, payers and other stakeholders, many safety net systems are not well equipped, structured or flexible enough to respond to operational demands of managed care (IOM, 2000). A good number of managed care programs have also not been implemented in a manner that adequately supports continuous care, provides access to necessary enabling services, and gives patients ready access to information sources that allow them to make informed decisions (IOM, 2000). Safety net systems that typically provide care for the uninsured population are particularly at risk as care for Medicaid beneficiaries becomes more increasingly separated from care for the uninsured (IOM, 2000).

Although Medicaid beneficiaries were not originally intended to subsidize care for uninsured populations, Medicaid revenues have in times past served as a source of revenue through which safety net providers could offset some of their overhead and infrastructure costs, thereby freeing up limited funds and other revenues to be used to support care for uninsured populations (IOM, 2000). New

care approaches that separate care for Medicaid beneficiaries from care for the uninsured, inadequate capitation rates and a lack of adequate risk-adjustment tools are however forcing safety nets to take on high levels of risk without sufficient reserves or other necessary protections (IOM, 2000).

A medical home/safety net hospital model of care was implemented between 2011 and 2014 in order to address these challenges at the hospital level and improve care and lower costs through a patient centered approach that also embraced the use of health IT (CMS, 2013; Rappleye, 2017). Specifically, health IT was intended to assist safety nets to become more competitive, patient focused, flexible and more able to respond competitively to market changes without compromising patient care (Rappleye, 2017). Some safety net providers received CMS funds and technical assistance between 2011 and 2014 to implement the medical home model (CMS, 2013; Witgert & Hess, 2012). Safety net hospitals participated in Health Care Innovation Awards projects that were supported by the CMS' Innovation Center in order to improve integration in areas such as the patient-centered medical home model, chronic disease management, and post-acute care transitions. (CMS, 2013; Witgert & Hess, 2012). Safety-net providers who participated in this effort were successful in improving access to care, but were unable to reduce the use of specialty care, acute care or Medicare expenditures over the time period studied (Timbie et al., 2017). Nevertheless, Safety net hospitals that adopted the medical home model were able to enhance their Health IT systems, and developed integrated systems with primary and

specialty care providers, while also aligning their safety net mission with the innovative changes (Witgert & Hess, 2012).

Medical Home/Safety Net Hospitals as Learning Organizations

As earlier stated, LOs are organizations that are skilled at creating, acquiring, and transferring knowledge, and modifying their behavior to reflect new knowledge and insights. Based on this, medical home/safety net hospitals due to their need to innovatively learn, and apply acquired knowledge to improve care processes, can be viewed as LOs or aspiring LOs (Garvin, 1993; Sugarman, Phillips, Wagner, Coleman, & Abrams, 2014; TCF, 2014). Like LOs, they need to become more flexible and able to competitively respond to patient needs and the changing market environment, in order to have the ability to secure more competitive advantages and based on this need to adopt LO concepts and health IT tools to assist with this (Senge, 1990b; Witgert & Hess, 2012).

Safety-net populations are very much at the center of the need for health care related innovation (TCF, 2014). This is due to their frequent use of health facilities, and their need for greater engagement and care coordination which make it necessary for them to embrace the concepts and methods of LOs (Senge, 1990b; TCF, 2014). LOs provide opportunities for continuous learning, use learning to reach their goals, and are continuously aware of the needs and opportunities within the environment with which they interact. Some safety net providers were positioned to embrace these concepts through the adoption of the

medical home model (Coughlin et al., 2012; HCNC, n.d.; Infed, n.d.; Kerka, 1995; NAPHHS, 2010).

The Use of Health IT Tools and PGHD in Medical Home/Safety Net Hospitals

Based on the afore highlighted needs, safety net hospitals incorporated the medical home model which leveraged on Health IT capabilities to enable patient engagement and precision in care targets to help address some of their concerns. A prior study examined five leading safety-net hospitals that prepared for reform by building upon strong organizational attributes such as health information technology and system integration, and by expanding the medical home model (Coughlin et al., 2012). Health IT was cited by health system leaders of all five medical home based safety net hospital as being critical to their systems' performance, with three of them (Parkland, Virginia Commonwealth, and Denver Health) having a long history of health IT use and investment (Coughlin et al., 2012). Virginia commonwealth developed a patient friendly EHR system, Parkland already had a fully integrated EHR system, and planned to join Virginia Commonwealth as one of the first public hospitals to offer patients access to that system.

Similarly, Denver Health initiated investments in health IT years ago by building a system that links operations and care delivery across its entire operation, including inpatient services, ambulatory care, the emergency department, and school-based clinics. Denver Health was named a "Top 100 Most Wired Hospital"

in 2011 (Coughlin et al., 2012). Health information technology has played a key role in helping these hospitals improve performance and respond to market and regulatory demands for increased efficiency and accountability. It has also yielded other advances. For example, HIT has helped improve the delivery of care, including better decision support for evidence-based medicine and chronic disease management systems; centralized tracking of medical tests, prescriptions, and appointments; and physician reminder systems to ensure the provision of timely and appropriate care. One Parkland initiative reduced readmission rates by 50 percent among patients with chronic obstructive pulmonary disease by using new technology to pull information from EHRs to identify high-risk patients (Coughlin et al., 2012).

Health IT has also improved financial management, including automated applications for Medicaid and self-pay patients (Coughlin et al., 2012). Denver Health noted that expanded efforts to establish Medicaid eligibility have generated an additional $5 million in revenue per year (Coughlin et al., 2012). Furthermore, Health IT has helped increase accountability and strengthen management. These improvements have taken the form of support for continuous feedback on care delivery and care outcomes, real-time performance monitoring, and systematic tracking of quality improvement initiatives (Coughlin et al., 2012). Leaders at Denver Health, Parkland, and Virginia Commonwealth whom were interviewed in a prior study said that they viewed such Health IT support systems as critical to improving efficiency, saving millions of dollars every year (Coughlin et al., 2012).

Despite these records of progress and advancements in the use of Health IT tools such as EHD from EHR systems to enable learning from EHD by medical home/safety net hospitals, and the expressed need for digitally enabled patient generated data sources within medical home/safety net hospitals, it is still unclear the extent to which these hospitals utilize individualized patient data in the form of PGHD to enable learning, and make improvements in care and continuous quality improvement processes (TCF, 2014).

Meaningful Use Stage Three Compliant Hospitals

The concept of “meaningful use” of EHD to improve health care and population health was introduced by The American Recovery and Reinvestment Act of 2009 (ARRA) (CDC, 2019; Friedman et al., 2010). ARRA included measures that were aimed at improving the US’ health infrastructure, such as the HITECH Act (CDC, 2019). The HITECH Act included the meaningful use of EHRs, which was an effort by the CMS and the Office of the National Coordinator for Health IT (ONC) to ensure the safe collection of high quality EHD and its substantial use in continuous improvement processes and care improvement targets (CDC, 2019). The HITECH act authorized the payment of incentives to eligible health professionals and hospitals that achieve meaningful use.

Meaningful use requires the adoption of certified EHR platforms, secure mobility and transference of health information, and accurate and safe reporting of quality measures (Friedman et al., 2010). Attaining meaningful use of data within

EHRs is intended to enable the safe and secure flow of clinical information between data collection platforms and data use platforms. Attaining meaningful use of EHD from EHR and other sources can facilitate the use of such data to inform care and continuous improvement processes which enable learning (Friedman et al., 2010). Hospitals and practice environments that achieve meaningful use are expected to adequately represent clinical information collected in the form of EHD by using precisely defined measures and standards that have been adopted for use across the US (Friedman et al., 2010). Standardized representations help ensure that the meaning of clinical information such as EHD from EHRs is preserved as the data move to new locations, thereby ensuring data integrity, and safe and meaningful interpretations of the data to inform learning.

The meaningful use concept was based on the five pillars of health outcomes policy priorities, including: 1) improving health care quality, safety, and efficiency, and reducing health disparities, 2) engaging patients and their families in their health, 3) improving care coordination 4) improving population and public health 5) insuring adequate privacy and security protection for collected personal health information (CDC-CSELS, 2019). Implementation of the meaningful use requirements involves three stages. Stage one, which promotes basic EHR adoption and data gathering; stage two, which emphasizes care coordination and exchange of patient information; and stage three which is aimed at improving healthcare outcomes. Until recently, the EHD that is used within EHRs has mostly been provider generated (Gold & McLaughlin, 2016; Reisman, 2017).

Provider generated EHD has enabled some EHR systems to successfully move through at least two of the three stages, and is being used to provide some level of clinical decision support, or to inform care or continuous improvement targets (Coughlin et al., 2012). However, PGHD, which is patient sourced and generated, has yet to make such progress across the initial two meaningful use stages (stages one and two), hence, the focus on PGHD use and capture in the meaningful use stage three requirements which was initially slated to become mandatory in 2018. However, HCOs and hospitals are still in the early stages of adopting and implementing stage three requirements which also includes PGHD adoption. Stage three meaningful use requirements also include the promotion of interoperable platforms through the use of application programming interfaces which would enable the safe sharing of PGHD among providers, patients, and public health systems (Gold & McLaughlin, 2016; Shapiro et al., 2011; Wu, 2014). Finally, stage three meaningful use requirements prioritized patients 'ability to access their health information using applications configured to APIs within EHRs; the ease of health information exchange that enables the sending or receiving of patients' data; and the ease of public health reporting (CDC-CSELS, 2019).

Meaningful Use Compliant Hospitals as Learning Organizations

According to the ONC's Health IT roadmap 2015 to 2024, the meaningful use stage three policy was enacted to enable hospitals to move forward towards the establishment of an interoperable learning health system that can facilitate

improvements in the health outcomes of Americans in order to achieve a better, smarter and healthier system and also enable PGHD capture and use (ONC, 2013, 2014, 2015; ONC Health IT, 2015). Based on this, learning was one of the goals of the meaningful use stage three rule, particularly inculcating learning from patient sourced data which was newly introduced as part of the stage three requirement (ONC, 2013, 2015). Meaningful use compliant hospitals can be characterized as LOs because they are committed to creating, acquiring and transferring knowledge, and to modifying their behavior to reflect new knowledge and insights (Dumaine B, n.d.; Garvin, 1993). This is based on the need for meaningful use compliant hospitals to use EHD collected from EHRs to inform care and continuous improvement processes, while also ensuring data integrity, data security and data protection through the use of safe and secure platforms.

LOs have been described as organizations that can quickly adapt to changes and thus secure more competitive advantages (Senge,1990). Meaningful use compliant hospitals can be likened to LOs based on their need to quickly adapt to or adjust their practices based on acquired data, such as provider or patient generated EHD. EHD from EHRs in these settings is obtained and used in a meaningful manner in order to gain and/or maintain a competitive edge in the dynamic health care environment.

Meaningful use stage three compliant hospitals are expected to be committed to collecting and using PGHD and, as PGHD enabled LOs, would have various opportunities for continuous learning from patient sourced data. Based on

this, meaningful use stage three compliant hospitals are expected to be committed to using such learning from PGHD to reach their goals, and are also expected to be continuously aware of the needs and opportunities within the environment with which they interact (Infed, n.d.; Kerka, 1995; Reddy, 2012). Currently, it remains unclear how much of the EHD based learning that occurs within meaningful use stage three compliant hospitals is PGHD informed, despite the requirements of the HITECH Act and the new interoperability rule that promotes PGHD capture and sharing (The Promoting Interoperability Rule) (CDC, 2019).

Learning from PGHD within Meaningful Use Stage Three Compliant Hospitals

Compliance with meaningful use requirements for EHD is necessary to establish the foundation for creation of a nationwide learning health system (Friedman et al., 2010). Federal incentives that directly promote the adoption and meaningful use of EHD, including PGHD captured within EHRs, move the nation a step closer toward achieving a nationwide learning system (Blumenthal & Tavenner, 2010). EHR adoption and meaningful use of EHR data comprised mainly of provider generated health data are necessary, but insufficient to achieve this goal. Additional data sources, such as PGHD that provides a holistic evaluation of patients' health status, are required to achieve the vision of a highly participatory learning health system in the US (Blumenthal & Tavenner, 2010).

The meaningful use program increasingly recognizes the need to link EHRs with external sources of clinical information, such as PGHD. Thus, starting in 2015

the stage three meaningful use requirement mandates that hospitals and health systems provide avenues for PGHD submission and use for their patient populations, with penalties for noncompliance beginning in 2018 (Gottlieb D & Weinstein S, 2015; Power et al., 2016). The new rule mandates that PGHD and other data from non-clinical settings is incorporated into the Certified EHR Technology (CEHRT) for at least five percent of unique patients discharged from an eligible or Critical Access Hospital (CAH) inpatient or emergency department during the EHR reporting period (CMS, 2015). This meaningful use requirement is meant to facilitate patient engagement requirements of the meaningful use program for hospitals to remain eligible for CMS reimbursements, thereby encouraging learning from PGHD to inform care and continuous improvement processes. Despite the requirements of the HITECH Act and the new rule of the meaningful use program, the extent to which PGHD is captured and used among hospitals that have attested to stage three meaningful compliance is currently unknown.

Defining HII Hospitals and HII Hospital Characteristics

LHS Hospitals have been observed to be interested in the use of real time data to enable patient focused continuous improvements in care processes (Wysham et al., 2016). As earlier stated, within LHS Hospitals, internal data and experience are systematically integrated with external evidence and the resulting knowledge is put into practice, to enable continuous improvement in care

processes and efficient and safer patient care (AHRQ, 2019; Maddox et al., 2017; Rubin et al., 2018). PCORI funded hospitals, have also been observed to adopt health IT tools that enable learning from data such as EHD to inform patient centered care and continuous improvement in care processes. (Finney Rutten et al., 2017; Friedman, Wong, & Blumenthal, 2010). Meaningful use stage three compliant hospitals have also been observed to be interested in creating, acquiring and transferring knowledge, and modifying their behavior to reflect new knowledge and insights (Dumaine B, n.d.; Garvin, 1993). This is based on their need to learn from EHD in order to inform care and continuous improvement, and enable patient centric approaches to care based on PGHD use (CMS, 2015). Lastly, medical home/safety net hospitals have invested in health IT tools in order to secure more competitive advantages. This has made them more patient focused, flexible, and more able to respond competitively to market changes without compromising patient care (Rappleye, 2017). This shows their interest in patient centered, EHD-driven, continuous improvement in care.

The afore described four hospital types are similar in their use of EHD to enable learning, continuous improvement in care, and patient - centric approaches to care (Coughlin et al., 2012; Dimaguila et al., 2020; Infed, n.d.; Kerka, 1995; Reddy, 2012). These hospitals have also been posited to be more likely to use patient sourced data such as PGHD (CDC-CSELS, 2019; Coughlin et al., 2012; Fleurence et al., 2014; Wysham et al., 2016). This suggests that they can be commonly grouped together. Based on the above, I define these four hospital

types as Health Information Interested (HII). Subsequently, in the next chapters, the term HII hospital characteristics or sub-types will refer to each of the four EHD-driven, patient – centric, and learning focused hospital types as earlier stated (LHS, PCORI funded, medical home/safety net, and meaningful use stage three compliant hospitals). The term HII Hospitals on the other hand will refer to all of the four HII hospital types as a whole. Groupings of HII Hospital characteristics or sub-types will be referred to as HII hospital groups.

Evaluating PGHD Capture and Use Comparatively among HII Hospitals

To address the lack of clarity regarding the extent to which PGHD is captured and used to enable learning among hospitals and inform improvements in care and continuous improvement processes, this study will evaluate the extent to which PGHD is captured and used within hospitals that identify as a LHS or have adopted LHS principles. This study will also identify other HII hospital characteristics that are more likely to result in more PGHD capture, with or without being recognized as a LHS, including PCORI and medical home/safety net hospitals, and hospitals that have demonstrated compliance with stage three meaningful use criteria. This study will also evaluate how changes in HII hospital characteristics have influenced PGHD capture and use across selected years.

In summary, this study will identify the characteristics of hospitals that are committed to being LHSs or electronic data-driven and patient focused and will evaluate how these HII hospitals, and their characteristics relate to PGHD capture

and use. Based on the elucidated need for PGHD capture and use among US health systems and hospitals that have a commitment to continuous improvement in care processes through the use of electronic data driven and patient focused approach to care, this study asks the following research questions:

1) What is the distribution of US hospitals that have HII characteristics related to being learning focused, patient-centric, and electronic data-driven?

2) How do these identified HII hospitals characteristics relate to the capture and use of PGHD?

Chapter Three - Research Methods

Introduction

Patient generated health data (PGHD) is a new form of electronic information that can potentially be used to enable patient focused continuous improvement in care and be incorporated into care and continuous improvement targets. For this reason, within the literature, PGHD has been identified as a potentially important part of health care organizations (HCOs) and hospitals that are patient focused, electronic health data (EHD) driven and learning focused (Kalra et al., 2017; Stoto et al., 2017; Wysham et al., 2016). For the purpose of this study, I define patient focused, EHD - driven and learning focused hospitals as Health Information Interested (HII) Hospitals as noted in chapter two. HII Hospitals in this study include Learning Health System (LHS) principles practicing, PCORI funded, medical home/safety net, and meaningful use stage three compliant hospitals (Barksdale et al., 2014; Budrionis & Bellika, 2016; CDC-CSELS, 2019; Coughlin et al., 2012; IOM, 2003; Rappleye, 2017). These specific hospitals which are subtypes of HII Hospitals will subsequently be referred to as HII subcategories or HII hospital characteristics, and their interactions will be reffered to as HII subcategory interactions. Based on this, HII subtypes will include HII subcategories and HII subcategory interactions. As suggested within the literature, I am focusing on these categories of hospitals as those that are more likely to capture and use PGHD.

Using quantitative methods, this study seeks to understand the prevalence and distribution of HII hospitals across its four subcategories. This will be done by creating a typology of HII hospital characteristics or subtypes that are posited to be more likely to be interested in PGHD capture and use. I will then assess whether HII Hospitals as a whole are more associated with PGHD capture and use than non - HII Hospitals. Following this, I will assess if the potential HII hospital subtypes are similarly associated with PGHD capture and use. I will also assess if changing hospital subtypes over time is associated with PGHD capture and use.

In this chapter, I will describe the research questions and aims in the next section, this will be followed by the design overview section, which will be followed by the data sets and study population section, which will be followed by the measures section, and then the methods section which will describe how the three study aims will be assessed. The last section of this chapter will describe study limitations and the purpose and significance of this study and will state the value of the research to health systems leaders, policy makers, and researchers. It will also describe how the study relates to future research.

Research Questions and Aims

To explore PGHD capture and use among HII hospitals and their subtypes, this study asks the following research questions:

1) What is the distribution of US hospitals that have HII characteristics related to being learning focused, patient-centric, and electronic data-driven?

2) How do these identified HII hospital characteristics relate to the capture and use of PGHD?

These research questions will be evaluated based on three aims. The first research question will be evaluated using aim one, which seeks to distinguish HII hospitals from those that are not, and then seeks to distinguish interrelationships between groups of HII hospitals by seeking to create a typology of HII hospital characteristics. The second research question will be evaluated based on aims two and three, which seek to ascertain the existence of relationships between identified HII hospital characteristics and PGHD capture and use using a cross sectional study and a difference in difference analysis.

Aim One:

To analyze the health IT characteristics of HII hospitals in order to observe how they go together and create a hospital typology of HII hospitals that are patient-centric, EHD-driven and learning focused. I will seek to examine US hospitals in order to understand the distribution of HII hospitals by using hospitals that practice LHS principles, PCORI funded, medical home/safety net and

meaningful use stage three compliant hospitals as the basis. To understand the degree to which hospitals are HII, I will first distinguish between HII hospitals and those that are not. I will then seek to distinguish interrelationships between identified groups of HII by specifically evaluating interrelationships between hospitals that practice LHS principles, PCORI funded hospitals, medical home/safety net hospitals, and meaningful use stage three compliant hospitals.

Existing data identifies hospitals as LHS, PCORI funded, medical home/safety net, and meaningful use stage three compliant hospitals, and a significant part of aim one is to understand how these hospitals interrelate. HII hospital characteristics are important because they point to hospitals' interest to use health IT tools to inform learning within patient-centric and EHD-driven hospitals, it is however not clear how HII hospitals group together based on these characteristics. I am hypothesizing that HII hospitals that are patient centric, EHD-driven, and learning focused are in the same category, however, I do not know how they go together or how different they are, the typology to be created as a part of aim one will help address this. Furthermore, it is also not clear how these characteristics relate to PGHD capture and use, which will be evaluated in aims two and three (Figure 3.1).

Aim Two:

To ascertain what identified HII characteristics of patient-centric, EHD-driven and learning focused hospitals are associated with PGHD capture and use.

It is important to this study to ascertain the HII hospital characteristics of patient-centric, EHD-driven and learning focused hospitals (identified in aim one) that are associated with PGHD capture and use. This will help to understand which of the patient-centric, EHD-driven and learning focused HII hospitals are more likely to capture and use PGHD and those that are not likely to. Based on a review of literature, these HII hospital subtypes are expected to be more able to facilitate PGHD capture and use. Based on the HII hospital characteristics that will be elicited in aim one, aim two of this study will evaluate the hospital characteristics that are associated with PGHD capture and use (Figure 3.1).

Aim Three:

To establish if there is a meaningful concept of HII hospital subtype that relates to PGHD capture and use by examining the relationship between change in HII hospital characteristics and change in PGHD capture and use. In this aim, I will ascertain if the observed relationship between HII hospital characteristics and PGHD capture and use can be explained by a change in the identity of HII hospitals (Figure I). To achieve this, I will seek to elicit a potential causal effect of HII hospital characteristics on PGHD capture and use on a basic level. This is to clarify that the observed associations in aim two are indeed due to the identified HII hospital characteristics in aim one. This is not a perfect causal study; it is to add to the evidence base on HII hospital characteristics and PGHD capture and use in order to guide future research.

Design Overview

In aim one, I will identify and interrelate the four specific HII hospital characteristics highlighted above to create a typology based on the AHA data. The typology will be dependent on the inter relationship of these HII hospital characteristics that I find in the data. As a component of this, I will use the data to create a measure of LHS practice as one of the HII hospital characteristics. A descriptive analysis of the other three identified HII hospital characteristics (PCORI funded hospitals, medical home/safety nets, and meaningful use stage three compliant hospitals) will also be conducted to show their distribution within the data. Distinct HII hospital groups will then be identified which will be evaluated in aims two and three (Figure 3.1). The end result may be to reframe the initial typology based on the results of aim one.

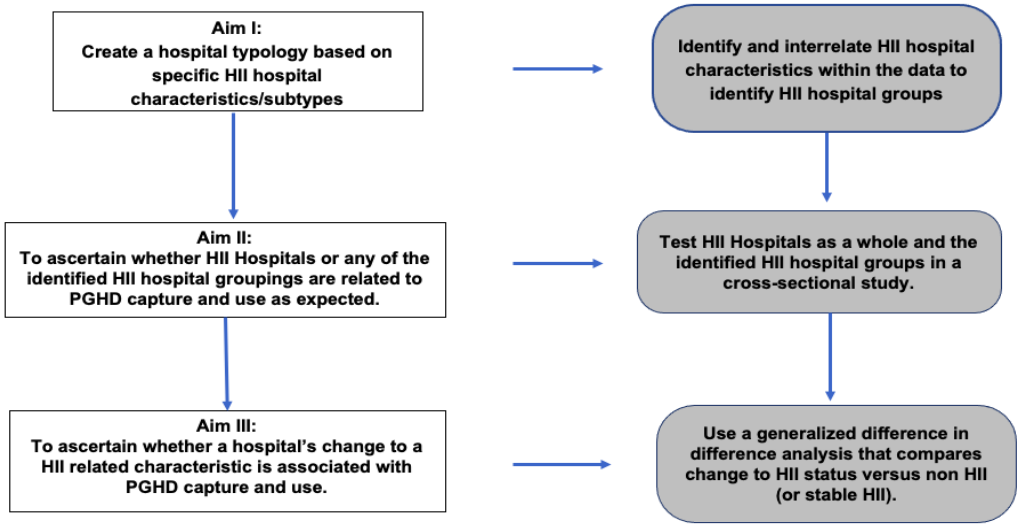

Figure *3.1*: A flow chart showing how aims one, two, and three will be evaluated

In aim two, I will ascertain whether HII Hospitals as a whole are associated with PGHD capture and use. I will then ascertain whether any of the identified hospital groups (in aim one) are actually related to PGHD capture and use as expected. To achieve this, I will first test for an association between HII Hospitals and PGHD capture and use, I will then test for an association between identified HII hospital groups and PGHD capture and use in a cross-sectional study.

In aim three, to better assess if the identified HII hospital characteristics are actually driving PGHD capture and use, I will use a generalized difference-in-difference model with fixed hospital and time effects to ascertain if changes in HII hospital characteristics across the three study periods are associated with changes in PGHD capture and use in comparison to hospitals with consistent characteristics. This will help to strengthen any observed associations (in aim two) between identified HII hospital groups and PGHD capture and use.

Data Sets and Study Population

The AHA conducts a yearly health IT supplemental survey (AHAIT) which forms the basis of this study. Supplemental data sets in this study will include the American Hospital Association's (AHA) annual survey (2013, 2016, 2018), the PCORI funded project list (2013, 2016, and 2018), and the Center for Medicaid and Medicare (CMS) 2012 innovation award funding list (CMS, 2013; PCORI, 2020).

AHA Data Sets

The AHAIT provides information on HII related hospital characteristics. Some of the HII related information provided in the AHAIT supplement include information on hospitals' computerized system capabilities, information exchange between providers, interoperability barriers, EHR system and IT vendors, compliance with EHR meaningful use/promoting interoperability program requirements, patients' ease of access to their health information, and the capture and use of patient generated health data (AHA, 2019). The AHAIT supplement also investigates questions related to health information exchange barriers, and reporting, and hospitals' level of transition to electronic data use. An average of 3,500 hospitals are surveyed annually with a response rate of about 50% (AHA-ONC, 2013, 2016; AHA, 2018, 2019).

Based on prior evaluations using the AHAIT data, it is expected that 50-60% of the hospitals in the study will be at stage two or three in the LHS cycle (1,750 to 2,100) of the at least 3250 to 3,500 hospitals included in the study). It is also expected that 40 to 50% of hospitals in the study will attest to at least two meaningful use stage three criteria (1,400 to 1,750) of the total number of hospitals studied) (AHAIT, 2018).

The second AHA data set in this study will be the AHA's annual survey which is one of the supplemental data sets. It provides information on general non health IT related hospital characteristics. In this study it will be used to obtain

information on hospitals' teaching status and urban/rural location of hospitals (SGIM, n.d.).

PCORI Data Set and the CMS Innovation Award Funding List

A publicly available web-based list of PCORI funded projects will be used in this study to identify specific hospitals that were funded by PCORI during the years studied (PCORI, 2020). PCORI funds public and private sector hospitals and health care systems to conduct research that facilitates care models that are patient centered and driven by electronic data. PCORI also funds studies that improve the methods available for patient-centered comparative effectiveness research (CER) and has developed a large, highly representative electronic-data infrastructure for improving the conduct of patient-centered CER (PCORI, 2014). PCORI funded 1,698 projects in US organizations, hospitals and health systems between years 2012 and 2020 (PCORI, 2020). 10 to 15% of hospitals included in the study are expected to be PCORI funded (170 - 250) across the years evaluated.

The CMS innovation award funding list will be used to identify medical home/safety net hospitals in this study (CMS, 2013). The CMS Innovation Center tests, evaluates, and disseminates information about new innovative health care delivery approaches. As part of its mission to improve access to care and the quality of care for underserved populations, the Center funded several innovative projects between 2011 and 2014 that were targeted at assisting safety net

hospitals to adopt the medical home model in order to improve their quality-of-care delivery. These safety net hospitals that adopted the medical home model between 2012 and 2014 will be evaluated in this study. It is expected that at least 20 to 30 hospitals will be listed as awardees of the funds to become medical home based safety net hospitals within the first study period (CMS, 2013).

Study Period

The AHAIT 2013, 2016, and 2018 data sets, will be the main data source in this study (AHA-ONC, 2013, 2016; AHA, 2018). These data sets are made up of the responses of the 50 – 55% of the 3283 to 3500 US hospitals that responded to the 2013, 2016, and 2018 AHAIT (SGIM, n.d.). The AHAIT data set will be used to identify hospitals that practiced LHS principles in years 2013, 2016, and 2018 (AHA-ONC, 2013, 2016; AHA, 2018). It will also be used to identify hospitals that complied with the meaningful use requirements in 2013, 2016, and 2018, as well as hospitals that captured and used PGHD in years 2013, 2016, and 2018 (AHA-ONC, 2018). The AHAIT will also be used to identify some other non HII related hospital characteristics such as hospital size, ownership, and location (urban/rural) based on hospitals' zip codes. The AHA annual survey which includes US hospital characteristics will be used to identify other hospital characteristics such as teaching status for the corresponding years (AHA, 2018; SGIM, n.d.).

PCORI has funded about 1,698 projects in US organizations, hospitals and health systems between years 2012 and 2020 (PCORI, 2020). The PCORI funded

projects web list will be used to identify hospitals that were funded by PCORI in years 2013, 2016, and 2018 (PCORI, 2020). The CMS innovation award funding list which comprises the 107 providers that received the 2012 innovation award will be used to identify safety net hospitals that became medical home/safety net providers in that time period (CMS, 2013).

Measures

In this section I will be describing the outcome measures, the measures of interest, and the control variables in this study.

Outcome Measures

The outcome measures that I will evaluate in this study include measures of PGHD uptake, and these are the capture and use of PGHD by the distinct hospitals or groups identified in the typology. I will make PGHD capture and/or use binary variables, with PGHD captured = 1; or PGHD used = 1; and PGHD not captured = 0; or PGHD not used = 0.

How the study will measure the capture and use of PGHD

The AHAIT data will be used to assess hospitals' capture and use of PGHD. Measuring PGHD capture and use is important in this study because it is an indicator of hospitals' interest to be patient focused through the capture and use of

EHD. Based on the AHAIT, hospitals are asked to indicate whether or not they capture PGHD (Q3i – 2016 & 2018; Q3viii – 2013), hospitals' yes or no responses to this question will be used to assess their capture of PGHD. One use of PGHD as measured within the AHAIT data set is PGHD's use to update or amend patient's record. Hospitals are asked to indicate within the AHAIT data whether or not patients are able to request updates or amendments to their health records (Q3iv - 2013; Q3d - 2016; Q 3e - 2018). Hospitals response to this question will be used to measure PGHD use (Table 3.1).

Table 3.1

Constructs and Measures of PGHD Capture and Use

Construct	**AHA Measure**
PGHD capture	Patients can submit patient-generated data (e.g., blood glucose, weight) (Q3i – 2016 & 2018; Q3viii – 2013)
PGHD use (e.g., to update or amend patient's record)	Offers support for patients to request an amendment to change/update their health/medical record (Q3iv - 2013; Q 3d - 2016; Q 3e - 2018)

Measures of Interest

The measures of interest in this study include the HII hospital characteristics that will be the basis for HII hospital groups to be identified in the typology. For these measures, I will create a dummy variable (0, 1) for each of the HII hospital group identified. This is to evaluate whether or not specific HII hospital characteristics of interest are present in a HII hospital group within a time period.

This measure will be represented as follows; HII hospital characteristic of interest present = 1; while HII hospital characteristic of interest absent = 0. HII hospital characteristics of interest in this study include hospitals' practice of LHS principles, hospitals' meaningful use compliance, PCORI funded hospitals, and medical home/safety net hospital characteristics.

How the study will measure the practice of LHS principles

The practice of LHS principles will be elicited from the AHAIT data and will be based on hospitals' 1) capacity to collect EHD; 2) capacity for evidence and data driven decision support 3) the use of EHD for quality improvement measures and population health improvement and 4) the use of safe and certified EHR platforms (AHA-ONC, 2013, 2016, 2018; C. P. Friedman et al., 2017; Mullins et al., 2018). The capacity to collect EHD is the first stage toward becoming a LHS and is an indicator of hospitals' interest to use EHD. The use of evidence and data driven decision support is the second indicator of hospitals' interest to be data driven through the practice of LHS principles. The use of EHD for quality improvement measures and population health improvement indicates hospitals' interest to be meaningfully data driven and to incorporate EHD into continuous improvement processes. It represents the third indicator of hospitals' practice of LHS principles. The use of safe and certified EHR platforms enables the safe capture and use of EHD and this is important for all levels of the practice of LHS principles (Table 3.2).

Table 3.2

LHS principles and AHAIT measures (Mullins et al 2018; Friedman et al 2017)

LHS Principle	**AHA Measure**
1) Capacity to collect and use EHD	Capacity for Electronic Clinical documentation (Q1)
2) Evidence and data-driven decision support	Capacity for decision support (Q1)
3) Quality improvement Population Health improvement	Use of EHD for quality improvement and population health measures (Q18 - 2013; Q25 f - j - 2016; 2018).
4) Use of safe and certified platforms such as certified EHR platforms and validated information exchange platforms.	Use of EHRs that are certified based on Federal standards (Q12 - 2013; Q18 - 2018; 2016: Q17).

The Degree of LHS Practice

LHS Hospitals will also be categorized based on their degree of LHS practice using the AHAIT data. Friedman et al's framework of the LHS learning cycle, and the infrastructures that support the execution of these cycles, will be used in this study to categorize LHSs (Friedman, Rubin, & Sullivan, 2017). The LHS learning cycles consist of three core stages, including: 1) converting data to knowledge (D2K), 2) applying knowledge to influence performance (K2P), and 3) documenting changes in performance to generate new data (P2D). LHS hospitals will be categorized based on their attainment of these stages in the LHS learning cycle (C Friedman et al., 2017).

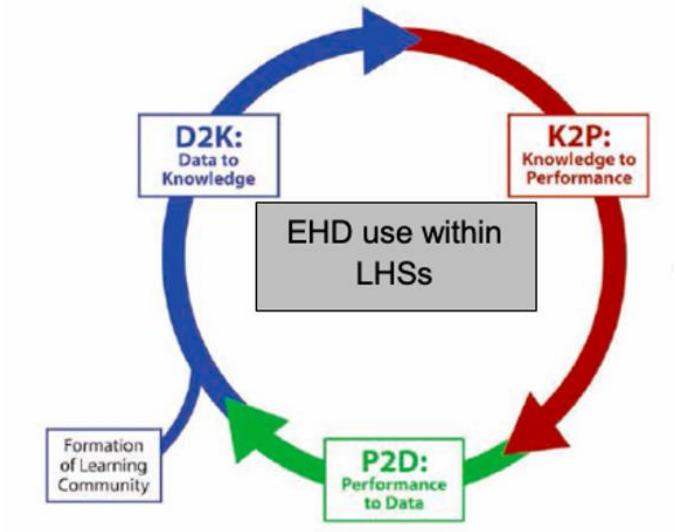

Figure 3.2 - LHS Learning Stages within the Learning Cycle (Adapted from Friedman et al's Learning Cycle)

Table 3.3

LHS Stages Based on Friedman et al's Learning Cycle (Friedman et al., 2017)

Learning Cycle Parameters and stages	**LHS stages**	**LHS Principles**	**AHA data measures**
Stage One: Converting data to knowledge (D2K)	Stage one	Principles one and four	**1)** Capacity for Electronic Clinical documentation (Q1), **4)** Use of EHRs that are certified based on Federal standards (Q12 - 2013; Q17 - 2016; 2016: Q18 - 2016).
Stage two: Applying knowledge to influence performance (K2P)	Stage one and two	Principle one, two, and four	**1)** Capacity for Electronic Clinical documentation (Q1- 2013; 2016; 2018)**, 2)** Capacity for decision support (Q1- 2013; 2016; 2018), **4)** Use of EHRs that are certified based on Federal standards (Q12 - 2013; Q17 – 2016; Q 18 - 2018).

Stage three: Documenting changes in performance to generate new data (P2D)	Stage one to three	All of principles one to four	**1)** Capacity for Electronic Clinical documentation (Q1 - 2013; 2016; 2018), Capacity for decision support (Q1 - 2013; 2016; 2018), **2)** Use of EHD for quality improvement and population health improvement measures (e.g., capacity for public health reporting) (Q18 - 2013; Q25 f-j - 2016; 2018). **4)** Use of EHRs that are certified based on Federal standards (Q12 - 2013; Q17 - 2016; 2018: Q18).

Meaningful Use Compliance

Meaningful use stage three compliance by HII and non HII hospitals will also be evaluated using the 2013, 2016 and 2018 AHAIT (AHA-ONC, 2013, 2016, 2018). Hospitals that will be considered meaningful use stage three compliant in this study include those which state that 1) they have not experienced any major challenges with trying to submit health information to public health agencies to meet meaningful use requirements; 2) their patients are able to access their medical information using applications configured to meet the application programing interfaces in their EHR; and 3) they provide support for Health Information Exchange (HIE) (sending and receiving of patients' health Information) through the use of Interface connection between EHR systems (e.g. HL7 interface) or through direct access to EHRs through remote or virtual access will be considered meaningful use stage three compliant in this study.

Given the early phase of the stage three requirement for meaningful use, this study will consider hospitals that meet two of the three above listed requirements as compliant for year 2018. These requirements are slightly different for each year within the AHAIT, particularly due to its enforcement which was to begin in 2018. For year 2016, two of the above stated requirements that are available within the data will be assessed. Hospitals that respond affirmatively to question one and any of the question three requirements within the AHAIT data for 2016 will be considered meaningful use stage three compliant. For year 2013, given that the level of health IT compliance that was required and assessed for hospitals were generally lower than that in 2016 and 2018, this study will be requiring all three requirements to be fulfilled for hospitals to be identified as having capacity to be meaningful use stage three compliant in 2013 (Table 3.4). The use of the AHAIT data set to assess compliance with meaningful use stage three criteria was based on the need to be able to ascertain with certainty which of the meaningful use criteria hospitals attest to. The decision was also based on the less biased nature of the AHAIT data set, which is not used for reimbursement or funding purposes.

Measures one to three in Table 3.4 summarize the above described meaningful use of EHR criteria that were introduced, in 2015 and were to become mandatory in 2018 in order to improve infrastructure for PGHD capture or use through the meaningful use stage three rules (CDC-CSELS, 2019). These measures and their corresponding AHA measures are shown in Table 3.4.

Table 3.4

Meaningful use stage three requirements used in this study and their corresponding AHA measures (AHA-ONC, 2013, 2016, 2018; CDC-CSELS, 2019)

	Meaningful use (promoting interoperability) stage three compliance measures in this study	**Question No. (AHAIT - 2018, 2016, 2013)**
1	Has not experienced any challenges with public reporting.	Q4i (2018), Q2 A4 - D4 (2016), Q2 A6 - Q2 C6 (2013)
2	Patients are able to access their medical information using applications configured to meet the API in their EHR.	Q3m (2018); (Equivalent question not available in 2016) Q1 C6 (2013)
3	Supports Health Information Exchange (Sending and Receiving Health Information): Uses Interface connection between EHR systems (e.g., HL7 interface) to send or receive patient information or has direct access to EHRs through remote or virtual access.	Q12d or e and Q13d or e (2018); Q6 C1 and C2 or Q 6F1 and F2 (2016); Q3B and Q6A and Q6B (2013).

PCORI Funded Hospitals

The PCORI web list will be used to obtain the names of PCORI funded hospitals for the years 2013, 2016, and 2018 (Table 3.5). PCORI has funded 1,698 projects between 2012 and 2020 (PCORI, 2020). (Table 3.5).

Table 3.5

Criteria for PCORI Funded Hospital Selection

PCORI Funded Hospitals	Hospitals that obtained PCORI funds for projects in years 2013, 2016, and 2018

Medical Home/Safety Net Hospitals

The CMS innovation award funding list will be used to identify safety net hospitals that became medical home/safety net hospitals between 2012 and 2014 (Table 3.6) (CMS, 2013). Funding for these projects lasted for three years. The list of the 107 medical home/safety net providers that received the award will be used in this study (CMS, 2013; Finkelstein et al., 2016). These safety net hospitals are designated medical home/safety net hospitals after obtaining CMS innovation award to attain the medical home/safety net hospital status. Safety net hospitals that are HII are more likely to obtain this funding to become medical home/safety net, and only a few safety net hospitals were able to become medical home/safety net hospitals between years 2012 and 2014.

Table 3.6

Criteria for Medical home/safety net Hospital Selection

Medical home/safety net hospitals	Hospitals that obtained CMS innovation award funding between years 2012 and 2014.

Control Variables

The control variables are other non – HII hospital characteristics that can also affect the capture and use of PGHD in addition to the measures of interest. The control variables include hospital location, size, teaching status, and ownership. Prior studies and evaluations based on the AHAIT data and meaningful

use attestations have shown that size, location, ownership, and teaching status have some effect on EHD adoption and use by hospitals. (AHAIT, 2018; Sandefer, Kleeberg, & David T, 2015). Rural hospitals, small sized hospitals, hospitals designated as critical access, state or local government-owned hospitals, and hospitals not engaged in graduate medical training (non-teaching hospitals) have been observed to have lower rates of EHD use when compared to other hospitals (AHAIT, 2018; Parasrampuria & Henry, 2015). Given the limited availability of large-scale studies on PGHD adoption by hospitals, EHD adoption is used above as a proxy for PGHD capture and use as stated above.

In this study, rural/urban designation will be based on hospital zip code, teaching status will be dependent on hospitals' participation in graduate medical education, and hospital size will be defined as the number of staffed beds. Hospitals with fewer than 100 beds will be categorized as small, those with 100 - 299 beds will be categorized as medium, and those with more than 300 beds will be categorized as large (AHAIT, 2018). Ownership categories will include publicly owned by a state or local government, and privately owned nonprofit, or for-profit hospitals.

Methods

In this section, I will describe the methods that will be used to assess the three aims.

Aim One

I will create a hospital typology that is functional and representative of my theoretical frame - HII hospitals that are EHD-driven, patient-centric and learning focused by identifying these hospital types within the AHAIT data. I will also examine their interrelationships within the data using cross tabulations. The chi-square test of association will be used to evaluate the differences across the years among identified subtypes and their interrelationships.

Essentially, in aim one, I will identify any distinct combinations of HII subcategories that I will compare with hospitals that are defined by unique subcategories or groups. I will seek to create a reasonable number of HII hospital groups in order to make sense of the data by identifying combinations of HII hospital characteristics for each year of the data and evaluate how they overlap (Figure 3.2). This will help to identify the distinct groupings by subtype of HII hospitals and to evaluate if their overlaps are incidental or if observed overlaps define new subtypes (Figure 3.2). Distinct groups with sizable numbers of hospitals will be identified, and groups that are too small to be evaluated in further analyses (e.g., regression) may be used as controls. (Figure 3.2). I will use a variety of methods to evaluate aim one, and these include cross tabulations, and tests of associations (e.g., chi-square) which will be used to examine if there are inter-relationships between identified distinct HII subcategories. The outcome of aim one will be to evaluate how valid HII hospitals are and to determine which of the

hospital subtypes should be dropped out of the HII typology. In aims two and three, identified HII hospitals and their subtypes will be evaluated comparatively to assess how much PGHD capture and use occurs in each subtype of HII hospitals.

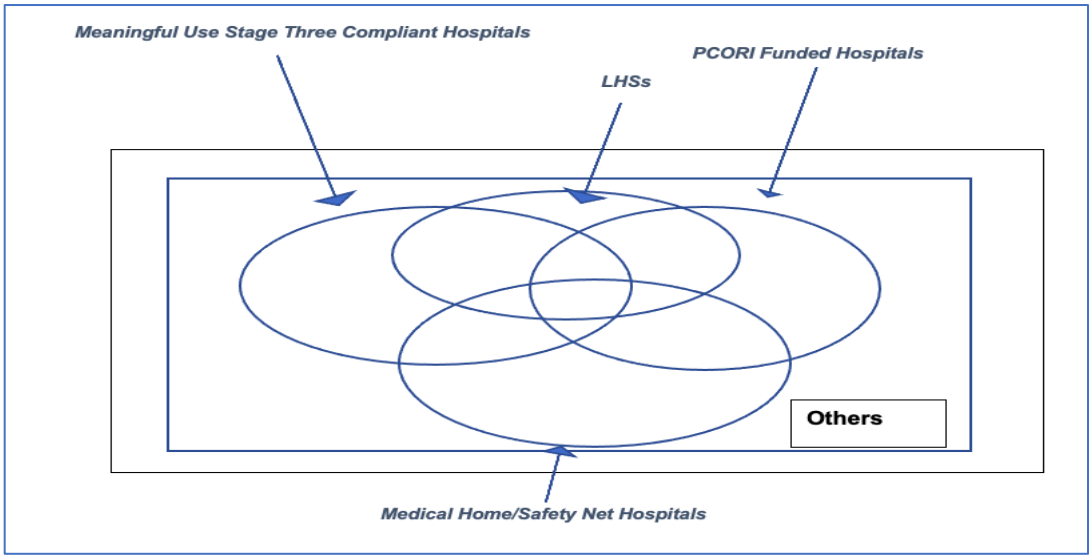

Figure 3.3: A Venn Diagram Showing Possible Interrelationships Between Hospitals Studied

Aim Two

Based on the typology created in aim one, aim two seeks to assess if HII hospitals as a whole or any of the hospitals that have been identified in aim one as HII hospital characteristics or HII subcategories (LHS principle practicing, meaningful use stage three compliant, PCORI funded, and medical home/safety net subcategories) (Figure 3.2) are more likely to capture and use PGHD using Linear Probability Models (LPMs). To achieve this, I will first ascertain if all HII

hospitals are associated with more PGHD capture and/or use when compared with non HII hospitals. I will then evaluate PGHD capture and use within each distinct identified HII hospital characteristic. I will use 2018 data to ascertain if HII hospitals are more associated with PGHD capture and/or use when compared with non HII hospitals. I will then use the 2018 data to further assess if any of the identified distinct HII hospital characteristic is more associated with PGHD capture and use. The use of the 2018 data is because the capture and use of PGHD has increased over time, and the final year of data is likely to show the strongest relationship with the outcome variable (PGHD capture or use). The LPM was selected for use in this study because the results directly identify the difference in the likelihood of a hospital capturing or using PGHD. The LPM is also more interpretable.

In this study, based on the LPM, the predicted outcome will be the probability that a hospital in a typology group would capture or use PGHD. In the comparative cross sectional analysis used, the coefficients of the hospital group/typology binary markers will estimate the difference in the probability that PGHD is captured or used for each group from the excluded comparison group i.e., hospitals that have none of the HII related EHD-driven, patient-centric, and learning focused hospital characteristics.

The regression specification can be summarized as:

PGHD capture or use $(Yi) = \beta_0 + \beta_1$ Hospital Group + β_2Controls + ϵ_i

Where:

- Y_i is either the PGHD use or capture outcome measure for each hospital i.
- β_0 is the intercept or estimated probability of PGHD use or capture for the comparison hospital group (not HII).
- Hospital group is the vector of binary or dummy variables indicating HIIs in general or hospital groups as identified by the typology. Hospital groups are the grouping of the hospitals based on the typology in aim one.
- β_1 is a vector of coefficients estimating the difference in the probability of the outcome for each hospital group from the comparison group, when other factors remain constant.
- Controls is the vector of hospital control variables noted above.
- β_2 is a vector of coefficients estimating the impact of control variables on the outcome.
- ϵ_i is a generalized error term for each hospital i

Aim Three

To better assess potential causal effects of HII hospital characteristics on PGHD capture and use on a basic level, I will use a generalized difference-in-

difference model with fixed hospital and time effects. Based on this, I will ascertain if there are changes in the capture or use of PGHD across the three study periods based on changes in HII hospital characteristics in comparison to hospitals with consistent HII or non HII hospital characteristics. I will first evaluate if joining any of the above specified programs (LHS, meaningful use stage three compliant, PCORI funded, and medical home/safety net subcategories) from a non HII status leads to a greater likelihood of PGHD capture and/or use. I will then evaluate if changing to a specific subtype of HII hospitals results in more PGHD capture and/or use.

Using the equation for aim two, I will add study year and hospital fixed effects. By adding the hospital and time fixed effects, the coefficients of the HII variables will enable an understanding of how changing to HII status generally or by specific subtype varies with hospital groups that did not change. To achieve this, I will first do a cross tabulation of the data to observe how changes occur over time. This will show me how many hospitals remain in their group and those that change status. I will then identify hospitals that are changing their HII status and carry out a regression analysis to evaluate if change in HII hospital characteristics is associated with changes in PGHD capture or use, compared to hospitals that change their HII hospital characteristics with those that remain static (e.g., comparing those that change from PCORI funded to PCORI funded and LHS with those that remain PCORI funded). Given that hospitals in the medical home/safety net subcategory do not change during the last two study periods (2016 and 2018)

I will not be able to assess change to a medical home/safety net subcategory (from being non HII) but I may be able to assess change from a medical home/safety net only subcategory to one that includes another HII subcategory, for example, assessing change to LHS status in addition to being a medical home/safety net subcategory.

Limitations

The categorization into hospital types will be based on LHS hospital characteristics within the literature and hospitals that are identified as PCORI grant funded or medical home/ safety net hospitals within the data. It will also be based on hospitals that are already complying with some of the meaningful use stage three criteria based on the AHAIT data. Also, the study will measure HII related hospital characteristics based on the available AHAIT data. Based on these, there may be unknown or missing characteristics that might have an influence on PGHD capture or use that is not captured in the study. Future studies that establish distinct hospital types within the US health system can be useful. Also, other factors that are unrelated to hospital type or characteristics measured in the study may be responsible for some of the observed changes in the capture and use of PGHD in hospitals. Such factors may not be readily captured in the data sets that will be used in this study, although future research could qualitatively examine hospital-specific organizational characteristics to identify and further understand

these factors. Secondly, there may be unmeasured confounders that can potentially bias the results, while measured HII hospital characteristics may be proxies for true characteristics that are driving PGHD capture and use.

Thirdly, given that in this study, there are three study periods, the generalized difference in difference analysis to ascertain potential causal effects of changes in HII characteristics on PGHD capture and use may not be strong enough to elicit the parallel trends assumption. Nevertheless, it will help to ascertain the existence of potential weak causal relationships between changes in HII characteristics and PGHD capture and use. Interrupted time series which is an alternative method could also be limited by the presence of few study periods in this study. Also, designation as medical home/safety net hospitals do not change from non HII to HII during the last two study periods, and their small sample size can also potentially limit their categorization into distinct groups. As earlier stated, I may be able to assess change from a medical home/safety net only status to one that includes another HII subtype during the study period.

The LPM could give individual observation estimates or the probability of association with PGHD association that are less than zero or greater than one, unlike logit and probit models which restrict estimates within the zero to one range. This is however unlikely an issue in this study because this study focusses on measuring mean effects of, or differences in PGHD capture and/or use, in HII hospital groups or subcategories. This study does not examine predictions of PGHD capture and/or use for individual hospitals.

Finally, this study measures PGHD capture and use through a focus on hospitals and their characteristics. In addition to hospital-related factors, it is likely that patient-related factors also influence PGHD capture and use. Future studies among patient populations can help shed more light on patient-related factors that may affect PGHD capture and use by health systems.

Purpose and Significance

A 2018 study among health care providers, health care administrators and health IT providers showed that 79% of respondents valued the use of PGHD to supplement consultations, while 72% saw PGHD as important in making more optimal decisions about patient care (Abdolkhani et al., 2019). PGHD allows for the augmentation of data captured in clinical settings with out-of-clinic patient data, which helps to deliver a more comprehensive picture of a patient's health status (Ancker, Mauer, Kalish, Vest, & Gossey, 2019). The provision of such patient sourced data has been observed to support improved personalized treatment plans (Abdolkhani et al., 2019; Rief et al., 2017). Other benefits include a reduction in hospital readmission and clinic visit rates, and improved facilitation of timely health provider advice (Abdolkhani et al., 2019).

These findings show that PGHD can facilitate improved care and therefore stimulate positive attitudes towards PGHD adoption within systems of care, but only if PGHD is captured and used meaningfully. This is more likely to occur among

hospitals that prioritize patient centric care and/or data - driven learning. In this analysis, I identify HII hospitals that do this through the following programs: LHS, meaningful use stage three compliance, PCORI funded, and medical home/safety nets. Prior studies on PGHD use have focused only on small scale interventions and over short periods of time. Little is known about whether hospitals are collecting and using PGHD on a larger scale, and perhaps more importantly, what policy levers can be used to promote PGHD collection and use. This study fills these gaps by evaluating PGHD adoption across US hospitals that respond to the AHAIT supplement within the three study periods. Furthermore, an evaluation of organizational programs and policies that are HII related and can influence PGHD capture and use in this study can assist health system leaders, policy makers, and researchers to understand the HII related hospital characteristics that are most amenable to PGHD capture and use.

In this study, it is expected that the prevalence of PGHD capture and use will be higher in hospitals that are electronic data driven and patient centric and implement principles of continuous learning and evidence-based improvement in care processes. Based on this, aim one of this study is focused on creating a typology of HII related hospitals or groups of hospitals that are related to being EHD-driven, learning focused and patient-centric. It is also expected that the number of hospitals with such characteristics has increased due to the increasing adoption of electronic data that is patient-sourced (Ancker et al., 2019; Austin et al., 2019). This adoption is facilitated by the US health system's interest in

improving care processes and facilitating patient centric continuous improvement in care processes (Austin et al., 2019; Austin & Pronovost, 2016; Pronovost et al., 2015).

The adoption of LHS principles, meaningful use stage three compliance, and the availability of PCORI and CMS funds for health IT innovation have facilitated the development of health IT driven – patient centric hospitals. This study assumes that this trend has facilitated PGHD capture and use among the hospitals and/or group(s) studied. Based on this, in aim two, this study expects that there will be some association between electronic data - driven and patient - centric hospitals and PGHD capture and/or use when compared to hospitals that do not have those characteristics. However, given the early phase of electronic PGHD capture and use across board, the relationship might not be as strong as is expected or can be. Changes are also expected to be observed in the level of PGHD capture and/or use among hospitals that are changing their characteristics to become more HII, electronic data driven and patient centric.

Aim three in this study which will help to clarify the relationships between these distinct HII hospital characteristics or group(s) is expected to show some causal relationships between programs and policies that were adopted to facilitate electronic data driven and patient centric approaches to care across the hospitals in the study. The basic potential causal relationships that may be elicited is expected to be homogenous in the direction of EHD-driven, patient - centric, HII

hospitals and their subcategories that have adopted organizational practices or policy incentives that facilitate health IT use.

Implications for Practice

The Identification of HII hospitals and their subtypes that are more likely to be associated with PGHD capture and use among patient focused and electronic data-driven hospitals might suggest the type of HII hospital principles that should be addressed in thinking about the capture and use of PGHD. An understanding of these HII hospital subtypes brings hospitals closer to being able to achieve their goal of improved care, that is delivered with precision, at a potentially lower cost and with less care fragmentation.

HII hospital characteristics that enable patient input in the form of PGHD to be used to inform care targets and continuous improvement purposes provide an avenue to learn from the data. This occurs by discovering associations, and understanding patterns and trends within the data, which has the potential to improve care, save lives and lower costs (Raghupathi & Raghupathi, 2014). Given that learning from patient sourced data can enable improved care and improved health outcomes, this study will further facilitate an understanding of the mechanisms through which this can be achieved. Findings from this study can also be used to inform the use of Senge's LO theory within systems of care that practice LO principles or identify as LOs.

Implications for Policy

An understanding of HII hospital characteristics that are most amenable to PGHD capture and use will enable policy makers to enact policies that are informed by this research. Also, an understanding of the effects of HII policy driven hospital characteristics evaluated in this study will enable hospital and health system leaders to understand the enabling and limiting effects of national scale health IT policies. Findings from this study will also facilitate health system leaders' and policy experts' understanding of the effects of PGHD and health IT related organizational policies on PGHD capture and use.

An understanding of the differential effects of these policies on different HII subcategories based on health IT policy adoption will also help to provide some information on HII hospital characteristics and policy types that can be replicated by hospitals that seek to become more patient focused through the use of EHD. Furthermore, policymakers are better able to understand the disparities in PGHD capture or use that may occur due to differences in HII hospital characteristics. Based on this, policy makers can make adjustment to how resources are allocated for PGHD capture and use in US hospitals. For example, hospitals in the medical home/safety net subcategory may need more support to attain their goals as it relates to the capacity for PGHD capture and use when compared to those in the PCORI funded subcategory.

Chapter Four - Study Findings

Introduction

This chapter of the dissertation discusses the results of the three study aims which were focused on understanding PGHD capture and use among HII hospitals and their subcategories through an exploration of two research questions. 1) What is the distribution of US hospitals that have Health Information Interested (HII) characteristics related to being learning focused, patient-centric, and electronic data-driven? 2) How do these identified HII hospital characteristics relate to the capture and use of PGHD? In this study I identify and refer to HII hospital characteristics as HII subcategories. This is given that each HII subcategory as earlier described has unique characteristics that pertain to being HII. Based on this, HII hospital characteristics or HII subcategories include being LHS, meaningful use stage three compliant, medical home/safety net and being PCORI funded. These HII hospital characteristics or HII subcategories were evaluated in this study using two research questions and three aims. The first research question was evaluated in aim one, which sought to distinguish HII hospitals from those that are not and then sought to distinguish interrelationships between subcategories of HII hospitals. The second research question was evaluated using aims two and three. Aim two sought to ascertain the existence of relationships between identified HII subcategories and PGHD capture and use through a cross sectional analysis

that was conducted using the latest year of data (2018). Aim three sought to ascertain if hospitals' change to a HII subcategory was associated with PGHD capture and use through difference in difference analyses that were conducted with the use of data from across all three study periods (2013, 2016, 2018). Each section of this chapter will begin with an overview of each aim, a brief description of how the HII hospital categories were evaluated, and a presentation of results of the analyses.

Aim One Results

In aim one, this study analyzed the health IT characteristics of HII hospitals based on the AHA heath IT supplement for 2013, 2016, and 2018. The study sought to examine US hospitals in order to understand the distribution of HII hospitals by using hospitals that practice LHS principles, PCORI funded, medical home/safety net and meaningful use stage three compliant hospitals as the basis. In order to understand the degree to which hospitals are HII, HII hospitals were first identified and distinguished from non HII hospitals as a whole, and then interrelationships between identified subcategories of HII hospitals were specifically identified using crosstabulations. This section will begin with a brief overview of the LHS principles that were used in this study to identify LHS hospitals and to evaluate their distribution and stages within the data. This will be followed by a brief overview of HII subcategories and their distribution and interactions

within the data. The section will then conclude with a summary table of the HII subcategories observed in the data across the three study periods.

Learning Health Systems Practicing Hospitals

Hospitals that were practicing LHS principles were identified by utilizing a multi - stage measure that was based on identified principles of LHS practicing hospitals within the literature which categorized hospitals with LHS related characteristics into stages of LHS development (C Friedman et al., 2017; Mullins et al., 2018). While only the highest stage of LHS development was determined to meet the HII definition for this study, the overall distribution of hospitals across LHS stages of development is explored to understand LHS development within the study period more fully. The literature based criteria for LHS stages were matched to corresponding questions within the AHA health IT supplement for 2013, 2016 and 2018 (C Friedman et al., 2017; Mullins et al., 2018). Table one below shows LHS stages one to three, their criteria, and the equivalent questions within the AHAIT supplement that were used to assess each of the stages.

Table 4.1

LHS Criteria for Each Stage Based on Friedman et al's Learning Cycle (Friedman et al., 2017)

		Equivalent questions within the AHA data		
LHS Stages	**LHS Criteria**	**2013**	**2016**	**2018**
LHS stage one	**Practices electronic clinical documentation and uses EHR platforms that are certified based on federal standards.**	**Yes (1) to Q1_A1 to Q1_G1 and Q12**	**Yes (1) to Q 1_A1 to Q1_G1 and Q 17**	**Yes (1) to Q1_A1 to Q1_F1, and to Q 18**
LHS stage two	Practices electronic clinical documentation and uses EHR platforms that are certified on federal standards. **Uses EHD for decision support**	Yes (1) to Q1_A1 to Q1_G1 and Q12 **Yes (1) to Q1_A4 to Q1_F4**	Yes (1) to Q 1_A1 to Q1_G1 and Q 17 **Yes (1) to Q1_A4 to F4**	Yes (1) to Q1_A1 to Q1_F1, and to Q 18 **Yes (1) to Q1_A4 to Q1_F4**
LHS stage three	Practices electronic clinical documentation and uses EHR platforms that are certified on federal standards. Uses EHD for decision support **Uses EHD for quality improvement and public health purposes**	Yes (1) to Q1_A1 to Q1_G1 and Q12 Yes (1) to Q1_A4 to Q1_F4 **Yes (1) to Q 18_6 to 9**	Yes (1) to Q 1_A1 to Q1_G1 and Q 17 Yes (1) to Q1_A4 to F4 **Yes (1) to Q25_F to Q25_J**	Yes (1) to Q1_A1 to Q1_F1, and to Q 18 Yes (1) to Q1_A4 to Q1_F4 **Yes (1) to Q25_F to Q25_J**

The specific requirement for each stage is written in bold

Table 4.2 shows the counts and percentages of hospitals that met the requirement for being categorized as meeting any LHS criteria and those that did not across the study periods. In 2013, of the 3,283 hospitals that responded to the AHAIT supplement 1,262 (38.4 %) total hospitals met the criteria for being categorized as meeting at least the first stage of LHS criteria. In 2016, of the 3,656 hospitals that responded to the AHAIT supplement 2,351 (64.3 %) hospitals met any LHS criteria. In 2018, of the 3,540 hospitals that responded to the AHAIT supplement 2,627 (74.2 %) hospitals met any LHS criteria.

Table 4.2

Hospitals That Met Any Criteria for Being Categorized as a LHS Hospital (2013 – 2016)

	2013		2016		2018	
Hospital Categories	**#**	**%**	**#**	**%**	**#**	**%**
Met any LHS Criteria	1262	38.4%	2351	64.3%	2627	74.2%
Did not meet any LHS criteria	2021	61.6%	1305	35.7%	913	25.8%
Total Respondents	**3283**		**3656**		**3540**	

The study then categorized each of the hospitals that met any LHS criteria into LHS stages one to three based on the previously defined LHS criteria. Table

4.3 describes the counts and percentages of the hospitals that met the criteria for each LHS stage across the study period. In 2013, LHS stage one hospitals were observed to be 352 (10.7%), stage two hospitals were observed to be 518 (15.8 %), while LHS stage three hospitals were observed to be 392 (11.9 %). In 2016, LHS stage one hospitals were 482 (13.2 %), LHS stage two hospitals were 763 (20.9 %), and LHS stage three hospitals were 1106 (30.3 %). In 2018, LHS stage one hospitals were 425 (12 %), LHS stage two were 884 (25 %), while LHS stage three were 1318 (37.2 %).

Table 4.3

Total Counts and Percentages of LHS and Non LHS Hospitals (2013 – 2018)

	2013		2016		2018	
LHS and Non LHS Hospitals	**#**	**%**	**#**	**%**	**#**	**%**
LHS Stage One	352	10.7%	482	13.2%	425	12.0%
LHS Stage Two	518	15.8%	763	20.9%	884	25.0%
LHS Stage Three	392	11.9%	1106	30.3%	1318	37.2%
Total non LHS	2021	61.6%	1305	35.7%	913	25.8%
Total Respondents	**3283**		**3656**		**3540**	

The large number of hospitals observed in LHS stage one, two, and three across the years was informative to this study given that the number of existing US LHS hospitals and their stages have not been evaluated in prior studies. Based on this gap, one of the goals of this exploratory study was to understand the number of hospitals practicing LHS principles, and to understand the degree to which these hospitals practice LHS principles by categorizing them into predefined LHS stages. This study observed that at least a third of all hospitals in each period are LHS stages one or two, which shows that a large proportion of hospitals are moving towards full LHS capacity (LHS stage three), however, are not there yet.

In this study, LHS stage three hospitals were categorized as full learning hospitals and they were identified as HII hospitals. This is because they meet all the criteria for being a full LHS hospital, which in turn meets all the criteria necessary to be categorized as a HII hospital as defined in this study. LHS stages one or two hospitals were categorized as emerging LHS hospitals because they do not meet all the criteria for being a LHS hospital and they were also identified as non HII hospitals. Given the large proportion of emerging LHS hospitals observed, they were retained as a group for further analysis throughout the study. Table 4.4 represents the count of full learning (stage three), emerging learning (stages one or two) and non-learning hospitals across the study. In 2013 the study observed that full LHS hospitals were 392 (11.9%), in 2016 they were 1106 (30.3%), and in 2018 they were 1318 (37.2%). In 2013, emerging LHS hospitals were 870 (26.5% of total respondents), in 2016, they were 1245 (34.1%), and in 2018, they were 1309 (37%).

Table 4.4

Full Learning, Emerging Learning, and Non-Learning hospitals

	2013		2016		2018	
Hospital Categories	**#**	**%**	**#**	**%**	**#**	**%**
Full Learning (LHS Stage Three)	392	11.9%	1106	30.3%	1318	37.2%
Emerging Learning (LHS One and Two)	870	26.5%	1245	34.1%	1309	37.0%
Non Learning	2021	61.6%	1305	35.7%	913	25.8%

Emerging LHS hospitals will be retained as a noted group within the study for analysis purposes because they are large and potentially different from either full LHS hospitals and non-HII hospitals. Other HII subcategories that were identified for inclusion in the study will be discussed in the next section.

HII Subcategories

HII hospitals are those that are patient centric and learning focused through the use of EHD as stated in the study's theoretical framework. HII hospitals, in addition to the full LHS HII subcategory defined above, included PCORI funded, medical home/safety nets and meaningful use stage three compliant subcategories. Table 4.5 represents the counts and percentages of the HII subcategories defined in the study. In 2013, of the 3,283 respondents, hospitals in the PCORI funded subcategory were 64 (2%), those in the medical home/safety net subcategory were 22 (0.7%), while those in the meaningful use stage three compliant subcategory were 295 (9%). In 2016, of the 3,656 total respondents, hospitals in the PCORI funded subcategory were 53 (1.5%), those in the medical home/safety net subcategory were (0.7%), while those in the meaningful use stage three compliant subcategory were 1,544 (42.2%). In 2018, of the 3,540 total respondents, hospitals in the PCORI funded subcategory were 101 (2.9%), those in the medical home/safety net subcategory were 14 (0.4%), while those in the meaningful use stage three compliant subcategory were 1,661 (46.9%). As shown in Table 4.5, hospitals in the PCORI funded subcategory were observed to be between one and three percent of all hospitals, while those in the medical home/safety net subcategory were observed to be less than one percent of all hospitals across the study periods. The small size of the medical home/safety net

subcategory made it difficult to accurately access their relationship to PGHD capture or use.

Table 4.5

HII Hospitals (2013 to 2018) (counts and percentages for each HII type are independent of other HII types .i.e. not additive)

	2013		2016		2018	
HII Hospital Categories	**#**	**%**	**#**	**%**	**#**	**%**
PCORI Funded	64	2.0%	53	1.5 %	101	2.9%
Medical Home/Safety Nets	22	0.7%	24	0.7 %	14	0.4%
Meaningful Use Stage three Compliant	295	9.0%	1544	42.2 %	1661	46.9%
Full LHS	392	11.9%	1106	30.3 %	1318	37.2 %
Total HII	652	19.9%	1825	49.9 %	2209	62.4 %
Non HII	2631	80.1 %	1831	50.1 %	1331	37.6 %
Total Respondents	**3283**		**3656**		**3540**	

Evaluating HII Subcategory Interactions

HII Crosstabulations

HII subcategory interactions were evaluated in order to understand how they interact. To achieve this, hospitals in the four HII subcategories were cross tabulated with each other per year of data. In this section, hospitals in the full LHS subcategory were first cross tabulated with those in the meaningful use stage three compliant subcategory, this was followed by full LHS and PCORI funded subcategory cross tabulations, and then full LHS and medical home/safety net subcategory cross tabulations. Hospitals in the meaningful use stage three compliant subcategory were then cross tabulated with those in the PCORI funded subcategory and this was followed by cross tabulations of hospitals in the

meaningful use stage three compliant subcategory with those in the medical home/safety net subcategory. Finally, hospitals in the PCORI funded subcategory were cross tabulated with those in the medical home/safety net subcategory.

Table 4.6 shows cross tabulations of hospitals in the full LHS and meaningful use stage three compliant subcategories across the study periods. Hospitals in the full LHS subcategory were more likely to be meaningful use stage three compliant than those in the non-full LHS category. Although hospitals in both the full LHS subcategory and those in the non-full LHS category increased their meaningful use stage three compliant status across the study periods. In 2013, 23.3% of hospitals in the full LHS subcategory were in combination with hospitals in the meaningful use stage three compliant subcategory when compared to 7.1 % of hospitals in the non-full LHS category (chi - sq = 110.2, $p < 0.01$). In 2016, the percentage of hospitals in the full LHS subcategory that were in combination with hospitals in the meaningful use stage three compliant subcategory grew to 75.5% when compared to 27.8% of hospitals in the non-full LHS category (chi - sq = 719, $p < 0.01$). In 2018, the percentage of hospitals in the full LHS subcategory that were in combination with those in the meaningful use stage three compliant subcategory dropped to 59.8% and this was still higher than the percentage of hospitals in the non-full LHS category that were in combination with hospitals in the meaningful use stage three compliant subcategory (39.3 %) (chi - sq = 139.6, $p < 0.01$).

Table 4.6

Full LHS and Meaningful Use Stage Three Compliant Subcategory Crosstabulations

	2013			2016			2018		
HII Sub - Category	Full LHS	Non Full LHS	Chi. sq	Full LHS	Non Full LHS	Chi. sq	Full LHS	Non Full LHS	Chi. sq
Meaningful use #	91	204	110.2**	835	709	719**	788	873	139.6**
Meaningful use %	23.3%	7.1%		75.5%	27.8%		59.8%	39.3%	
Non meaningful use #	301	2687		271	1841		530	1349	
Non meaningful use %	76.8%	92.9%		24.5%	72.2%		40.2%	60.4%	
*p < 0.05 , **p<0.01									

Table 4.7 shows the cross tabulations of hospitals in the full LHS and PCORI funded subcategories across the study period. Hospitals in the PCORI funded subcategory were more likely to be in combination with those in the full LHS subcategory when compared with hospitas in the non PCORI funded category, although the percentages of hospitals in both the PCORI funded HII subcategory and those in the non PCORI funded category that were in combination with hospitals in the full LHS subcategory increased across the study period. In 2013, 21.9% of hospitals in the PCORI funded subcategory were in combination with hospitals in the full LHS subcategory when compared with 11.7% of hospitals in the non PCORI funded subcategory (chi - sq = 6.1, $p < 0.05$). In 2016, the percentage of hospitals in the PCORI funded subcategory that were in combination with those in the full LHS subcategory grew to 54.7% when compared to 29.9% of hospitals in the non PCORI funded category (chi - sq = 15.3, $p < 0.01$). In 2018, the percentage of hospitals in the PCORI funded subcategory that were in combination with those in the full LHS subcategory further increased to 67.3% when compared to 36.3% of hospitals in the non PCORI funded category (chi – sq = 40.3, $p < 0.01$).

Table 4.7

Full LHS and PCORI Funded Subcategory Crosstabulations (2013 – 2018)

	2013			2016			2018		
HII Sub - Category	PCORI	Non PCORI	Chi. sq	PCORI	Non PCORI	Chi. sq	PCORI	Non PCORI	Chi. sq
Full LHS #	14	378	6.1*	29	1077	15.3**	68	1250	40.3**
Full LHS %	21.9%	11.7%		54.7%	29.9%		67.3%	36.3%	
Non Full LHS #	50	2841		24	2526		33	2189	
Non Full LHS %	78.1%	88.3%		45.3%	70.1%		32.7%	63.7%	
*p < 0.05 , **p<0.01									

Table 4.8 shows the cross tabulations of hospitals in the full LHS and medical home/safety net subcategories across the study periods. In 2016 and 2018, hospitals in the medical home/safety net subcategory were more likely to be in combination with those in the full LHS subcategory when compared with hospitals in the non-medical home/safety net category. In 2016, hospitals in the medical home/safety net subcategory that were in combination with those in the full LHS subcategory grew to 91.7% when compared with 29.8% of hospitals in the non-medical home/safety net category (chi - sq = 43.2; $p < 0.01$). In 2018, hospitals in the medical home/safety net subcategory that were in combination with those in the full LHS subcategory grew to 92.9% when compared with 37% of those in the non-medical home safety net category (chi - sq = 18.6; $p < 0.01$).

Table 4.8

Full LHS and Medical Home/Safety Net Subcategory Crosstabulations (2013 - 2018)

	2013			2016			2018		
HII Sub - Category	MH/SN	Non MH/SN	Chi. sq	MH/SN	Non MH/SN	Chi. sq	MH/SN	Non MH/SN	Chi. sq
Full LHS #	5	387	2.5	22	1084	43.2**	19	1305	18.6**
Full LHS %	22.7%	11.9%		91.7%	29.8%		92.9%	37.0%	
Non Full LHS #	17	2874		2	2548		1	2221	
Non Full LHS %	77.3%	88.1%		8.3%	70.2%		7.1%	63.0%	
*p < 0.05 , **p<0.01	MH/SN: Medical Home/Safety Nets								

Table 4.9 shows crosstabulations of hospitals in the meaningful use stage three compliant and the PCORI funded subcategory across the study periods. Hospitals in the PCORI funded subcategory were more likely to be in combination with those in the meaningful use stage three compliant subcategory when compared to hospitals in the non PCORI funded category, although the percentage of hospitals in the non PCORI funded category that were in combination with hospitals in the meaningful use stage three compliant subcategory also increased across the study periods. In 2013, 20.3% of hospitals in the PCORI funded subcategory were in combination with those in the meaningful use stage three compliant subcategory when compared with 9% of hospitals in the non PCORI funded category. In 2016, hospitals in the PCORI funded subcategory that were in combination with hospitals in the meaningful use stage three complaint subcategory increased to 76% when compared with 42% of hospitals in the non PCORI funded category (chi - sq = 24.4, $p < 0.01$). In 2018 although the percentage of hospitals in the PCORI funded subcategory that were in combination with hospitals in the meaningful use stage three compliant subcategory decreased to 60%, this was still greater than the percentage of hospitals in the non PCORI funded category that were in combination with hospitals in the meaningful use stage three compliant subcategory (47%) (chi – sq = 7.6, $p < 0.01$).

Table 4.9

Meaningful Use Stage Three Compliant and PCORI Funded Subcategory Crosstabulations

	2013			2016			2018		
HII Subcategory	**PCORI**	**Non PCORi**	**Chi. Sq**	**PCORI**	**Non PCORI**	**Chi. Sq**	**PCORI**	**Non PCORI**	**Chi. sq**
Meaningful use #	13	282	10.2*	40	1504	24.4**	61	1600	7.6**
Meaningful use %	20%	9%		76%	42%		60%	47%	
Non meaningful use #	51	2937		13	2099		40	1839	
Non meaningful use %	79.7%	91.2%		24.5%	58.3%		39.6 %	53.5%	
***p<0.05, **p<0.01**									

Table 4.10 shows the cross tabulation of hospitals in the meaningful use stage three compliant and medical home safety net subcategories across the study periods. Hospitals in the medical home/safety net subcategory were more likely to be in combination with those in the meaningful use stage three compliant subcategory. In 2013, 13.6% of hospitals in the medical home/safety net subcategory were in combination with those in the meaningful use stage three compliant subcategory when compared with 9% of hospitals in the non-medical home/safety net category (chi – sq = 1, p = 0.444). In 2016, hospitals in the medical home/safety net subcategory that were in combination with hospitals in the meaningful use stage three compliant subcategory grew to 83.3 % when compared to 42% of hospitals in the non-medical home/safety net categrory (chi - sq = 16.7, $p < 0.01$). In 2018, although the percentage of hospitals in the medical home safety net subcategory that were in combination with hospitals in the meaningful use stage three subcategory reduced to 71.4%, this was still higher than the percentage of hospitals in the non-medical home/safety net category that were in combination with hospitals in the meaningful use stage three compliant subcategory (chi - sq = 3.4, $p < 0.05$).

Table 4.10

Meaningful Use Stage Three Compliant and Medical Home/Safety Net Subcategory Cross tabulations (2013 – 2018)

	2013			2016			2018		
HII Sub - Category	**MH/SN**	**Non MH/SN**	**Chi. sq**	**MH/SN**	**Non MH/SN**	**Chi. sq**	**MH/SN**	**Non MH/SN**	**Chi. sq**
Meaningful use #	3	292	1	20	1524	16.7**	10	1651	3.4*
Meaningful use %	13.6%	9.0%		83.3%	42%		71.4%	48.6%	
Non meaningful use #	19	2969		4	2108		4	1875	
Non meaningful use %	86.4%	91%		16.7%	58%		28.6%	53.2%	
***p < 0.05 , **p<0.01**	MH/SN: Medical Home/Safety Nets								

Table 4.11 shows the crosstabulations between hospitals in the PCORI funded and medical home/safety net subcategories across the study periods. Hospitals in the medical home/safety net subcategory were more likely to be in combination with those in the PCORI funded subcategory when compared with hospitals in the non-medical home/safety net category. In 2013, 13.6% of hospitals in the medical home/safety net subcategory were in combination with hospitals in the PCORI funded subcategory when compared with 1.9% of hospitals in the non-medical home/safety net category (chi - sq = 15.8, $p < 0.001$). By 2016, hospitals in the medical home/safety net subcategory that were in combination with hospitals in the PCORI funded subcategory dropped to 4.2%, but this was still higher than the percentage of hospitals in the non-medical home/safety net category that were in combination with hospitals in the PCORI funded subcategory (1.4%) (chi - sq = 1.2, $p = 0.264$). By 2018, hospitals in the medical home/safety net subcategory that were in combination with hospitals in the PCORI funded subcategory grew to 21.4% and this was higher than the percentage of hospitals in the non-medical

home/safety net category that were in combination with hospitals in the PCORI funded subcategory (2.8%) (chi - sq = 17.5, p < 0.001).

Table 4.11

PCORI funded and Medical Home/Safety Net Subcategory Cross tabulations (2013 – 2018)

	2013			2016			2018		
HII Sub - Category	MH/SN	Non MH/SN	Chi. sq	MH/SN	Non MH/SN	Chi. sq	MH/SN	Non MH/SN	Chi. sq
PCORI funded #	3	61	15.8**	1	52	1.2	3	98	17.5**
PCORI funded %	13.6%	1.9%		4.2%	1.4%		21.4%	2.8%	
Non PCORI funded #	19	3200		23	3580		11	3428	
Non PCORI funded %	86.4%	98.1%		95.8%	98.6%		78.6%	97.2%	

*p < 0.05 , **p<0.01

Summary Table of Hospital Categories Observed in Aim one

This section summarizes the HII subcategories that were observed in aim one. Table 4.12 shows a list of HII hospital categories across the three study periods by single or multiple subcategories and their unique counts and percentages (i.e., when they are not in other groups). The table begins with the single and multiple HII subcategories observed in 2013 and continues till 2018. The table was organized from the largest to the smallest category of HII subcategories based on the 2018 data because the 2018 data will be the focus of further regressions in aim two of this study. In 2018, the full LHS subcategory, the meaningful use stage three compliant subcategory and hospitals in the full LHS and meaningful use stage three compliant subcategory interaction were the dominant hospital categories. The PCORI funded subcategory made up less than

1 % of all HII hospitals, and no stand-alone medical home/safety net hospitals were observed. Stand - alone triple and quadruple hospital categories (e.g., combinations that included full LHS, meaningful use stage three compliant, and medical home safety net subcategories or combinations that involved all four HII subcategories) were generally less than one percent or non – existent. The next section will describe how these HII subcategories and their interactions were evaluated in aim two in order to understand their relationship with PGHD capture and use.

Table 4.12

HII Hospital Single and Multiple Subcategories Across the Study Period (2013 – 2018)

	2013		2016		2018	
HII Sub - Category	**#**	**%**	**#**	**%**	**#**	**%**
Meaningful use stage three only	195	29.9 %	694	38.0 %	858	38.8 %
Full LHS and Meaningful use stage three	85	13 %	791	43.4 %	734	33.2 %
Full LHS only	289	38.9 %	264	14.5 %	505	22.9 %
Full LHS & Meaningful Use Stage3 & PCORI	5	0.8 %	25	1.4 %	44	2 %
Full LHS & PCORI	8	1.20%	4	0.2 %	22	1 %
PCORI only	41	6.3 %	9	0.5 %	17	0.8 %
Meaningful Use Stage 3 & PCORI	7	1.1 %	14	0.8 %	15	0.7 %
Full LHS & Meaningful use Stage 3 & Medical Home Safety Nets	1	0.2 %	19	1.0 %	8	0.4 %
Full LHS & Medical Home Safety Nets	3	0.5 %	3	0.2 %	3	0.1 %
All Four	0	0	0	0	2	0.1 %
PCORI & Medical Home Safety Nets	1	0.2 %	0	0	1	0.1 %
Medical Home Safety Nets only	14	2.1 %	1	0.1 %	0	0
Meaningful Use Stage 3 & PCORI & Medical Home Safety Nets	1	0.2 %	1	0.1 %	0	0
Full LHS & PCORI & Medical Home Safety Nets	1	0.2 %	0	0	0	0
Meaningful Use Stage 3 & Medical Home Safety Nets	1	0.2%	0	0	0	0
Total HIIs Per Year	**652**	**100**	**1825**	**100**	**2209**	**100**
Non HIIs	2631	80.1 %	1831	50.1 %	1331	37.6 %
Total Respondent	3283	100	3656	100	3540	100

Aim Two Results

Aim two of this study sought to ascertain the existence of relationships between identified HII subcategories and PGHD capture and use by using a cross sectional study that was conducted using the latest year of data. Based on the hospital categories identified in aim one, aim two of this study assessed if HII Hospitals as a whole or any of the hospitals that have been identified in aim one as HII subcategories are more likely to capture and use PGHD by using LPMs. To achieve this, the study first ascertained if all HII hospitals are associated with more PGHD capture and use when compared with non HII hospitals. The study then evaluated PGHD capture and use within each distinct identified HII subcategory. This section of aim two results will begin with descriptive summaries of the non-health IT hospital characteristics of HII hospitals and their subcategories that were used as control variables in the aim two regressions. These descriptive summaries will then be followed by the results of the LPMs that were used to assess PGHD capture and use among HII hospitals as a whole and then among distinct HII subcategories and their interactions.

Descriptive Summaries of the Hospitals in the Study

This section will discuss descriptive summaries of non-health IT characteristics of the HII and non HII hospitals in the study. The descriptive summaries included teaching, location, ownership and bed size status of the

hospitals in the study. These non-health IT characteristics of HII and non HII hospitals were based on the 2018 data.

HII and non HII Hospitals

Table 4.13 below shows the descriptive summaries of HII and non HII hospitals in the study sample for 2018. Approximately two thirds (63.8 %) of the hospitals in the study sample were non-teaching, and HII and non HII hospitals were statistically different (chi. sq = 63.4, $p < 0.001$) with more than two thirds of non HII hospitals having non-teaching status (72.4% versus 58.5%). More than half (58.5%) of all hospitals sampled were metro located and HII and non HII hospitals in the data were statistically different (chi. sq = 29.9, $p < 0.001$) with approximately two thirds (62 %) of HII hospitals and more than half of non HII hospitals being metro located (62% versus 52.7%). More than half (59.5%) of all hospitals in the study sample were nonprofit and HII and non HII hospitals were statistically different (chi - sq = 225.7, $p < 0.001$) with about two thirds of HII hospitals and nearly half of non HII hospitals being nonprofit (68.8% versus 43.3%). Nearly half (49.7%) of all hospitals sampled were small (< 100 staffed beds) and less than one-fifth were large (18.5%). HII and non HII hospitals were statistically different (chi - sq = 173.6, $p < 0.001$) with non HII hospitals having a higher percentage of small hospitals than HII hospitals (62.5% versus 42%).

Table 4.13

Descriptive Summaries for HII and Non HII hospitals (2018)

	Total 2018 Sample		HII		Non-HII		
Sample Characterstics	#	%	#	%	#	%	chi-sq
Total	3540	100	2209	100	1331	100	
Teaching							83.4**
Major	214	6.0 %	177	8.0%	37	2.8%	p < 0.001
Minor	1069	30.2 %	739	33.5%	330	24.8%	
Not Teaching	2257	63.8 %	1293	58.5%	964	72.4%	
Location							29.9**
Metro	2071	58.5 %	1370	62.0%	701	52.7%	p < 0.001
Rural	1038	29.3 %	592	26.8%	446	33.5%	
Unknown	431	12.2 %	247	11.2%	184	13.8%	
Ownership							225.7**
For Profit	690	19.5 %	328	14.8%	362	27.2%	p < 0.001
Non-Profit	2096	59.2 %	1519	68.8%	577	43.3%	
Fed. Gov.	59	1.7 %	35	1.6%	24	1.8%	
Non-Fed Gov.	688	19.4 %	324	14.7%	364	27.3%	
Unknown(?)	7	0.2 %	3	0.1%	4	0.3%	
Bed Size							173.6**
Small (< 100 beds)	1760	49.7 %	928	42.0%	832	62.5%	p < 0.001
Medium (100 - 299 beds)	1125	31.8 %	752	34.0%	373	28.0%	
Large (> 300 beds)	655	18.5 %	529	23.9%	126	9.5%	
**=p<.01, *=p<.05							

HII Subcategories in the Study

Tables 4.14 and 4.15 show the descriptive summaries for the HII subcategories in the study. Table 4.14 shows descriptive summaries comparing hospitals in the full LHS HII subcategory to those in the non-full LHS category, and hospitals in the meaningful use stage three compliant HII subcategory to those that were not. For hospitals in the study sample that were in the full LHS subcategory, approximately two thirds (63.8%) of the hospitals were non-teaching and hospitals

in the full LHS HII subcategory and those in the non-full LHS category were statistically different (chi - sq = 107.1, p < 0.001) with more than two thirds of hospitals in the non-full LHS category and more than half of hospitals in the full LHS subcategory having non-teaching status (69.6% versus 53.9%). Nearly three fifth (58.5%) of all hospitals sampled were metro located and hospitals in the full LHS HII subcategory and those in the non-full LHS subcategory were statistically different (chi - sq = 111.1, p < 0.001) with more than two thirds of those in the full LHS subcategory and more than half of those in the non-full LHS category being metro located (68.7% versus 52.4%). Nearly three fifth (59.5%) of all hospitals in the study sample were nonprofit and those in the full LHS subcategory and those in the non-full LHS category were statistically different (chi - sq = 201.3, p < 0.001) with nearly three fourth of hospitals in the full LHS subcategory and about half of those in the non-full LHS subcategory being nonprofit (73.9% versus 50.5%). Nearly half (49.7%) of all hospitals sampled were small (< 100) and less than one-fifth were large (18.5%). Hospitals in the full LHS and those in the non-full LHS category were statistically different (chi - sq = 255.1, p < 0.001) with those in the non-full LHS category having a higher percentage of small hospitals than those in the full LHS subcategory (59.3% versus 33.6%).

For hospitals in the the study sample that were in the meaningful use stage three compliant subcategory approximately two thirds (63.8%) of the hospitals were non-teaching and hospitals in the meaningful use stage three compliant subcategory and those in the non-meaningful use stage three compliant category

were statistically different (chi - sq = 34.3, p < 0.001) with more than two thirds of hospitals in the non-meaningful use stage three compliant category and less than three fifth of those in the meaningful use stage three compliant subcategory having non-teaching status (67.1% versus 60%). Nearly three fifth (58.5%) of all hospitals sampled were metro located and those in the meaningful use stage three compliant subcategory and those in the non-meaningful use stage three compliant category in the data were statistically different (chi - sq = 9.3, p = 0.009) with nearly three fifth and more than half of hospitals in the meaningful use stage three compliant subcategory and those in the non-meaningful use stage three compliant category being metro located (58.6% versus 52.4%). Nearly three fifth (59.5%) of all hospitals in the study sample were nonprofit and hospitals in the meaningful use stage three compliant subcategory and those in the non-meaningful use stage three compliant category were statistically different (chi - sq = 241.9, p < 0.001) with more than two thirds of hospitals in the meaningful use stage three compliant subcategory and nearly half of those in the non-meaningful use stage three compliant category being nonprofit (71.6% versus 48.3%). Nearly half (49.7%) of all hospitals sampled were small (< 100) and less than one-fifth were large (18.5 %) and those in the meaningful use stage three compliant subcategory and those in the non-meaningful use stage three compliant category were statistically different (chi - sq = 26.6, p < 0.001) with hospitals in the non-meaningful use stage three compliant category having a higher percentage of small hospitals than

hospitals in the meaningful use stage three compliant subcategory (52.6% versus 46.4%).

Table 4.14

Descriptive Summaries for Full LHS and Meaningful Use Stage Three Compliant HII Subcategories (2018)

	Total 2018 Sample		Full LHS		Non Full LHS			Total 2018 Sample		MU		Non MU		
Sample Characterstics	#	%	#	%	#	%	chi-sq	#	%	#	%	#	%	chi-sq
Total	3540	100	1318	100	2222	100		3540	100	1661	100	1879	100	
Teaching							107.1**							34.3**
Major	214	6.0 %	129	9.8 %	85	3.8 %	p < 0.001	214	6%	137	8.2 %	77	4.1 %	p < 0.001
Minor	1069	30.2 %	479	36.3 %	590	26.6 %		1069	30.2 %	527	31.7 %	542	28.8 %	
Not Teaching	2257	63.8 %	710	53.9 %	1547	69.6 %		2257	63.8 %	997	60%	1260	67.1 %	
Location							111.1**							9.3**
Metro	2071	58.5 %	906	68.7 %	1165	52.4 %	p < 0.001	2071	58.5 %	974	58.6 %	1097	58.4 %	p = 0.009
Rural	1038	29.3 %	253	19.2 %	785	35.3 %		1038	29.3 %	512	30.8 %	526	28%	
Unknown	431	12.2 %	159	12.1 %	272	12.2 %		431	12.2 %	175	10.5 %	256	13.6 %	
Ownership							201.3**							241.9**
For Profit	690	19.5 %	198	15%	492	22.1 %	p < 0.001	690	19.5 %	166	10%	524	27.9 %	p < 0.001
Non-Profit	2096	59.2 %	974	73.9 %	1122	50.5 %		2096	59.2 %	1189	71.6 %	907	48.3 %	
Fed. Gov.	59	1.7 %	12	0.9 %	47	2.1 %		59	1.7 %	31	1.9 %	28	1.5 %	
Non-Fed Gov.	688	19.4 %	132	10 %	556	25.0 %		688	19.4 %	273	16.4 %	415	22.1 %	
Unknown(?)	7	0.2 %	2	0.2 %	5	0.2 %		7	0.2 %	2	0.1 %	5	0.3 %	
Bed Size							255.1**							26.6**
Small (< 100 beds)	1760	49.7 %	443	33.6%	1317	59.3%	p < 0.001	1760	49.7 %	771	46.4%	989	52.6%	p < 0.001
Medium (100 - 299 beds)	1125	31.8 %	493	37.4%	632	28.4%		1125	31.8 %	526	31.7%	599	31.9%	
Large (> 300 beds)	655	18.5 %	382	29.0%	273	12.3%		655	18.5 %	364	21.9%	291	15.5%	
**=p<.01, *=p<.05 Meaningful Use: MU														

Table 4.15 shows descriptive summaries for hospitals in the PCORI funded and medical home/safety net HII subcategories in the study sample. For hospitals in the PCORI funded subcategory, approximately two thirds (63.8%) were non-teaching and hospitals in the PCORI funded subcategory and those in the non-PCORI funded category were statistically different (chi - sq = 195.4, $p < 0.001$) with nearly two thirds of hospitals in the non-PCORI funded category and more than a third of hospitals in the PCORI funded subcategory having non-teaching status

(64.6% versus 36.6%). Nearly three fifth (58.5%) of all hospitals sampled were metro located and hospitals in the PCORI funded subcategory and those in the non-PCORI funded category in the data were statistically different (chi - sq = 30.4, $p < 0.001$) with about three fourth of those in the PCORI funded subcategory and nearly three fifth of those in the non-PCORI funded category being metro located (76.2% versus 58%). Nearly three fifth (59.5%) of all hospitals in the study sample were nonprofit and hospitals in the PCORI funded subcategory and those in the non-PCORI funded category were statistically different (chi square of 31.4, $p < 0.001$) with more than five sixth of hospitals in the PCORI funded subcategory and nearly three fifth of hospitals in the non PCORI funded category being nonprofit (85.1% versus 58.4%). Nearly half (49.7%) of all hospitals sampled were small (< 100) and less than one-fifth were large (18.5%) and hospitals in the PCORI funded subcategory and those in the non-PCORI funded category were statistically different (chi - sq = 90.3, $p < 0.001$) with hospitals in the non PCORI funded category having a higher percentage of small hospitals than those in the PCORI funded subcategory (50.7% versus 14.9%).

For hospitals in the medical home/safety net subcategory in the study sample, approximately two thirds (63.8%) of the hospitals were non-teaching and hospitals in the medical home/safety net subcategory and those in the non-medical home/safety net category were statistically different (chi - sq = 70.4, $p < 0.001$) with none of the hospitals in the medical home/safety net subcategory and two thirds of those in the non-medical home/safety net category having non-teaching

status (0% versus 64%). Nearly three fifth (58.5%) of all hospitals sampled were metro located and hospitals in the medical home/safety net subcategory and those in the non-medical home/safety net category within the data were statistically different (chi - sq = 10, $p < 0.001$) with all hospitals in the medical home/safety net subcategory and three fifths of hospitals in the non-medical home/safety net category being metro located (100% versus 58.3%). Nearly three fifth (59.5%) of all hospitals in the study sample were nonprofit and hospitals in the medical home/safety net subcategory and those in the non-medical home/safety net category were statistically different (chi - sq = 3.9, $p < 0.001$) with more than three quarters of hospitals in the medical home/safety net subcategory and nearly three fifth of hospitals in the non-medical home/safety net category being nonprofit (78.6% versus 59.1%). Nearly half (49.7%) of all hospitals sampled were small (< 100) and less than one-fifth were large (18.5%) and hospitals in the medical home/safety net subcategory and those in the non-medical home/safety net category were statistically different (chi - sq = 26.9, $p < 0.001$) with hospitals in the non-medical home/safety net category having a higher percentage of small hospitals than those in the medical home/safety net subcategory (49.9% versus 1%).

Table 4.15

Descriptive Summaries for PCORI Funded and Medical Home/Safety Net HII subcategories (2018)

	Total 2018 Sample		PCORI		Non PCORI			Total 2018 Sample		MH/SN		Non MH/SN		
Sample Characterstics	#	%	#	%	#	%	chi-sq	#	%	#	%	#	%	chi-sq
Total	3540	100	101	100	3439	100		3540	100	14	100	3526	100	
Teaching							195.4**							70.4**
Major	214	6.0 %	39	38.6%	175	5.1%	p < 0.001	214	6%	8	57.1%	206	5.8%	p < 0.001
Minor	1069	30.2 %	25	24.8%	1044	30.4%		1069	30.2 %	6	42.9%	1063	30.1%	
Not Teaching	2257	63.8 %	37	36.6%	2220	64.6%		2257	63.8 %	0	0%	2257	64	
Location							30.4							10**
Metro	2071	58.5 %	77	76.2%	1994	58%	p < 0.001	2071	58.5 %	14	100%	2057	58.3%	p < 0.001
Rural	1038	29.3 %	5	5.0%	1033	30.0%		1038	29.3 %	0	0%	1038	29.4 %	
Unknown	431	12.2 %	19	18.8%	412	12.0%		431	12.2 %	0	0%	431	12.2 %	
Ownership							31.4							3.9**
For Profit	690	19.5 %	3	3.0%	687	20.0%	p < 0.001	690	19.5 %	0	0%	690	19.6%	p < 0.001
Non-Profit	2096	59.2 %	86	85.1%	2010	58.4%		2096	59.2 %	11	78.6%	2085	59.1%	
Fed. Gov.	59	1.7 %	0	0.0%	59	1.7 %		59	1.7 %	0	0%	59	1.7 %	
Non-Fed Gov.	688	19.4 %	12	11.9%	676	19.7%		688	19.4 %	3	21.4%	685	19.4%	
Unknown(?)	7	0.2 %	0	0.0%	7	0.2 %		7	0.2 %	0	0%	7	0.2 %	
Bed Size							90.3**							
Small (< 100 beds)	1760	49.7%	15	14.9%	1745	50.7%	p < 0.001	1760	49.7%	7.1	1%	1759	49.9%	26.9**
Medium (100 - 299 beds)	1125	31.8%	33	32.7%	1092	31.8%		1125	31.8%	21.4	3%	1122	31.8%	p < 0.001
Large (> 300 beds)	655	18.5 %	53	52.5%	602	17.5%		655	18.5%	71.4	10%	645	18.3%	
**=p<.01, *=p<.05 MH/SN: Medical Home/Safety Nets														

HII Subcategory Interactions

Table 4.16 compares characteristics of hospitals in the meaningful use stage three compliant and full LHS subcategory interaction to those that are not. The full LHS and meaningful use stage three compliant subcategory interaction was compared in this study because it was the dominant HII subcategory intersect that was observed among the hospitals in the study sample. Given the larger size of the meaningful use stage three compliant subcategory, it was first used as the

reference point for the total study sample for this intersect in Table 4.16 after which the full LHS subcategory was used as the reference point for the total sample size for the intersect in Table 4.17.

In 2018, three fifth (60%) of hospitals in the meaningful use stage three compliant subcategory in the study sample were non - teaching and hospitals in the meaningful use stage three compliant and full LHS subcategory interaction and those in the meaningful use stage three compliant and non-full LHS interaction in the study were statistically different (chi - sq = 36, $p < 0.001$.) Nearly two thirds of hospitals in the meaningful use stage three compliant and non-full LHS interaction had non - teaching status while more than half of those in the meaningful use stage three compliant and full LHS subcategory interaction had non - teaching status (65.4% versus 54.1%). Nearly three fifth (58.6%) of hospitals in the meaningful use stage three compliant subcategory in the study sample were metro located. The meaningful use stage three compliant and full LHS subcategory interaction and the meaningful use stage three compliant and non-full LHS interaction were statistically different (chi - sq = 56.3%, $p < 0.001$) with two thirds of hospitals in the meaningful use stage three compliant and full LHS subcategory interaction being metro located, while slightly more than half of hospitals in the meaningful use stage three compliant and non-full LHS interaction, were metro located (66.1% versus 51.9%). Nearly three fourth (71.6 %) of all hospitals in the meaningful use stage three compliant subcategory in the study were for profit. Hospitals in the meaningful use stage three compliant and full LHS subcategory

interaction and those in the meaningful use stage three compliant and non-full LHS interaction were statistically different (chi square of 114.2%, $p < 0.001$) with about five sixth of hospitals in the meaningful use stage three compliant and full LHS subcategory being for profit while three fifth of hospitals in the meaningful use stage three compliant and non-full LHS interaction were for profit (83.9% versus 60.5%). Nearly half (46.4%) of all hospitals in the meaningful use stage three compliant subcategory sampled were small (< 100) and about one-fifth (20.9%) were large. Hospitals in the meaningful use stage three compliant and full LHS subcategory and those in the meaningful use stage three compliant and non-full LHS interaction were statistically different (chi. sq = 60.8%, $p < 0.001$) with hospitals in the meaningful use stage three compliant and non-full LHS interaction having a higher percentage of small hospitals than those in the meaningful use stage three compliant and full LHS subcategory interaction (55% versus 36.9%).

Table 4.16

Descriptive Summaries for Meaningful Use Stage Three Compliant and Full LHS HII Subcategory Interactions

	Total 2018 MU		MU and full LHS		MU and non full LHS		
Sample Characterstics	#	%	#	%	#	%	chi-sq
Total	1661	100	788	100	873	100	
Teaching							36**
Major	137	8.2 %	94	11.9 %	43	4.9 %	p < 0.001
Minor	527	31.7 %	268	34 %	259	29.7 %	
Not Teaching	997	60.0 %	426	54.1 %	571	65.4 %	
Location							55.3**
Metro	974	58.6 %	521	66.1 %	453	51.9 %	p < 0.001
Rural	512	30.8 %	173	22.0 %	339	38.8 %	
Unknown	175	10.5 %	94	11.9 %	81	9.3 %	
Ownership							114.2**
For Profit	166	10.0 %	37	4.7 %	129	14.8 %	p < 0.001
Non-Profit	1189	71.6 %	661	83.9 %	528	60.5 %	
Fed. Gov.	31	1.9 %	8	1.0 %	23	2.6 %	
Non-Fed Gov.	273	16.4 %	81	10.3 %	192	22%	
Unknown(?)	2	0.1 %	1	0.1 %	1	0.1 %	
Bed Size							60.8**
Small (< 100 beds)	771	46.4%	291	36.9%	480	55.0%	p < 0.001
Medium (100 - 299 beds)	526	31.7%	275	34.9%	251	28.8%	
Large (> 300 beds)	364	21.9%	222	28.2%	142	16.3%	
**=p<.01, *=p<.05							

Table 4.17 compares characteristics of hospitals that are in the full LHS and meaningful use stage three compliant subcategory interaction to those that are not. In 2018, more than half (53.8%) of hospitals in the full LHS subcategory in the study sample were non-teaching and hospitals in the full LHS and meaningful use stage three compliant subcategory interaction and hospitals in the full LHS and non-meaningful use stage three compliant interaction were statistically different (chi - sq = 12.1, p = 0.01.) There was a slight difference percentage wise between the two category interatcions with nearly half of both interactions having non-

teaching status (54.1% versus 53.6%). More than three fifth (68.7%) of hospitals in the full LHS subcategory in the study sample were metro located. Hospitals in the full LHS hospitals and meaningful use stage three compliant subcategory interaction and those in the full LHS and non-meaningful use stage three compliant interaction were statistically different (chi - sq = 9.8%, $p < 0.047$) with two thirds of hospitals in the full LHS and meaningful use stage three compliant subcategory interaction being metro located, while close to three fourth of hospitals in the full LHS and non-meaningful use stage three compliant interaction were metro located (66.1% versus 72.6%). Nearly three fourth (73.9%) of hospitals in the full LHS subcategory in the study sample were for profit. Hospitals in the full LHS and meaningful use stage three compliant subcategory interaction and those in the full LHS and non-meaningful use stage three compliant interaction in the study sample were statistically different (chi - sq = 166, $p < 0.001$) with about five sixth of those in the full LHS and meaningful use stage three compliant subcategory interaction being for profit while nearly three fifth of those in the full LHS and non-meaningful use stage three compliant interaction were for profit (83.9% versus 59.1%). More than one third (37.4%) of hospitals in the full LHS subcategory in the study sample were medium (100 - 299) and about one-third (33.6%) were small. Hospitals in the full LHS and meaningful use stage three compliant subcategory interaction and those in the full LHS and non-meaningful use stage three compliant interaction were statistically different (chi - sq = 10.2%, $p = 0.037$) with hospitals in the full LHS and non-meaningful use stage three compliant interaction having a higher

percentage of medium hospitals than those in the full LHS and meaningful use stage three compliant subcategory interaction (41.1% versus 34.9%). The next section will be focused on how this study evaluated PGHD capture and use among these HII subcategories and their interactions.

Table 4.17

Descriptive Summaries for Full LHS and Meaningful Use Stage Three Compliant HII Subategory Interactions

	Total 2018 full LHS		Full LHS and MU		Full LHS and Non MU		
Sample Characterstics	**#**	**%**	**#**	**%**	**#**	**%**	**chi-sq**
Total	1318	100	788	100	530	100	
Teaching							12.1*
Major	129	9.8 %	94	11.9 %	35	6.6 %	p = 0.016
Minor	479	36.3 %	268	34 %	211	39.8 %	
Not Teaching	710	53.9 %	426	54.1 %	284	53.6 %	
Location							9.8*
Metro	906	68.7 %	521	66.1 %	385	72.6 %	p = 0.047
Rural	253	19.2 %	173	22%	80	15.1 %	
Unknown	159	12.1 %	94	11.9 %	65	12.3 %	
Ownership							166**
For Profit	198	15%	37	4.7 %	161	30.4 %	p < 0.001
Non-Profit	974	73.9 %	661	83.9 %	313	59.1 %	
Fed. Gov.	12	0.9 %	8	1%	4	0.8 %	
Non-Fed Gov.	132	10 %	81	10.3 %	51	9.6 %	
Unknown(?)	2	0.2 %	1	0.1 %	1	0.2 %	
Bed Size							10.2*
Small (< 100 beds)	443	33.6%	291	36.9%	152	28.7%	p = 0.037
Medium (100 - 299 beds)	493	37.4%	275	34.9%	218	41.1%	
Large (> 300 beds)	382	29.0%	222	28.2%	160	30.2%	
****=p<.01, *=p<.05**							

Aim Two Linear Regression Results

To evaluate the relationship between HII hospitals and PGHD capture and use, this study used the LPM to conduct a cross sectional study using the latest year of data. HII hospitals as a whole were first evaluated to assess their relationship with PGHD capture and use. Then individual HII subcategories and their intersects were evaluated to assess their relationship with PGHD capture and use. Table 4.18 shows the linear regression coefficient estimates for PGHD capture and use in HII hospitals as a whole. HII hospitals (coefficient = 0.395) had a 39.5% greater rate of PGHD capture than non HII hospitals and 30.7% (constant = 0.307) of non HII hospitals captured PGHD. The summary estimate for PGHD capture rate for HII hospitals (0.307 + 0.395) was 70.2%. For PGHD use, HII hospitals (coefficient = 0.319) had a 31.9% greater rate of PGHD use than non HII hospitals and 54.2% (constant = 0.542) of non HII hospitals used PGHD. The summary estimate for PGHD use rate for HII hospitals (0.542 + 0.319) was 86.1%. The higher rate of PGHD use when compared to PGHD capture in HII hospitals might be due to PGHD use from non – standardized PGHD capture sources.

Table 4.18

Linear regression coefficient estimates assessing PGHD capture and use in HII hospitals

Linear regression coefficient estimates assesing PGHD capture and use in HII hospitals								
	PGHD capture				PGHD use			
Hospital Category/Characteristics	***B***	**SE**	**p value**	**Sig**	***B***	**SE**	**p value**	**Sig**
Constant	0.307	0.168	0.067		0.542	0.166	0.001	**
HII	0.395	0.016	< 0.001	**	0.319	0.016	< 0.001	**
Minor Teaching	0.026	0.019	0.182		0.045	0.019	0.019	*
Major Teaching	0.084	0.037	0.023	*	0.061	0.036	0.092	
Medium bed size	-0.023	0.017	0.162		0.2	0.016	0.217	
Large bed size	0.056	0.02	0.004	**	0.087	0.019	< 0.001	**
Government non Federal	-0.134	0.168	0.424		-0.228	0.166	0.17	
Government Federal	0.073	0.177	0.678		-0.25	0.174	0.153	
Non Profit	0.004	0.167	0.979		-0.1	0.165	0.544	
For Profit	-0.143	0.168	0.393		-0.315	0.166	0.057	
Metro	-0.054	0.025	0.032	*	-0.018	0.025	0.471	
Rural	-0.092	0.026	< 0.001	**	0.041	0.026	0.118	*
R Square	0.223				0.195			
No of Observations	3540				3540			
Significance (Sig) (=p<.01, *=p<.05)**	SE: Standard Error							

Table 4.19 shows the linear regression coefficient estimates for PGHD capture and use in HII subcategories relative to non HII hospitals. The full LHS subcategory (coefficient = 0.404) had a 40.4% greater rate of PGHD capture than non HII hospitals, while 29.7 % of non HII hospitals (constant = 0.297) captured PGHD. The summary estimate for PGHD capture rate for the full LHS subcategory was (0.297 + 0.404) 70.1%. For PGHD use, the full LHS subcategory (coefficient = 0.331) had a 33.1% greater rate of PGHD use than non HII hospitals and 54.1% (constant = 0.541) of non HII hospitals used PGHD. The summary estimate for PGHD use rate for the full LHS subcategory (0.541 + 0.331) was 87.2%.

Meaningful use stage three compliant and PCORI funded subcategories were observed to have a 15 – 16% greater PGHD capture rate and a 9.5 % - 11.2% greater PGHD use rate than non HII hospitals.

With emerging LHS as a control in the model, for PGHD capture, the coefficient for the full LHS subcategory increased to 0.506 which indicated that full LHS hospitals had a 50.6% greater rate of PGHD capture than non HII nonemerging LHS hospitals. Including emerging LHS as a control in the model makes the comparison of HII hospitals and their subcategories to non HII hospitals starker. The constant for non HII hospitals dropped to 0.171, which indicated that 17.1% of non HII hospitals captured PGHD. The summary estimate for PGHD capture rate for the full LHS subcategory (0.171 + 0.506) then became 67.7 %. For PGHD use, the coefficient for the full LHS subcategory was 0.488, which indicated that the full LHS subcategory had a 48.8% greater rate of PGHD use than non HII nonemerging LHS hospitals. The constant for non HII hospitals was 0.346, which indicated that 34.6% of non HII hospitals used PGHD. The summary estimate for PGHD use rate for the full LHS subcategory with emerging LHS hospitals as control (0.488 + 0.346) was 83.4%.

Table 4.19

Linear Regression Coefficient Estimates Assessing PGHD Capture and Use in HII Subcategories

	Linear regression coefficient estimates assesing PGHD capture and use in individual HII hospitals															
	PGHD capture				PGHD use				PGHD capture				PGHD use			
Hospital Category/Characteristics	Estimates	SE	p value	Sig	Estimates	SE	p value	Sig	Estimates	SE	p value	Sig	Estimates	SE	p value	Sig
Constant	0.297	0.163	0.068		0.541	0.163	< 0.001	**	0.171	0.162	0.289		0.346	0.16	0.031	*
Full LHS	0.404	0.016	< 0.001	**	0.331	0.016	< 0.001	**	0.506	0.02	< 0.001	**	0.488	0.02	< 0.001	**
Meaningful Use	0.159	0.015	< 0.001	**	0.095	0.015	< 0.001	**	0.143	0.015	< 0.001	**	0.071	0.015	< 0.001	**
Medical Home	-0.04	0.116	0.727		-0.073	0.116	0.531		-0.035	0.115	0.758		-0.065	0.114	0.567	
PCORI funded	0.161	0.045	< 0.001	**	0.112	0.045	0.013	*	0.157	0.044	< 0.001	**	0.104	0.044	0.018	*
Minor Teaching	0.026	0.019	0.162		0.046	0.019	0.016	*	0.025	0.019	0.175		0.044	0.019	0.017	*
Major Teaching	0.035	0.036	0.343		0.029	0.037	0.426		0.036	0.036	0.321		0.031	0.036	0.385	
Medium bed size	-0.03	0.016	0.059		0.014	0.016	0.383		-0.031	0.016	0.05		0.013	0.016	0.418	
Large bed size	0.042	0.019	0.027	*	0.076	0.019	< 0.001	**	0.035	0.019	0.06		0.065	0.019	< 0.001	**
Government non Federal	-0.095	0.162	0.557		-0.192	0.163	0.239		-0.048	0.161	0.763		-0.119	0.16	0.455	
Government Federal	0.164	0.171	0.339		-0.17	0.172	0.322		0.239	0.17	0.16		-0.054	0.168	0.749	
Non Profit	0.014	0.162	0.931		-0.083	0.163	0.609		0.054	0.16	0.735		-0.021	0.159	0.896	
For Profit	-0.104	0.162	0.523		-0.285	0.163	0.082		-0.024	0.161	0.882		-0.161	0.16	0.313	
Metro	-0.049	0.025	0.048	*	-0.013	0.025	0.609		-0.057	0.024	0.019	*	-0.026	0.024	0.279	
Rural	-0.055	0.026	0.032	*	0.073	0.026	0.005	*	-0.076	0.026	0.003	**	0.04	0.025	0.113	
Emerging LHS									0.16	0.019	< 0.001	**	0.248	0.019	< 0.001	**
R Square	0.27				0.22				0.29				0.26			
No of Observations	3540				3540				3540				3540			
Significance (Sig) (**=p<.01, *=p<.05)	SE: Standard Error															

Table 4.20 shows the linear regression coefficient estimates for PGHD capture and use among HII subcategory interactions. The regressions did not make use of distinct HII subcategories, therefore, in order to obtain the full effect of HII subcategory cross products such as full LHS and meaningful use stage three compliant subcategory interactions, the sum of the individual HII subcategories that make up the HII subcategory cross product needs to be added. Based on this, for PGHD capture, the combined coefficient for full LHS and meaningful use stage three compliant subcategory interaction (-0.168 + 0.223 + 0.497) was 0.552 ($p < 0.001$) which indicates that full LHS and meaningful use stage three compliant subcategory interaction had a 55.2% greater rate of PGHD capture than non HII hospitals. The constant for non HII hospitals was 0.28, and this indicates that 28.1% of non HII hospitals captured PGHD. The summary estimate for PGHD

capture rate for full LHS and meaningful use stage three compliant subcategory interaction (0.28 + 0.552) was 83.2%. For PGHD use, the combined coefficient for full LHS and meaningful use stage three compliant subcategory interaction (- 0.197 + 0.447 + 0.173) was 0.422 ($p < 0.001$) and this indicates that full LHS and meaningful use stage three compliant subcategory interaction had a 42.2% greater rate of PGHD use than non HII hospitals. The constant for non HII hospitals was 0.517 and this indicates that 51.7% of non HII hospitals used PGHD. The summary estimate of PGHD use rate for the full LHS and meaningful use stage three compliant subcategory interaction was (0.517 + 0.422) 93.9%. The full LHS and PCORI funded subcategory interaction were observed to have a combined coefficient of (-0.402 + 0.447 + 0.479) 0.524 ($p < 0.001$), and this indicates that they had 52.4% greater PGHD use rate than non HII hospitals.

Table 4.20

Linear Regression Coefficient Estimates Assessing PGHD Capture and Use Among HII Subcategory Interactions

Linear regression coefficient estimates assesing PGHD capture and use among HII hospital Interactions								
	PGHD capture				PGHD use			
Hospital Category/Characteristics	**Estimates**	**SE**	**p value**	**Sig**	**Estimates**	**SE**	**p value**	**Sig**
Constant	0.28	0.162	0.083		0.517	0.162	0.001	**
Full LHS	0.497	0.023	< 0.001	**	0.447	0.023	< 0.001	**
Meaningful Use	0.223	0.019	< 0.001	**	0.173	0.019	< 0.001	**
Medical Home	0.196	0.555	0.723		0.342	0.554	0.537	
PCORI funded	0.272	0.088	0.002	**	0.479	0.088	< 0.001	**
Full LHS and Meaningful Use	-0.168	0.031	< 0.001	**	-0.198	0.031	< 0.001	**
Full LHS and PCORI funded	-0.127	0.095	0.178		-0.402	0.095	< 0.001	**
Full LHS and Medical Home	0.009	0.607	0.989		-0.314	0.607	0.605	
PCORI funded and Meaningful Use	-0.049	0.091	0.592		-0.153	0.091	0.094	
Medical Home and Meaningful Use	-0.385	0.289	0.183		-0.053	0.289	0.854	
PCORI funded and Medical Home	0.217	0.342	0.526		-0.342	0.342	0.316	
Minor Teaching	0.025	0.019	0.177		0.045	0.019	0.017	*
Major Teaching	0.042	0.036	0.251		0.044	0.036	0.224	
Medium bed size	-0.033	0.016	0.04	*	0.01	0.016	0.542	
Large bed size	0.032	0.019	0.093	*	0.062	0.019	0.001	*
Government non Federal	-0.094	0.162	0.56		-0.19	0.162	0.24	
Government Federal	0.157	0.17	0.356		-0.178	0.17	0.297	
For Profit	-0.115	0.162	0.478		-0.296	0.162	0.067	*
Non Profit	0.011	0.161	0.945		-0.088	0.161	0.586	
Metro	-0.051	0.024	0.037	*	-0.014	0.024	0.559	
Rural	-0.062	0.026	0.016	*	0.067	0.026	0.008	**
R Square	0.28				0.29			
No of Observations	3540				3540			
Significance (Sig) (=p<.01, *=p<.05)**	SE: Standard Error							

Table 4.21 shows the linear regression coefficient estimates for PGHD capture and use among HII subcategory interactions with emerging LHS as a control in the model. For PGHD capture, the combined coefficient for full LHS and meaningful use stage three compliant subcategory interaction (0.568 + 0.195 – 0.129) increased to 0.634 ($p < 0.001$) which indicated that full LHS and meaningful use stage three compliant subcategory interaction had a 63.4% greater rate of PGHD capture than non HII nonemerging LHS hospitals. The constant for non HII hospitals dropped to 0.17, which indicated that 17.1% of non HII hospitals captured

PGHD. The summary estimate for PGHD capture rate for full LHS and meaningful use stage three compliant subcategory interaction (0.171 + 0.634) then became 80.5%. For PGHD use, the combined coefficient for full LHS hospitals and meaningful use stage three compliant subcategory interaction (0.56 + 0.128 – 0.136) was 0.552 ($p < 0.001$), this indicated that full LHS hospitals and meaningful use stage three compliant subcategory interaction had a 55.2% greater rate of PGHD use than non HII nonemerging LHS hospitals. The constant for non HII hospitals was 0.342 and this indicated that 34.2% of non HII hospitals used PGHD. The summary estimate for PGHD use rate for full LHS and meaningful use stage three compliant subcategory interaction with emerging LHS as control (0.552 + 0.342) was 89.4%.

The full LHS and PCORI funded subcategory interaction were observed to have a combined coefficient of (0.56 + 0.46 - 0.362) 0.658 ($p < 0.001$), which indicated that full LHS and PCORI funded subcategory interaction had a 65.8% greater rate of PGHD use than non HII nonemerging LHS hospitals. Among hospitals in the PCORI funded and meaningful use stage three compliant subcategory interaction the combined coefficient for PGHD (0.46 + 0.128 – 0.178) was 0.41 ($p < 0.001$) and this indicated that the PCORI funded and meaningful use stage three compliant subcategory interaction had a 41% greater rate of PGHD use than non HII nonemerging LHS hospitals.

Table 4.21

Linear Regression Coefficient Estimates Assessing PGHD Capture and Use Among HII Subcategory Interactions (with Emerging LHS in the model)

Linear regression coefficient estimates assesing PGHD capture and use among HII hospital Interactions (with Emerging LHS)								
	PGHD capture				PGHD use			
Hospital Category/Characteristics	Estimates	SE	p value	Sig	Estimates	SE	p value	Sig
Constant	0.17	0.161	0.292		0.342	0.159	0.032	*
Full LHS	0.568	0.025	< 0.001	**	0.56	0.024	< 0.001	**
Meaningful Use	0.195	0.019	< 0.001	**	0.128	0.019	< 0.001	**
Medical Home	0.143	0.55	0.795		0.258	0.544	0.851	
PCORI funded	0.261	0.087	0.003	**	0.46	0.086	< 0.001	**
Full LHS and Meaningful Use	-0.129	0.031	< 0.001	**	-0.136	0.031	< 0.001	**
Full LHS and PCORI funded	-0.102	0.094	0.278		-0.362	0.093	< 0.001	**
Full LHS and Medical Home	0.076	0.602	0.9		-0.207	0.595	0.728	
PCORI funded and Meaningful Use	-0.065	0.091	0.474		-0.178	0.09	0.047	*
Medical Home and Meaningful Use	-0.398	0.287	0.165		-0.074	0.283	0.793	
PCORI funded and Medical Home	0.222	0.339	0.513		-0.335	0.335	0.318	
Minor Teaching	0.025	0.019	0.183		0.044	0.018	0.017	*
Major Teaching	0.041	0.036	0.252		0.044	0.036	0.221	
Medium bed size	-0.033	0.016	0.036	*	0.009	0.016	0.557	
Large bed size	0.028	0.019	0.135		0.056	0.019	0.003	**
Government non Federal	-0.052	0.161	0.747		-0.122	0.159	0.44	
Government Federal	0.226	0.169	0.181		-0.068	0.167	0.686	
For Profit	-0.04	0.161	0.804		-0.178	0.159	0.264	
Non Profit	0.048	0.16	0.764		-0.029	0.158	0.853	
Metro	-0.058	0.024	0.016	*	-0.026	0.024	0.281	
Rural	-0.079	0.026	0.002	**	0.039	0.025	0.119	
Emerging LHS	0.145	0.02	< 0.001	**	0.23	0.019	< 0.001	**
R Square	0.29				0.27			
No of Observations	3540				3540			
Significance (Sig) (**=p<.01, *=p<.05)	SE: Standard Error							

For HII subcategory interactions, to evaluate if the difference of being a joint HII subcategory in comparison to being a single HII subcategory on PGHD capture and use is statistically significant, post combination linear regression tests were carried out. In the case of full LHS and meaningful use stage three compliant subcategory interaction, with emerging LHS in the model, the difference of being full LHS and meaningful use stage three compliant on PGHD capture was compared to the effect of being a full LHS hospital. This yielded a coefficient of

0.066 (p = 0.008), while for PGHD use it yielded a coefficient of -0.008 (p = 0.744). This shows that there was a small additive effect of 6.6% of being full LHS on full LHS and meaningful use stage three compliant subcategory interaction for PGHD capture. There was no significant additive effect of being full LHS on full LHS and meaningful use stage three compliant hospitals in the case of PGHD use.

The effect of being a full LHS subcategory on the PCORI funded and full LHS subcategory interaction was examined for PGHD capture (with emerging LHS in the model) and this yielded a coefficient of 0.16 (p = 0.049). This shows that there was a slight additive effect of 1.6% of being a full LHS subcategory on the full LHS and PCORI funded subcategory interaction. For PGHD use, the effect of being a PCORI funded subcategory on full LHS and PCORI funded subcategory interaction yielded a coefficient of 0.197 (p = 0.035). This shows that there was a 19.7% additive effect of being a PCORI funded subcategory on the full LHS and PCORI funded subcategory interaction. To further understand the associations observed in aim two, aim three in the next section will be focused on understanding the relationship between change in hospital category and PGHD capture and use.

Aim Three Results

Aim three of this study sought to ascertain if the observed relationship between HII subcategories and PGHD capture and use can be explained by a change in the identity of HII hospitals. This was to clarify that the observed associations in aim two are indeed due to the identified HII subcategories in aim

one. This was not a perfect causal study; it was carried out to add to the evidence base on HII subcategories and PGHD capture and use in order to guide future research. For aim three, this study used a generalized difference-in-difference model with fixed hospital and time effects to ascertain if changes in HII hospital status and HII subcategories across the three study periods are associated with changes in PGHD capture and use in comparison to hospitals with consistent characteristics. This helped to strengthen any observed associations (in aim two) between identified HII subcategories and PGHD capture and use. This section will begin with a descriptive summary of changes in HII subcategories across the study periods. This will begin with changes from non HII hospital status to HII hospital status and wil be followed by changes among HII subcategories. This will be followed by the results of fixed effects regression for HII hospitals, which will be followed by fixed effects regression for individual HII subcategories and the section will conclude with fixed effects regression results for HII subcategory interactions.

Descriptive Summary of HII and non HII Hospitals that changed their subcategories across the study periods

This section summarizes changes from non HII to HII hospitals and from a HII subcategory to another HII subcategory across the study periods. Overall, of the total respondent hospitals in 2013 (3,283), 2016 (3,656) and in 2018 (3,540), only 1, 431 hospitals were consistently available in all three years. Table 4.22

shows the counts and percentages of non HII to HII hospitals between 2013 and 2016, 2016 and 2018 and 2013 and 2018. The table was organized from the largest to the smallest category of changing non HII to HII subcategories based on the changes observed between years 2013 and 2018. Between 2013 and 2018, 57.3% (629) of non HII hospitals in the study sample changed their designation from non HII to HII hospitals, and the percentage of change was lower between 2013 and 2016 (46.5%) and stayed nearly the same between 2016 and 2018 (47.9%). Non HII hospitals that changed their designation to meaningful use stage three compliant subcategory between 2013 and 2018, were 43.7% (480), and this dropped to (38.0%) between 2013 and 2016, and then increased to 40.2% between 2016 and 2018. Non HII hospitals that became part of the full LHS subcategory between 2013 and 2018 were 29.2% (320). Non HII hospitals that became part of the PCORI funded subcategory were 2.6 % (28) between 2013 and 2018, this dropped to 0.8% (9) between 2013 and 2016 and increased to 2.3% (15) between 2016 and 2018.

Table 4.22

Non HII to HII Hospital Changes in Designation Across the Study Periods

	2013 - 2016		2016 - 2018		2013 - 2018	
Changes in Hospital Designation	**#**	**%**	**#**	**%**	**#**	**%**
Non HII to HII	512	46.5 %	315	47.9 %	629	57.3 %
Non HII to Meaningful use stage three	417	38.0 %	264	40.2 %	480	43.7 %
Non HII to Full LHS	251	22.9 %	140	21.3 %	320	29.2 %
Non HII to PCORI	9	0.8 %	15	2.3 %	28	2.6 %
Non HII to Medical Home/Safety Nets	0	0	0	0	0	0

Table 4.23 shows the counts and percentages of changes within HII subcategories among the 1,431 hospitals in the study sample that were present in the data across the study period. Hospitals in the medical home/safety net

subcategory that became part of the full LHS subcategory between 2013 and 2018 were 90% (9) and this remained the same between 2016 and 2018 however was slightly lower between 2013 and 2016 at 80% (8). Hospitals in the full LHS subcategory that became part of the meaningful use stage three compliant subcategory between 2013 and 2018 were 82.5% (175) and this reduced to 67.2% (312) between 2016 and 2018 and was slightly higher at 69.8% (148) between 2013 and 2016. Hospitals in the PCORI funded subcategory that became part of the meaningful use stage three compliant subcategory were 71.1% (27) between 2013 and 2018 and this was higher between 2016 and 2018 at 78.6% (22) and between 2013 and 2016 at 73.7% (28). Hospitals in the PCORI funded subcategory that became part of the full LHS subcategory were 71.1% (27) between 2013 and 2018, and this was lower between 2016 and 2018 at 46.4% (13) and slightly higher between 2013 and 2016 at 63.2% (24). Hospitals in the medical home/safety net subcategory that became part of the meaningful use stage three compliant subcategory were 70% (7) between 2013 and 2018, and this remained the same between 2016 and 2018 and was slightly higher between 2013 and 2016 at 80% (8). Hospitals in the meaningful use stage three compliant subcategory that became part of the full LHS subcategory between 2013 and 2018 were 61.1% (88) and this was lower between 2016 and 2018 at 52.3% (337) and 63.2% (91) between 2013 and 2016. Hospitals in the full LHS subcategory that became part of the PCORI funded subcategory were 7.1% (15) between 2013 and 2018, and this was lower between 2016 and 2018 at 5.6% (26) and 1.9% (4)

between 2013 and 2016. Hospitals in the meaningful use stage three compliant subcategory that became part of the PCORI funded subcategory were 6.3% (9) between 2013 and 2018 and were nearly the same at 6.2% (40) between 2016 and 2018, and this was lower between 2013 and 2018 at 4.9% (7). Overall, hospitals in the medical home/safety net and PCORI funded subcategories which had smaller changes and tended to take on full LHS or meaningful use stage three compliant subcategories were part of the largest HII subcategory changes percentage wise. The next section will discuss the fixed effect regression results of HII hospitals, HII subcategories and HII subcategory interactions across the study periods.

Table 4.23

Changes in Designation Among HII Hospitals Across The Study Periods

	2013 - 2016		2016 - 2018		2013 - 2018	
HII to HII Change in Designation	**#**	**%**	**#**	**%**	**#**	**%**
Medical Home/Safey Net to Full LHS	8	80.0 %	9	90.0 %	9	90.0 %
Full LHS to Meaningful use stage three compliant	148	69.8 %	312	67.2 %	175	82.5 %
PCORI to meaningful use stage three complaint hospitals	28	73.7 %	22	78.6 %	27	71.1 %
PCORI to Full LHS	24	63.2 %	13	46.4 %	27	71.1 %
Medical Home/Safey Net to Meaningful use stage three complaints hospitals	8	80.0 %	7	70.0 %	7	70,0 %
Meaningful use stage three complaint to Full LHS	91	63.2 %	337	52.3 %	88	61.1 %
Full LHS to PCORI	4	1.9 %	26	5.6 %	15	7.1 %
Meaningful use stage three complaint to PCORI	7	4.9 %	40	6.2 %	9	6.3 %
Total Migrating HII	263	79.0 %	613	79.2 %	298	32.1 %

Fixed Effects Regression Results

Table 4.24 shows the fixed effect panel regression estimates for PGHD capture and use in HII hospitals as a whole across the three study periods. For PGHD capture, the coefficient for HII hospitals across the study period was 0.075

(p < 0.001) which indicates that PGHD capture in hospitals that changed to HII hospitals increased by 7.5% across the study period when compared to non HII hospitals and hospitals with constant status. The coefficients for PGHD capture for years 2016 and 2018 were 0.196 and 0.308 respectively (both p < 0.001). For PGHD use, the coefficient for HII hospitals across the study periods was 0.107 (p < 0.001), which indicated that the PGHD use in hospitals that changed to HII hospitals increased by 10.7% across the study periods when compared to non HII hospitals and hospitals with stable status. The coefficients for PGHD use for year 2016 and 2018 were 0.017 and 0.018 respectively (p < 0.001).

Table 4.24

Fixed Effect Panel Regression for HII Hospitals (2013 - 2018)

Panel regression coefficient estimates assesing PGHD capture and use in HII hospitals										
	PGHD capture					PGHD use				
Hospital Category	**Coefficients**	**SE**	**p value**	**Sig**	**95 % CI**	**Coefficients**	**SE**	**p value**	**Sig**	**95 % CI**
Constant	0.131	0.009	< 0.001	**	0.114 - 0.149	0.351	0.01	< 0.001	**	0.332 - 0.371
HIIs	0.075	0.018	< 0.001	**	0.040 - 0.110	0.107	0.02	< 0.001	**	0.068 - 0.146
Year 2016	0.196	0.014	< 0.001	**	0.169 - 0.223	0.361	0.017	< 0.001	**	0.328 - 0.394
Year 2018	0.308	0.015	< 0.001	**	0.279 - 0.337	0.263	0.018	< 0.001	**	0.227 - 0.299
R Squared Within	0.25					0.23				
No of Observations	1431									
Significance (Sig) (=p<.01, *=p<.05)**	SE: Standard Error									

Table 4.25 shows the fixed effect panel regression for PGHD capture and use in individual HII subcategories across the three study periods. The full LHS subcategory had a coefficient of 0.131 (p < 0.001) which indicates that hospitals that changed to the full LHS subcategory had 13.1% greater PGHD capture when compared to non HII hospitals and hospitals with stable status. For PGHD use, full LHS subcategory had a coefficient of 0.098 (p < 0.001) which indicates that

hospitals that became full LHS had 9.8% greater PGHD use than non HII hospitals and hospitals that remained in their category. For PGHD capture, the meaningful use stage three compliant subcategory had a coefficient of 0.072 ($p < 0.001$) which indicates that hospitals that changed to the meaningful use stage three compliant subcategory had 7.2% greater PGHD capture than non HII hospitals and hospitals with constant status. For PGHD use, the meaningful use stage three compliant subcategory had a coefficient of 0.059 ($p < 0.001$) which indicates that hospitals that changed to the meaningful use stage three compliant subcategory had 5.9% greater PGHD use than non HII hospitals. The coefficients for PGHD capture and use for years 2016 and 2018 were 0.172 and 0.28 and 0.358 and 0.26 respectively ($p < 0.001$).

Table 4.25

Fixed Effect Panel Regression for HII Subcategories (2013 – 2018)

Panel regression coefficient estimates assesing PGHD capture and use in Individual HII Hospital Subcategories										
	PGHD capture					PGHD use				
Hospital Category	Coefficients	SE	p value	Sig	95 % CI	Coefficients	SE	p value	Sig	95 % CI
Constant	0.123	0.008	< 0.001	**	0.106 - 0.136	0.352	0.01	< 0.001	**	0.334 - 0.371
Full LHS	0.131	0.021	< 0.001	**	0.089 - 0.172	0.098	0 .022	< 0.001	**	0.056 - 0.141
Meaningful Use	0.072	0.017	< 0.001	**	0.039 - 0.105	0.059	0.018	p = 0.001	**	0 .023 - 0.095
PCORI	-0.053	0.043	p = 0.213		-0.137 - 0.030	0.04	0.042	p = 0.353		-0.044 - 0.122
Medical Home	Omitted					Omited				
Year 2016	0.172	0.014	< 0.001	**	0.144 - 0.199	0.358	0.017	< 0.001	**	0.325 - 0.392
Year 2018	0.28	0.015	< 0.001	**	0.250 - 0.309	0.26	0 .018	< 0.001	**	0.225 - 0.296
R Squared Within	0.21					0.23				
No of Observations	1431					1431				
Significance (Sig) (**=p<.01, *=p<.05)	SE: Standard Error									

Table 4.26 shows the fixed panel regression for individual HII subcategories with emerging LHS as a control in the model. For PGHD capture, the coefficient for the full LHS subcategory increased to 0.142, while that of the meaningful use stage three compliant subcategory remained 0.072 ($p < 0.001$). This indicated that

hospitals that became full LHS had 14.2% greater PGHD capture than non HII hospitals and hospitals that remained in their category. The coefficients for PGHD capture for years 2016 and 2018 remained nearly the same at 0.168 and 0.275 respectively ($p < 0.001$). For PGHD use, the coefficient for the full LHS subcategory increased to 0.174, while that of the meaningful use stage three compliant subcategory reduced slightly to 0.06 ($p < 0.001$). This indicated that hospitals that became full LHS had 17.4% greater PGHD use than non HII hospitals and hospitals that remained in their category. The coefficients for PGHD use for years 2016 were 0.337 and 0.23 for 2018 ($p < 0.001$).

Table 4.26

Fixed Effect Panel Regression for HII Subcategories with Emerging LHS in the Model (2013 - 2018)

Panel regression coefficient estimates assesing PGHD capture and use in HII Hospital Subcategories (with Emerging LHS)										
	PGHD capture					PGHD use				
Hospital Category	**Coefficients**	**SE**	**p value**	**Sig**	**95 % CI**	**Coefficients**	**SE**	**p value**	**Sig**	**95 % CI**
Constant	0.117	0.011	< 0.001	**	0.095 - 0.138	0.312	0.013	< 0.001	**	0.286 - 0.337
Full LHS	0.142	0.026	< 0.001	**	0.092 - 0.193	0.174	0.027	< 0.001	**	0.120 - 0.227
Meaningful Use	0.072	0.017	< 0.001	**	0.039 - 0.105	0.058	0.018	p = 0.001	**	0.023 - 0.094
PCORI	-0.053	0.043	p = 0.214		-0.136 - 0.031	0.04	0.041	p = 0.332	**	-0.040 - 0.120
Medical Home	Omitted					Omited				
Year 2016	0.168	0.015	< 0.001	**	0.139 - 0.197	0.337	0.018	< 0.001	**	0.302 - 0.372
Year 2018	0.275	0.016	< 0.001	**	0.243 - 0.306	0.23	0.019	< 0.001	**	0.192 - 0.268
Emerging LHS	0.017	0.019	p = 0.373		-0.020 - 0.053	0.106	0.023	< 0.001	**	0.061 - 0.152
R Squared Within	0.22					0.24				
No of Observations	1431					1431				
Significance (Sig) (=p<.01, *=p<.05)**	SE: Standard Error									

Table 4.27 and 4.28 show the fixed effect panel regression analyses for PGHD capture and use in HII subcategory interactions across the three study periods with (Table 4.28) and without (Table 4.27) emerging LHS in the model. For PGHD capture the coefficients for full LHS and meaningful use stage three compliant subcategory interactions were full LHS (B = 0.075, p = 0.005);

meaningful use stage three compliant (*B* = 0.029, p = 0.182) and full LHS and meaningful use stage three compliant (*B* = 0.100, p = 0.002). Altogether, the full LHS and meaningful use stage three compliant subcategory interaction had a combined coefficient (0.100 + 0.029 + 0.075) of 0.204 (p < 0.001) which indicated that hospitals that changed to the full LHS hospital and meaningful use stage three compliant subcategory interaction had 20.4% greater PGHD capture than non HII hospitals and hospitals that remained in their category. For the PCORI funded and medical home/safety net subcategory interaction, the coefficients for the PCORI funded subcategory was -0.163 (p = 0.02) and the coefficient for PCORI funded and medical home/safety net subcategory interaction was -0.481 (p < 0.001). Their combined coefficient for the PCORI funded subcategory interaction (-0.481 + (-0.163)) was - 0.644 (p < 0.001). This indicates that hospitals that changed to PCORI funded and medical home/safety net subcategory interaction had a 64.4% drop in PGHD capture when compared to non HII hospitals and hospitals that remained in their category. The coefficients for PGHD capture and use for years 2016 and 2018 were 0.175 and 0.287, and 0.357 and 0.255 respectively (p < 0.001).

With emerging LHS in the model, for PGHD capture, the coefficients for full LHS and meaningful use stage three compliant subcategory interaction were full LHS (*B* = 0.09, p = 0.003), meaningful use stage three compliant (*B* = 0.025, p = 0.238), and full LHS and meaningful use stage three compliant (*B* = 0.107, p = 0.001). Altogether, for the full LHS and meaningful use stage three compliant

subcategory interaction, their combined coefficient (0.107 + 0.025 + 0.09) was 0.222 ($p < 0.001$). This indicates that hospitals that changed to the full LHS and meaningful use stage three compliant subcategory interaction had 22.2 % greater PGHD capture than non HII hospitals and hospitals that remained in their HII designation. For those that changed to the PCORI funded and medical home/safety net subcategory interaction, for PGHD capture, the coefficient for the PCORI funded subcategory was (*B* = -0.165, p = 0.018), and that of the PCORI funded and medical home/safety net subcategory interaction was (*B* = -0.487, $p < 0.001$). Their combined coefficient for the PCORI funded and medical home/safety net subcategory interaction was -0.652 (p = 0.02). This indicates that with emerging LHS in the model, hospitals that changed their designation to the PCORI funded and medical home/safety net subcategory interaction had a 65.2% drop in PGHD capture. The coefficients for PGHD capture and use for years 2016 were 0.171 and 0.336, and 0.28, and 0.23 for 2018 ($p < 0.001$).

Table 4.27

Fixed Effect Panel Regression for HII Subcategory Interactions (2013 – 2018)

Panel regression coefficient estimates assesing PGHD capture and use in HII Hospital Subcategories										
	PGHD capture					PGHD use				
Hospital Category	**Coefficients**	**SE**	**p value**	**Sig**	**95 % CI**	**Coefficients**	**SE**	**p value**	**Sig**	**95 % CI**
Constant	0.132	0.009	p < 0.001	**	0.115 - 0.149	0.349	0.010	p < 0.001	**	0.329 - 0.368
Full LHS	0.075	0.027	p = 0.005	**	0.022 - 0.129	0.130	0.028	p < 0.001	**	0.076 - 0.184
Meaningful Use	0.029	0.021	p = 0.182		-0.013 - 0.070	0.082	0.024	p = 0.001	**	0.036 - 0.129
Medical Home	Omitted					Omitted				
PCORI	-0.163	0.070	p = 0.02	**	-0.30 - (-0.026)	0.050	0.077	p = 0.518		-0.101 - 0.200
Full LHS and Meaningful Use	0.100	0.032	p = 0.002	**	0.037 -0.165	-0.063	0.033	p = 0.058		-0.128 - .0020
Full LHS and PCORI	0.071	0.087	p = 0.418		-0.100- 0.242	-0.014	0.098	p = 0.889		-0.206 - 0.179
Full LHS and Medical Home	-0.073	0.104	p = 0.484		0.276 - 0.131	0.214	0.114	p = 0.062		-0.01 - 0.438
PCORI and Meaningful Use	0.158	0.094	p = 0.093		-0.026 - 0.343	0.016	0.086	p = 0.856		-0.153 - 0.186
PCORI and Medical Home	-0.481	0.072	p < 0.001	**	-0.622 - (-0.340)	-0.294	0.360	p = 0.414		-0.10 - 0.411
Medical Home and Meaningful Use	0.122	0.128	p = 0.338		-0.128 - 0.373	-0.143	0.148	p = 0.335		-0.432 - 0.148
year_2016	0.175	0.014	p < 0.001	**	0.147 - 0.202	0.357	0.017	p < 0.001	**	0.323 - 0.390
year_2018	0.287	0.015	p < 0.001	**	0.257 - 0.317	0.255	0.018	p < 0.001	**	0.219 - 0.292
R Squared Within	0.22					0.23				
No of Observations	1431					1431				
Significance (Sig) (=p<.01, *=p<.05)**	SE: Standard Error									

Table 4.28

Fixed Effect Panel Regression for HII Subcategory Interactions with Emerging LHS in the Model (2013 – 2018)

Panel regression coefficient estimates assesing PGHD capture and use in HII Hospital Subcategories (With Emerging LHS)										
	PGHD capture					PGHD use				
Hospital Category	**Coefficients**	**SE**	**p value**	**Sig**	**95 % CI**	**Coefficients**	**SE**	**p value**	**Sig**	**95 % CI**
Constant	0.122	0.011	p < 0.01	**	0.1 - 0.144	0.31	0.013	p < 0.001	**	0.284 - 0.336
Full LHS	0.091	0.030	p = 0.002	**	0.032 - 0.149	0.192	0.031	p < 0.001	**	0.131 - 0.252
Meaningful Use	0.026	0.021	p = 0.219		-0.016 - 0.068	0.073	0.024	p = 0.002	**	0.027 - 0.120
Medical Home	Omitted					Omitted				
PCORI	-0.165	0.070	p = 0.018	**	-0.302 - (-0.028)	0.0428	0.074	p = 0.560		-0.101 - 0.187
Full LHS and Meaningful Use	0.106	0.033	p = 0.001	**	0.042 - 0.171	-0.04	0.034	p = 0.228		-0.106 - 0.025
Full LHS and PCORI	0.075	0.088	p = 0.393		-0.097 - 0.247	0.0032	0.097	p = 0.973		- 0.186 - 0.193
Full LHS and Medical Home	-0.071	0.104	p = 0.491		-0.276 - 0.132	0.219	0.115	p = 0.056		-0.006 - 0.444
PCORI and Meaningful Use	0.158	0.094	p = 0.095		-0.028 - 0.34	0.013	0.085	p = 0.879		-0.153 - 0.179
PCORI and Medical Home	-0.487	0.073	p < 0.001	**	0.630 - (-0.034)	-0.318	0.353	p = 0.368		-1.00 - 0.375
Medical Home and Meaningful Use	0.120	0.129	p = 0.356		-0.134 - 0.37	-0.154	0.142	p = 0.277		-0.432- 0..123
Emerging LHS	0.026	0.019	p = 0.167		-0.011 - 0.063	0.104	0.023	p < 0.001	**	0.058 - 0.149
year_2016	0.170	0.015	p < 0.001	**	0.142 - 0.20	0.336	0.018	p < 0.001	**	0.301 - 0.372
year_2018	0.280	0.0161	p < 0.001	**	0.248 - 0.312	0.227	0.019	p < 0.001	**	0.190 - 0.266
R Squared Within	0.22					0.24				
No of Observations	1431					1431				
Significance (Sig) (=p<.01, *=p<.05)**	SE: Standard Error									

Chapter Five – Discussion and Conclusions

Introduction

This chapter of the dissertation discusses the study results that were obtained in chapter four. As earlier stated, this study sought to understand Patient Generated Health Data (PGHD) uptake among HII hospitals and their subcategories. This was based on the premise that a good number of health care institutions were becoming more invested in EHD - driven continuous improvement in care processes through the capture and use of PGHD. Furthermore, prior review of the literature showed that some health care institutions were beginning to institute approaches to learn from the data in order to drive care and continuous improvement in care processes through a patient centric approach that learns from electronically generated patient sourced health data (S. M. Bradley, 2020; Jakicic et al., 2016; Treskes et al., 2020). These studies suggested that the observed changes were spurred on by the need to improve care by embracing an approach that utilized EHD and a patient - centric disposition to care through PGHD capture and use (Austin et al., 2019; E. H. Bradley, Curry, & Devers, 2007). Additional reasons for this shift included the need to curb the rising cost of care, reduce medical errors, and reduce care fragmentation. These changes also facilitated wholistic care approaches that enabled providers to evaluate patients outside of the traditional clinical setting, while also encouraging patients to actively participate in their care by collecting their own health data outside of clinical settings and using

that data to inform their care decisions. Hospitals observed within the literature to be using this EHD – driven and patient centric approach to care were termed HII hospitals in this study.

HII hospitals that were evaluated in this study include LHS practicing hospitals, meaningful use stage three compliant hospitals, medical home/safety net hospitals and PCORI funded hospitals. These hospitals evolved or were created or adapted to incorporate the increased need for EHD driven and patient centric health IT tools to improve care delivery. The LHS approach to care is a technology and electronic data driven approach that has the potential to mitigate the care fragmentation problem and the need for patient centric care approaches within the US Health System through a commitment to patient focused outcome measures to drive continuous improvement in care processes (Dinh-Le et al., 2019; Foley & Vale, 2017). Meaningful use stage three compliant hospitals emerged following the government's meaningful use of health IT policy (HITECH Act) and was meant to increase patients' access to their health data, the electronic sharing of patients' health information between providers such as hospitals and physician practices, and the use of PGHD to inform public health (Gold & McLaughlin, 2016; US-DHHS & ONC, 2015). Medical home/safety net hospitals were instituted to address the need for care coordination and more innovative care approaches that embraced the use of health IT tools (C. J. Sia et al., 2002; Stange et al., 2010). PCORI was established to fund US HCOs to conduct research related to patient related outcomes based on information systems and technology in order

to contribute complementary data to clinician-derived metrics traditionally used to inform health care decision-making (Bingham et al., 2016).

Together these four HII subcategories were referred to in this study as HII hospitals and the study first assessed in aim one their distribution within the study's data and how they group together. Secondly this study assessed their health IT use to enable patient centric care approaches by assessing their PGHD capture and use. This chapter will begin with a discussion section that is focused on providing a summary of the study results, and this will be followed by a section on study conclusions. The study conclusion section will include subsections focused on discussing the relevance of study results within the literature, study limitations, and the chapter will be concluded with a subsection on study's purpose and significance which will include implications for practice, policy and future research.

Discussion of Study Results

Aim One - The Distribution of HII Hospitals in the Study Sample

Aim one of this study sought to evaluate the distribution of US HII hospitals and how they group together. HII hospitals in this study included full LHS, meaningful use stage three compliant, PCORI funded and medical home safety net hospitals. Full LHS hospitals were those that were observed to be practicing all LHS principles which were derived from Senge's LO principles. LHS principles practiced per hospital were directly measured to identify the degree to which

hospitals engaged in their practice. Meaningful use stage three compliant hospitals were those that responded affirmatively to meaningful use stage three compliance criteria, while PCORI funded and medical home/safety net hospitals were those that obtained fuding to become PCORI funded and medical home/safety net hospitals respectively during the study periods. It is important to note that the LHS criteria which were derived from Senge's LO principles show some LO aspects while the other three HII were implied by literature and were not directly derived or measured based on LO principles.

In this study HII hospitals more than tripled (19.9% to 62.4%) over the five-year study period between 2013 and 2018. Of these increasing HII hospitals, about 60% were consistently full LHS hospitals across the years. This shows that overall, full LHS and HII hospitals (as a whole) grew at the same rate across the five-year period. In 2016, with the big post 2015 meaningful use stage three law spurt, meaningful use stage three compliant hospitals were the most common (84.6%) among the HII subcategories. The new law facilitated hospitals to make the transition to become meaningful use stage three compliant. Medical home/safety net and PCORI funded hospitals were generally fewer across the period, with the proportion of both hospitals decreasing across the study period. Medical home/safety net hospitals decreased from 3.4% to 0.006% while PCORI funded hospitals decreased from 9.8% to 4.6% across the study period. Summarily, HII hospitals increased steadily from 2013 to 2018, full LHS hospitals consistently made up a majority 60% throughout, while meaningful use stage three compliant hospitals became the largest subcategory from 2016.

The study observed that hospitals that met any of the LHS criteria increased progressively between 2013 and 2018, with emerging LHS and full LHS hospitals increasing across the study period. By 2018, nearly three quarters (74%) of the hospitals in the study sample met any LHS criteria (LHS stages one to three). Increasing numbers of hospitals were also observed to become meaningful use stage three compliant across the study period and by 2018, nearly half (46.9%) of the hospitals in the study sample had become meaningful use stage three compliant. This shows that across the study period, more hospitals became HII hospitals by responding to the call to adopt the HITECH Act's meaningful use stage three program which was a Federal incentive program for hospitals to participate in electronic data driven and patient - centric measures through the capture and use of PGHD (US-DHHS & ONC, 2015). The HITECH Act was enacted in 2009 to promote the adoption and meaningful use of health IT and its meaningful use stage three component was released in 2015 to become mandatory with penalties for noncompliance by 2018 (Chin & Sakuda, 2012; CMS, 2011, 2021). By 2018, which is the year that was initially set for penalties for non-compliance to the stage three rule to begin, nearly half (46.9%) of the hospitals in the study sample had become meaningful use stage three compliant.

Medical home/safety net hospitals were observed to decrease by more than one third (36.4%) between 2013 and 2018 given the end in funding. This indicates that the number of hospitals that continued this designation beyond the initial funding period were fewer. Medical home/safety net hospitals were initiated in 2013 to use innovative health IT tools to improve patient centric care and care

coordination (CMS, 2013). The funding was to last for three years, and in the post funding period fewer hospitals were observed to continue in this designation within the study sample. Based on this, less than one percent of the HII hospitals in the study sample across the three study periods were medical home/safety net hospitals.

HII Subcategory interactions

Interactions among HII subcategories evaluated in this study showed that single and multiple category HII hospitals exist within the study sample. In 2013, single category HII hospitals made up 82.7% (539) of the total HII hospitals in the study sample. In 2016, they decreased to 53% (968) and later increased to 62.5% in 2018. Among hospitals with multiple categories (i.e. HII subcategory interactions), in 2013, the most common HII subcategory interaction was the full LHS and meaningful use stage three complaint hospital which made up 13% (85) of the HII hospitals in the study sample. In 2016, this dominant HII subcategory interaction increased to 43.4% of the total HII hospitals in the study sample and later decreased in 2018 to 33.2% and were still the largest HII subcategory interaction.

In 2016 and 2018, more than a third of each HII hospital subcategory was in combination with other HII hospitals, and medical home/safety net hospitals and PCORI funded hospitals were more likely to be in combination with other HII hospitals. In 2016 and 2018 at least half of each of PCORI funded or medical

home/safety net hospitals were in combination with either full LHS or meaningful use stage three compliant hospitals and medical home/safety net hospitals were less likely to be PCORI funded. This shows that nearly a third of full LHS, meaningful use stage three compliant and PCORI funded hospitals were in one combination or the other among themselves between 2016 and 2018. Medical home/safety net hospitals as well were also more in combination with full LHS hospitals or meaningful use stage three compliant hospitals.

HII Hospital Typology

Given the above-described interactions among HII hospitals in the study sample, the typology of HII hospitals and their subcategories was such that by 2018, full LHS and meaningful use stage three compliant hospitals and their intersects were the dominant HII hospital categories. Single category PCORI funded hospitals were less than 1% of all HII hospitals, and no single category medical home/safety net hospitals were observed. Medical home/safety net and PCORI funded hospitals constituted minimal HII subcategories, however, they may serve as meaningful additions to full LHS or meaningful use stage three compliant HII hospital designations in being more likely to signal PGHD capture or use. Full LHS, meaningful use stage three compliant, and combinations of full LHS and meaningful use stage three compliant subcategories were the dominant HII subcategories overall. PCORI funded and medical home/safety net subcategories

were so small as to be negligible but may add some explanatory power in combination with the dominant categories.

Aim Two Cross Sectional Study

Aim two of this study was focused on conducting a cross - sectional study to assess PGHD capture and use among HII hospitals and their subcategories within the 2018 study sample. To achieve this, descriptive evaluations of the interactions of the non - health IT characteristics such as teaching, location, ownership, and bed size status of the hospitals in the study sample was first carried out. This began with a descriptive analysis of the non - health IT characteristics of HII and non HII hospitals as a whole and was followed by descriptive analyses of specific HII subcategories and HII subcategory interactions within the 2018 study sample. A cross sectional analysis that used LPMs to evaluate the association of HII hospitals, HII subcategories, and HII subcategory interactions with PGHD capture and use was then conducted.

Non HII Related Hospital Characteristics

Summarily, HII hospitals generally and by subcategory followed nearly similar patterns regarding teaching status, location, ownership, and bed size and were more likely to be teaching, nonprofit, larger in size, and metro located. About

two - fifths (41.5%) of HII hospitals had teaching status, while only slightly more than a quarter (27.6%) of non HII hospitals had teaching status (chi. sq. = 83.4) and this was statistically significant. This shows that HII hospitals were twice as likely to be teaching hospitals when compared to non HII hospitals. Either jointly or as single HII hospitals, full LHS and meaningful use stage three compliant hospitals in the study were majority non-teaching. Accordingly, full LHS hospitals in combination with meaningful use stage three compliant hospitals, and as single categories, full LHS hospitals, and meaningful use stage three compliant hospitals were 54.1%, 53.9% and 60.0% non-teaching respectively. The majority of PCORI funded hospitals (63.4%) and all medical home/safety net hospitals in the study sample for 2018 were teaching hospitals. This shows that the dominant HII hospital categories (full LHS and meaningful use stage three compliant hospitals) in this study were mainly made up of hospitals with non-teaching status, while the less dominant hospital groups (PCORI and medical home/safety net hospitals) were majority teaching hospitals. Overall, HII hospitals appear to be more likely to be teaching hospitals than non HII hospitals, however, most HII hospitals are non-teaching hospitals. Based on this, teaching status appears to be influential in being a HII hospital, it is however, not dominant. This follows the pattern within the literature that teaching hospitals were more likely to adopt health technology (Adler-Milstein, Kvedar, & Bates, 2014).

As regards hospital location status, both HII and non HII hospitals were majority metro located, however, metro located hospitals were slightly more prevalent among HII hospitals (62.2% vs 52.7%: chi. sq. = 29.9) and this was

statistically significant. HII subcategories and their interactions were also majorly located in metro areas (58.6 –100%). The observation in this study that metro located hospitals were slightly more prevalent among HII hospitals follows the pattern within the literature that the use of health IT in hospitals increases with urbanicity or metro location status (Chen, Amaize, & Barath, 2020). The modest difference (9.5 %) observed in this study between the prevalence of metro and rural located hospitals might be because in the overall study sample for 2018 a majority (58.5%) of the hospitals were metro located.

As regards hospital ownership status, approximately three fifth (59.2%) of all hospitals in the study sample were nonprofits, while more than two thirds (68.8%) of all HII hospitals but only two fifths (43.3%) of all non HII hospitals were nonprofits. Either jointly or as single HII subcategories, more than two thirds to more than four fifths (71.9% – 85.1%) of HII subcategories and their interactions were more likely to be nonprofit hospitals while only about a half to three fifths (48.3% - 59.1%) of their non HII counterparts were also nonprofit hospitals. This shows that although both HII and non HII hospitals were majority nonprofit hospitals in 2018, HII hospitals were still more likely to be nonprofit hospitals when compared with non HII hospitals. This follows the pattern within the literature that nonprofit hospitals were more likely to adopt health information technology such as telehealth (Adler-Milstein et al., 2014).

As regards hospital bed size, slightly more than half (50.3%) of all hospitals in the study sample for 2018 were medium (100 – 299 beds) and large (> 300 beds) and HII hospitals were more likely to be medium (34%) or large (23.9%). HII

subcategories followed the same pattern with about a third of full LHS (37.4%), a third of meaningful use stage three compliant (31.7%) and a third of PCORI funded hospitals (32.7%) being medium sized. Nearly a third of full LHS (29.0%), more than one fifth (21.9%) of meaningful use stage three compliant, more than half (52.5%) of PCORI funded hospitals and nearly three quarters (71.4%) of medical home/safety net hospitals were large. This is important to note because large hospitals or hospitals that are part of larger health systems that have resources that might be lacking in small hospitals were more often at the fore front of adoptions such as this (Adler-Milstein et al., 2014). Summarily, based on the 2018 study sample, HII hospitals were more often likely to be medium or large hospitals, however many of them were also small. This shows that HII hospital status is more influenced by other factors other than hospital size. The next section will discuss PGHD capture and use among HII hospitals, their subcategories, and their interactions.

PGHD Capture and Use Among HII Hospitals and HII subcategories, and Respective interactions

In year 2018, PGHD capture, and use were generally higher among HII hospitals when compared to non HII hospitals. PGHD capture among HII hospitals occurred at more than double (70.2%) the rate of PGHD capture among non HII hospitals (30.7%). For PGHD use, HII hospitals had 31.9% greater use with 86.1% of HII hospitals versus 54.2% of non HII hospitals using PGHD. It is important to

note that generally, in the 2018 study sample, the rate of PGHD use among hospitals was observed to be higher than the rate of PGHD capture (62.3% use vs 46.7% capture). The observed higher rate of PGHD use when compared to PGHD capture in HII hospitals (76.7% use vs 63.6% capture) might be due to PGHD use from non-standardized PGHD capture sources. Standardized frameworks that can enable standardized PGHD collection to become an integral part of routine care and research at scale through the use of interoperable standards are currently being developed (Sayeed, Gottlieb, & Mandl, 2020).

Among HII subcategories, full LHS hospitals had more than double the PGHD capture (70.1%) of non HII hospitals (29.7%). It is important to note that full LHS hospitals and non HII hospitals were both nearly two fifth (37.2% and 37.6% respectively) of the hospitals in the study sample for 2018. When emerging LHS hospitals were included as a control in the model, PGHD capture among full LHS hospitals in comparison to non HII nonemerging LHS hospitals increased by 10.2% (from 40.4%) and full LHS hospitals had nearly four times (67.7%) the PGHD capture rate of non HII nonemerging LHS hospitals (17.1%). Including emerging LHS as a control in the model means that the comparison of full LHS hospitals is to non HII nonemerging LHS hospitals which is more stark given that emerging LHS hospitals are more likely than other non HII hospitals to capture or use PGHD. For PGHD use, while more than half of non HII hospitals used PGHD (54.1%), full LHS hospitals had 33.1 % greater PGHD use than non HII hospitals with 87.2% of full LHS hospitals using PGHD. With emerging LHS in the model, PGHD use

increased by 15.7% (from 33.1%) and full LHS hospitals had more than double (83.4%) the PGHD use rate (34.6%) of non HII nonemerging LHS hospitals.

Meaningful use stage three compliant hospitals had 15.9% higher PGHD capture than non HII hospitals and PGHD capture among meaningful use stage three compliant hospitals that were also categorized as emerging LHS was 45.6%. With emerging LHS in the model, meaningful use stage three compliant hospitals were observed to have 14.1% higher PGHD capture than non HII nonemerging LHS hospitals. PGHD capture among meaningful use stage three compliant hospitals, then became 31.4%. Incremental change with and without emerging LHS in the model was about the same (15.9% vs 14.1%). For PGHD use without emerging LHS in the model, meaningful use stage three compliant hospitals had 9.5% higher PGHD use than non HII hospitals. PGHD use among meaningful use stage three compliant hospitals that can also be emerging LHS was 63.6%. With emerging LHS in the model, meaningful use stage three compliant hospitals had 7.1% higher PGHD use than non HII and nonemerging LHS hospitals. PGHD use among meaningful use stage three compliant hospitals then became 41.7%. Incremental change with and without emerging LHS in the model was about the same (9.5% vs 7.1%).

Among PCORI funded hospitals, without the emerging LHS variable in the model, PGHD capture was 16.1% more than that of non HII hospitals and PGHD capture among PCORI funded hospitals that could also be emerging LHS was 45.8%. With emerging LHS in the model the rate of incremental change remained nearly the same at 15.7%. PGHD capture among PCORI funded hospitals then

became 32.8% and this was nearly double the PGHD capture rate of non HII nonemerging LHS hospitals (17.1%). Based on this full LHS hospitals in the study sample were observed to capture and use PGHD two to three times more than other HII subcategories. With emerging LHS in the model, full LHS hospitals had two to four times the initial rate of increase in PGHD use or capture, and the effect sizes were as large as those observed among meaningful use stage three or PCORI funded hospitals. This shows that being a full LHS hospital is the most significant factor as it relates to PGHD capture or use. For HII subcategory interactions, full LHS and meaningful use stage three compliant hospitals had 63% greater PGHD capture and 55.2% greater PGHD use than non HII nonemerging LHS hospitals respectively, while full LHS and PCORI funded hospitals had 65.8% greater PGHD use than non HII nonemerging LHS hospitals. This further shows that hospital combinations that involved full LHS hospitals had higher rates of PGHD capture or use when compared to non HII nonemerging LHS hospitals. This further suggests that being full LHS was the main driver of PGHD capture or use. The next section will discuss how change in hospital designation affected PGHD capture and use.

Aim Three Discussion

Aim three of this study was focused on conducting fixed effects panel regression analyses to ascertain if the observed relationship between HII subcategories and PGHD capture, and use can be explained by a change in the

designation of HII subcategories or their interactions. To achieve these, descriptive analyses of the changes in hospital designation of the 1,431 hospitals that were available across the three study periods was first conducted and this was followed by fixed effects panel regression analyses that evaluated the effect of change in hospital designation on PGHD capture and use, among HII hospitals, HII subcategories, and HII hospital subcategory interactions in comparison to non HII hospitals and hospitals with stable characteristics. This was to explore the possibility of a causal association between change in hospital designation and PGHD capture and use.

Change in Hospital Designation and PGHD Capture and Use

Non HII to HII hospital change in designation and change in hospital designation from one HII subcategory to another occurred frequently across the study periods. Between 2013 and 2018, nearly two thirds (57.3 %) of non HII hospitals in the study sample changed their designation to HII subcategories. More than two fifths (43.7%) changed from non HII to meaningful use stage three compliant hospitals and nearly a third (29.2%) of non HII hospitals changed their designation to full LHS hospitals. The largest HII to HII hospital change in designation between years 2013 and 2018 occurred among hospitals that changed their designation from medical home/safety nets to full LHS HII subcategory (90%) and this was followed by those that changed their designation from full LHS HII subcategory to meaningful use stage three compliant HII subcategory (82.5%).

Overall, PGHD capture in hospitals that changed to HII hospitals (from non HII hospital status) increased by 7.5% across the three study periods, while PGHD use increased by 10.7% when compared to stable non HII hospitals and hospitals that remained in their HII hospital category, and this was statistically significant. For HII subcategories, PGHD capture and use was observed to be higher among hospitals that changed their designation to full LHS hospitals than those that changed their designation to meaningful use stage three compliant hospitals. The change to full LHS hospital status elicited nearly double the PGHD capture (13.0% versus 7.2%) and PGHD use rate (9.8% versus 5.9%) of meaningful use stage three compliant hospitals. In hospitals that changed to full LHS and meaningful use stage three compliant hospitals, PGHD capture increased by 20.4%. In hospitals that changed to PCORI funded and medical home safety net hospitals however, PGHD capture was observed to reduce by about 64.4% across the study period. The few numbers of hospitals in this category did not allow for a substantial assessment of changes in their PGHD capture rate across the study period and this might have led to the observed reduction in PGHD capture rate in this category. With emerging LHS in the model, PGHD capture among hospitals that became full LHS hospitals increased slightly to 14.2% while among those that changed to meaningful use stage three compliant hospitals it remained 7.2%. In hospitals that changed to full LHS and meaningful use stage three compliant hospitals, PGHD capture increased by 22% and this was higher than in either of the two HII subcategories alone. PGHD use among hospitals that became full LHS

hospitals increased to 17.4%, while among those that changed to meaningful use stage three compliant hospitals it dropped to 5.8%.

This fixed effect panel regression analyses show that the full LHS HII subcategory is still the most dominant HII subcategory when evaluating PGHD capture and use among HII hospitals in this study. The effects observed in these fixed effects regression analyses overall were much smaller than those observed in the cross - sectional linear regression analyses. The larger effects in the cross-sectional study show that hospitals' HII status are more associated with PGHD capture or use, rather than change in hospital designation, although change in hospital designation also showed some causal effects with PGHD capture or use. Overall, HII hospitals in this study and their subcategories showed strong associative effects with PGHD capture or use. Furthermore, across the study period, PGHD capture and use was higher in 2016 than 2013 and higher in 2018 than 2016. This signifies that overall PGHD capture and use increased across the study periods as shown by hospitals changing their designation to HII hospitals. This is also shown among hospitals that changed their designation to the more dominant HII subcategory interaction (the full LHS and meaningful use stage three compliant subcategory) which were observed to have more association with PGHD capture and use in the earlier cross - sectional linear regression.

Conclusions

HII Hospitals and Subcategories

This exploratory study sought to understand the distribution of HII hospitals, how they group together, and if and how their HII status influenced PGHD uptake. Prior to this study, it was not known how much PGHD capture, or use was occurring in HII hospitals such as LHS, meaningful use stage three compliant, medical home/safety net, and PCORI funded hospitals. Dominant HII hospital types in this study include meaningful use stage three compliant hospitals which by 2018 had made up nearly half (46.9%) of the HII hospitals in the study sample and full LHS hospitals which had formed nearly two fifths (37.2%) of the HII hospitals in the study sample. By 2018, about 34.1% of HII hospitals met criteria to be categorized as being in at least two HII subvcategories, while 4.3% of HII hospitals met the criteria to be in two or three other HII subcategories. The full LHS and the meaningful use stage three compliant hospitals formed the largest HII subcategory interaction (43.4% in 2016, and 33.2% in 2018) that was observed within the data, and at least half of PCORI funded and medical home/safety net hospitals overlapped with full LHS hospitals and meaningful use stage three compliant hospitals in the last two study periods. This shows that HII subcategories sometimes (about a third of the time) overlapped with each other and particularly overlapped with either full LHS or meaningful use stage three compliant hospitals.

In the case of the LHS hospital subcategory, prior to this study, it was not clear the extent to which hospitals were engaging in the practice of LHS principles, or how many hospitals actually met any or all of the LHS criteria. The study showed that a good number of hospitals were practicing LHS principles and the percentage of hospitals that met any LHS criteria increased from 38.4% to 74.2% across the study period. Furthermore, hospitals that met all of the LHS criteria increased from about 11.9% in year 2013 to about 37.2% in 2018, and these hospitals were referred to in this study as full LHS hospitals.

PGHD Uptake within HII Hospitals and their Subcategories

The study hypothesized that HII hospitals were more likely to capture and use PGHD when compared with non HII hospitals, and the study confirmed this hypothesis by showing that overall, among the hospitals in the study sample, PGHD capture and use was positively associated with HII status. HII hospitals as a whole, and three out of the four HII subcategories (with the exception of medical home/safety net hospitals) were observed to be positively associated with PGHD capture or use. Based on the study's theoretical framework which is focused on HII hospitals as LOs that seek to utilize a systemic approach to learn from patient sourced data such as PGHD to make continuous improvement in care processes, HII hospitals can be described as HCOs that seek to capture and use PGHD for organizational learning.

Among HII subcategories such as full LHS hospitals, prior to this study, it was not clear if the practice of all LHS principles was associated with the capture

or use of PGHD when compared to hospitals that did not practice any of the principles. Full LHS hospitals in this study were shown to be positively associated with PGHD uptake. Emerging LHS hospitals, although they were not categorized as HII hospitals, were also observed to have some positive association with PGHD uptake. Although, this might have been due to the categorization criteria of LHS hospitals that was utilized in this study which due to the high criteria for achieving full LHS may have included some hospitals that were almost full LHS in the emerging LHS category thereby resulting in increased PGHD uptake among emerging LHS hospitals. This pattern of PGHD uptake observed among LHS hospitals in this study, and particularly full LHS hospitals, is corroborated by the study's theoretical framework. The framework describes the LHS hospital as a HCO that seeks to learn from every patient through the use of digital health information such as PGHD. PGHD in this study is a major source of EHD that needs to be captured and used by HCOs in order to achieve LHS goals of continuous improvement in care processes, improved patient experience and improved health outcomes. Meaningful use stage three compliant hospitals showed positive association with PGHD capture (15.9%) and use (9.5%) however, this association was not as strong as that observed among full LHS hospitals which was 40.4 % for PGHD capture and 33.1% for PGHD use. PCORI funded hospitals also showed positive association with PGHD capture (16.1%) and PGHD use (11.2%).

As earlier stated, HII subcategories were more often than not in combination with at least one other HII hospital such as full LHS or meaningful use stage three

compliant hospitals. The extent to which HII subcategories captured or used PGHD was observed to be mainly influenced by their combination with hospitals in the full LHS subcategory. PGHD uptake was observed to be more significant in linear regression analysis when HII hospitals such as meaningful use stage three compliant and PCORI funded hospitals were in combination with hospitals in the full LHS subcategory. PGHD capture and use was also observed to be influenced by hospitals' change from non HII to HII hospital status or when hospitals changed their HII designation from one HII subcategory to another, particularly when hospitals changed to the more dominant HII subcategories. In hospitals that changed their designation to HII hospitals across the study period, PGHD capture was observed to increase by 7.5 % and PGHD use was observed to increase by 10.7%. PGHD uptake was significant in fixed effects panel regression analysis in hospitals that changed their designation to full LHS hospitals, or meaningful use stage three compliant hospitals. PGHD uptake in those that changed to full LHS hospital was however nearly double that observed in those that changed their designation to meaningful use stage three compliant hospitals (PGHD capture rate 13% versus 7.2% and PGHD use rate 9.8% versus 5.9%). Changes in designation that involved full LHS hospitals had higher rates of PGHD capture or use. The effects observed in the fixed effects regression analysis were however smaller than those observed in the linear regression analysis.

Cross - sectional analyses and the panel regression analyses in this study showed that being full LHS is a key driver of PGHD capture and use. This confirms the study's hypothesis and theoretical framework which was based on Senge's

LO's theory and supports the concept of the LHS as organizations that utilize a systemic approach and endeavor to learn from EHD such as PGHD to inform patient centric care. A review of literature showed that LHS hospitals are HCOs that endeavor to incorporate learning throughout their care delivery processes and believe that learning can be better achieved with PGHD incorporation into LHSs (Budrionis & Bellika, 2016; IOM, 2003). It was not clear prior to this study, the extent to which LHS hospitals captured or used PGHD. This study has however shown that PGHD capture and use is associated with full LHS hospital status and this needs to be considered when designing programs for hospitals to engage in that can facilitate EHD-driven, patient centric care among HII hospitals through PGHD capture and use.

Meaningful use stage three compliant hospitals were also observed to be positively associated with PGHD capture and use in this study. The meaningful use stage three compliance policy is a recent meaningful use of health IT policy that emanated from the HITECH act and carried a penalty for hospitals that were non compliant by the 2018 deadline. One of the major end goals of the meaningful use stage three policy was to facilitate the meaningful use of health IT to improve the quality and efficiency of care (US-DHHS & ONC, 2015). Although hospitals must meet this requirement to continue to be eligible for benefits and reimbursements, it was not clear, prior to this study, if the fulfillment of this requirement by hospitals is associated with PGHD capture or use in compliant hospitals. Given that full LHS status was more strongly associated with PGHD capture and use, LHS principles used in this study could be included in meaningful

use criteria. This can be helpful to move hospitals in the meaningful use stage three HII subcategory forward toward becoming more EHD-driven and patient centric through the capture and use of PGHD.

PCORI funded subcategory hospitals showed some positive association with PGHD capture or use however, the association they showed was not as strong as that observed in hospitals that were in the full LHS subcategory. The association with PGHD use was more pronounced when PCORI funded subcategory hospitals were in combination with full LHS subcategory hospitals (10.4% versus 65.5% (with emerging LHS in the model). Given PCORI's interest to fund EHD - driven, patient centric comparativeness effectiveness research within HCOs that enables patients to collaborate with providers in their own care, it is important to note the HII combinations with PCORI funded hospitals that resulted in increased use or capture of PGHD among PCORI funded hospitals. This study showed that being a PCORI funded hospital alone does not indicate EHD – driven, patient centric care through PGHD capture and use. Given the observed additive effect of full LHS on PCORI funded and full LHS hospitals, full LHS status of PCORI funded hospitals can assist PCORI funded hospitals to capture or use more PGHD.

Medical home/safety net hospitals, on the other hand, although identified as HII hospitals within the study's theoretical framework did not elicit a positive association with PGHD capture or use, neither did their combination with full LHS hospitals result in increased PGHD uptake. This group was not functional given the loss of funding post initial funding period and due to their small size across the

study period. Hence, there is the need for medical home/safety net hospitals or related initiatives to re – evaluate their health IT characteristics. Furthermore, medical home/safety net hospitals may be more focused on other non PGHD related patient centric measures that was not the focus in this study. Nevertheless, adopting some of the health IT characteristics of full LHS hospitals as seen in this study could be helpful.

This study showed that HII hospitals (as a whole) have a positive association with PGHD capture and use. It also shows that among the HII subcategories full LHS hospitals are the prominent hospital subcategory as it relates to PGHD capture and use. Overall, the effects observed with PGHD capture and use among full LHS hospitals in this study were mainly strong associative effects. Other HII subcategories such as meaningful use stage three compliant and PCORI funded HII subcategories were also observed to have some association with PGHD capture and use, however these were not as strong as those observed in the full LHS subcategory. Overall, study results showed that the LHS subcategory which was derived from Senge's LO principles clearly showed aspects of being a LO as it relates to PGHD capture and use while the other three HII subcategories which were implied by literature and essentially presumed did not show as much LO aspects as the LHS. Future research may further explore the potential for strong causal effects between full LHS hospitals and PGHD capture and use.

Limitations

There are several limitations to this study, including the identification, definition and operationalization of variables (or categories and subcategories), measurements and types of statistical tests used. Hospitals were categorized into LHS stages based on a translation of the LHS criteria within the literature to related questions within the AHAIT survey for 2013, 2016, and 2018. Meaningful use stage three compliance criteria were also translated in the same manner to the AHAIT. The AHAIT survey, although designed to evaluate the meaningful use of EHR technology, was not specifically designed to evaluate LHS criteria. Furthermore, meaningful use stage three was first released in 2015, and this study in aim three evaluated meaningful use stage three compliance beginning from year 2013, this is given the exploratory nature of this study. Based on these needs and constraints, accurately translating some of the required criteria to what was available within the AHAIT survey and data was challenging in some cases and might have led to measurement errors. Also, there might be other HII subcategories that were not identified in the study. Nevertheless, this exploratory study showed that HII hospitals exist, and that hospitals are generally increasing in their health IT characteristics by changing from non HII hospital status to HII hospital status, or by changing their designation to HII subcategories that showed more association with PGHD capture or use such as the full LHS hospital.

Issues related to the identification, definition and operationalization of study categories and subcategories include the categorization of emerging LHS

hospitals as non HII hospitals. Emerging LHS hospitals were observed to elicit some association with PGHD capture and use. It might be necessary in future studies to re-evaluate the LHS criteria for emerging LHS (particularly the LHS stage two component). Some hospitals which were nearly becoming full LHS hospitals could have been categorized as emerging LHS hospitals thereby increasing the association observed with PGHD capture or use among this non HII hospital subcategory. In evaluating change in hospital designation and PGHD capture or use, hospitals were observed to not only move from non HII to HII hospital status, but they also moved from HII hospital status back to non HII hospital status. This reversal in HII hospital status to non HII hospital status could have reflected in the PGHD capture or use rates among HII hospitals when compared to non HII hospitals. In addition to potential identification, definition, categorization and measurement issues, limitations in interpretation include the observation that PGHD use was higher than PGHD capture in some cases. It was also not clear if PGHD capture or use as reported within the data occurred from standardized sources.

Measurement related limitations include the use of the cross - sectional study in aim two which is limited because it revealed associations but did not clearly establish causal relationships between HII hospitals as a whole or HII subcategories and their interactions with PGHD capture or use. The fixed effects panel regression analyses bridged this gap to an extent because it associates change in non HII and HII status with changes in PGHD capture and use and has some limited causal findings. However, given the short study period (three years

of data) and the complexity of status changes this study was not able to test or evaluate all the assumptions of a full difference in difference model. Future studies that are specifically focused on evaluating causality between hospitals such as these and PGHD capture and use can be helpful.

Other measurement related limitations include the use of the LPM for regression analyses in this study despite some of its known limitations which includes heteroskedasticity in standard errors and the potential for giving individual predicted probabilities that are beyond the range of zero and one. The LPM was used due to the study's focus on the evaluation of mean effects and differences among hospital groups and not individual predictions and the study's large samole size. LPM coefficients are directly interpretable as probability differences, and concerns about inconsistent standard errors due to heteroskedasticity are more relevant for studies with smaller sample sizes. Despite these measurement related limitations, this exploratory study was able to show that hospitals were generally moving towards becoming HII hospitals and that HII hospitals and most of their subcategories showed positive associations with PGHD capture or use.

Purpose and Significance

New and emerging technologies enable the passive and active collection, storage, analysis, use and transfer of large amounts of data electronically with little or no efforts on the part of end-users such as patients and providers. Patient and provider populations daily experience the impact of these possibilities from

smartphones, mobile and wearable devices that have the capacity to collect information about the user's health and behaviors by capturing the user's habits and activity pattern. These increasing possibilities are enabling the US Health System to become more digital with providers being able to get access to patient's data that is collected outside of clinical settings (Okun et al., 2012). These out of clinic, patient sourced data permits providers to have a glimpse of patients' health status, activities and behavior patterns outside the clinical setting thereby providing a holistic view of the patients' health situation (Cohen et al., 2016; Wood et al., 2015). Furthermore, these patient sourced data such as PGHD enable patients to become active participants in their care, while also helping to improve health outcomes by increasing the potential for more targeted treatments due to increased access to patients' data (E. Austin et al., 2019; Fowe, 2020b).

PGHD capture and use within US HCOs can improve individual health by providing necessary data that can be used to facilitate personalized care by helping to inform the decision-making process by patients and providers during clinical visits. PGHD capture and use can enable public health by providing data that can be used to improve disease monitoring and tracking (Nittas et al., 2019). It can also help to provide information that can help to better target medical services which can result in better health outcomes and savings on cost of care. PGHD can help within systems of care to avoid harm to patients by making it possible for medication errors or adverse drug reactions to be captured even when the patient might not be aware of it. PGHD can also help to avoid unnecessary costs that are often associated with repeat testing and repeated delivery of

unsuccessful treatments (Angelique Cortez, Peggy Hsii, Emily Mitchell, Virginia Riehl, 2018). PGHD capture and use can help to facilitate, accelerate and improve how research is used within systems of care to provide answers to medical questions in more effective and efficient ways (Okun et al., 2012).

PGHD is growing and an important new tool within healthcare. This study developed a concept of HCO characteristics that are expected to be related to PGHD capture and use which was called HII Hospitals. HII hospitals are EHD-driven, learning focused and patient centric HCOs that are posited in this study to seek to capture or use PGHD. This study was able to use this concept to identify some potential hospital types either by direct measurement or review of literature (LHS, meaningful use stage three, PCORI funded and medical home/safety net HII subcategories). The study was able to evaluate the relationship of these HII construct, their subcategories and interactions to understand which ones were most likely to capture or use PGHD. This study provides information that informs hospital practice and related policy in support of the meaningful use of PGHD as well as future research paths.

Implications for Practice

HII subcategories in this study showed different HII health IT characteristics, most of which were observed to be associated with PGHD capture and use, particularly that of full LHS hospitals. The associations between full LHS and PGHD found in this study suggest that becoming full LHS can facilitate PGHD capture and use and can be replicated in aspiring HII hospitals. Study results show

that meaningful use stage three compliant hospitals can benefit from the inclusion of full LHS criteria in their health IT characteristics. Including PCORI funded hospitals and medical home/safety net hospitals did not add much information to study results since both HII subcategories had small sample sizes. Given that the LHS was the strongest HII subcategory associated with PGHD capture and use, hospitals that want to develop capacity to capture or use PGHD need to pay attention to organizational structures or principles that are related to Senge's LO theory. These principles may be less technical so those that seek to support or encourage PGHD capture and use should focus more on developing organizational structures and/or culture that enable learning. Furthermore, the combination of full LHS and meaningful use had the highest level of association, this suggests that there is a balance of technical and organizational principles that can facilitate PGHD capture and use.

Implications for Policy

The policy supported HII subcategories (meaningful use stage three, medical home/safety nets, PCORI funded) were not as strongly related to PGHD capture and use as the created measure of LHS. In this study, hospitals that were in the meaningful use stage three compliant HII subcategory emanated from the HITECH act which was a federal policy that was put in place to ensure the meaningful use of health IT tools within HCOs such as hospitals. PCORI was created by the US Congress as part of the Patient Protection and Affordable Care Act of 2010 to fund patient directed research aimed at assisting patients,

caregivers, researchers, clinicians, and other stakeholders to make informed health decisions (Barksdale et al., 2014). The medical home/safety net hospital model of care was implemented between 2011 and 2014 in order to address hospital level challenges that were related to providing improved care at lower costs through a patient centered approach that also embraced the use of health IT (CMS, 2013; Rappleye, 2017). Study results however indicate that policies such as these need to be more tailored towards LHS criteria to achieve one of their intended outcomes, which is PGHD capture or use. This is given that study results showed that hospitals that incorporated full LHS principles were more associated with PGHD capture and use. Based on this, the development of policy intended to support health IT innovations such as PGHD capture and use should consider learning related organizational measures.

The CMS and the ONC already suggest that meaningful use stage three policy should be designed to facilitate HCOs to become LHSs and this study supports that conclusion. ONC's fact sheet that describes the ONC and CMS' agenda for moving forward towards an interoperable learning health system: suggests that the meaningful use stage three rule can be useful in achieving this (ONC, 2014, 2015). Currently based on study results, only about a third of meaningful use stage three compliant hospitals in this study are also full LHS. This shows that more needs to be done to facilitate meaningful use stage three compliant hospitals to incorporate LHS criteria. Furthermore, the linear regression and fixed effects regression analysis showed that full LHS in combination with meaningful use stage three compliant hospitals had higher effects with PGHD

capture or use than full LHS hospitals which had the highest PGHD capture and use effects among the individual HII subcategories. These findings suggest that the LHS measures developed in this study can provide some attributes or measurements that can be added to meaningful use attestations to evaluate systemic learning competencies.

Implications for Future Research

Future studies that seek to establish more standardized and detailed measures of PGHD capture and use are needed. The PGHD measures that were used in this study were unspecified and PGHD use was observed to be greater than PGHD capture. This led to questions in this study about whether PGHD capture or use occurred from standardized sources and this may be a pointer to poor PGHD capture or use standards across board. EHD collected can only be meaningfully useful at scale if data is collected in standardized formats and data sharing systems are interoperable (Lehne, Sass, Essenwanger, Schepers, & Thun, 2019). Studies that are focused on improving data standards for PGHD collection and use through standardized sources can be helpful. Currently there are few examples of large scale PGHD collection and use in clinical settings (Adler-Milstein & Nong, 2019). Based on this, an understanding of the type of PGHD needed in various institutions and among various patient populations are needed and this can facilitate the development of standardized PGHD measures. Studies

that are focused on the development of data quality standards for PGHD collection from various sources are also needed.

Future studies that evaluate more specific institutional characteristics and their relationship to PGHD capture and use can be helpful. This study did not have in depth organizational characteristics of the HII subcategories involved and other unmeasured organizational characteristics in this study could be responsible for some of the effects observed with PGHD capture and use. Furthermore, future qualitative studies that establish what PGHD capture and use mean to specific institutions and the types of PGHD captured or used in specific institutions and among different patient populations can be helpful. Understanding what PGHD capture, or use means within different hospitals and how different HII hospitals perceive or relate to standardized PGHD capture or use could be helpful in developing infrastructure that can enable standardized PGHD capture and use across various types of HII hospitals. It can also enable the institution of efficient and effective data standards and EHD sharing capabilities for individual and population health purposes.

Future studies that connect PGHD use to health outcomes are needed. We know that HII related characteristics are related to PGHD capture and use, but we don't know its relationship to outcomes. An understanding of how PGHD capture and use can facilitate improved health outcomes can be useful in improving population health. Future studies that show better understanding of causal relationships of PGHD capture and use and organizational characteristics are needed. This is given that the cross - sectional linear regression results were

stronger than the fixed effects regression, i.e., the associative relationship is stronger than the implied causal relationship in aim three. Based on this, future research that uses more study periods to evaluate how changes in hospital designation can influence PGHD capture, or use can be more informative. More study periods can also help to strengthen the observed limited causal effect between full LHS hospitals and PGHD capture or use observed in the fixed effects regression analyses. Future studies that focus on understanding practice implications of PGHD capture or use among health providers can also be helpful. An understanding of practice implications for PGHD capture and use can assist policy makers to address elicited areas of need and proffer solutions to practice related challenges that may have led to the limited capture or use of PGHD within existing or aspiring HII hospitals.

Future studies that explore other organizational and social factors that may be related to the adoption of health IT characteristics and PGHD capture and use in hospitals through qualitative or mixed methods study designs can be helpful. This is because other organizational factors that were not measured in this study could be driving some of the associations with PGHD capture and use that were observed. Some of these unmeasured organizational factors include the types of hospitals that could be more likely to become HII hospitals and consequently capture or use PGHD. Others could include the participation of some hospitals in the study sample in large hospital systems which could facilitate PGHD capture or use due to the potential for improved capacity to capture or use PGHD when compared to stand alone hospitals. Some of these unmeasured factors could be

responsible for the associations with PGHD capture or use observed among HII hospitals and their subcategories in this study. Based on this, future studies may be able to show organizational factors that may facilitate or limit the capture or use of PGHD despite investments into creating a HII hospital. Future studies may also explore how other non - health IT characteristics such as metro, or rural location of hospitals can facilitate or limit PGHD capture or use.

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